



NJD-iScience

№186

The Norwegian Journal of Development of
the International Science





№186/2026

Norwegian Journal of development of the International Science

ISSN 3453-9875

It was established in November 2016 with support from the Norwegian Academy of Science.

DESCRIPTION

The Norwegian Journal of Development of the International Science, established in 2016 with support from the Norwegian Academy of Science, offers a platform for global researchers, academics, and students. Publishing 24 times annually, it covers current science topics. Submitting your article provides exposure to a diverse audience, enhancing your career. Our commitment to research and SEO ensures timely visibility. Submit to the Norwegian Journal of Development of the International Science today and join esteemed authors.

Editor in chief – Karin Kristiansen (University of Oslo, Norway)

The assistant of the editor in chief – Olof Hansen

- James Smith (University of Birmingham, UK)
- Kristian Nilsen (University Centre in Svalbard, Norway)
- Arne Jensen (Norwegian University of Science and Technology, Norway)
- Sander Svein (University of Tromsø, Norway)
- Lena Meyer (University of Gothenburg, Sweden)
- Hans Rasmussen (University of Southern Denmark, Denmark)
- Chantal Girard (ESC Rennes School of Business, France)
- Ann Claes (University of Groningen, Netherlands)
- Ingrid Karlsen (University of Oslo, Norway)
- Terje Gruterson (Norwegian Institute of Public Health, Norway)
- Sander Langfjord (University Hospital, Norway)
- Fredrik Mardosas (Oslo and Akershus University College, Norway)
- Emil Berger (Ministry of Agriculture and Food, Norway)
- Sofie Olsen (BioFokus, Norway)
- Rolf Ulrich Becker (University of Duisburg-Essen, Germany)
- Lutz Jäncke (University of Zürich, Switzerland)
- Elizabeth Davies (University of Glasgow, UK)
- Chan Jiang (Peking University, China) and other independent experts

1000 copies

Norwegian Journal of development of the International Science

Iduns gate 4A, 0178, Oslo, Norway

email: publish@nor-ijournal.com

site: <https://nor-ijournal.com>

CONTENT

EARTH SCIENCES

Makarov V. PROSPECTING FOR ORE DEPOSITS HIDDEN UNDER GLACIERS IN THE ARCTIC REGIONS	3
Bochkarev V., Bochkarev Ar. TIGHT-SHALE BURGER: CO-DEVELOPMENT OF THE PIMIENTA SHALE OIL FORMATION AND JURASSIC- CRETACEOUS TIGHT RESERVOIRS ONSHORE THE SURESTE BASIN (MEXICO)	9

ECONOMIC SCIENCES

Abdullayev R. MACROECONOMIC GROWTH AND AGRICULTURAL EXPORT PERFORMANCE IN TRANSITION ECONOMIES: EVIDENCE FROM A TWO-WAY FIXED EFFECTS GROWTH MODEL	24
---	----

MATHEMATICAL SCIENCES

Milyute E., Milyus A. THE MICROVORTEX CIRCULATION VECTOR AS AN INTEGRAL CHARACTERISTIC OF COHERENT VORTEX FILAMENTS	29
---	----

MEDICAL SCIENCES

Artemyeva I. THE INSTRUMENTATION GAP IN NAIL SERVICE MASTER TRAINING: WHY ENGAGEMENT METRICS CANNOT VALIDATE PROCEDURAL SAFETY	34
Aliakhunova M. CLINICAL AND LABORATORY CHARACTERISTICS OF RHEUMATOID ARTHRITIS ASSOCIATED WITH AUTOIMMUNE THYROIDITIS	39

PHILOLOGICAL SCIENCES

Mykhailenko V. RECEPTION OF THE IMAGE OF THE MODERN WOMAN IN AMERICAN LITERATURE	44
Kostanian Z. DEICTIC DIMINISHMENT: THE STRATEGIC USE OF PRONOMINAL REFERENCE IN POLITICAL OTHERING (ON THE EXAMPLE OF 2024 US PRESIDENTIAL DEBATE BETWEEN REPUBLICAN NOMINEE DONALD TRUMP AND DEMOCRATIC NOMINEE KAMALA HARRIS)	48

PHYSICAL SCIENCES

Antonov A. TIME TRAVELS IS PHYSICALLY POSSIBLE AND READY TO USE	57
Dr Hossain K. EVALUATION OF SMART CITY AS A GLOBAL WONDER IN THE ERA OF ADVANCED TECNOLOGY	69

SOCIAL SCIENCES

Dr. Aghayeva M. USE OF ARTIFICIAL INTELLIGENCE IN FAMILY RELATIONSHIPS	102
Vekua D., Vekua G. RISKS OF THE CIRCULAR ECONOMY AND PROSPECTS FOR THEIR NEUTRALIZATION IN GEORGIA	107

TECHNICAL SCIENCES

Kyryk Ya., Herhi M., Ratnikov D., Hrynchevskiy S. SYSTEMS MODELING OF CONSTRUCTION ORGANIZATION UNDER WARTIME RISKS: NONLINEAR INTERDEPENDENCIES, FUNCTIONAL RESILIENCE, AND TRANSFORMATIVE RECOVERY SCENARIOS	109
---	-----

EARTH SCIENCES

PROSPECTING FOR ORE DEPOSITS HIDDEN UNDER GLACIERS IN THE ARCTIC REGIONS

Makarov V.

PhD (Geology and Mineralogy), Dr. Habil, professor, Institute of Permafrost Science of the Siberian Branch of the Russian Academy of Sciences
<https://doi.org/10.5281/zenodo.21982201>

Abstract

The article considers the results of geochemical studies conducted in the area of the high-mountain gold ore deposit Kumtor Sredinny Tien Shan. The work was focused on cold and warm glaciers: Petrov, Sary-Tor, Davydov, Lysy, No. 354 and Boordu, overlapping the mineralized zone and ore bodies. It was established that cryogenic geochemical fields (CGF) are formed in the ice of glaciers. The chemical composition of the CGF of glaciers reflects the composition of ore bodies and endogenous halos of the Kumtor deposit. The features of the CGF formed on the surface of glaciers in the epicenters of ore bodies with an established ice thickness of up to 175 m are characterized. The extent of geochemical anomalies of the CGF on the surface of glaciers from the epicenter of the ore body in the direction of ice movement varies from 50-100 to 600 m. Recommendations are given for the use of CGF in forecasting and prospecting work in glacial areas in the Arctic.

Keywords: ore deposits, geochemical prospecting, glaciers, the Arctic

Introduction

Large and easily discoverable mineral deposits in Russia are nearly exhausted. Geologists are forced to push ever deeper into the Arctic zone and remote regions of Siberia. The vast territory of Russia's Arctic zone holds promise for the discovery of new large deposits of strategic metals [1]. However, geological and geophysical research, as well as the state of the region's infrastructure as a whole, are insufficient to fully integrate their mineral resource base into the country's economic activity [2]. Inaccessible areas of the Russian Arctic still contain "blank" areas—completely unexplored territories. These territories include glaciated regions, the glacier-covered islands of the Russian Arctic, and the subarctic mountainous regions of the North, Northeast Siberia, the Koryatsky Highlands, and Kamchatka. According to the "Glaciers of Russia" database [3], there are currently 7,478 glaciers in the Russian Federation, grouped into 22 glacier systems. The largest glacial systems by area are located in the Arctic on the Novaya Zemlya (over 22,000 km²), Severnaya

Zemlya (16,500 km²), and Franz Josef Land (12,500 km²) archipelagos. New large deposits may be located and discovered in glacier-covered Arctic and subarctic territories. In recent years, high global prices for precious metals have been one of the main drivers of geological exploration in remote Arctic regions. Historically, gold has been the primary target for geological exploration in these areas [4]. An example of such a deposit, partially located beneath a thick layer of glacial ice, is the Kumtor gold deposit. The deposit is located in the eastern part of the Central Tien Shan on the north-western macroslope of the Ak-Shyirak glacier massif, at an altitude of over 4,000-4,200 meters above sea level, in the permafrost zone. The Ak-Shyirak mountain range is a weakly dissected mountain uplift with an average absolute elevation in the central parts of approximately 4,600 m. The relief is glacial: large glacial cirques and cirques with modern glaciers alternate with steep ridges and flat watersheds. The ice thickness of the Ak-Shyirak glaciers in the Kumtor deposit area averages 60-100 m, with a maximum of 175 m (Table 1).

Table 1.

Ice thickness of the Ak-Shyirak glaciers in the Kumtor deposit area, m [5]

Glaciers		Average	Maximum
Petrova		70	173
Lysy		60	-
Davydov	Eastern	90	175
	Central	100	160
	Western	85	170
Sary-Tor		-	165
Boordu		100	-

The climatic conditions are associated with the intra-mountain location of the region and are characterized by significant continentality and a harsh climate with a negative average annual temperature of -7.8 °C, which is comparable to the harsh climatic conditions of the Arctic (Novaya Zemlya) [6]. The coldest month is January, and the warmest is July. The absolute mini-

mum temperature is -45 °C. The average long-term annual precipitation at the Tien Shan hydrometeorological station during the baseline observation period of 1961-1990 was 371 mm, of which only 49 mm, or 13.2%, fell during the cold period (November - March). The bulk of precipitation falls during the warm period, with most of it in the form of snow and only 8% of the annual amount falling as liquid precipitation, which is

observed on only 11 days a year. Permafrost is continuously distributed, 90-370 m thick, and temperatures range from minus 1.7 to 4.9°C. Talik zones are found only beneath large valley glaciers [7]. The main waterway is the Kumtor River and its left tributaries, the Sarytor and Boordu Rivers. In winter (December-February), the rivers freeze to the bottom. The Kumtor gold deposit is unique in its reserves, making it a world-class gold mine. It is among the five largest mines in the world by gold reserves, with confirmed and projected reserves amounting to approximately 700 tonnes. From the start of commercial production in May 1997 to June 30, 2022, Kumtor has produced over 430 tonnes of gold [10]. The Kumtor mine is located at elevations of 3,600-4,400 meters above sea level in the nival-glacial belt of the Tien Shan. The Kumtor gold deposit is one of the highest-altitude deposits in the world, along with, for example, the Pascua Lama gold and silver mine, located at elevations of 4,800-5,200 meters. The geological structure of the deposit area is determined by its belonging to the miogeosynclinal zone of the Caledonian-Hercynian folding of the Tien Shan. Thick strata of Riphean-Vendian metavolcanic sedimentary rocks unconformably overlie the ancient granite-gneiss basement. The rocks are represented by high-carbon and siliceous schists and phyllites. Granitoid and metasomatic rocks are located along faults. The Kumtor gold-(tungsten)-sulfide deposit is controlled by the Main Mineralized Zone, along the strike of which metasomatites and mineralization are located. Ore bodies are localized in the Kumtor shear zone, more than 7 km long and 300-400 m thick. The deposit is partially hidden under thick ice layers of the Davydov, Sary-Tor, Lysy, Petrov, No. 354, and Bordu glaciers. Currently, the gold-bearing ore body being developed lies near and under the Lysy, Davydov, and Sary-Tor glaciers. The flanking areas: Petrov, Bordu, and other glaciers are promising [8]. The ore bodies are represented by linear mineralized zones with disseminated-veinlet and stockwork mineralization, which have distinct structural and lithological-stratigraphic controls, manifested in the confinement of the ore bodies to a zone of increased tectonic deformations in a carbonaceous pyrite-bearing phyllitic ore-bearing formation. The main ore mineral, which is associated with the bulk of the gold, is pyrite. The content of sulfides in the ores ranges from 5 to 20-30% (averaging 15-20%). The ore field is accompanied by complex endogenous geochemical halos: Au, Ag, Mo, W, Pb, Zn, Cu, Co, Ni, Ba, Ti, Mn, V, Be, K, and Na. The ore bodies are productive gold-tungsten-sulfide "deposits" of pyrite-feldspar-carbonate metasomatites accompanied by contrasting endogenous halos of Au, Ag, Mo, W, K, and Na. The potential for geochemical prospecting for glacier-covered ore bodies was studied at the Kumtor gold deposit in 1988-1989. Geochemical fields in glaciers were studied in glaciers located in the eastern part of the inner Tien Shan (Kyrgyzstan). Geological exploration at the deposit at that time was in the exploration phase and was concentrated

in the northwestern part of the ore field near the Davydov Glacier. The location of ore bodies on the flanks of the ore field beneath the overlying glaciers was unknown.

Research Methods

Geochemical studies were conducted in 1988-1989 on the northwestern macroslope of the Ak-Shyrak Ridge in the area of the Kumtor gold deposit. During this period, exploration work was conducted at the deposit in the area of the Davydov Glacier. The locations of ore bodies beneath the remaining glaciers were unknown. Geochemical studies focused on cold and warm glaciers: Petrov, Sary-Tor, Davydov, Lysy, No. 354, and Boordu, which overlie the Main Mineralized Zone and ore bodies.

On each glacier, exploration routes were completed along the glacier from its crest to its tongue, with ice samples collected from the glacier surface. Ice samples were collected from the glacier surface immediately beneath the firn. The distance between samples was 50-100 meters. A total of 93 ice samples were collected from each glacier. The sample weight of 1.0-1.5 kg was limited to the required volume of melted ice for a comprehensive water analysis—1 liter. Ice melting and water packaging in chemically clean containers were carried out at room temperature in the village of Kumtor at the field base of the high-altitude laboratory of the Permafrost Institute (IP) SB RAS.

Analytical processing of geochemical samples was conducted in Yakutsk. A complete chemical analysis of water (ice) was performed in the Cryolithozone Geochemistry Laboratory of the IPP SB RAS. An approximate quantitative atomic emission spectral analysis of the trace element composition of water for 35 elements and atomic absorption determination of gold (Perkin-Elmer, with a graphite cuvette) were performed at the Central Geological Laboratory of the PGO "Yakutskgeologiya." Mathematical processing of analytical hydro- and lithochemical data was performed in the IT department of the Yakutsk Territorial Geological Administration using standard statistical applications such as Geoanalytics and others.

Results and Discussion

Geochemical studies have established that complex anomalies of indicator elements for gold mineralization are observed on the ice surfaces of glaciers overlying the mineralized zone and ore bodies. These geochemical anomalies on the glacier surfaces are due to the formation of cryogenic geochemical fields of indicator elements within the glaciers overlying the ore bodies. The composition of the superimposed halos corresponds to that of the ore bodies and endogenous halos. Clear geochemical anomalies of elements that determine the geochemical characteristics of the system—typomorphic elements for the ore body and endogenous halos—were established on the surfaces of all glaciers overlying the ore bodies and mineralized zone: Au, W, Pb, Cr, Cu, and Sn (Fig. 1

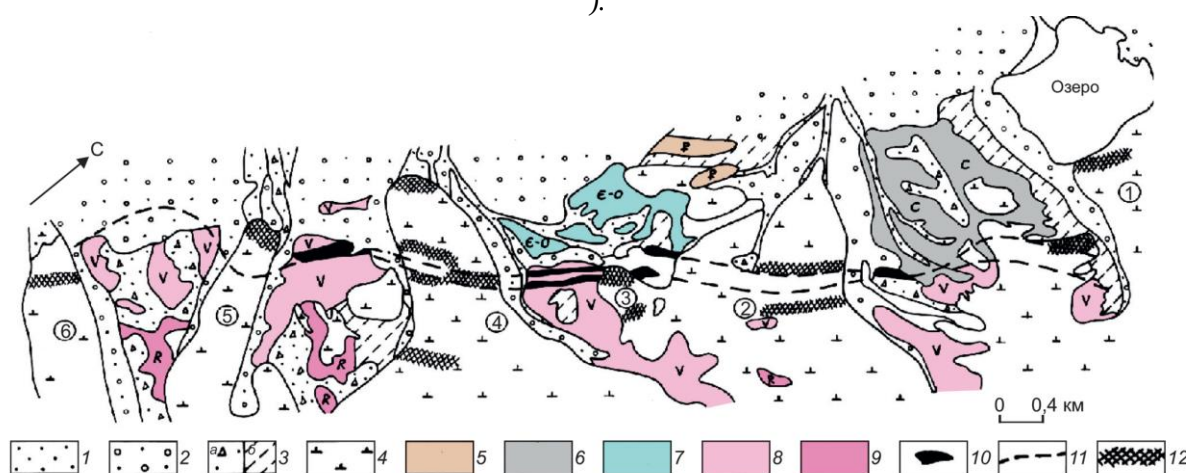


Fig. 1. Anomalies of cryogenic geochemical fields (CGF) on the surface of glaciers of the Kumtor ore field

Cenozoic deposits: 1 - alluvial, pebbles, sands; 2 - eluvial-deluvial, crushed stone, gruss, sands; 3 - glacial (a) and deluvial-proluvial (b), boulders, pebbles, crushed stone, sand, loams; 4 - glacial ice (glaciers: 1 - Petrov; 2 - Lysy; 3 - Davydov; 4 - Sary-Tor; 5 - Boordu; 6 - No. 354).

Geological formations: 5 - Paleogene and 6 - Lower Carboniferous sandstones, siltstones; 7 - Cambrian-Ordovician limestones; 8 - Vendian shales, phyllites; 9 - Riphean volcanogenic-sedimentary deposits; 10 - ore bodies; 11 - faults; 12 - cryogenic geochemical fields

Halos of gold and typomorphic elements are located on the glacier surface at the epicenter directly above the projection of the ore zone. The anomalies typically extend 150-200 m in the direction of glacier movement, sometimes reaching its tongue.

The southwestern flank of the Central Area of the deposit is overlain by the Davydov Glacier.

The glacier is 0.8-0.9 km wide at its base, and its ice thickness reaches 160-175 m, with an average thickness of 85-100 m. According to thermometry, the ice temperature is -6°C at a depth of 5 m and approaches the melting point at depths greater than 30 m. The depth interval of 40-109 m is filled with melted water, and the ice temperature in this interval is no lower than -0.5°C .

The glacier tongue is fractured in its middle and upper parts and is divided longitudinally into two branches by a medial moraine. The glacier branches exhibit varying activity. The surface velocity of the right branch of the glacier in summer is 1-2 cm/day; the left branch is more active, at 1-4 cm/day. The slope of the tongue is $5-6^{\circ}$. Below the glacier, between the tongue and the terminal rampart of moraine ridges 80-90 m high, there is a vast outwash field.

On the tongue of the glacier, the thickness of the accumulated snow layer varies from 20 cm at the base to 150 cm at the alimantation level, with a density of 0.36 g/cm^3 .

In cross-section, the glacier has an asymmetric structure, with the greatest ice thicknesses confined to its left side.

The bottom of the glacier is composed of ice with a relatively high content of moraine debris, with a total

thickness ranging from several meters to 11 m. The upper layer of the glacier is composed of relatively clean ice. Geochemical sampling on the Davydov Glacier was conducted along two profiles along both branches of the tongue. Sampling intervals were generally 100 m. In areas where the ore zone is presumably overlain by a glacier, clear geochemical anomalies of elements typomorphic to the ore body and endogenous aureole are recorded on the glacier surface: Au, W, Pb, Cr, Cu, and Sn. The contrast of these anomalies, relative to the background content in glaciers of the Ak-Shyrak glacier massif, decreases in the following order: Au(20) - Pb(5) - Cr, Cu, Mo(3) - W, Sn(2).

The aureoles of typomorphic elements are located on the glacier surface at the epicenter of the ore zone, overlain by a thick layer of ice. The anomalies extend 150-200 m along the glacier's direction of movement. Two adjacent ore zones, northern and southern, are suspected to be located on the right branch of the tongue. These zones, exposed by subsequent mining operations (see Fig. 2), have a combined thickness of approximately 0.3 km and form a common anomalous region, extending approximately 600 m for gold and up to 900 m for sulfates.

Anomalies of indicator elements of gold mineralization on the surface of the Davydov Glacier form both above the ore body and within endogenous halos, reflecting the composition of the ore mineralization.

An increase in pH and Eh (with an Eh gradient of 70-84 mV) is observed directly at the epicenter of the ore zone. Indicator elements of endogenous halos—Cu, Mo, and Cr—form bimodal halos with modes on the sides of the ore zone projection [7]. Within the aureole formed above the ore zone, elevated contents of sodium and sulfate ions are noted. While somewhat more contrasting sulfate and sodium halos are recorded above the right branch of the Davydov Glacier, elevated contents of most heavy metals are observed above its left part. The extent of the aureoles also increases above the left branch of the glacier. For example, for gold halos, it almost doubles—from 0.7 km to 1.4 km. Moreover, the ice thickness is noticeably greater above the left branch of the Davydov Glacier. The extensive extent of the anomalies and their complexity indicate a more complex structure of the ore zone beneath the glacier

and the existence of a sublatitudinal tectonic fault in the central part of the glacier. Indeed, the nature of the ore zone to the southwest of the Davydov Glacier changes significantly, as recorded during glacier penetration during subsequent geological exploration of the deposit [3, 5, 10]. Lysy Glacier is located 2.0 km northeast of the Central section of the deposit. A gold-bearing ore body is currently being mined within and beneath the

glacier. Lysy Glacier is a hanging-type glacier located at elevations of 4,050–4,200 m. The ice thickness in the study area is 60 m. According to thermometry data from mine workings within the glacier, the ice temperature ranges from -6°C at the surface to -2.5°C at the bottom.

The glacier overlies the gold ore body for nearly 300 m (Fig. 2).

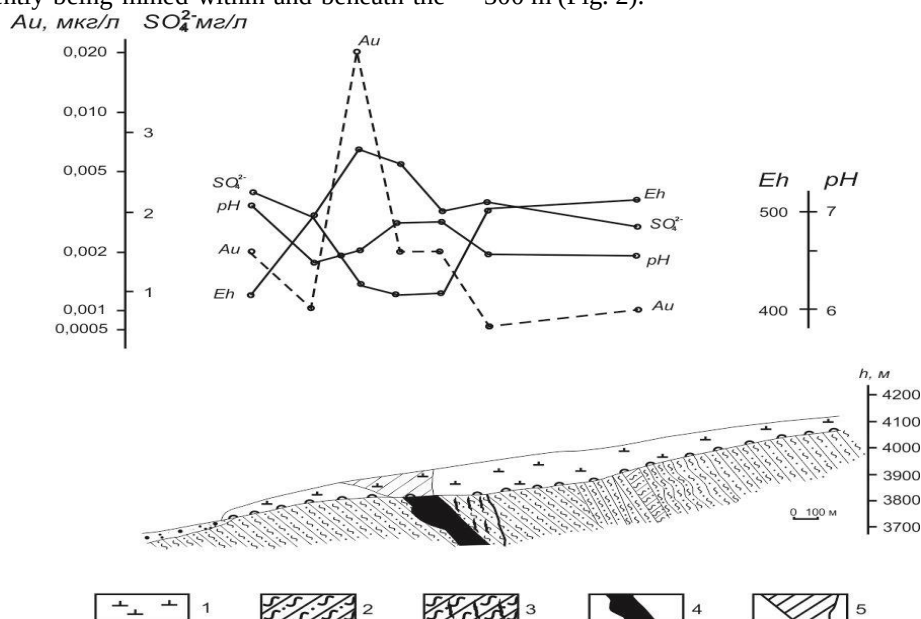


Fig. 2. CGP anomalies on the surface of the Davydov Glacier at the epicenter of the ore body.
1 - glacier; 2 - sandy-clayey shales; 3 - metamorphosed shales; 4 - ore metasomatites; 5 - endogenous and cryogenic geochemical halos

The base of the glacier, within the deepest part of the bed, is located at an elevation of 4,050 m. It has been established that the content of typomorphic elements in glacial ice in the contact zone with rock, 0.1–0.3 m from the ore, is tens of times higher than the background content in the glaciers of the massif. The penetration of chemical elements into ice is caused by cryogenic migration and the formation of a dispersion halo. The maximum contrast of the geochemical halo is observed directly at the contact of the ice with ore metasomatites and decreases with distance from the ore to the glacier surface. On the glacier surface above the ore

Anomalies of indicator elements for gold mineralization in the glacier form both above the ore body and within endogenous halos, reflecting the composition of the ore mineralization.

The distribution of chemical elements on the glacier surface is non-uniform. Directly at the epicenter of the ore body, anomalies of gold, zinc, copper, tungsten, and chromium are observed on the glacier surface with virtually no displacement. Negative anomalies above the deposit are formed by sulfates and the redox potential (Eh). In some places, a shift of gold halos toward the glacier tongue is observed, reaching 80 m in some

areas. A number of indicator elements—Ag, Sn, Pb, Zn, Sc, and Be, form more contrasting anomalies on the glacier surface above the northeastern part of the enriched section of the ore body. Thus, superimposed cryogenic geochemical halos of indicator elements form within the glacier overlying the orebody. The composition of the superimposed halos corresponds to the composition of the orebody and the endogenous halos. More contrasting geochemical anomalies form above the richer sections of the orebody in the glacier. The vertical range of indicator element migration and, consequently, the thickness of the superimposed halos on Lysyi Glacier are limited by an ice thickness of 50–60 m.

The structure of cryogenic geochemical fields on the glaciers of the Kumtor deposit is characterized by qualitative (chemical elements and compounds) and quantitative (element concentrations, halos extent) parameters, regularly distributed within the ice mass on the surface. The composition of the cryogenic geochemical fields of the glaciers reflects the composition of the orebodies and endogenous halos at the Kumtor deposit (Table 2).

Table 2.

Composition of cryogenic geochemical fields (CGF) of glaciers and endogenous halos at the Kumtor deposit

Glaciers	Composition of cryogenic geochemical fields on the glacier surface	Length of cryogenic geochemical fields, m	Glacier thickness, m	Sources of KGP discovered by mining operations
Petrova	Au, W, V, Cr, Cu, Zn, Mo, Sn, Pb, Bi	250	70-173	Ore mineralization
Lysy	Cu, Zn, W, Au, Cr	200	60	Ore body
Davydov	Au, Pb, Cr, Cu, Mo, W, Sn, Na, S	200-600	85-175	Ore body
Sary-Tor	Be, Cu, Zn, Sn, Cr, Pb, Mn, Tl, Au, Mo, TR	50-100	165	Ore body
Boordu	Au, Cu, Zn, Mo, Sn, Pb, W, Bi, V, Cr, S	200-250	100	Ore mineralization
№ 121*	Au, W, Ag, Cr, Cu, Zn, Mo, Sn, Pb	100-150	50-60	Ore body
Kumtor deposit [8, 11, 12]				
Endogenous geochemical halos	Au, Ag, Mo, W, Pb, Zn, Cu, Co, Ni, Ba, Ti, Mn, V, Be, K, Na			Ore field
	Au, Ag, Mo, W, K, Na			Ore body

* a small hanging glacier in the area of the Davydov Glacier

The formation of local geochemical fields on the glacier surface occurs as a result of the upward cryogenic migration of chemical elements, including ore elements, from the ore body (endogenous aureole) to the surface within the glacial ice. The composition of the local geochemical fields corresponds to the composition of the ore body and the endogenous aureole (see Table 2). More contrasting geochemical anomalies form above the richer sections of the ore body within

the glacier. The vertical range of indicator element migration, and consequently the thickness of the superimposed aureole, is limited by the ice thickness and ranges from 50-60 m (Lysy Glacier) to 165-175 m (Davydov, Petrov, and Sary-Tor Glaciers).

The thickness of glaciers in the continental and island regions of the Arctic and Subarctic can significantly exceed the ice thickness in the Kumtor deposit area (Table 3), particularly on Arctic islands (Severnaya Zemlya, Franz Josef Land, and others).

Table 3.

Thickness of glaciers in the island regions of the Arctic and Subarctic

Islands	Glacier thickness, m	Islands	Glacier thickness, m
Spitsbergen, Norway	80-500	Ushakov, Russia	250
Ellesmere, Canada	до 199	Franz Josef Land, Russia	300-450
De Long Island, Russia	80 – 150	Novaya Zemlya, Nordenskjöld Glacier, Russia	300-400
Severnaya Zemlya, October Revolution Island, Russia	up to 200-400	Severnaya Zemlya, Komsomolets Island, Russia	up to 500

The vertical range of cryogenic geochemical fields could theoretically reach hundreds of meters. The maximum thickness of their manifestation in the Middle Tien Shan (Kumtor) has not been established and is limited by the ice thickness of the studied glaciers – up to 175 m [5, 7].

The process of cryogenic migration of chemical elements during the formation of cryogenic geochemical fields is analogous to the cryogenic salt dispersion of ore components in permafrost deposits [13].

The concepts developed by Russian geochemists [13, 14, and others] regarding the characteristics of geochemical processes in the cryolithozone have made it possible to identify and study the previously unknown phenomenon of cryogenic salt dispersion of ore components. This phenomenon involves the migration of ore components from the ore body to the earth's surface (ice) at subzero temperatures in loose permafrost deposits and ice overlying ore bodies, caused by a concentration gradient of salts in non-freezing, ultra-thin

films of bound water. In this case, superimposed cryogenic dispersion halos are formed over deep-seated ore bodies.

The high rate of formation of geochemical fields, their morphology, and the distribution of positively and negatively charged ions in ice on the glacier surface are satisfactorily explained by the electrochemical model of their formation [15, 16, 17].

Conclusion

Conducted studies have shown that geochemical methods are promising for solving the challenges of prospecting for ore deposits in glacier-covered Arctic and Subarctic regions.

Geochemical studies were conducted at the Kumtor high-altitude gold deposit in the Middle Tien Shan (Kyrgyzstan). The region's climate is characterized by its harsh climate, with an average annual temperature of -7.8°C, comparable to the harsh Arctic conditions (Novaya Zemlya, etc.). The study focused on cold and warm glaciers: Petrov, Sary-Tor, Davydov,

Lysy, No. 354, and Boordu, which overlie the mineralized zone and ore bodies of the deposit. It was established that cryogenic geochemical field (CGF) anomalies form in the glacier ice at the epicenters of the ore bodies. The structure of the glacier-glacier ore bodies at the Kumtor deposit is characterized by qualitative (chemical elements and compounds) and quantitative (element concentrations, aureole extent) parameters, regularly distributed within the ice mass on the surface. The chemical composition of the glacier ore bodies reflects the composition of the ore bodies and endogenous aureoles of the Kumtor gold-tungsten deposit.

The glacier ore bodies form on the surface of glaciers at the epicenters of ore bodies with an established ice thickness of up to 175 meters. The extent of glacier ore body anomalies from the epicenter in the direction of ice movement ranges from 50-100 to 600 meters.

The formation of glacier ore body ore bodies on glaciers makes it possible to explore for mineral deposits overlain by thick ice sheets in the Arctic and subarctic regions of the North. In Russia alone, glacial systems in the northern regions of the country cover an area of approximately 53,000 km², within which large deposits can be found.

References:

1. Galyamov A.L., Volkov A.V., Lobanov K.V., Murashov K.Yu. Prospects for identifying deposits of strategic metals in the Arctic zone of Russia // *Arctic: ecology and economy*. 2017. No. 1 (25). pp. 59-74. DOI: 10.25283/2223-4594-2017-1-59-74.
2. Kaminsky V.D., Suprunenko O.I., Smirnov A.N. Mineral and raw materials resources of the Arctic continental outskirts of Russia and the prospects for their development // *Arctic: ecology and economy*. 2014, No. 3 (15). pp. 52-61. - DOI: .
3. New Catalog of Russian glaciers based on satellite data (2016–2019). THOSE. Khromova, G.A. Nosenko, A.F. Glazovsky, A.Ya. Muravyov, S.A. Nikitin, I.I. Lavrentiev // *Ice and Snow*. 2021, T. 61, No. 3. P. 341-358. Doi: 10.31857/S2076673421030093.
4. Volkov A.V., Galyamov A.L. Prospects for the mining industry in Greenland // *Arctic: ecology and economics*. 2016. No. 2 (22). pp. 24–34.
5. Petrakov D.A., Kovalenko N.V., Lavrentyev I.I., Usabaliev R.A. Thickness, volume, and recent changes in the Sary-Tor glacier (Ak-Shyirak massif, Inner Tien Shan) // *Earth's Cryosphere*, Vol. XVIII, No. 3, 2014. Pp. 91-100.
6. Semenov I. N. Physical and geographical characteristics of the Novaya Zemlya archipelago (literature review) // *Soil Science*, 2021, No. 10, pp. 1207-1230. DOI: 10.13140/RG.2.2.15583.20642.
7. Ermoolin E. D., Nemov A. E., Popov M. V. Permafrost-geothermal characteristics of the Kumtor deposit // In the collection: *Geocryological studies in the mountains*. Yakutsk: Permafrost Institute of the Siberian Branch of the USSR Academy of Sciences. 1989, pp. 31-40.
8. Shevkunov A. G., Guda A. A., Skorynina A. A., McKnight S. V. Study of the mineral composition of ores of the Kumtor deposit (Middle Tien Shan) by the QXRD and XRF methods // *Mineralogy*. Vol. 8, No. 3. 2022. Pp. 79–101.
9. Makarov V. N. Geochemical prospecting for deposits covered by glaciers. - *Geology and mineral resources of North-East Russia: Proceedings of the All-Russian scientific and practical conference*, 1–3.04.14. Yakutsk: Publishing house of NEFU, 2014. Pp. 271–276.
10. Cutler R. The largest gold deposit in Kyrgyzstan is losing its luster. - 09:53 21.07.2012. "Asia Times".
11. Nikonorov V.V., Karaev Yu.V., Borisov F.I., Tolsky V.I., Zamaletdinov T.S., Larina T.V., Gorbaneva T.V. Gold of Kyrgyzstan. Book 2 Description of deposits. Ore. Bishkek, "Nasi", 2004, 272 pp.: ISBN 9967-22-339-2.
12. Torgoev I.A. Glaciers, gold and geoecology of Kumtor. Riga, Lambert Academic Publishing, 2017, 204 p.
13. Makarov V.N. Geochemical fields in the permafrost zone. Yakutsk: Publishing house of the Institute of Permafrost Science SB RAS, 1998. 116 p.
14. Melnikov P.I., Ivanov O.P., Makarov V.N., Pitulko V.M., Shvartsev S.L. Phenomenon of cryogenic migration of chemical elements and its significance for prospecting for deposits in permafrost areas // *Reports of the USSR Academy of Sciences*. 1988, Vol. 303, No. 4, pp. 963-967. 15. Makarov, V.N. Natural electric fields and electrochemical anomalies at mineral deposits in the cryolithozone (pp. 228-235). In: V.S. Yakupov. *Geophysics of the cryolithozone*. Yakutsk: Publishing house of the Yakutsk University. 2008. 342 p.
16. Ryss Yu.S. Geoelectrochemical exploration methods. Introduction to geoelectrochemistry. - L.: Nedra, 1983. - 255 p.
17. Makarov V.N. The geochemical phenomenon - local geochemical fields in a glacier. – *Environmental Research in the Arctic 2000, Memoirs of National Institute of Polar Research. Special Issue*, No. 54, Tokyo, Japan. 2001, pp. 271-278. 1

**TIGHT-SHALE BURGER: CO-DEVELOPMENT OF THE PIMIENTA SHALE OIL FORMATION
AND JURASSIC-CRETACEOUS TIGHT RESERVOIRS ONSHORE THE SURESTE BASIN
(MEXICO)**

Bochkarev V.

PhD

Independent Upstream consultant, Mexico.

ORCID: 0009-0004-3642-6561

Bochkarev Ar.

PhD candidate, Gubkin Russian State University of Oil and Gas.

ORCID: 0009-0000-8526-3755

<https://doi.org/10.5281/zenodo.21982203>

Abstract

A Tight-Shale Burger concept is proposed — the first template, in Mexico (and worldwide), for simultaneous rather than sequential development of a source-rock interval and the adjacent tight reservoir it has charged. In the Sureste basin (the southeastern end of Veracruz state, the whole of Tabasco, and the western part of Campeche), the Tithonian Pimienta shale formation (Edzná) acts as the “patty,” while the overlying Jurassic-Cretaceous tight reservoirs — Oxfordian sandstones of the Ek-Balam group, Kimmeridgian oolites of the Akimpech formation, and Lower Cretaceous fractured dolomites — act as the “buns,” developed from a single wellpad and, where geometry allows, from a single horizontal wellbore. The central thesis: the economics of each of the two targets on its own is marginal, while combining them radically changes that economics through shared drilling and pad tie-in costs, diversification of the production profile, and infrastructure synergy. A differentiated completion design accounts for the difference in flow mechanisms (diffusion-matrix in the shale, fracture-dominated in the carbonate). A solution for flare-free utilization of sour associated gas is proposed: injection into depleted, oxidized Miocene sandstones, which serve simultaneously as underground gas storage and as a natural reactor for mineral hydrogen sulfide sequestration (a subsurface analogue of iron sponge). The applicability zone covers the southeastern tip of Veracruz state, the whole of Tabasco, and western Campeche (the latter predominantly a gas window). The approach's applicability beyond Mexico is shown — in the Maracaibo basin in Venezuela (La Luna formation). Target: a 4–6-fold increase in the region's onshore production by 2033–2035, to a level of 1.5–2 million bbl/d.

Keywords: Pimienta formation; Edzná; tight reservoirs; co-development; source rock; Tight-Shale Burger; Sureste basin; Salina del Istmo; Comalcalco; Reforma-Akal; Macuspana; differentiated completion; underground gas storage; mineral hydrogen sulfide sequestration; iron sponge; La Luna; Maracaibo.

1. The gap between a depleted surface and an undrilled depth

The Sureste basin and its four onshore structural provinces — Salina del Istmo, Comalcalco, Reforma-Akal, and Macuspana — stretching from the southern tip of Veracruz state through the whole of Tabasco to western Campeche, form one of the key oil and gas production regions of southeastern Mexico (Figure 1). It hosts both Miocene oil and condensate fields and sub-

stantial untapped potential in the deep Jurassic-Cretaceous section — and given the shared Late Triassic–Jurassic rift basement and the common Pimienta/Edzná source-rock interval, a similar “shale—tight reservoir” architecture is expected across all four provinces. This work details the concept using the Comalcalco sub-basin as the most thoroughly studied example, with direct applicability of the described solutions to the other three sub-provinces.

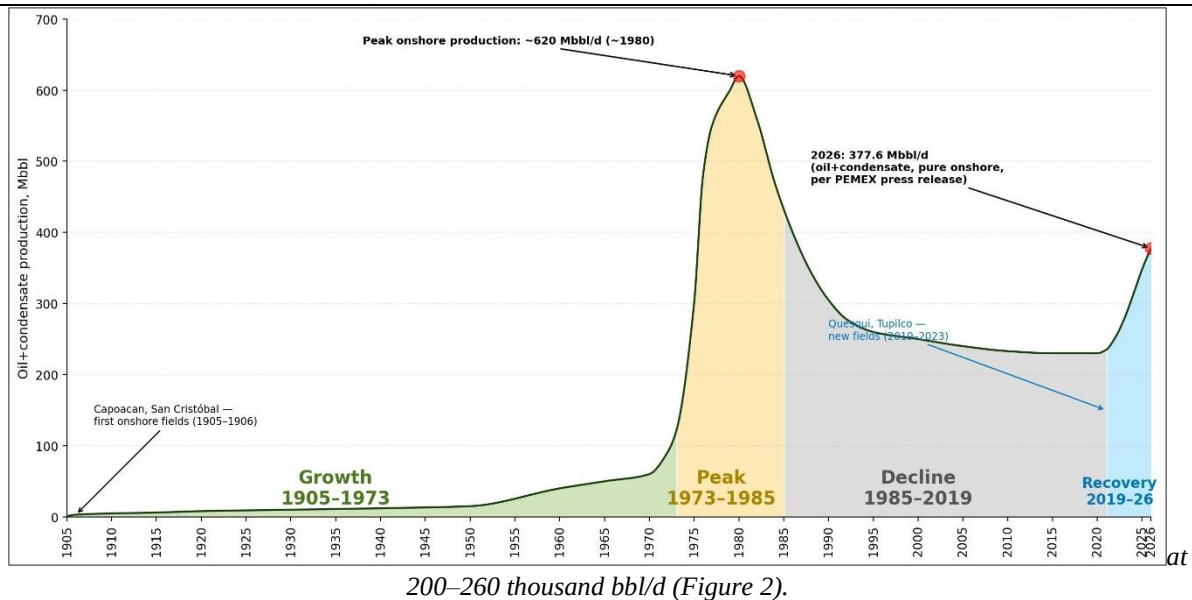


Figure 2. Oil and condensate production in Tabasco state, 1905–2026.

It is precisely this gap — between depleted Miocene accumulations at the surface of the play and the essentially undrilled Jurassic-Cretaceous complex at depth — that forms the economic logic of Tight-Shale Burger co-development. Infrastructure, well stock, and a century of field experience already exist at the surface; the resource lies at depth beneath them. The concept links the two.

2. Geology, stratigraphy, and source-rock intervals of the Comalcalco sub-basin

2.1. Structural-tectonic framework

The Comalcalco sub-basin is one of four structural provinces of the Sureste basin (alongside Salina del Istmo, Reforma-Akal, and Macuspana), treated in this work as a single applicability zone for the concept owing to their shared Late Triassic–Jurassic rift basement. Continental red beds of the Late Triassic–Early Jurassic lie at the base of the section; during the Callovian, a

Pacific marine transgression occurred, and under the resulting conditions of restricted circulation and elevated evaporation a thick evaporite sequence formed — the very salt whose tectonics (diapirs, salt pillows and walls, “rollers”) [12, 22] shaped almost all of the region's structural traps, including the Santuario block. Salt thickness in the Comalcalco sub-basin reaches 1,200 m. Carbonate deposition prevailed from the Late Jurassic to the Late Cretaceous, giving way to terrigenous deposition in the Paleogene amid the Laramide orogeny and formation of the fold-and-thrust structures of the Sierra Madre and the Chiapas range [21]. In the Middle Miocene (Serravallian), these structures were further deformed by lateral compression associated with movement of the Chortis block and subduction of the Cocos plate, followed by tilting to the north-northwest as salt was mobilized — it was this late-stage tectonics that formed the traps of the Miocene accumulations at Santuario and neighboring blocks (Figure 3).

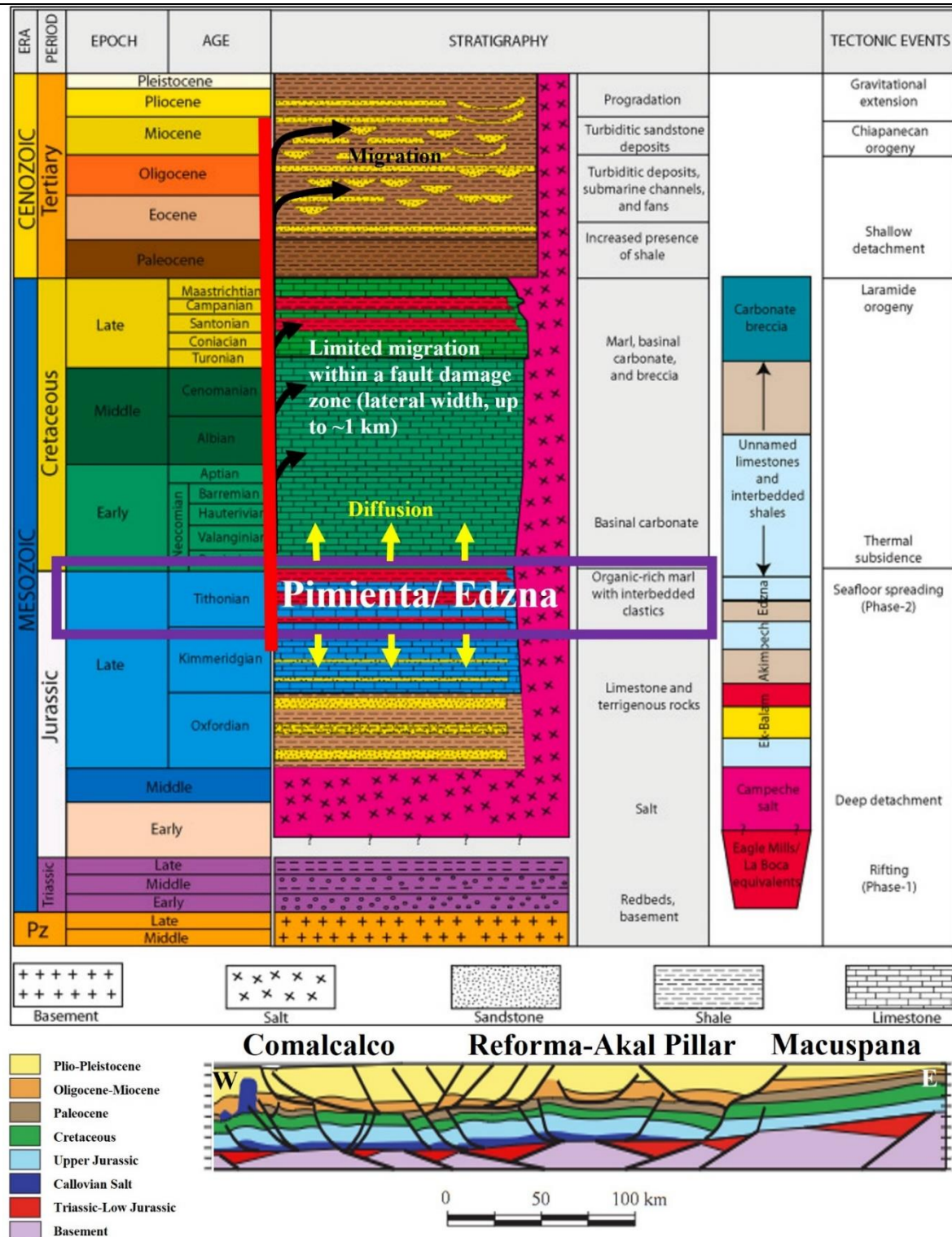


Figure 3. Average lithostratigraphic section of the Sureste basin, showing the principal hydrocarbon migration mechanism from the Upper Jurassic source-rock formation (Pimienta/Edzná), and a regional sub-latitudinal cross-section across the Sureste basin (from open sources).

2.2. Lithostratigraphy of the productive section

Formal lithostratigraphic names for the Comalcalco Jurassic-Cretaceous complex are scarce in the open literature — most PEMEX publications use the informal terms “Jurassic-Cretaceous Complex” (Complejo Jurásico-Cretácico) and “Cretaceous Breccia” (Brecha Cretácica). However, Comalcalco and Reforma-Akal are part of the single Sureste basin together with the Campeche shelf (the Cantarell, Sihil, and Ek-Balam complexes), where the stratigraphy is

formalized in detail and can serve as the nearest regional reference for correlating the Santuario section.

From bottom to top, the reference section of the Sureste basin includes: Callovian salt (Sal Calloviana) at the base; the Oxfordian stage — eolian sandstones of the Bacab formation and the terrigenous-evaporite sequence of the Ek-Balam Group, comprising three members, the middle one of which, predominantly sandy, is the main reservoir at the eponymous Campeche shelf field; the Kimmeridgian — the Akimpech Formation,

divided into four members, the uppermost of which, oolitic limestones, is the main tight-reservoir facies of the Kimmeridgian (an analogue of oolitic shoal bars); the Tithonian–Lower Berriasian — the Edzná Formation, the lateral and age-equivalent of the onshore Pimienta formation [20]; bituminous calcareous shales, the basin's main source-rock interval; the Cretaceous — dolomitized and intensively micro-fractured limestones, grading upward into a dolomitized breccia at the Cretaceous–Paleogene boundary; the Paleocene — the Cantarell and Abkatún formations, mudstones with a basal iridium-enriched ash layer (a marker of the Chicxulub impact event), acting as the regional seal; the Miocene — terrigenous deltaic sandstones, the productive interval of the Santuario, El Golpe, and Ogarrio fields.

2.3. The Pimienta / Edzná formation — the source-rock interval

The Pimienta formation (in its Campeche-shelf facies expression — the Edzná formation; Tithonian stage of the Upper Jurassic, locally grading into the Lower Berriasian) is the principal source-rock interval not only of the Comalcalco sub-basin but of the entire southern Gulf of Mexico, and is present in 4 Mexican states (Tamaulipas, Veracruz, Tabasco, and Campeche): according to a number of researchers [2, 5, 7, 18], it generated the hydrocarbons that filled practically all the giant onshore and offshore fields, including the heavy-oil fields of the Panuco–Ebano–Altamira blocks, the Golden Lane, Antonio J. Bermúdez, Cantarell, KMZ, and many others. Lithologically it is a black and dark-gray calcareous shale (carbonate mudstone) with interbeds of bituminous limestone and chert.

Key geochemical parameters (from regional analogue sections of the Gulf of Mexico): TOC averaging 3.0–4.5%, up to 5% in individual interbeds; kerogen predominantly Type II, of marine origin; gross interval thickness in the most thoroughly studied sections (Tampico-Misantla) reaches 300–500 m, with an organically enriched effective interval of 100–200 m; matrix permeability is extremely low — after secondary fracturing and diagenetic alteration it does not exceed a few hundred nanodarcies (up to ~300 nD), typical of carbonate-type shale formations, which necessitates hydraulic fracturing [2–8, 14, 17]. In Comalcalco, where the Pimienta/Edzná burial depth is substantially greater than in Tampico-Misantla, a higher thermal maturity is expected, and correspondingly a shift in the generated hydrocarbon composition toward light oil and condensate (Figure 4).

2.4. Jurassic-Cretaceous tight reservoirs

Below and partly within the Jurassic-Cretaceous section lie tight reservoirs comprising at least three productive levels: (1) Oxfordian terrigenous-carbonate deposits of the Ek-Balam group (a siliciclastic shelf bar); (2) Kimmeridgian oolitic shoal bars of the Akimpech formation, associated with structural highs — relicts of rift topography; (3) Lower Cretaceous dolomitized and fractured limestones. This very three-tier stack — Oxfordian sandstone, Kimmeridgian oolite, Cretaceous dolomite — has been documented as the reservoir sequence at the Sihil field (a neighboring block of the Cantarell complex) [23] and is regarded as a structural analogue of the section expected within the onshore part of Tabasco state.

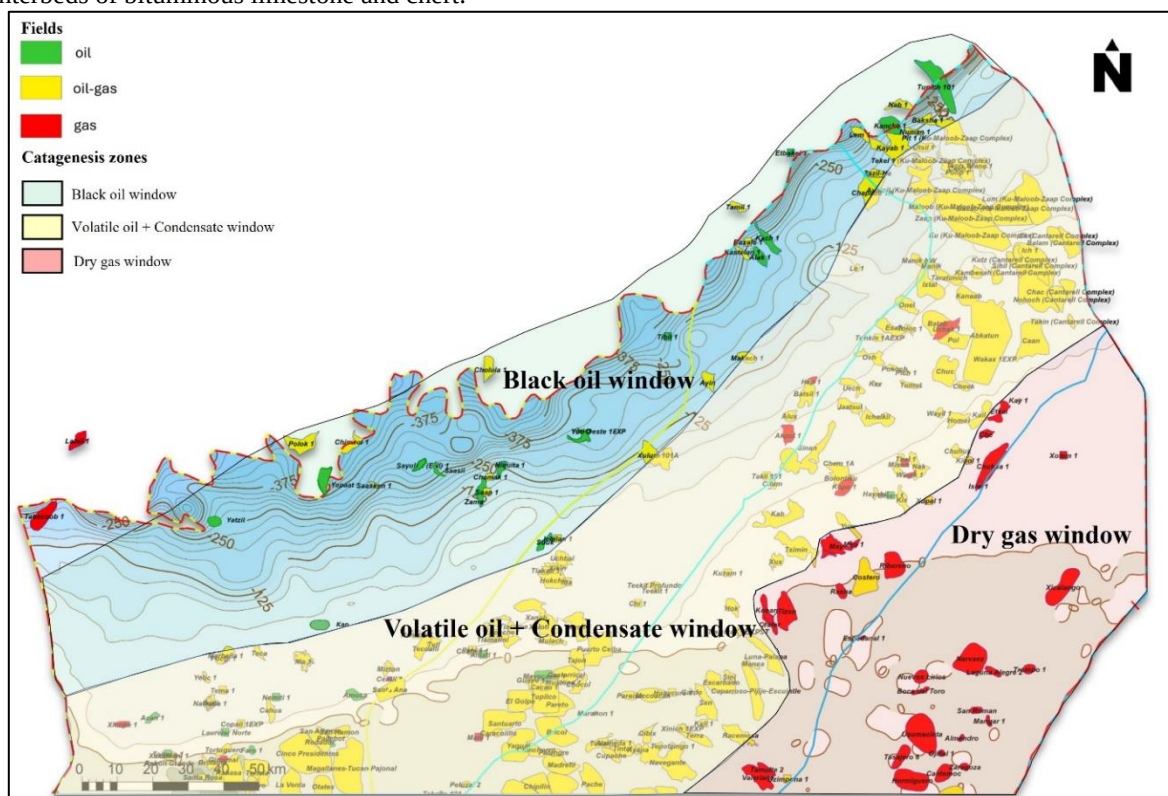


Figure 4. Catagenetic zonation of the Pimienta/Edzná source-rock formation within the Sureste basin.

Porosity in these reservoirs is predominantly secondary in origin — the result of dissolution, dolomitization, and intensive microfracturing [26]. Based on

analogue Cretaceous sections in the region (the Poza Rica–Tampico trend), typical porosity values are 8–12% in grain-dominated facies [15, 24] and around 3%

in mudstones, while matrix permeability averages no more than 2 mD, rarely reaching a few hundred millidarcies owing to the fracture component. It is precisely this secondary (fracture) permeability that historically delivered the commercial rates of the giant Bermúdez, Catal, and Sitio-Grande fields — and it retains its defining role for the prospective tight targets of the on-shore Sureste basin (southern Veracruz, Tabasco, and western Campeche).

Productivity of the Jurassic-Cretaceous complex has already been proven at a number of fields: Tupilco, Yaxché, Palangre, Chinchorro, Pareto, Mayacaste, Arastradero, Tajón, Puerto Ceiba, Xanab, and others. At these fields, the Jurassic-Cretaceous complex yields light and medium oil at 33–45° API, consistent with the general characterization of the Mesozoic accumulations of the Reforma province as predominantly light-oil targets (Table 1).

Table 1. J

Jurassic-Cretaceous tight reservoirs of the Comalcalco sub-basin

Level	Age / lithology	Porosity type	Porosity / permeability	Analogue fields
I (upper)	Oxfordian deposits of the Ek-Balam group (siliciclastic shelf bars)	Primary + secondary	8–12% in grain-dominated facies	Sihil (Cantarell complex)
II (middle)	Kimmeridgian oolitic shoal bars of the Akimpech formation	Secondary (dissolution, dolomitization)	~3% in mudstones, matrix <2 mD	Reforma-Bermúdez (~8 billion bbl), Catal, Sitio Grande
III (lower)	Lower Cretaceous dolomitized and fractured limestones	Fracture (secondary)	Matrix <2 mD, fractures — a few hundred mD	Tupilco, Yaxché, Palangre, Chinchorro, etc. (33–45° API)

2.5. Traps, seals, migration

Traps in the Jurassic-Cretaceous complex are predominantly structural, associated with salt domes, diapirs, and fault-block highs, complicated by normal and thrust faults of the Laramide and Miocene deformation phases. At a number of fields (Puerto Ceiba), the internal seal between the Kimmeridgian and Cretaceous productive levels is the Tithonian Pimienta/Edzná itself — a thin but laterally persistent impermeable interval. The regional seal for the entire Mesozoic complex is provided by the Paleocene mudstones of the Cantarell and Abkatún formations, with an iridium-enriched ash layer at the base — a geochemical marker of the Chicxulub event [16], reliably traceable across the whole southern Gulf of Mexico section.

Hydrocarbons generated in the Pimienta/Edzná migrated upward along the fault and fracture system. In zones of active faulting, the most intensive saturation of tight reservoirs occurs across the full height of the section, including into the overlying Tertiary deposits. This migration mechanism is associated with the fault damage zone — a fracture-enhanced permeability halo

whose lateral width, according to the literature, ranges from a few hundred meters up to ~1 km depending on fault displacement [1, 11]; within it, migration proceeds as through an ordinary fractured reservoir, while beyond its boundary the matrix remains tight and impermeable. In zones remote from faults, a diffusion-dominated migration mechanism prevails, and reservoir saturation takes on a more uneven, patchy character: saturation is concentrated mainly at the direct contact zone between the shale and the tight formation, while in the middle and upper part of the tight formation it is limited or entirely absent. This distribution directly determines the placement strategy for the first pads and horizontal wells, sub-parallel to the Chiapas fold system.

3. Tight-Shale Burger — a new development paradigm

The concept is named “Tight-Shale Burger” (or “Pimienta Burger”): the Pimienta shale formation acts as the “patty,” while the Upper Jurassic and Lower Cretaceous tight reservoirs act as the “buns,” forming a multi-layer hydrocarbon “burger” (Figure 5).

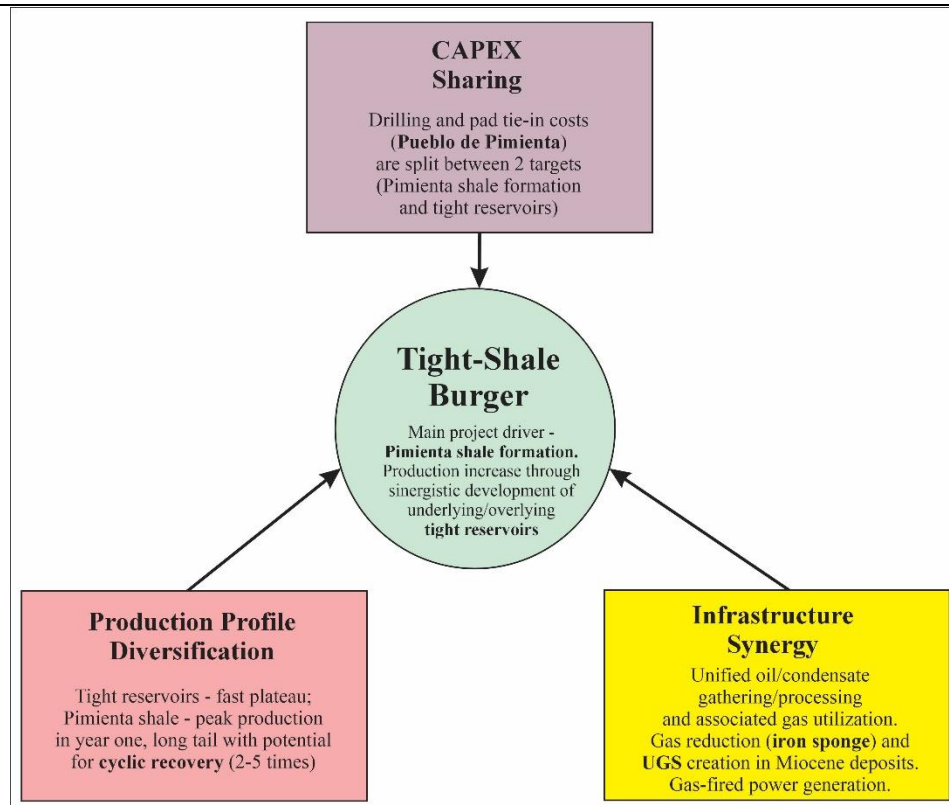


Figure 5. Architecture of the Tight-Shale Burger approach.

3.1. Why this is a new paradigm

In global practice, a source-rock shale and the adjacent reservoir it has charged are traditionally developed separately and sequentially — first as a conventional target (sometimes for decades), then, as a separate program, as an unconventional one. The classic example is the Eagle Ford–Austin Chalk system in Texas, USA: the thin, bituminous Cretaceous deposits of the Austin Chalk formation were developed as a conventional fractured reservoir starting in the 1970s, while the underlying Eagle Ford source-rock shale was not brought into development until 40 years later, with the advent of horizontal drilling and multistage fracturing, and is today regarded as a “hybrid petroleum system,” with the Austin Chalk formation charged by fluids from the Eagle Ford shale interval along fractures [4, 8]. A similar logic applies to the Woodford/Mississippi Lime (SCOOP/STACK) system of the Anadarko basin.

Tight-Shale Burger takes this logic to a qualitatively new level: instead of sequential development of the source and the reservoir, it proposes their simultaneous co-development from a single pad from day one of the field's life. For southern Mexico, where Jurassic-Cretaceous tight targets such as Tupilco and Puerto Ceiba have already proven commercial productivity, while the Pimienta shale had previously not been considered a standalone target, this is the country's first systematic template for genuinely joint, rather than sequential, development of a shale formation and a tight reservoir.

3.2. Economic rationale of the “burger”

The key proposition underlying the concept's viability is as follows: the synergy of the two targets substantially increases the economic effectiveness of co-

developing the shale and tight formations compared with developing them separately.

Isolated tight-carbonate lenses of the Kimmeridgian and Cretaceous, remote from major structures (targets of the Tupilco type), are characterized by limited productivity, often compartmented by fracture blocks; the matrix, away from faults, lacks oil saturation owing to the limited reach of diffusive migration from the Pimienta formation. Standalone development of such tight reservoirs will therefore have marginal economics.

Combining both targets in a single wellbore and a single pad changes the economics along three independent dimensions simultaneously:

- Capital cost sharing. Drilling, tie-in, and pad-construction costs are allocated not to one but to two productive targets — unit CAPEX per barrel drops multiple-fold, since the most expensive component (the wellbore, the pad, the infrastructure) is shared.
- Diversification of the production profile. The carbonate interval delivers a fast initial plateau (fracture permeability, immediate inflow); the shale delivers a peak followed by a sharp decline over 12–15 months, with potential for cyclic recovery. The combined profile is smoother and more predictable than that of either target on its own.
- Infrastructure synergy. A single gathering, processing, power-generation, and — critically — gas utilization system serves both targets. Pimienta's gas solves the energy-supply and injection problem for the entire pad.

It is precisely this triple synergy — not the productivity of either target on its own — that is the source of the concept's high profitability. Tight-Shale Burger is

first and foremost an economic, and only then a technological, innovation (Figure 6, Table 2).

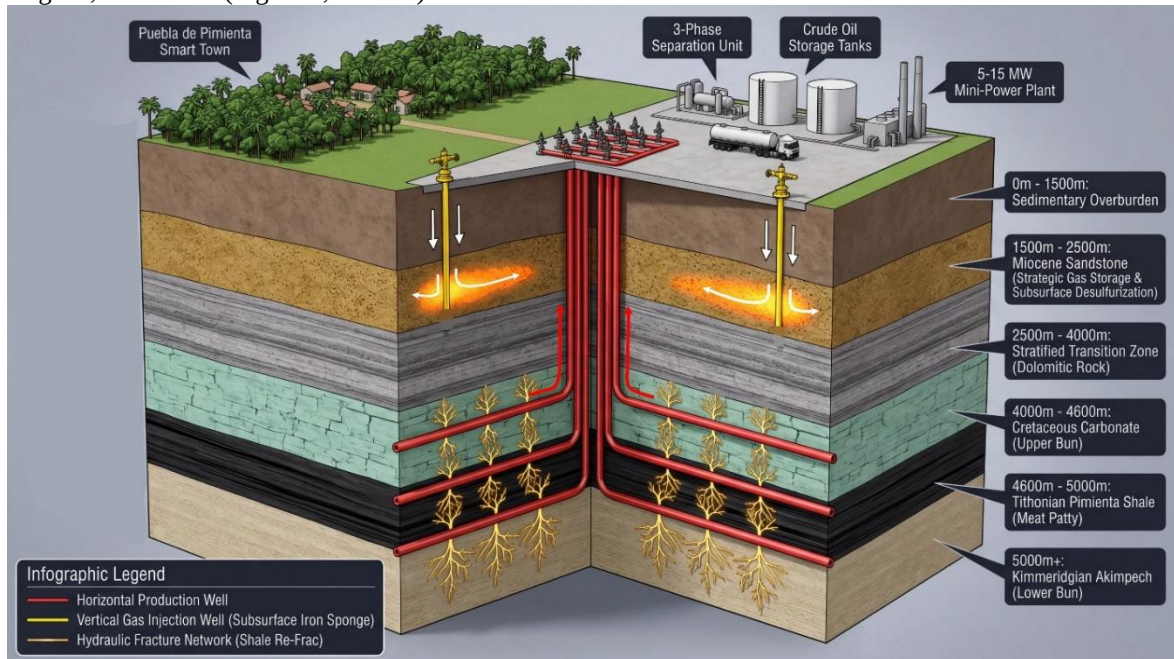


Figure 6. Conceptual pad layout (Pueblo de Pimienta) for co-development of the shale and tight formations (Tight-Shale Burger)

Table 2.

Triple economic synergy of Tight-Shale Burger

Synergy direction	Mechanism	Effect
Capital cost sharing	Drilling, tie-in, and pad-construction costs are allocated to two productive targets	Multiple-fold reduction in unit CAPEX per barrel
Diversification of production profile	Tight reservoirs — fast initial plateau; shale — peak production and sharp decline over 12–15 months, then a long “tail” with potential for cyclic recovery (re-frac)	Smoother, more predictable combined production profile
Infrastructure synergy	Unified gathering, processing, power-generation, and associated-gas utilization system	Pimienta's gas covers power supply and injection for the entire pad

3.3. Completion design

Flow mechanisms in the shale and in the tight reservoirs are fundamentally different — diffusion-matrix in the Pimienta versus fracture-matrix in the Jurassic-Cretaceous carbonates. Despite this, a single technological fracturing protocol is proposed for both targets (one fleet, one base fracturing fluid), with a single adjustable parameter — the presence or absence of an acid stage: it is not required for the Pimienta, while for the tight carbonates it is introduced to reactivate the existing natural fracture network. This is not two incompatible completion designs but a single protocol with a switchable parameter, which removes the question of sleeve and packer compatibility between intervals:

- Pimienta interval — 2,000-m horizontal wellbores are oriented parallel to the Chiapas fold system (maximum stress direction), with a dense grid of frac ports (plug-and-perf), reduced cluster spacing (18–25 stages), and increased proppant intensity, aimed at creating the well's own network of induced fractures in the low-permeability matrix. Horizontal wells are placed at the top and base of the shale formation to simultaneously cover both the shale and tight intervals, creating a production synergy with a high initial rate and a sustained plateau owing to cyclic development of the shale formation.

- Tight-carbonate interval — 2,000-m horizontal wells are placed at 2/3 of the reservoir thickness from its base for maximum coverage of the tight reservoir. A wider stage spacing (10–15 stages) with a hybrid (slickwater + acid) fracturing design is proposed, targeting both the creation of new fractures and the reactivation and cleanup of the existing natural fracture network (by analogy with practice at the Austin Chalk formation in the US). Well orientation is the same as in the shale formation.

- Within each wellpad, in addition to the synergy wellbores at the top and base of the Pimienta, dedicated calibration wells are drilled separately — one horizontal well into the shale formation and one into the tight reservoir, both in the middle of the respective formation, outside the contact zone. Their purpose is to determine the production capability of each target individually, so that the contribution of each formation to the combined rate of the synergy wellbores can be correctly assessed. Final pad layout: 20 wells into the Pimienta shale (10 at the top, 10 at the base) plus 16–20 wells into the tight reservoirs (calibration and coverage wells) — 36–40 horizontal wells per Pueblo de Pimienta in total.

4. Technical development parameters

The unit of development is the Pueblo de Pimienta wellpad cluster. Each Pueblo comprises 36–40 horizontal wells (20 into the Pimienta and 8–10 into each of 2 tight reservoirs), 2 km long, spaced 400 m apart. Horizontal wellbore orientation is chosen parallel to the Chiapas fault system (along the maximum horizontal stress direction, SHmax) to create an optimal fracture network transverse to the wellbore (Table 3).

Wellbore placement within the section is determined by structural position:

- At the areas of existing fields and structural highs, horizontal wells are drilled at the top and base of the Pimienta formation — this provides simultaneous coverage of both the shale interval and the adjacent tight reservoirs (full realization of the “burger”).
- In inter-structural zones (between discovered fields), horizontal wells are placed in the middle of the Pimienta to minimize the risk of aquifer breakthrough [19] (aquifer presence in the tight reservoirs requires confirmation at the pilot stage).

Cyclic development of the Pimienta shale interval (shutting in wells after 36 months of continuous production for 2–3 weeks to stabilize the near-wellbore

zone, followed by a re-frac) allows rates to be restored to 70–90% of initial values and additionally recovers hydrocarbons from the kerogen's unrealized generation potential (S2). The physical basis of this mechanism — removal of the pressure brake on generation upon draw-down — is presented separately by the authors and is the subject of a standalone work (Figure 7) [2–8].

5. Associated gas utilization: underground storage with mineral desulfurization

Co-development of the shale and tight formations will inevitably generate significant volumes of dissolved gas, which, at the early pilot stage — given the distance from gas-processing infrastructure — risk being flared. This is a direct loss of a marketable product and, at the same time, a regulatory and reputational risk (CO₂ and methane emissions). The proposed solution follows from the geology of the old Miocene fields themselves: injecting the surplus gas into depleted Miocene sand intervals, turning them into underground gas storage.

It is important to separate this solution into two levels, differing in technological maturity and risk.

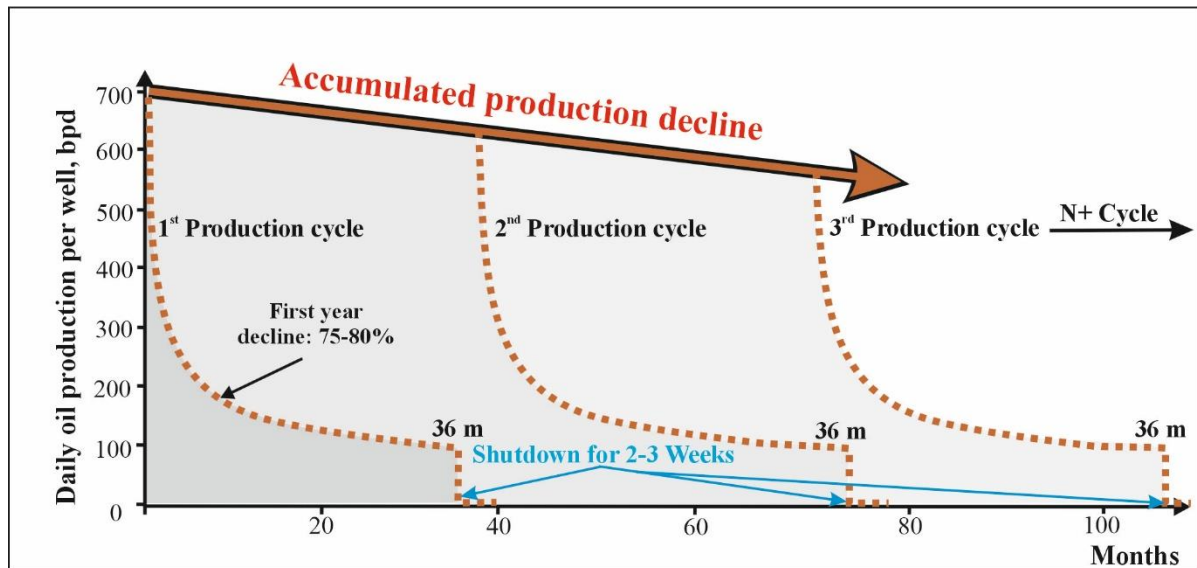


Table 3. Technical parameters of the Pueblo de Pimienta pad

Parameter	Value
Number of horizontal wells per pad	36–40
Horizontal wellbore length	2 km
Well spacing	400 m
Wellbore orientation	Parallel to the Chiapas fault system (along SHmax)
Section placement — field/high areas	Top and base of the Pimienta, plus placement at 2/3 thickness from the base within tight reservoirs (full “burger” realization)
Section placement — inter-structural zones	Middle of the Pimienta (reduces aquifer-breakthrough risk). Aquifer presence in tight reservoirs is verified during pilots.
Shale-interval development cycle	2–3-week shut-in + re-frac
Rate recovery after re-frac	70–90% of initial
Initial rate, shale well	400–800 bbl/d
Initial rate, tight well	500–1,200 bbl/d
Initial rate, wellpad	25–35 thousand bbl/d

Figure 7. The principle of cyclic development of shale formations [2, 5–7, 9].

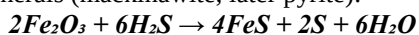
5.1. Underground gas storage — a mature, low-risk foundation

Creating underground gas storage (UGS) in a depleted reservoir is a proven technology, applied worldwide for decades. The depleted Miocene sandstones of the Reforma-province fields, with their developed well stock and well-known geology, are ready-made assets for storing surplus gas (the Santuario field is 73% depleted, El Golpe 90%, Caracolillo fully depleted). Already at this level, the main objective is achieved: elimination of flaring and formation of a strategic gas reserve for subsequent power generation, petrochemistry, or export. This level contains no hypothetical assumptions and constitutes a reliable foundation for the solution.

5.2. Mineral hydrogen sulfide sequestration — a promising add-on

Part of the gas from the Pimienta formation contains sour components (H_2S , CO_2) — a typical feature of gases generated in a reducing, organic- and sulfate-rich (salt, anhydrite) setting. Instead of carrying this gas to a surface desulfurization unit (amine process), the concept proposes using the terrigenous Miocene reservoirs themselves as a natural polishing reactor.

Mechanism: in oxidized, near-surface, or previously oxygen-water-flushed intervals of the Miocene sandstones (near paleo gas-water contacts, in the updip parts of structures), iron is present predominantly in the trivalent form — within hematite-goethite film cements. On contact with hydrogen-sulfide-bearing gas, this oxidized iron is reduced, binding H_2S into stable sulfide minerals (mackinawite, later pyrite):



This is a direct subsurface analogue of the industrial “iron sponge” process, applied for decades to sweeten sour gas at the surface — only here the scrubber's role is played by the reservoir rock itself.

5.3. Static regime and the timescale of the effect

It is essential that the proposed scheme is not designed for a fast effect and is not a flow-through treatment. Gas is injected and deposited; the binding reaction proceeds in a static regime over years. It is precisely this regime that removes the main kinetic objections: slow diffusive mass transfer between the gas and the rock grains, as well as gradual passivation of the iron by the forming sulfide crust, are not obstacles where the process is allotted a decade-long timescale. Monitoring is simple and cheap: an annual gas sample from a monitoring well, plotting an H_2S concentration curve over time. A declining concentration confirms binding; stability disproves it.

5.4. Capacity limitation and mineralogical screening

The scheme's viability may face two possible limitations, which must be verified on available Miocene core:

First — the form of the iron. Published studies on underground gas storage also document the reverse process: pyrite already present in a reduced (mature, long in contact with hydrocarbons) reservoir may, conversely, serve as a source of H_2S rather than a sink for it [13]. The scheme's viability depends directly on the

initial redox form of the iron: specifically oxidized forms (hematite/goethite), not reduced ones (pyrite/siderite), are required. This is checked by X-ray diffraction analysis of core to determine the iron speciation at the pilot stage of the project.

Second — binding capacity. The effect is limited by the amount of available trivalent iron: the total mass of sulfur that can be bound is finite and is determined by the mass of reactive Fe^{3+} per unit reservoir volume. For gas with a low H_2S content (fractions of a percent to a few percent), the capacity of a depleted sand body may suffice for very large gas volumes; for highly sour gas it will be exhausted faster. In other words, for fields with high H_2S content, this is about reducing the surface sulfur load, not fully replacing desulfurization under reservoir conditions. Capacity and passivation-rate assessment is performed by a core-flood column experiment with hydrogen-sulfide-bearing gas.

If the concept is confirmed, the benefit is clear: instead of flaring, a strategic underground gas reserve is formed; emissions and associated costs are reduced; capital costs for surface desulfurization are partly offset by using the existing well stock of depleted Miocene fields; and sulfur is bound mineralogically in the rock rather than being brought to the surface, requiring storage and disposal.

6. Incremental approach and placement of the first pads

The first Pueblo de Pimienta pads are placed only near faults, along which active vertical migration of hydrocarbons from the Pimienta occurs (Figure 8). In these zones, tight reservoirs are maximally saturated across the full height of the section, including into the overlying Tertiary deposits. The farther from the faults, the greater the role played by diffusive charging from the Pimienta — hydrocarbon distribution takes on an uneven, patchy character: saturation is concentrated mainly at the direct contact zone between the shale and the tight formation, while in the middle and upper part of the tight formation it is limited or entirely absent, which is indirectly confirmed by the development of similar tight reservoirs offshore the Gulf of Mexico (the Och, Pokoch, Ichakil, Jeatsul, Sinan, Chuc, and many other fields).

This placement implements the incremental principle common to the entire series of concepts: start in zones of maximum geological certainty (fault zones with proven saturation), confirm the technology and economics there, and only then extend development to zones remote from faults with diffusive saturation. Each subsequent step builds on a confirmed result from the previous one, not on an assumption. In inter-structural zones (outside the fields), the presence of an aquifer in the tight reservoirs must be confirmed to remove the risk to co-development of the shale and tight reservoirs (Figure 8).

Part of the produced dissolved gas is used on-site for power generation, and the remainder for injection into depleted Miocene structures to form an underground gas reserve, instead of surface desulfurization and flaring.

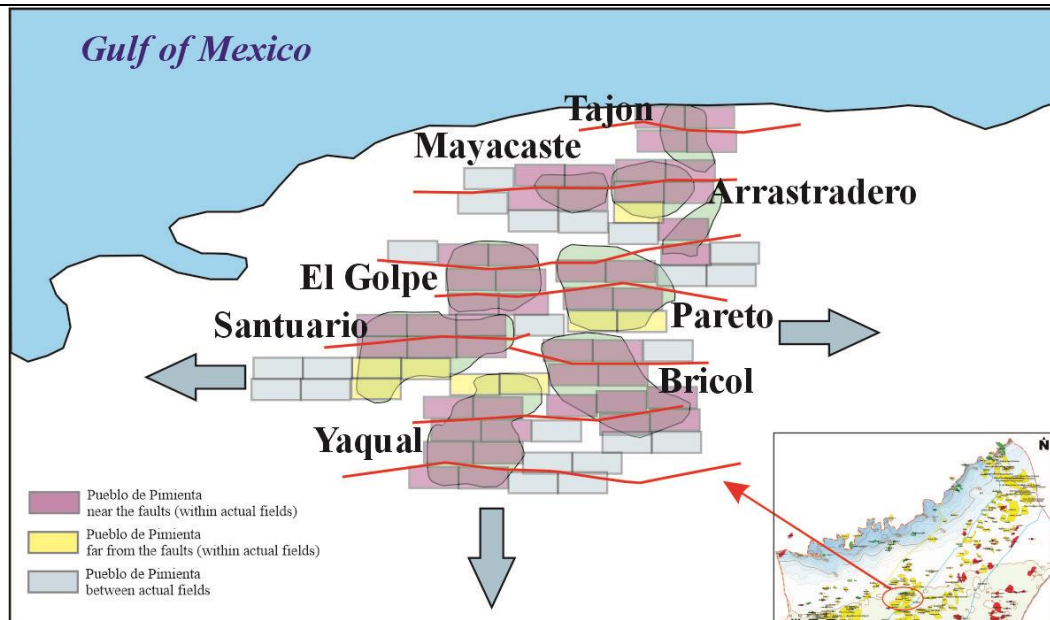


Figure 8. Drilling priority for Pueblo de Pimienta pads by position relative to faults within the fields of the Comcalco sub-basin, illustrated by the Tajón, Mayacaste, Arrastradero, El Golpe, Pareto, Santuario, Bricol, and Yaqual fields.

7. Applicability of the approach beyond Mexico: the Maracaibo basin

The Tight-Shale Burger concept is not confined to the Sureste basin. Its direct structural analogue beyond Mexico is the Maracaibo basin (Venezuela), where the full “source—adjacent underlying carbonate—overlying sandy reservoir” configuration is reproduced.

Here, the Upper Cretaceous La Luna formation — the region's main source-rock interval, accounting for over 98% of the basin's reserves [27, 28] and, by geochemical parameters (TOC up to 9%, Type I–II kerogen, marine anoxia), close to the Pimienta formation — charged, along sub-vertical strike-slip faults, both the adjacent fractured Cretaceous carbonates (the La Paz, Mara, and Rosario fields — among the world's best-known fractured carbonate reservoirs) and the overlying Eocene-Miocene sandstones of the Bolívar coastal belt (Lagunillas, Bachaquero, Tia Juana, Cabimas).

It is significant that this analogy extends beyond the “burger” to the gas solution as well. The sand reservoirs of the Bolívar belt have been produced since the 1940s and are substantially depleted (more than 90%); this is a ready-made system of huge, depleted, oxidized sand reservoirs — a direct candidate for underground sour-gas utilization with mineral hydrogen sulfide sequestration, analogous to what is proposed for the depleted Miocene sandstones of the Reforma-province fields. Thus, in Maracaibo, two of the concept's three elements are simultaneously applicable: co-development of the source rock and adjacent tight carbonates, and mineral H₂S sequestration in the overlying depleted Miocene sandstones.

It is also worth noting the applicability of the mineral hydrogen sulfide sequestration solution to sour gas giants in other regions of the world. In particular, for the Tengiz field (Caspian region, Kazakhstan), with its high H₂S content, injection of sour gas into the nearly depleted Jurassic-Cretaceous North Buzachi field has previously been considered, where oxidized sandstones with high iron-compound content are capable of binding hydrogen sulfide mineralogically while simultaneously forming a gas reserve, and dissolution of the sour gas in Buzachi's heavy, biodegraded oil reduces its viscosity, giving an associated enhanced-oil-recovery effect. For gas with high H₂S content, this is about reducing the surface sulfur load; quantitative injection parameters are not considered in this work — only the applicability of the approach is presented.

8. Risks and solutions

The concept rests on a number of assumptions, each subject to verification. Below they are organized in a form suitable for pilot-program planning, with the corresponding solution indicated (Table 4).

1. Lack of direct data for Pimienta/Edzná in Comcalco. The geochemical parameters presented are regional analogues. Solution: pilot drilling with core recovery, Rock-Eval, and determination of maturity and phase composition at specific wells.

2. Aquifer breakthrough in inter-structural zones. When wellbores are placed in the middle of the Pimienta outside structural highs (open fields), an influx of formation water is possible. Solution: hydrodynamic studies and trial production at the pilot before scale-up.

Table 4.

Concept risks and their solutions		
No.	Risk	Mitigation
1	Lack of direct data for Pimienta/Edzná in Comalcalco — the geochemical parameters presented are regional analogues	Pilot drilling with core recovery, Rock-Eval, determination of maturity and phase composition
2	Aquifer breakthrough in inter-structural zones — formation-water influx possible where wellbores are placed outside structural highs	Hydrodynamic studies and trial production at the pilot

9. Potential and economic effect for Tabasco state

With successful piloting and scale-up of the approach, onshore production in Tabasco could be increased 4–6-fold relative to the current level already in the coming years. With cyclic development of the shale interval applied, cumulative production across the prospective clusters would grow 2–5-fold relative to a traditional depletion scheme.

Reaching a level of 1.5–2 million bbl/d by 2033–2035 will require the phased construction of approximately 150–200 Pueblo de Pimienta pads. These indicators are a project target, subject to refinement based on pilot-phase results; their achievability is determined above all by confirmation of the joint productivity of the shale and tight intervals at pilot pads (Table 2, Figure 8).

Table 5.

Target indicators for Tabasco state	
Indicator	Value
Growth in Tabasco onshore production	4–6-fold relative to the current level
Growth in cumulative production under cyclic development	2–5-fold relative to a traditional depletion scheme
Target daily production level	1.5–2 million bbl/d by 2033–2035
Required number of Pueblo de Pimienta pads	~150–200

This growth gives the state a powerful development impulse: modernization of refining and petrochemistry, construction of water-treatment and desalination plants, growth of gas-fired power generation (including based on underground gas storage), tens of thousands of new jobs, and infrastructure and social projects. Significantly, this effect is achieved on territory with a century-long oil history and ready-made infrastructure — that is, with minimal added environmental burden and maximum use of the existing well stock and field base. It is also worth noting the high payback of shale projects implemented in the US, Canada, and Argentina [10].

10. Environmental and social component

The project's environmental component is not a compensatory obligation added to production but follows from its structure: development takes place on territory with a century-long oil history and ready-made infrastructure, which in itself minimizes new impact, while the project's cash flow, for the first time in decades, creates a funding source for programs that, absent production, have no funding vehicle.

10.1. Water-treatment and desalination plants: infrastructure for hydraulic fracturing and the region's social needs

A large-scale multistage fracturing program — across 150–200 Pueblo de Pimienta pads with 36–40 wells each — is, by definition, water-intensive. Supplying it with fresh water from the region's natural sources is problematic. The project's infrastructure therefore includes construction of two types of facilities, with different degrees of replication depending on the water source and logistics:

A desalination plant — a single, central facility in the city of Paraíso (a coastal municipality of Tabasco

state, near the Dos Bocas terminal), distributing desalinated water via a pipeline network to the wellpads. Centralization is justified: clean water is transported by pipeline without contamination risk and without distance limitations.

Water-treatment plants (treatment and recycling of produced water/flowback) — at least three, at a rate of roughly one plant per 50–70 wellpads — unlike clean water, transporting contaminated flowback over long distances is impractical and carries additional environmental risk. Tentatively, by the geography of the Comalcalco sub-basin (the cities of Comalcalco, Cunduacán, Huimanguillo); the exact distribution among them will be refined against the actual pad-siting map at the pilot stage.

Significantly, the combined capacity of these plants is excessive relative to fracturing needs during inter-cycle periods and phases of reduced drilling activity. This surplus capacity will be directed toward water supply for coastal and inland municipalities of Tabasco — a region regularly facing both flooding and a shortage of quality drinking water. The network of water-treatment plants and the desalination plant become triple-purpose assets — industrial, municipal, and agricultural.

10.2. Restoration of lagoons and lakes

The coastal and inland part of Tabasco is a region of extensive wetlands, lagoons, and lakes, including the Pantanos de Centla system — one of the most important wetland complexes in Mesoamerica, holding biosphere reserve status since 1992 and protected under the Ramsar Convention as a wetland of international importance since 1995 (Site No. 733, area 302.7 thousand ha) — which have suffered oil contamination over a century of industrial production. Their cleanup and restoration is a task that, under current conditions, goes

unsolved, since neither a dedicated budget nor an economic actor interested in funding it exists. Implementing the shale-and-tight co-development program creates both.

The water-body restoration program includes: survey and mapping of bottom and shoreline contamination; removal of historical oil lenses and oil-stained soils accumulated over a century of production; restoration of the hydrological regime and vegetation cover; a water-quality and biota monitoring program. Critically, the Tight-Shale Burger technology creates no new impact on these water bodies — development is conducted from existing field sites and deep horizontal wellbores — meaning the restoration work is not compensation for current damage but a pure improvement.

A formulation worth stating explicitly: the project does not require environmental compensation — it creates an environmental program that would otherwise never be implemented at all, since in the absence of production there is no actor in the territory capable of funding it.

10.3. Coastline and wetland monitoring

The project's field infrastructure — a distributed network of wellpads, power supply, and communications across the entire play — serves as a carrier for an environmental monitoring system whose creation as a standalone program would be incomparably more expensive. It provides for: monitoring of coastline condition and wetland dynamics (satellite and ground-based tracking of erosion, flooding, and mangrove-ecosystem degradation); monitoring of surface- and groundwater quality; and an early spill detection system, including for spills unrelated to the project — from the historical well stock and from third-party river traffic on the Grijalva and Usumacinta rivers. Tabasco regularly suffers from flooding, and the distributed hydrological and meteorological monitoring network has standalone value for the region, beyond the oilfield itself.

10.4. Flare-free gas utilization and the carbon loop

The project's environmental cornerstone is its gas solution (Section 5): associated and dissolved gas is not flared but injected into depleted Miocene sandstones serving as underground gas storage, with associated mineral binding of hydrogen sulfide in the rock. This eliminates both CO₂ and methane emissions from flaring and the accumulation of sulfur at the surface, while the well infrastructure of the depleted fields itself provides the foundation for a full carbon capture and storage (CCS) loop on the same asset base, forming underground gas storage for the region's future needs.

10.5. Social component

Southeastern Tabasco is a historic oil-producing district whose population has been tied to the industry for a century and has, in recent decades, watched it decline. Resuming development does not mean creating a new dependency but restoring employment lost in a region where the oil profession is traditional: tens of thousands of jobs in drilling, field operations, power generation, water treatment, and — as a separate track — in water-body restoration and monitoring programs, providing employment independent of the production cycle. Overall, the project returns to the territory not only production but also a functioning environmental,

water, and monitoring infrastructure that would otherwise never have been built. The project's scale implies unprecedented employment (70–90%) of the population in its implementation and a reduction in social tension.

Conclusions

1. The Tight-Shale Burger concept is proposed — the first template, in Mexico (and worldwide), for simultaneous rather than sequential development of a source-rock interval (the Pimienta/Edzná shale — the “patty”) and the adjacent Jurassic-Cretaceous tight reservoirs it has charged (Ek-Balam Oxfordian sandstone, Akimpech Kimmeridgian oolite, Cretaceous fractured dolomite — the “buns”) from a single pad.

2. The resource potential of the Pimienta formation and its adjacent tight formations within the onshore Sureste basin is estimated by the authors at tens of billions of barrels.

3. The central thesis is economic, not technological: the synergy of developing the shale and tight formations makes the project highly profitable through three independent effects — shared capital costs across the two targets, diversification of the production profile (a fast carbonate plateau plus cyclic shale development), and infrastructure synergy, including gas utilization.

4. Flow mechanisms in the shale and in the tight reservoirs are fundamentally different — diffusion-matrix in the Pimienta versus fracture-matrix in the Jurassic-Cretaceous carbonates. Despite this, a single technological fracturing protocol is proposed for both targets (one fleet, one base fracturing fluid), with a single adjustable parameter — the presence or absence of an acid stage: it is not required for the Pimienta, while for the tight carbonates it is introduced to reactivate the existing natural fracture network.

5. Associated gas is utilized flare-free by injection into depleted Miocene sandstones serving as underground gas storage. The solution is split into two levels: formation of UGS — a mature, low-risk foundation that eliminates flaring and creates a gas reserve; mineral binding of hydrogen sulfide by the rock's oxidized iron (a subsurface analogue of iron sponge) — a promising add-on that shifts sulfur from a surface problem to a mineral-bound form in the reservoir. Mineral desulfurization is designed for a static regime and a decade-long timescale, which removes the kinetic objections (slow diffusion and passivation are not critical given the allotted time), and monitoring reduces to an annual H₂S measurement from a monitoring well.

6. Incremental placement of Pueblo de Pimienta pads: the first ones in fault zones with proven vertical saturation of the tight reservoirs, where geological certainty is greatest; extension to zones remote from faults with diffusive saturation only after the technology and economics are confirmed at the first stage.

7. The Tight-Shale Burger approach is applicable beyond Mexico. A direct analogue is the Maracaibo basin (Venezuela): the La Luna formation charges both adjacent fractured Cretaceous carbonates (La Paz, Mara, Rosario) and the overlying, 90%+-depleted sandstones of the Bolívar belt, reproducing both the

“burger” and a ready-made system for mineral H₂S sequestration. The desulfurization solution is also applicable to sour gas giants elsewhere (for example, the Tengiz–North Buzachi pair in the Caspian region, with an associated effect of reducing heavy-oil viscosity).

8. Target effect for Tabasco state: a 4–6-fold increase in onshore production relative to the current level, 2–5-fold growth in cumulative production with cyclic development of the Pimienta shale formation, reaching 1.5–2 million bbl/d by 2033–2035 with construction of 150–200 Pueblo de Pimienta pads. The project target will be confirmed by the pilot.

9. The environmental component follows from the project's structure rather than being added to it: development on territory with a century-long history and ready-made infrastructure minimizes new impact, while the cash flow creates, for the first time, a funding source for programs with no other vehicle — restoration of lagoons and lakes contaminated over a century (the Pantanos de Centla system), coastline and wetland monitoring, flare-free gas utilization. The desalination and water-treatment plants are designed comprehensively from the outset — not as facilities later adapted to the region's needs, but built from day one for a triple purpose: industrial (fracturing), municipal, and agricultural water supply. The project does not require environmental compensation — it creates an environmental program that could not otherwise be implemented.

Through the Pueblo de Pimienta system, Tight-Shale Burger transforms a territory with a century-long oil history, ready-made infrastructure, and seemingly exhausted potential into one of Mexico's most dynamic oil and gas regions of the 21st century. This is not only a technical innovation - the country's first template for simultaneous development of a source rock and adjacent tight reservoirs, complemented by flare-free gas utilization through natural subsurface desulfurization — but also a powerful driver of socio-economic development for the entire southeast of the country.

References:

1. Бочкарев А.В., Бочкарев В.А. Катагенез и прогноз нефтегазоносности недр // ВНИИОЭНГ. - 2006. - 321 с. <https://doi.org/10.61726/9424.2024.69.60.001>
2. Бочкарев В.А. Концепция освоения сланцевых углеводородов – М.: ДПК Пресс, 2021. – 332 с. <https://doi.org/10.25996/6492.2023.86.41.001>
3. Бочкарев В.А., Бочкарев А.В. Восполняемые запасы залежей углеводородов. – М.: ОАО «ВНИИОЭНГ». – 2017. – 276 с. <https://doi.org/10.61726/3912.2024.76.35.001>
4. Бочкарев В.А., Качалова Е.А. Сланцевый углеводородный потенциал формации Игл Форд (мексиканский сектор), условия его реализации и освоения. - Нефтепромышленное дело. - 2015. - № 2. – С.5-14.
5. Bochkarev V. Principles and approaches of the geological and geophysical studies, Development and Production of HC shale. Danish Scientific Journal, 82, 2024. P. 9-20. <https://doi.org/10.5281/zenodo.10899563>

6. Bochkarev, V.A.; Krivobokov, D.M.; Bochkarev, Art.V. Gas potential of Eagle Ford/ Agua Nueva formation in Mexico. Annali d'Italia, Scientific journal of Italy, 65, 2025. P. 11-20. <https://doi.org/10.5281/zenodo.15089357>
7. Bochkarev, V.A.; Krivobokov, D.M.; Bochkarev, Art.V. Development of the Pimienta shale formation –the key to the growth of daily oil production in Mexico. Znanstvena Misel, Scientific journal of Slovenia, 105, 2025. P. 11-20. <https://doi.org/10.5281/zenodo.17012660>
8. Бочкарев В.А. Модель формирования коллекторской ёмкости и залежей нефти и газа в глинистых сланцах на юге США // Зоны концентрации углеводородов в нефтегазоносных бассейнах суши и акваторий. СПб.: ВНИГРИ, 2010. С. 87–92.
9. Bochkarev V.A. The Hydrocarbon Shales Production concept // VIII International Scientific and Practical Conference «Questions. Hypotheses. Answers: Science XXI Century», May 14–15, 2024, Toronto, Canada. P. 33–47. <https://doi.org/10.5281/zenodo.11246386>
10. Репник А.А., Бочкарев В.А. Анализ макроэкономической конъюнктуры сырьевого рынка и прогнозирование его развития до 2040 г. // Проблемы экономики и управления нефтегазовым комплексом. 2016. № 11. С. 45–61.
11. V.A. Bochkarev, A.V. Bochkarev. Faults and hydrocarbons potentials. M.: JSC “VNIIOENG”, 2017. – 392p.
12. Angeles Aquino F.J. et al. Tectónica salina en el Sureste de México. Boletín de la Asociación Mexicana de Geólogos Petroleros, 1992.
13. Bourgeois J.P., Aupaix N., Bloise R., Millet J.L. Proposition d'explication de la formation d'hydrogène sulfuré dans les stockages souterrains de gaz naturel par réduction des sulfures minéraux de la roche magasin. Revue de l'Institut Français du Pétrole, 1979.
14. EIA / Advanced Resources International. Mexico — World Shale Gas and Shale Oil Resource Assessment, 2013 (раздел по формации Пимиянта, бассейна Тампико).
15. Enos P. Evolution of pore space in the Poza Rica trend (mid-Cretaceous), Mexico. Sedimentology, 1988.
16. Grajales-Nishimura J.M. et al. Stratigraphic architecture and sedimentology of the main oil-producing interval at the Cantarell oil field: K/T boundary succession, 2002.
17. Jarvie D.M., Maende A. Mexico's Tithonian Pimienta Shale: Potential for Unconventional Production. Unconventional Resources Technology Conference (URTeC), 2016.
18. Magoon L.B. et al. Petroleum systems of the southern Gulf of Mexico. AAPG, 2001.
19. Marín-Orsorio A. et al. A method for aquifer identification in petroleum reservoirs: case study of Puerto Ceiba oilfield. Journal of Petroleum Science and Engineering, 2012.
20. Ornelas-Sánchez M. et al. The Tithonian (Upper Jurassic) Edzná Formation: An important hydrocarbon reservoir of the Campeche shelf, Gulf of Mexico, 2005.

21. Padilla y Sánchez R.J. Evolución geológica del sureste mexicano desde el Mesozoico al presente en el contexto regional del Golfo de México. Boletín de la Sociedad Geológica Mexicana, 2007.
22. Peel F.J. et al. Regional Neogene Salt Tectonics in the Offshore Salina del Istmo Basin, South-eastern Mexico. AAPG Memoir, 2009.
23. Pérez-Cruz G.A. Sihil Field: Another giant below Cantarell, offshore Campeche, Mexico.
24. Ramírez-Alanís D. et al. Diagenetic evolution and origin of cements of the Cretaceous carbonates in the Akal Block, southeast Gulf of Mexico, 2024.
25. Shann M. et al. The Sureste Basin of Mexico: Its Framework, Future Oil Exploration Opportunities and Key Challenges Ahead, 2020.
26. Viniegra-O. F. Great carbonate bank of Yucatán, southern Mexico. Journal of Petroleum Geology, 1981.
27. Talukdar S. et al. Cretaceous source rocks and the La Luna / Querecual petroleum systems, Venezuela.
28. Magoon L.B., Escalona A. et al. La Luna petroleum system, Maracaibo Basin (обзорные материалы).

ECONOMIC SCIENCES

MACROECONOMIC GROWTH AND AGRICULTURAL EXPORT PERFORMANCE IN TRANSITION ECONOMIES: EVIDENCE FROM A TWO-WAY FIXED EFFECTS GROWTH MODEL

Abdullayev R.

PhD in Economics, Associate Professor

Department of Economic Problems of the Agrarian Sector, Institute of Economics, Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan

ORCID: 0000-0003-2025-1571

<https://doi.org/10.5281/zenodo.21982205>

Abstract

This study investigates the short-run relationship between macroeconomic growth and agricultural export performance in seven transition economies over the period 2000–2023. Annual agricultural export data were obtained from the FAOSTAT database, while macroeconomic indicators, including gross domestic product (GDP), gross fixed capital formation, and agricultural value added, were sourced from the World Bank's World Development Indicators. To mitigate the influence of common trends in macroeconomic level data, the empirical analysis employs annual logarithmic growth rates estimated within a two-way fixed effects panel framework that controls for both country-specific heterogeneity and time-specific effects. The baseline model comprises 161 country-year observations, while the extended specification includes 158 observations due to limited data availability for agricultural value added in Georgia. The empirical findings indicate that GDP growth exhibits the strongest positive association with agricultural export growth across both model specifications. The estimated GDP coefficient equals **0.412** in the baseline specification ($p = 0.074$) and **0.304** in the extended model ($p = 0.010$). In contrast, changes in the gross fixed capital formation share and agricultural value-added growth are not statistically significant. Overall, the results suggest that short-run agricultural export performance is more closely associated with broad macroeconomic expansion than with contemporaneous changes in investment intensity or sector-specific production. These findings should be interpreted as evidence of conditional associations rather than causal relationships.

Keywords: agricultural exports; economic growth; gross fixed capital formation; panel data; transition economies.

JEL Classification: Q17, F14, C23, O11

1. INTRODUCTION

Agricultural exports are an important component of development strategies in transition economies because they generate foreign-exchange earnings, support rural incomes and employment, and connect domestic producers to international markets. At the same time, export performance depends on conditions extending beyond the agricultural sector itself. Economic scale, investment capacity, infrastructure and the broader institutional environment can influence the ability of producers and firms to reach foreign markets [1, 12, 15].

The export-led growth literature emphasizes the interaction between trade expansion and aggregate economic performance [2, 8]. Structural transformation research similarly shows that changes in productivity and resource allocation across sectors are closely related to the wider development process [14, 15, 17]. For agricultural trade, this implies that sectoral production growth may be necessary but not sufficient: export outcomes can also depend on macroeconomic expansion and the investment environment.

Previous empirical studies have examined export diversification, trade costs, global value chains and structural change [1, 5, 9, 10, 11, 16]. However, a practical difficulty in cross-country work is that strong common trends in GDP, investment and exports can generate apparently strong relationships in level regressions.

This issue is particularly relevant for transition economies, where structural change and price dynamics have been substantial over the last two decades.

To address this problem, the present study focuses on annual changes rather than levels. It asks whether year-to-year agricultural export performance is more closely associated with economy-wide GDP growth, changes in investment intensity, or growth in agricultural value added. The analysis covers Azerbaijan, Georgia, Kazakhstan, Poland, Türkiye, Ukraine and Uzbekistan over 2000–2023 and applies a two-way fixed effects growth model. This specification mitigates the influence of persistent cross-country heterogeneity and common time-specific shocks, thereby providing a more rigorous assessment of short-run macroeconomic relationships with agricultural export performance. By distinguishing the relative importance of overall economic growth, investment intensity, and agricultural value-added growth within a unified empirical framework, this study provides updated comparative evidence on the short-run macroeconomic determinants of agricultural export performance in transition economies. The scientific contribution of this study lies in re-examining the relationship between macroeconomic conditions and agricultural export performance using a two-way fixed effects growth model. Unlike previous studies that primarily rely on level-based

specifications, this study employs annual logarithmic changes to reduce the influence of common long-run trends and identify short-run within-country relationships. Furthermore, by jointly examining GDP growth, gross fixed capital formation, and agricultural value-added growth within a unified empirical framework, the study clarifies the relative importance of these variables in explaining agricultural export performance across seven transition economies over the period 2000–2023.

2. LITERATURE REVIEW

Classical trade theory identifies market size and trade costs as central determinants of international trade flows [1, 10]. The export-led growth hypothesis further links external-sector expansion to productivity gains, investment and economic growth [2, 8]. At the same time, structural transformation theory emphasizes that development is associated with changes in the allocation of resources and productivity across sectors [14, 15, 17].

Research on export diversification shows that the composition and breadth of exports evolve with the development process [5, 11, 16]. Agricultural export performance is also influenced by infrastructure, logistics and the ability of firms to participate in international value chains [12]. These mechanisms suggest that agricultural export growth should be analysed within a broader macroeconomic framework rather than as a function of agricultural output alone.

The present study contributes to this literature by using annual logarithmic changes to distinguish short-run co-movement from long-run common trends. Rather than assuming that a large coefficient in a level model demonstrates macroeconomic dominance, the empirical strategy tests whether changes in GDP, investment intensity and agricultural value added are associated with changes in agricultural export values after controlling for country and year effects. Nevertheless, relatively limited evidence is available on whether the relationships reported in level-based models remain robust after removing common macroeconomic trends through annual logarithmic changes. By focusing on within-country changes rather than long-run co-movements, this study offers updated comparative evidence on the short-run macroeconomic determinants of agricultural export performance across transition economies.

3. MATERIALS AND METHODS

3.1. Sample and data

The empirical sample comprises seven transition economies: Azerbaijan, Georgia, Kazakhstan, Poland, Türkiye, Ukraine and Uzbekistan. Annual observations cover 2000–2023. Agricultural export values are constructed from the FAOSTAT Crops and Livestock Products trade database by aggregating product-level export values for each country and year [7]. FAOSTAT reports these values in current US dollars. These countries were selected because they represent transition economies at different stages of economic and institutional development while exhibiting substantial varia-

tion in agricultural trade structures. This diversity provides sufficient cross-country heterogeneity for panel-data analysis while maintaining comparability within a common transition-economy context.

Macroeconomic indicators are obtained from the World Bank World Development Indicators [18]. GDP and agriculture, forestry and fishing value added are measured in constant 2015 US dollars. Investment intensity is represented by gross fixed capital formation as a percentage of GDP. Gross fixed capital formation is used instead of the constant-dollar gross capital formation series because the latter has major coverage gaps for several countries in the sample. This choice preserves a substantially more balanced panel and reduces sample-selection problems.

The previously considered total-exports control is not included in the preferred specification because the constant-2015-US-dollar series is highly incomplete for Azerbaijan and Georgia during the study period. Excluding this variable allows the analysis to retain all seven countries and avoids a regression sample dominated by only five economies.

3.2. Variable transformation and model specification

To reduce spurious correlation arising from common trends in macroeconomic level variables, all continuous variables enter the preferred model as annual logarithmic changes. For variable X , the transformation is $\Delta \ln(X_{it}) = \ln(X_{it}) - \ln(X_{it-1})$. For gross fixed capital formation, the logarithmic change is calculated from its share of GDP. Agricultural export growth is calculated from FAOSTAT export values in current US dollars. Year fixed effects are included to absorb common global price and trade shocks affecting all countries in a given year.

$$\Delta \ln(\text{AgriExp}_{it}) = \alpha + \beta_1 \Delta \ln(\text{GDP}_{it}) + \beta_2 \Delta \ln(\text{GFCFshare}_{it}) + \mu_i + \lambda_t + \varepsilon_{it}$$

The extended specification incorporates agricultural value-added growth, $\Delta \ln(\text{AgriVA}_{it})$, to assess whether sector-specific output growth provides additional explanatory power. Country fixed effects (μ_i) control for persistent country-specific characteristics, while year fixed effects (λ_t) capture common shocks affecting all economies. Given the relatively small number of countries included in the sample, the estimated relationships should be interpreted with appropriate caution. Accordingly, the reported coefficients are interpreted as conditional associations rather than causal effects, consistent with standard panel-data econometric practice [3].

4. RESULTS

4.1. Descriptive statistics

Table 1 summarizes the annual logarithmic changes used in the preferred models. Agricultural export growth is considerably more volatile than GDP growth, reflecting sensitivity to commodity prices, harvest conditions, market access and exchange-rate developments. GDP growth averages approximately 4.7% across country-years, while changes in investment intensity and agricultural value added display substantial cross-country and temporal variation.

Table 1.

Descriptive statistics of annual logarithmic changes, 2001–2023.

Variable	N	Mean (%)	Std. Dev.	Min (%)	Max (%)
Agricultural export growth	161	10.14	21.12	-61.75	71.62
GDP growth	161	4.73	5.99	-33.91	29.61
Change in GFCF share	161	0.23	13.50	-34.66	51.61
Agricultural value-added growth	158	2.75	7.06	-28.99	23.51

Source: FAOSTAT and World Bank World Development Indicators; author's calculations.

4.2. Baseline two-way fixed effects model

The baseline model contains 161 country-year observations. GDP growth is positively associated with agricultural export growth. The estimated coefficient is 0.412, implying that a 1% increase in real GDP is associated with approximately a 0.41% increase in agricultural export value, conditional on country effects, year effects and changes in investment intensity. The coefficient is significant at the 10% level ($p = 0.074$), indicating suggestive rather than definitive evidence.

The coefficient on the change in the gross fixed capital formation share is negative (-0.250) but statistically insignificant ($p = 0.135$). This result indicates that short-run increases in the investment share of GDP do not translate mechanically into contemporaneous agricultural export growth. Investment may affect exports with lags or through specific forms of infrastructure and productive capital that are not captured by an aggregate investment-intensity measure.

Table 2.

Baseline two-way fixed effects growth model.

Variable	Coefficient	Standard Error	p-value
GDP growth	0.412*	0.191	0.074
Change in GFCF share	-0.250	0.145	0.135

Observations = 161; $R^2 = 0.341$; Adjusted $R^2 = 0.189$. Country and year fixed effects included.

* $p < 0.10$.

The consistency of the GDP coefficient across both specifications suggests that the observed relationship is robust and not driven by model specification.

4.3. Extended model with agricultural value-added growth

The extended model adds agricultural value-added growth and contains 158 observations. GDP growth remains positive and becomes more precisely estimated,

with a coefficient of 0.304 and $p = 0.010$. This result provides the strongest evidence in the analysis that economy-wide growth is positively associated with agricultural export performance.

Agricultural value-added growth has a positive coefficient (0.199) but is statistically insignificant ($p = 0.530$). The change in the gross fixed capital formation share also remains insignificant. Thus, after controlling for country and year effects, contemporaneous sectoral output growth does not independently explain agricultural export growth as consistently as GDP growth.

Table 3.

Extended two-way fixed effects growth model.

Variable	Coefficient	Standard Error	p-value
GDP growth	0.304***	0.082	0.010
Change in GFCF share	-0.252	0.152	0.149
Agricultural value-added growth	0.199	0.298	0.530

Observations = 158; $R^2 = 0.337$; Adjusted $R^2 = 0.174$. Country and year fixed effects included. *** $p < 0.01$.

The inclusion of agricultural value added does not materially alter the estimated GDP coefficient, indicating that the relationship between economic growth and agricultural export growth is robust to the inclusion of sector-specific production dynamics.

5. DISCUSSION

The results provide a more conservative interpretation than conventional level-based specifications. Once common trends are removed through annual log-

arithmic changes, GDP growth remains the variable exhibiting the most consistent positive association with agricultural export performance. This finding is broadly consistent with previous empirical evidence emphasizing the role of macroeconomic development, trade integration, and structural transformation in supporting export expansion and improving firms' participation in international markets [2, 8, 14, 15]. At the same time, the results do not support a simple interpretation that all macroeconomic variables automatically enhance agricultural exports. Changes in the gross fixed capital formation share are not statistically significant, suggesting that aggregate investment intensity

may be too broad to capture the specific investments most relevant to agricultural exports, such as cold-chain infrastructure, storage facilities, transport networks, certification systems, and processing capacity. The insignificant agricultural value-added coefficient is also informative. Agricultural production growth expands potential supply, but export performance depends on whether additional output is competitive, marketable, and connected to external demand. Quality standards, logistics, trade costs, and market access can weaken the short-run link between production growth and exports [1, 12]. This helps explain why GDP growth exhibits a more stable association with agricultural exports than agricultural output growth itself.

The analysis also demonstrates the importance of model specification. Strong positive coefficients obtained from level-based data may reflect common long-run trends rather than stable within-country relationships. Estimating the model in annual logarithmic changes provides a more stringent test and leads to more cautious conclusions. The findings therefore support a qualified macroeconomic-growth interpretation rather than a broad claim of unconditional scale dominance. Several limitations should be acknowledged. First, agricultural export values are measured in current US dollars; although year fixed effects absorb common global price shocks, they cannot fully eliminate country-specific exchange-rate effects. Second, the relatively small number of countries included in the sample limits statistical power and requires cautious interpretation of the estimated relationships. Third, the model does not explicitly account for logistics quality, institutional factors, product composition, or destination-market structure. Future research could expand the country sample, incorporate product-level trade data, and employ dynamic panel estimation techniques or external instruments to investigate longer-term relationships. These results suggest that the determinants of agricultural export performance differ between long-run structural development and short-run macroeconomic adjustment. While sustained improvements in agricultural productivity remain essential for long-term export capacity, year-to-year export performance appears to depend more strongly on overall macroeconomic conditions than on contemporaneous changes in agricultural production.

6. CONCLUSIONS

This study reassesses the relationship between macroeconomic conditions and agricultural export performance in seven transition economies over 2000–2023 using a two-way fixed effects growth model. By estimating annual logarithmic changes rather than trending levels, the analysis provides a more conservative assessment of short-run relationships.

The principal finding is that GDP growth has the clearest positive association with agricultural export growth. The coefficient is positive in both specifications and statistically significant in the extended model. By contrast, changes in gross fixed capital formation intensity and agricultural value-added growth are not statistically significant. These results suggest that agricultural export performance is linked to broader economic growth, but they do not imply that investment or

agricultural production are unimportant. Rather, their effects may operate through specific channels, with time lags, or in interaction with infrastructure, institutions and market access.

From a policy perspective, agricultural export strategies should therefore be integrated with broader economic development policies while maintaining targeted sectoral measures. Macroeconomic stability, efficient infrastructure, access to finance, quality upgrading and international market integration remain important complements to agricultural production growth.

Future research could extend the analysis by incorporating institutional quality, logistics performance, destination-market diversification and dynamic panel estimation techniques to examine longer-term causal relationships.

References:

1. Anderson J.E., van Wincoop E. Trade costs // *Journal of Economic Literature*. — 2004. — Vol. 42, No. 3. — P. 691–751. DOI: 10.1257/0022051042177649.
2. Balassa B. Exports and economic growth: Further evidence // *Journal of Development Economics*. — 1978. — Vol. 5, No. 2. — P. 181–189. DOI: 10.1016/0304-3878(78)90006-8.
3. Baltagi B.H. *Econometric Analysis of Panel Data*. — 6th ed. — Cham: Springer, 2021.
4. Beverelli C., Keck A., Larch M. Institutions and global value chains // *The World Economy*. — 2018. — Vol. 41, No. 10. — P. 2760–2786. DOI: 10.1111/twec.12642.
5. Cadot O., Carrère C., Strauss-Kahn V. Export diversification: What's behind the hump? // *Review of Economics and Statistics*. — 2011. — Vol. 93, No. 2. — P. 590–605. DOI: 10.1162/REST_a_00078.
6. Food and Agriculture Organization (FAO). *The State of Agricultural Commodity Markets 2022: The Geography of Food and Agricultural Trade*. — Rome: FAO, 2022.
7. Food and Agriculture Organization (FAO). *FAOSTAT Statistical Database*. — Rome: FAO, 2026. — URL: <https://www.fao.org/faostat/> (accessed: 11.08.2026).
8. Frankel J.A., Romer D. Does trade cause growth? // *American Economic Review*. — 1999. — Vol. 89, No. 3. — P. 379–399. DOI: 10.1257/aer.89.3.379.
9. Hausmann R., Hwang J., Rodrik D. What you export matters // *Journal of Economic Growth*. — 2007. — Vol. 12, No. 1. — P. 1–25. DOI: 10.1007/s10887-006-9009-4.
10. Helpman E., Melitz M.J., Rubinstein Y. Estimating trade flows: Trading partners and trading volumes // *Quarterly Journal of Economics*. — 2008. — Vol. 123, No. 2. — P. 441–487. DOI: 10.1162/qjec.2008.123.2.441.
11. Imbs J., Wacziarg R. Stages of diversification // *American Economic Review*. — 2003. — Vol. 93, No. 1. — P. 63–86.
12. Limao N., Venables A.J. Infrastructure, geographical disadvantage, transport costs, and trade //

- Economic Journal. — 2001. — Vol. 111, No. 473. — P. 451–479. DOI: 10.1111/1468-0297.00631.
13. Matsuyama K. Agricultural productivity, comparative advantage, and economic growth // *Journal of Economic Theory*. — 1992. — Vol. 58, No. 2. — P. 317–334. DOI: 10.1016/0022-0531(92)90057-0.
14. McMillan M., Rodrik D., Verduzco-Gallo Í. Globalization, structural change, and productivity growth // *World Development*. — 2014. — Vol. 63. — P. 11–32. DOI: 10.1016/j.worlddev.2013.10.012.
15. Timmer M.P., de Vries G.J., de Vries K. Patterns of structural change in developing countries // *Journal of Development Studies*. — 2015. — Vol. 51, No. 11. — P. 1377–1394.
16. Parteka A., Tamberi M. What determines export diversification in the development process? // *The World Economy*. — 2020. — Vol. 43, No. 7. — P. 1827–1850. DOI: 10.1111/twec.12969.
17. Wooldridge J.M. *Econometric Analysis of Cross Section and Panel Data*. — 2nd ed. — Cambridge, MA: MIT Press, 2010.
18. World Bank. *World Development Indicators*. — Washington, DC: World Bank, 2026. — URL: <https://data.worldbank.org/> (accessed: 11.08.2026).

MATHEMATICAL SCIENCES

THE MICROVORTEX CIRCULATION VECTOR AS AN INTEGRAL CHARACTERISTIC OF COHERENT VORTEX FILAMENTS

Milyute E.

Milyus A.

IRG "LITAVEM-3"

Vilnius, Lithuania

<https://doi.org/10.5281/zenodo.21982207>

Abstract

A geometric and hydrodynamic model of a unified ellipsoidal vortex with a central concave helical kern is developed from the viewpoint of the integral rotational characteristics of vortex filaments. The principal object introduced in this work is the microvortex circulation vector, $\boldsymbol{\mu} = \Gamma \mathbf{T}$, which combines the local circulation with the tangent orientation of an individual material filament. Unlike the classical vorticity field, the proposed vector represents the oriented flux of vorticity through the transverse cross-section of a vortex tube and therefore provides an integral description of the local rotational state. The evolution of the microvortex circulation vector is derived for both ideal and viscous fluids. It is shown that, under Kelvin circulation conservation, the magnitude of $\boldsymbol{\mu}$ remains invariant whereas its direction evolves together with the deformation of the material filament. Explicit expressions are obtained for the material and spatial derivatives of $\boldsymbol{\mu}$, demonstrating their dependence on the local velocity gradient, transverse deformation, curvature and torsion of the filament. A continuous transition of the vector field from the internal concave kern to the external shell is established, ensuring conservation of the oriented vorticity flux along the same material filament. The relation between the microvortex circulation vector, the vector potential of the flow, and the local helicity is derived. It is shown that the sign of the helicity is determined by the consistency between the direction of longitudinal transport and the sign of the circulation. The proposed formulation provides an integral framework for describing coherent vortex structures and forms a mathematical basis for subsequent investigations of vortex stability, helicity transport, and topological invariants of three-dimensional vortex flows.

1. Introduction.

The mathematical description of vortex structures has traditionally been based on the local fields of velocity and vorticity introduced in the classical works of Helmholtz, Kelvin and Lamb. In this formulation the vorticity

$$\boldsymbol{\omega} = \nabla \times \mathbf{v}$$

plays the role of the principal local characteristic of rotational motion, while the circulation

$$\Gamma = \oint_C \mathbf{v} \cdot d\mathbf{l}$$

is regarded as an integral invariant associated with a material contour.

Although these quantities provide the foundation of classical vortex dynamics, neither of them simultaneously describes both the magnitude of circulation and its spatial orientation along an evolving vortex filament. The circulation is a scalar associated with a closed contour, whereas the vorticity is a differential field depending on local derivatives of the velocity. During deformation of three-dimensional coherent vortices, it becomes desirable to introduce an integral quantity attached directly to the material filament and evolving together with it.

The present work introduces such a quantity in the form of the **microvortex circulation vector**

$$\boldsymbol{\mu} = \Gamma \mathbf{T},$$

where Γ denotes the circulation around the transverse cross-section of a vortex filament and $\mathbf{T}$ is the unit tangent vector of the material curve. This vector represents the oriented flux of vorticity through the local cross-section of the filament and therefore combines

the integral circulation with the geometric orientation of the vortex line. Unlike the vorticity field, the vector $\boldsymbol{\mu}$ is attached to the material filament itself and naturally follows its deformation.

The analysis is carried out for a unified ellipsoidal vortex possessing a central concave helical kern [1-2]. The proposed geometry differs from classical cylindrical vortex-core models by introducing a narrowing funnel-shaped kern whose helical filaments continuously emerge into an external quasi-meridional shell. This geometry provides a convenient framework for studying the transport of circulation from the internal rotating region toward the outer vortex envelope while preserving the orientation of individual material filaments.

Within this framework explicit expressions are derived for the material and spatial evolution of the microvortex circulation vector. The governing equations show that in an ideal incompressible fluid the magnitude of $\boldsymbol{\mu}$ remains constant as a consequence of Kelvin's circulation theorem [3-5], whereas its direction changes due to transverse deformation and local rotation of the surrounding medium. The spatial derivatives of the vector are expressed through the curvature and torsion of the vortex filament, establishing a direct connection between geometry and integral rotational dynamics.

The paper also establishes the relationship between the microvortex circulation vector, the vector potential of the velocity field, and the local hydrodynamic helicity. These results demonstrate that $\boldsymbol{\mu}$ serves as the principal integral characteristic of the rotational state of an individual vortex filament and provides a natural mathematical language for describing coherent vortex

structures whose geometry evolves continuously in space and time.

2. Definition of the Microvortex Circulation Vector $\boldsymbol{\mu}$.

To provide an integral description of the rotational state of the central concave kern, we introduce the microvortex circulation vector

$$\boldsymbol{\mu}_\alpha(s, t) = \Gamma_\alpha(s, t) \mathbf{T}_\alpha(s, t),$$

which combines the magnitude of the local circulation with the orientation of the corresponding vortex filament. Unlike the vorticity $\boldsymbol{\omega}$, which is a local field quantity, the vector $\boldsymbol{\mu}_\alpha$ is an integral characteristic representing the flux of vorticity through a small transverse cross-section of a vortex tube. For the concave helical kern, this definition is applied to the entire family of internal filaments, since their tangent directions vary continuously along the narrowing funnel.

Let an individual filament of the kern be represented by the regular material curve $\mathbf{Y}_{K,\alpha}(s, t)$, where s is the arc-length parameter, t is time, and α labels the individual filaments. The corresponding unit tangent vector is

$$\mathbf{T}_\alpha(s, t) = \frac{\partial_s \mathbf{Y}_{K,\alpha}}{|\partial_s \mathbf{Y}_{K,\alpha}|}.$$

Around this filament, choose a small closed material contour $C_\alpha(s, t)$, lying in the plane normal to $\mathbf{T}_\alpha$. The local circulation is defined by

$$\Gamma_\alpha(s, t) = \oint_{C_\alpha(s, t)} \mathbf{v} \cdot d\mathbf{l}.$$

By Stokes' theorem,

$$\Gamma_\alpha(s, t) = \int_{S_\alpha(s, t)} \boldsymbol{\omega} \cdot \mathbf{n}_\alpha dS, \quad \boldsymbol{\omega} = \nabla \times \mathbf{v},$$

where S_α is the surface bounded by the contour C_α , and its unit normal is chosen consistently with the tangent direction, $\mathbf{n}_\alpha = \mathbf{T}_\alpha$.

The microvortex circulation vector is defined by

$$\boxed{\boldsymbol{\mu}_\alpha = \Gamma_\alpha \mathbf{T}_\alpha}.$$

Its magnitude is $|\boldsymbol{\mu}_\alpha| = |\Gamma_\alpha|$, while its direction coincides with the local orientation of the vortex filament. The physical dimension of this vector is the same as that of circulation,

$$[\boldsymbol{\mu}] = \frac{L^2}{T}.$$

Therefore $\boldsymbol{\mu}$ should not be identified with the vorticity $\boldsymbol{\omega}$, whose dimension is T^{-1} .

In the thin-vortex-tube approximation, where the vorticity is nearly uniform over the cross-section and is predominantly aligned with the filament,

$$\boldsymbol{\omega}_\alpha \simeq \omega_{\parallel,\alpha} \mathbf{T}_\alpha,$$

one has $\Gamma_\alpha \simeq \omega_{\parallel,\alpha} A_\alpha$, where A_α denotes the cross-sectional area of the filament. Consequently,

$$\boldsymbol{\mu}_\alpha \simeq A_\alpha \boldsymbol{\omega}_\alpha.$$

Thus, the vector $\boldsymbol{\mu}_\alpha$ represents the oriented flux of vorticity through the local transverse cross-section of the vortex tube.

For a filament of the concave kern, parameterized by the longitudinal coordinate σ , the non-unit tangent vector is given by

$$\partial_\sigma \mathbf{Y}_{K,\alpha} = R_K'(\sigma) \mathbf{e}_r + R_K(\sigma) q_K(\sigma) \mathbf{e}_\varphi + z_K'(\sigma) \mathbf{e}_z.$$

Introduce the notation

$$\Lambda_K(\sigma) = \sqrt{(R_K'(\sigma))^2 + R_K^2(\sigma) q_K^2(\sigma) + (z_K'(\sigma))^2}.$$

Then the unit tangent vector is

$$\mathbf{T}_{K,\alpha} = \frac{R_K' \mathbf{e}_r + R_K q_K \mathbf{e}_\varphi + z_K' \mathbf{e}_z}{\Lambda_K},$$

and the microvortex circulation vector inside the kern is written as

$$\boldsymbol{\mu}_{K,\alpha} = \frac{\Gamma_{K,\alpha}}{\Lambda_K} (R_K' \mathbf{e}_r + R_K q_K \mathbf{e}_\varphi + z_K' \mathbf{e}_z).$$

Its components in the natural local basis are

$$\begin{aligned} \mu_r &= \Gamma_{K,\alpha} \frac{R_K'}{\Lambda_K}, & \mu_\varphi &= \Gamma_{K,\alpha} \frac{R_K q_K}{\Lambda_K}, & \mu_z &= \Gamma_{K,\alpha} \frac{z_K'}{\Lambda_K}. \end{aligned}$$

The radial component reflects the progressive narrowing of the funnel, the azimuthal component characterizes the helical orientation of the filament, and the longitudinal component describes the transport of circulation from the northern inlet toward the central outlet. The sign of the azimuthal component is determined by the product $\Gamma_{K,\alpha} q_K$, which expresses the consistency between the **dynamic circulation** and the **geometric orientation** of the helical filament.

For a vortex of the first kind, the signs of the circulation and the winding density are assumed to be consistent for all internal filaments:

$$\Gamma_{K,\alpha} \Gamma_{K,\beta} > 0, \quad q_{K,\alpha} q_{K,\beta} > 0$$

for any pair of filaments α and β . Consequently, the azimuthal components of the microvortex circulation vectors have a common orientation:

$$\mu_{\varphi,\alpha} \mu_{\varphi,\beta} > 0.$$

The chirality of the vector $\boldsymbol{\mu}_\alpha$ is determined by the sign of the circulation for a fixed orientation of the material filament:

$$\chi_{\mu,\alpha} = \text{sgn } \Gamma_\alpha.$$

The direction of traversal of the transverse contour is chosen according to the **right-hand rule** with respect to the tangent vector $\mathbf{T}_\alpha$ [1]. Accordingly, $\chi_{\mu,\alpha} = +1$ corresponds to positive circulation with respect to the oriented local frame, whereas $\chi_{\mu,\alpha} = -1$ corresponds to the opposite orientation.

3. Material Evolution of the Vector.

In an ideal incompressible barotropic fluid acted upon only by conservative body forces, the circulation around a material contour is conserved:

$$\frac{D\Gamma_\alpha}{Dt} = 0. (**)$$

The material derivative of the microvortex circulation vector is

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \frac{D\Gamma_\alpha}{Dt} \mathbf{T}_\alpha + \Gamma_\alpha \frac{D\mathbf{T}_\alpha}{Dt}.$$

If the circulation is conserved (**), then

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \Gamma_\alpha \frac{D\mathbf{T}_\alpha}{Dt}.$$

Thus, the magnitude of the vector remains constant, whereas its direction changes together with the tangent direction of the material filament. Since $\mathbf{T}_\alpha \cdot \mathbf{T}_\alpha = 1$, it follows that

$$\mathbf{T}_\alpha \cdot \frac{D\mathbf{T}_\alpha}{Dt} = 0.$$

Hence,

$$\boldsymbol{\mu}_\alpha \cdot \frac{D\boldsymbol{\mu}_\alpha}{Dt} = 0$$

whenever the circulation is conserved, and therefore

$$\frac{D}{Dt} |\boldsymbol{\mu}_\alpha|^2 = 0.$$

Consequently, $|\boldsymbol{\mu}_\alpha(t)| = |\boldsymbol{\mu}_\alpha(0)|$ as long as the circulation conservation law remains valid.

For a material filament, the evolution of the unit tangent vector is expressed through the velocity-gradient tensor:

$$\frac{D\mathbf{T}_\alpha}{Dt} = (\mathbf{I} - \mathbf{T}_\alpha \otimes \mathbf{T}_\alpha)(\nabla \mathbf{v})\mathbf{T}_\alpha.$$

Consequently,

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \Gamma_\alpha (\mathbf{I} - \mathbf{T}_\alpha \otimes \mathbf{T}_\alpha)(\nabla \mathbf{v})\mathbf{T}_\alpha.$$

The operator

$$\mathbf{P}_\perp = \mathbf{I} - \mathbf{T}_\alpha \otimes \mathbf{T}_\alpha$$

is the orthogonal projector onto the plane normal to the filament. Therefore, the change in the direction of $\boldsymbol{\mu}_\alpha$ is determined by the transverse component of the local deformation induced by the velocity field.

Let the velocity-gradient tensor be decomposed into its symmetric and antisymmetric parts: $\nabla \mathbf{v} = \mathbf{D} + \mathbf{W}$, where

$$\mathbf{D} = \frac{1}{2} (\nabla \mathbf{v} + (\nabla \mathbf{v})^\top)$$

is the rate-of-strain tensor, and

$$\mathbf{W} = \frac{1}{2} (\nabla \mathbf{v} - (\nabla \mathbf{v})^\top)$$

is the local rotation tensor. Then

$$\frac{D\mathbf{T}_\alpha}{Dt} = \mathbf{P}_\perp \mathbf{D} \mathbf{T}_\alpha + \mathbf{P}_\perp \mathbf{W} \mathbf{T}_\alpha.$$

Since $\mathbf{W}$ is antisymmetric

$$\mathbf{T}_\alpha \cdot \mathbf{W} \mathbf{T}_\alpha = 0,$$

and therefore

$$\mathbf{P}_\perp \mathbf{W} \mathbf{T}_\alpha = \mathbf{W} \mathbf{T}_\alpha.$$

The tangent-evolution equation may consequently be written as

$$\frac{D\mathbf{T}_\alpha}{Dt} = (\mathbf{I} - \mathbf{T}_\alpha \otimes \mathbf{T}_\alpha) \mathbf{D} \mathbf{T}_\alpha + \mathbf{W} \mathbf{T}_\alpha.$$

For conserved circulation, the evolution equation for the microvortex circulation vector becomes

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \Gamma_\alpha \mathbf{P}_\perp \mathbf{D} \mathbf{T}_\alpha + \Gamma_\alpha \mathbf{P}_\perp \mathbf{W} \mathbf{T}_\alpha.$$

Since, for any vector $\mathbf{a}$,

$$\mathbf{W} \mathbf{a} = \frac{1}{2} \boldsymbol{\omega} \times \mathbf{a},$$

and the vector $\boldsymbol{\omega} \times \mathbf{T}_\alpha$ is already orthogonal to $\mathbf{T}_\alpha$, we obtain

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \Gamma_\alpha [(\mathbf{I} - \mathbf{T}_\alpha \otimes \mathbf{T}_\alpha) \mathbf{D} \mathbf{T}_\alpha + \mathbf{W} \mathbf{T}_\alpha].$$

Using $\boldsymbol{\mu}_\alpha = \Gamma_\alpha \mathbf{T}_\alpha$ this equation can equivalently be expressed directly in terms of $\boldsymbol{\mu}_\alpha$:

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \left(\mathbf{I} - \frac{\mathbf{T}_\alpha \otimes \mathbf{T}_\alpha}{|\boldsymbol{\mu}_\alpha|^2} \right) \mathbf{D} \boldsymbol{\mu}_\alpha + \mathbf{W} \boldsymbol{\mu}_\alpha$$

provided that $D\Gamma_\alpha/Dt = 0$. The first term describes the turning of the filament caused by the transverse deformation of the flow, whereas the second term represents its rotation induced by the local rotational motion of the surrounding medium.

Thus, the antisymmetric part $\mathbf{W}$ rotates the microvortex circulation vector locally, whereas the symmetric part $\mathbf{D}$ changes its direction through transverse stretching and deformation while preserving its magnitude when the circulation remains constant.

In the stationary geometric description, the derivative of the microvortex circulation vector $\boldsymbol{\mu}_\alpha$ with respect to the arc length is

$$\frac{d\boldsymbol{\mu}_\alpha}{ds} = \frac{d\Gamma_\alpha}{ds} \mathbf{T}_\alpha + \Gamma_\alpha \frac{d\mathbf{T}_\alpha}{ds}.$$

According to the Frenet formula, $\frac{d\mathbf{T}_\alpha}{ds} = \kappa_\alpha \mathbf{N}_\alpha$, where κ_α is the curvature and $\mathbf{N}_\alpha$ is the principal normal vector. Therefore,

$$\frac{d\boldsymbol{\mu}_\alpha}{ds} = \frac{d\Gamma_\alpha}{ds} \mathbf{T}_\alpha + \Gamma_\alpha \kappa_\alpha \mathbf{N}_\alpha.$$

If the circulation remains constant along the filament, $\frac{d\Gamma_\alpha}{ds} = 0$, then

$$\frac{d\boldsymbol{\mu}_\alpha}{ds} = \Gamma_\alpha \kappa_\alpha \mathbf{N}_\alpha.$$

Thus, the spatial derivative of the microvortex circulation vector is directed along the principal normal and is proportional to the curvature of the filament. Along a straight segment, where $\kappa_\alpha = 0$, the direction of $\boldsymbol{\mu}_\alpha$ remains unchanged.

The second spatial derivative for the case of conserved circulation is

$$\frac{d^2\boldsymbol{\mu}_\alpha}{ds^2} = \Gamma_\alpha \frac{d}{ds} (\kappa_\alpha \mathbf{N}_\alpha).$$

Using the Frenet formula $\frac{d\mathbf{N}_\alpha}{ds} = -\kappa_\alpha \mathbf{T}_\alpha + \tau_\alpha \mathbf{B}_\alpha$, we obtain

$$\frac{d^2\boldsymbol{\mu}_\alpha}{ds^2} = \Gamma_\alpha (-\kappa_\alpha^2 \mathbf{T}_\alpha + \kappa'_\alpha \mathbf{N}_\alpha + \kappa_\alpha \tau_\alpha \mathbf{B}_\alpha).$$

The tangential component is determined by the square of the curvature, the normal component by the variation of the curvature, and the binormal component by the combined action of curvature and torsion. Consequently, the spatial evolution of the microvortex circulation vector $\boldsymbol{\mu}_\alpha$ directly reflects the geometry of the helical filament.

Within the concave kern, both the curvature and the torsion depend on the functions $R_K(\sigma)$, $z_K(\sigma)$, $q_K(\sigma)$. Since, in the present model, $R_K'(\sigma) \neq 0$, $q_K'(\sigma) \neq 0$, the filament is not an ordinary cylindrical helix of constant radius and pitch. As the filament approaches the central outlet, the geometric direction of the vector $\boldsymbol{\mu}_\alpha$ changes together with the tangent vector, whereas its magnitude may remain constant provided that the circulation is conserved.

In a viscous fluid, exact conservation of circulation is generally violated. For a Newtonian fluid, the material derivative of the circulation around a material contour can be expressed as

$$\frac{D\Gamma_\alpha}{Dt} = \nu \oint_{C_\alpha} \Delta \mathbf{v} \cdot d\mathbf{l} + \oint_{C_\alpha} \mathbf{f}_{nc} \cdot d\mathbf{l},$$

where ν is the kinematic viscosity and $\mathbf{f}_{nc}$ denotes the nonconservative body force per unit mass. Thus, we have

$$\frac{D\boldsymbol{\mu}_\alpha}{Dt} = \frac{D\Gamma_\alpha}{Dt} \mathbf{T}_\alpha + \Gamma_\alpha \frac{D\mathbf{T}_\alpha}{Dt}.$$

The first term changes the magnitude of μ_α , whereas the second changes its direction. In the metastable regime, it is assumed that the relative variation of the circulation is small on the characteristic time scale of the geometric evolution:

$$\left| \frac{1}{\Gamma_\alpha} \frac{D\Gamma_\alpha}{Dt} \right| \ll \left| \frac{D\mathbf{T}_\alpha}{Dt} \right|.$$

Under this condition, the vector μ_α primarily rotates together with the filament, while its magnitude varies slowly and preserves its sign.

4. Spatial Evolution and Continuity of the Vector.

When the filament leaves the central kern, the continuity condition for the microvortex circulation vector is introduced:

$$\mu_{s,\alpha}(0) = \mu_{K,\alpha}(L_K).$$

For nonzero circulation, this condition is satisfied by the simultaneous fulfillment of

$$\Gamma_{s,\alpha}(0) = \Gamma_{K,\alpha}(L_K) \text{ и } \mathbf{T}_{s,\alpha}(0) = \mathbf{T}_{K,\alpha}(L_K).$$

Consequently, the tangential departure of a material filament from the surface of the funnel is accompanied by the continuous transfer of its integral circulation characteristic into the outer region of the vortex. For a smoothly oriented family of filaments, one may introduce the distributed field

$$\mu(\mathbf{r}, t) = \Gamma(\mathbf{r}, t) \mathbf{T}(\mathbf{r}, t).$$

In the thin-vortex-tube approximation, $\mu \simeq A_f \omega$, where A_f denotes the area of the local cross-section of an elementary vortex tube. Under incompressible deformation, the volume of a small material element of the vortex tube is conserved:

$$A_f(s, t) dl(s, t) = A_f(s, 0) dl(s, 0).$$

If the vorticity flux is conserved, $\Gamma = A_f \omega_\parallel = \text{const}$, then

$$\omega_\parallel = \frac{\Gamma}{A_f}.$$

Therefore, a reduction of the cross-sectional area is accompanied by an increase in the longitudinal vorticity, although the magnitude of the integral vector μ remains equal to the conserved circulation.

For a vortex of the first kind, the circulations of all filaments are required to have the same sign:

$$\Gamma_\alpha \Gamma_\beta > 0.$$

The local vectors μ_α are not required to be mutually parallel, since the filaments occupy different spatial positions and possess different tangent directions. Hence, the global condition

$$\mu_\alpha \cdot \mu_\beta > 0$$

is meaningful only after the compared vectors have been parallel transported to a common point, or for sufficiently nearby filaments for which the effects of spatial curvature can be neglected. Γ_α with respect to the chosen orientation of the material foliation.

The integral circulation vector of the entire kern may be defined as the total vorticity flux through its transverse cross-section:

$$\mu_K(\sigma, t) = \int_{S_K(\sigma, t)} \omega(\mathbf{r}, t) d\mathbf{S},$$

where $d\mathbf{S} = \mathbf{n}_K dS$ is oriented along the local longitudinal direction of the kern. If the vorticity is nearly parallel to the filament tangent and varies only weakly across the cross-section, then

$$\mu_K \simeq \Gamma_K \mathbf{T}_K.$$

5. Relation to the Vector Potential and Helicity.

The connection between the microvortex circulation vector and the vector potential of the velocity field is established through the relations [1-2] is established through the relations

$$\mathbf{v} = \nabla \times \mathbf{A}, \quad \boldsymbol{\omega} = \nabla \times \nabla \times \mathbf{A}.$$

Therefore,

$$\mu_K = \int_{S_K} (\nabla \times \nabla \times \mathbf{A}) d\mathbf{S},$$

while the circulation is

$$\Gamma_K = \oint_{C_K} (\nabla \times \mathbf{A}) \cdot d\mathbf{l}.$$

Thus, the vector potential determines the local velocity and vorticity fields, whereas μ_K characterizes the integral flux of vorticity through the transverse cross-section of the kern.

The microvortex circulation vector also appears in the local expression for the hydrodynamic helicity. If, within a thin vortex filament, $\mathbf{v} \simeq U_\parallel \mathbf{T}$, and $\boldsymbol{\omega} \simeq \mu/A_f$, then

$$h = \mathbf{v} \cdot \boldsymbol{\omega} \simeq \frac{U_\parallel}{A_f} \mathbf{T} \cdot \boldsymbol{\mu}.$$

Since $\boldsymbol{\mu} = \Gamma \mathbf{T}$, it follows that

$$h \simeq \frac{U_\parallel \Gamma}{A_f}.$$

Therefore, the sign of the local helicity is determined by the consistency between the direction of the longitudinal transport and the sign of the circulation.

Thus, the vector

$$\boxed{\boldsymbol{\mu} = \Gamma \mathbf{T}}$$

constitutes the principal integral characteristic of the rotational state of an individual vortex filament. Its magnitude is equal to the local circulation, while its direction coincides with the tangent to the material curve. The spatial derivative of $\boldsymbol{\mu}$ is governed by the curvature and torsion of the filament, whereas its material derivative is determined by the transverse deformation of the flow and the local rotation of the surrounding fluid. In the ideal regime, the magnitude of the vector is conserved, whereas in a viscous metastable regime it may vary gradually without a reversal of the circulation sign. The continuity of $\boldsymbol{\mu}$ across the outlet cross-section ensures the transfer of the oriented vorticity flux from the internal concave kern to the outer continuation of the same material filament.

6. Fundamental Theorem on the Microvortex Circulation Vector.

The principal properties of the microvortex circulation vector may be summarized in the following theorem.

Theorem 1 (Existence and Evolution of the Microvortex Circulation Vector).

Let $\gamma(s, t)$ be a smooth material vortex filament transported by an incompressible barotropic flow. Assume that the circulation $\Gamma(s, t)$ is defined around every sufficiently small material contour normal to the filament. Then the vector $\boldsymbol{\mu}(s, t) = \Gamma(s, t) \mathbf{T}(s, t)$, where $\mathbf{T} = \frac{\partial \gamma}{|\partial \gamma|}$ is the unit tangent vector, possesses the following properties.

1. The magnitude of the vector equals the local circulation, $|\boldsymbol{\mu}| = |\Gamma|$.
2. The direction of the vector coincides with the tangent direction of the material filament.
3. If Kelvin's circulation theorem holds, $\frac{d\Gamma}{dt} = 0$, then $\frac{D\boldsymbol{\mu}}{Dt} = \Gamma(\mathbf{I} - \mathbf{T} \otimes \mathbf{T})(\nabla \mathbf{v})^T$, and therefore $\frac{D|\boldsymbol{\mu}|^2}{Dt} = 0$.
4. The spatial derivative of the vector is determined by the local geometry of the filament: $\frac{d\boldsymbol{\mu}}{ds} = \Gamma \kappa \mathbf{N}$, provided that $\frac{d\Gamma}{ds} = 0$.
5. The second spatial derivative satisfies $\frac{d^2\boldsymbol{\mu}}{ds^2} = \Gamma(-\kappa^2 \mathbf{T} + \kappa' \mathbf{N} + \kappa \tau \mathbf{B})$, thus depending explicitly on the curvature and torsion of the vortex filament.
6. If the filament passes continuously from the concave kern into the outer shell, $\boldsymbol{\mu}_S(0) = \boldsymbol{\mu}_K(L_K)$, then the oriented vorticity flux is continuously transported along the same material filament.

Proof. The first two statements follow immediately from the definition $\boldsymbol{\mu} = \Gamma \mathbf{T}$.

The evolution equation is obtained by differentiating this expression with respect to time and using Kelvin's theorem, $\frac{d\Gamma}{dt} = 0$, together with the transport equation for the tangent vector,

$$\frac{D\mathbf{T}}{Dt} = (\mathbf{I} - \mathbf{T} \otimes \mathbf{T})(\nabla \mathbf{v})^T.$$

Since $\mathbf{T} \cdot \frac{D\mathbf{T}}{Dt} = 0$, the magnitude of the vector remains unchanged,

$$\frac{D|\boldsymbol{\mu}|^2}{Dt} = 2\boldsymbol{\mu} \cdot \frac{D\boldsymbol{\mu}}{Dt} = 0.$$

The spatial derivatives follow directly from the Frenet formulas

$$\frac{d\mathbf{T}}{ds} = \kappa \mathbf{N}, \quad \frac{d\mathbf{N}}{ds} = -\kappa \mathbf{T} + \tau \mathbf{B}.$$

Finally, the continuity condition at the outlet cross-section guarantees that both the circulation and the tangent orientation remain continuous across the interface, implying continuity of the microvortex circulation vector itself. Therefore, the oriented vorticity flux is preserved along the same material vortex filament. ■

7. Conclusion.

The present work introduces the microvortex circulation vector

$$\boldsymbol{\mu} = \Gamma \mathbf{T}$$

as a new integral characteristic of coherent vortex filaments. Unlike the classical vorticity field, the pro-

posed vector combines the magnitude of the local circulation with the geometric orientation of the material filament and therefore provides an oriented description of the rotational state of the flow.

Explicit evolution equations have been obtained for both the material and spatial derivatives of the vector. They demonstrate that the geometry of the filament, through its curvature and torsion, together with the local velocity-gradient tensor, completely determines the evolution of the direction of the microvortex circulation vector, while its magnitude remains conserved under Kelvin's circulation theorem and varies only gradually in a viscous metastable regime.

The established continuity of the vector field across the outlet section of the concave kern provides a mathematical description of the transfer of the oriented vorticity flux from the internal rotating region to the external continuation of the same material filament. The obtained relation between the microvortex circulation vector, the vector potential and the local hydrodynamic helicity demonstrates that the sign of the helicity is governed by the consistency between the longitudinal transport direction and the circulation sign.

Thus, the microvortex circulation vector forms a natural integral variable for the mathematical description of coherent vortex structures. The proposed formulation provides a foundation for future investigations of vortex stability, helicity transport, spectral properties of perturbations, and topological invariants associated with the linking and twisting of three-dimensional vortex filaments.

References:

1. Milyute E., Milyuvene V., Milyus A. Geometric and Hydrodynamics Model of a unified ellipsoidal Vortex with a Central Concave Kern and Intrinsic Helicity, NJD-iScience, 2026, **186**
2. Milyute E. Derivative of the circulation invariant and preservation of the diffeomorphism of vortex filaments. Book of Abstracts, 2026 International Congress of Mathematicians, Philadelphia, Pennsylvania, USA
3. Kelvin W. T. On Vortex Motion. *Transactions of the Royal Society of Edinburgh*. 1867. **Vol. 25**. 217–260.
4. Lamb H. *Hydrodynamics*. 6th ed. Cambridge University Press, 1932.
5. Moffatt H. K. *Helicity and singular structures in fluid dynamics*. PNAS., 2014, **111**, Nr. 10, 3663-3670.

MEDICAL SCIENCES

THE INSTRUMENTATION GAP IN NAIL SERVICE MASTER TRAINING: WHY ENGAGEMENT METRICS CANNOT VALIDATE PROCEDURAL SAFETY

Artemyeva I.

*Director of the Training Center, Academy of Aesthetic Technologies LLC
Rostov-on-Don, Russia*

<https://doi.org/10.5281/zenodo.21982209>

Abstract

Training programs for nail service masters have adopted virtual reality, augmented reality, and AI-driven adaptive platforms at a pace that outstrips the field's capacity to verify what these tools actually teach. Existing evaluations of digital training interventions in cosmetology and adjacent vocational domains report gains in engagement, motivation, and declarative test performance, and treat these gains as proxies for professional competence. This article argues that such gains hold only for content that requires no calibration against a physical safety threshold. The dominant evaluation paradigm has failed to separate attitudinal and knowledge-based outcomes from the procedural mastery of threshold-dependent parameters such as UV/LED cure completeness, where under-execution produces measurable, clinically documented harm. Drawing on photopolymerization chemistry, occupational dermatology, and a structurally identical training-evaluation problem already documented in restorative dentistry, the analysis identifies the specific metric a genuine competency-based evaluation of digital nail-training tools would need to adopt: degree of monomer conversion. Even where this metric has been measured directly, improved procedural delivery has failed to guarantee improved chemical outcome. The article concludes that reforming professional training in this sector requires threshold-based, formulation-aware outcome measures, and that platform adoption alone cannot supply them.

Keywords: nail service training, UV/LED photopolymerization, procedural competency, vocational EdTech, degree of conversion, theory-practice gap

Introduction

A gel nail coating is considered safely cured once its degree of methacrylate group conversion clears roughly ninety percent; below that threshold, unreacted monomer remains mobile within the film and migrates into the surrounding skin, where it functions as a potent sensitizer [2]. 2-Hydroxyethyl methacrylate appears in 58 percent of 394 commercial nail gel products surveyed in a recent market audit, so undercuring produces a documented mechanism of occupational and consumer allergic contact dermatitis [18]. Correct execution of this single step, holding a lamp of adequate and verified output over a layer of appropriate thickness for the full specified interval, counts among the few genuinely safety-critical procedures a nail service master performs, and a vocational training system exists to certify precisely this kind of procedure before a technician works unsupervised.

Digital platforms now routinely supplement or replace apprenticeship-style instruction in nail-service training: the field's own literature reports that VR, AI-driven content sequencing, and online delivery increase engagement and personalize what a trainee sees, without stating what, procedurally, a trainee can then do that could not be done before [10]. These interventions demonstrate improvement in immersion, satisfaction, and declarative recall. They demonstrate nothing about whether a trainee reliably produces a coating above the conversion threshold that separates a safe cure from a sensitizing one. This evaluative gap carries weight: it means the field's central claim, that digital tools improve training, has been validated against outcomes structurally incapable of detecting the failure mode responsible for the profession's best-documented harm.

The gap has a specific mechanistic explanation. Media-comparison research established four decades ago that performance gains attributed to a new instructional medium are routinely confounded by the novelty of the medium itself and by uncontrolled differences in instructional method, so satisfaction or short-term recall scores collected shortly after a platform's introduction signal the novelty of encountering the platform as much as anything the technology itself contributed [5]. That confound has never been resolved for nail-service EdTech specifically, because no study in this domain has isolated procedural outcome from either variable.

This gap extends beyond cosmetology. Vocational and health-adjacent training research distinguishes knowledge and attitudinal acquisition from durable, transferable procedural competence, a distinction nursing education had to formalize once simulation-based interventions began reporting strong immediate knowledge gains whose durability under real conditions had not been separately tested [1]. Nail-service training differs from most of that literature in one respect: the procedure in question carries an explicit, chemically defined pass-fail criterion, degree of monomer conversion. That specificity makes the absence of threshold-based evaluation in current assessments of nail-training EdTech conspicuous, and it also permits this article to borrow a fully worked precedent from a field where an almost identical photopolymerization threshold has already been measured directly against training method. That precedent supplies the gap this article addresses, and it resolves, by name, the specific question of whether instrumented training feedback closes it.

Literature Review

The literature evaluating digital and immersive tools in vocational and cosmetology-adjacent training converges on a shared evaluative assumption: gains in learner engagement, motivation, and attitudinal or declarative outcomes constitute evidence that a training method transfers into professional competence. Chiang et al. [4] tested this assumption directly in a cosmetology-adjacent field, applying flow theory and an extended technology acceptance model to 1,200 Taiwanese vocational students learning hair braiding in VR. Their instrument measured perceived usefulness and ease of use as predictors of attitude toward use and behavioral intention, found both pathways significant, and the authors read this as evidence that VR immersive learning sustains vocational training outcomes. That conclusion rests entirely on acceptance and intention variables, so it establishes learner buy-in, a distinction the study does not test against execution quality, and Clark's [5] account of confounded novelty effects predicts that exactly this kind of short-horizon acceptance measure will run inflated. Maroungkas et al. [13] synthesized 69 studies on immersive VR personalization published between 2012 and 2022 and extend this picture: even where researchers attempt to move past attitudinal measures toward adaptive, individualized content, most reviewed applications still fail to incorporate adaptive learning content consistently, so the infrastructure needed to check an individual trainee against an individual performance criterion remains underdeveloped across the reviewed literature as a whole, not in any single study alone. Stefan et al. [17] supply the field-wide quantification this pattern needed. Reviewing 136 VR safety-relevant training studies published between 2016 and 2021 and coding each against Kirkpatrick's four evaluation levels, they find that a large majority assess reaction and learning outcomes; behavior- and results-level evidence, the levels at which procedural transfer to real conditions would actually be verified, remains scarce across the corpus. Kirkpatrick's levels were designed specifically to separate a trainee's response to a program from what that program changes in subsequent job performance, so this finding names, at the level of an entire research field, the exact distinction nail-training evaluation has also failed to make. Nuraini et al. [15] narrow this finding to the beauty sector: their PRISMA-based review of 32 studies on immersive simulation in makeup and beauty education, published between 2016 and 2026, documents real gains in psychomotor skill, engagement, and professional confidence, while stating explicitly that the presence of technology alone does not guarantee learning effectiveness and that studies addressing cosmetology education specifically remain limited. This confirms, from inside the target domain, that the pattern identified in adjacent fields holds here too. Harleni et al. [12] and Ezzaim et al. [9] mapped 41 and 93 studies respectively on AI-assisted adaptive learning across vocational education broadly and generalize the limitation further: both identify a persistent gap in longitudinal and outcome-based evaluation across the entire AI-in-TVET literature, which places the absence of procedural-

threshold verification as a structural feature of how vocational EdTech research is currently designed, a feature that reaches beyond nail services. Gorbacheva [10] supplies the field's own instance of this pattern: reviewing VR, AI, and e-learning applications in U.S. nail technician training, the account reports gains in engagement and personalized content delivery consistent with the broader literature, names the preservation of hands-on experience as an unresolved concern in its own conclusion, and proposes no metric against which that concern could be tested. These seven sources indicate that engagement and attitude-based validation dominates the field's methodology because it is the measurement infrastructure educational research already possesses, and Clark's [5] novelty-confound together with Stefan et al.'s [17] Kirkpatrick-level count explain why that infrastructure persists and why it cannot detect the specific failure this article addresses.

Two adjacent fields, nursing simulation and restorative dentistry, have already operationalized the separation between attitudinal and procedural outcomes for procedures with an externally verifiable correctness criterion. Alharbi et al. [1] reviewed simulation-based learning in nursing education across studies from 2017 to 2023 using Joanna Briggs appraisal criteria and found that simulation reliably improves knowledge and skill scores immediately after training; few of the reviewed studies test retention beyond five months, and this gap forced the field to build a distinction between acquisition and durable competence once it became clear the two do not move together. Daneshfar and Moonaghi [6] synthesized simulation research in nursing education from 2010 to 2025, named the phenomenon directly as a theory-practice gap, and found that high-fidelity, structured scenario-based simulation proves particularly effective for procedures with an external correctness criterion, citing cardiopulmonary resuscitation and infection control as examples, both verifiable independent of the learner's own judgment or confidence. Restorative dentistry has confronted a version of this problem that maps onto nail-gel curing almost exactly: dental composite resins cure through the same photopolymerization chemistry, share the same conversion-threshold logic, and have generated a direct empirical literature testing whether training changes the outcome that matters. Price et al. [16] established the baseline problem: curing-unit irradiance varies between devices and is frequently misreported, because the value manufacturers quote reflects an averaged output at the light tip this finding reproduces, in a clinically regulated field, the same lamp-output uncertainty that governs nail gel curing [2]. De Souza et al. [8] tested whether training corrects for this uncertainty, comparing light-curing performance among dental students taught by different training methods immediately after instruction and again one year later. Burrer et al. [3] isolated the mechanism further, using a patient simulator with real-time irradiance feedback to measure both the light energy 42 dental students delivered and the resulting degree of conversion, measured directly by FT-IR spectroscopy, before and after individual instruction. Individualized, instrumented training produced a significant increase in delivered irradiance ($p <$

.001) with markedly reduced variability across students, exactly the kind of procedural, threshold-relevant outcome the nail-training literature has never measured. Degree of conversion, the chemical endpoint itself, showed no corresponding significant improvement. Because these two adjacent fields share an identical chemical mechanism with nail gel curing, their combined finding supplies more than a template for what to measure: it establishes that a training intervention correctly aimed at the procedural bottleneck, verified irradiance delivery instead of self-reported confidence, can still fail to close the gap between what the trainee does and what the material chemistry requires, a result the discussion below returns to directly.

Four sources trace the causal chain connecting nail-product formulation chemistry to a documented clinical harm, running from device output through layer geometry to allergic sensitization. Gorbacheva [11] describes intelligent UV/LED curing systems built around sensor feedback and microcontroller-adjusted output, designed to match the emitted spectrum, typically centered near 365 and 405 nanometers, to the absorption band of the gel's photoinitiator, and identifies layer thickness as a governing variable: light intensity attenuates through a pigmented film according to the Bouguer-Lambert relationship, leaving the base of a thick layer under-cured even when the surface appears solid. Bednarczyk and Rożniakowski [2] supply the missing empirical link at the formulation level. Using real-time FT-IR spectroscopy under dual 365/405 nanometer LED irradiation, they measured degree of methacrylate conversion directly across several photoinitiator systems and found that different systems reach adequate conversion at different exposure times, a result that rules out any single fixed cure duration as safe across products and directly complicates any training curriculum built around a memorized count, epoxide, and thiol chemistries used in UV-curable nail polishes generally and confirm that this thickness- and formulation-dependent conversion problem characterizes the product category, not one manufacturer's chemistry. De Groot and Rustemeyer [7] close the chain at the clinical endpoint: their extensive case-series review documents 2-hydroxyethyl methacrylate as the most frequently reacting allergen in patch-tested nail technicians and consumers, a finding Steunebrink et al. [18] corroborate in an eight-year retrospective clinical study of acrylate-containing nail cosmetics. Together, this cluster establishes a complete, instrumented chain from photoinitiator chemistry, through device output and layer geometry, to a specific, epidemiologically documented harm, and a training curriculum needs to verify mastery of this exact chain, not general digital literacy.

Discussion

Digital training tools improve engagement, confidence, and declarative recall; the first cluster of evidence is consistent on this point. The field has validated their success against outcomes that were never designed to register a specific failure mode, because attitudinal and procedural competence occupy separate dimensions that co-occur in some content and diverge sharply in others. Chiang et al.'s [4] flow-theory and ex-

tended technology-acceptance framework treats perceived usefulness and behavioral intention as adequate evidence that a vocational training method sustains its stated purpose; the evidence assembled here indicates that this equivalence breaks down exactly where a physical threshold governs correct execution. Degree of monomer conversion is a function of irradiance, wavelength match, and layer thickness [2], none of which correlate with the perceived-usefulness or flow-experience constructs Chiang et al.'s instrument measures. A highly engaged, confident trainee operating a degraded or underpowered lamp can still produce an undercured, sensitizing coating while scoring at ceiling on every attitudinal item in the survey. Chiang et al.'s domain, hair braiding, has no equivalent chemical threshold, so their acceptance-based validation suits their own case; the reviewed nail-training literature applies the same validation logic to a curing procedure, extending a method beyond the conditions under which Clark [5] and Stefan et al. [17] show it holds.

The nursing simulation literature shows that recognizing this distinction changes what gets measured. Daneshfar and Moonaghi [6] and Alharbi et al. [1] document that criterion-based procedures were pulled out of general knowledge-and-attitude assessment and given dedicated, instrument-verified outcome measures once retention data revealed that early gains did not predict later procedural reliability. Nail-service curing carries the same structural property that triggered this methodological shift in nursing, a checkable pass-fail threshold, which is why the absence of an equivalent shift in nail-training research reads as an import failure, not a domain-specific limitation.

The dental-curing literature complicates a simpler version of this argument in a way the analysis has to state directly. One could conclude that the fix is straightforward: replace attitudinal survey outcomes with instrumented, threshold-based procedural measures, following the nursing precedent, and the gap closes. Burrer et al. [3] show this conclusion falls short. Individualized, real-time-feedback training in their study produced a clear, statistically robust improvement in the procedural variable most directly under the trainee's control, delivered irradiance, with sharply reduced between-student variability, exactly the kind of result a well-designed nail-curing training module should also produce. Degree of conversion, the chemical endpoint that determines whether the material is safe, did not improve to a statistically significant degree alongside it. This result does not undercut threshold-based training evaluation; it demonstrates that the threshold sits downstream of more variables than trainee technique alone, including the formulation- and thickness-dependent factors Bednarczyk and Rożniakowski [2] and Gorbacheva [11] identify. A training intervention that corrects irradiance delivery alone targets one node in a causal chain that also runs through product selection, layer application thickness, and photoinitiator-spectrum matching, and the trainee's lamp technique cannot compensate for any of these on its own. Burrer et al.'s [3] null result on conversion, obtained in a field that has already built the instrumentation this article argues nail-training research lacks, stands as the

strongest available evidence that closing the nail-service instrumentation gap will not by itself guarantee safe outcomes. It supplies the precondition for discovering which further variable, product formulation, application protocol, or device calibration, is responsible when a trained technician's cure still falls short, a diagnostic capacity current engagement-based evaluation cannot provide at all.

The clearest evidence for this divergence appears within a single author's own published output, where the oversight shows itself as structural. The account of digital training technologies for nail-service education [10] evaluates VR and AI tools exclusively through immersion, personalization, and satisfaction outcomes. The companion account of intelligent UV/LED curing systems [11] independently establishes the precise physical criterion, spectral-matched, sensor-verified conversion, against which any training method's procedural output could in principle be checked.

Conclusion

This analysis makes possible a specific reframing of what "effective training" should mean for digital and immersive tools in nail-service education. The reframing sets aside improved engagement or attitude scores, outcomes the existing literature already documents adequately, and demands demonstrated trainee output at or above a defined degree-of-conversion threshold, verified by instrument. The dental-curing precedent adds a caution to this standard: improved trainee technique alone may fail to guarantee that threshold. The materials-science and device-engineering literature, including work on sensor-verified intelligent curing systems [11], has already built part of the measurement apparatus this reframing requires. What remains is importing it into training-outcome design, following the precedent set by criterion-based simulation research in nursing and dental education, while treating the dental field's own null result on conversion as a warning against assuming that a fixed training pipeline resolves a chain that also runs through formulation and equipment.

References:

1. Alharbi, A., Nurfianti, A., Mullen, R. F., McClure, J. D., & Miller, W. H. (2024). The effectiveness of simulation-based learning (SBL) on students' knowledge and skills in nursing programs: A systematic review. *Bmc Medical Education*, 24(1), 1099. <https://doi.org/10.1186/s12909-024-06080-z>
2. Bednarczyk, P., & Rożniakowski, K. (2025). The influence of the photoinitiating system on residual monomer contents and photopolymerization rate of a model pigmented UV/LED nail gel formulation. *Coatings*, 15(10), 1125. <https://doi.org/10.3390/coatings15101125>
3. Burrer, P., Par, M., Attin, T., & Tauböck, T. T. (2021). Real-time feedback of the applied light-curing technique and its impact on degree of conversion of composite restorations — A study with undergraduate dental students. *Journal of Personalized Medicine*, 11(10), 1012. <https://doi.org/10.3390/jpm11101012>
4. Chiang, S., Chiang, D., Chang, S.-H., & Yao, K.-C. (2025). Innovative virtual reality teaching for the sustainable development of vocational high school students: A case study of hair braiding. *Sustainability*, 17(9), 3945. <https://doi.org/10.3390/su17093945>
5. Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research*, 53(4), 445–459. <https://doi.org/10.3102/00346543053004445>
6. Daneshfar, M., & Moonaghi, H. K. (2025). The impact of clinical simulation on bridging the theory–practice gap in nursing education: A systematic review. *BMC Medical Education*, 25, 1216. <https://doi.org/10.1186/s12909-025-07790-8>
7. de Groot, A. C., & Rustemeyer, T. (2023). 2-Hydroxyethyl methacrylate (HEMA): A clinical review of contact allergy and allergic contact dermatitis. Part 1. Introduction, epidemiology, case series and case reports. *Contact Dermatitis*, 89(6), 401–433. <https://doi.org/10.1111/cod.14405>
8. De Souza, G. M., El-Badrawy, W., & Tam, L. E. (2018). Effect of training method on dental students' light-curing performance. *Journal of Dental Education*, 82(8), 864–871. <https://doi.org/10.21815/JDE.018.081>
9. Ezzaim, A., Dahbi, A., Haidine, A., & Aqqal, A. (2023). AI-based adaptive learning: A systematic mapping of the literature. *Journal of Universal Computer Science*, 29(10), 1161–1197. <https://doi.org/10.3897/jucs.90528>
10. Gorbacheva, I. (2025). Digital educational technologies in training beauty industry professionals. In N. Khodakova (Ed.), *Recent Scientific Investigation: Proceedings of the LXXIII International Multidisciplinary Conference* (pp. 6–41). Primedia E-launch LLC.
11. Gorbacheva, Iu. (2025). Интеллектуальные UV/LED-системы для безопасного моделирования ногтей [Intelligent UV/LED systems for safe nail modeling]. LAP LAMBERT Academic Publishing.
12. Harleni, H., Giatman, M., Syah, N., Ganefri, G., Jalinus, N., Ridwan, R., & Krismadinata, K. (2025). Bibliometric and systematic review of AI-assisted adaptive learning applications in vocational education (2018–2023). *AI-Ishlah: Jurnal Pendidikan*, 17(4), 8634–8646.
13. Maroungkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2024). How personalized and effective is immersive virtual reality in education? A systematic literature review for the last decade. *Multimedia Tools and Applications*, 83, 18185–18233. <https://doi.org/10.1007/s11042-023-15986-7>
14. Mierîna, I., Grigale-Sorocina, Z., & Birks, I. (2025). The chemistry behind UV-curable nail polishes. *Polymers*, 17(9), 1166. <https://doi.org/10.3390/polym17091166>
15. Nuraini, I., Mukti, R. A., Fatmasari, F. H., & Joshua, Q. P. (2026). From conventional practice to immersive simulation: A systematic literature review on virtual professional makeup as transformative learning media. *Edcomtech: Jurnal Kajian Teknologi Pendidikan*, 11(1), 86–107.
16. Price, R. B., Ferracane, J. L., & Shortall, A. C. (2015). Light-curing units: A review of what we need to know. *Journal of Dental Research*, 94(9), 1179–1186. <https://doi.org/10.1177/0022034515594786>

17. Stefan, H., Mortimer, M., & Horan, B. (2023). Evaluating the effectiveness of virtual reality for safety-relevant training: A systematic review. *Virtual Reality*, 27, 2839–2869. <https://doi.org/10.1007/s10055-023-00843-7>
18. Steunebrink, I. M., de Groot, A., & Rustemeyer, T. (2024). Contact allergy to acrylate-containing nail cosmetics: A retrospective 8-year study. *Contact Dermatitis*, 90(3), 262–265. <https://doi.org/10.1111/cod.14475>

**CLINICAL AND LABORATORY CHARACTERISTICS OF RHEUMATOID ARTHRITIS
ASSOCIATED WITH AUTOIMMUNE THYROIDITIS****Aliakhunova M.***Doctor of Medical Sciences, Professor, Head of the Rheumatology Laboratory at the Republican Specialized Scientific and Clinical Medical Center for Therapy and Medical Rehabilitation under the Ministry of Health of the Republic of Uzbekistan***КЛИНИЧЕСКИЕ И ЛАБОРАТОРНЫЕ ХАРАКТЕРИСТИКИ РЕВМАТОИДНОГО АРТРИТА,
АССОЦИИРОВАННОГО С АУТОИММУННЫМ ТИРЕОИДИТОМ.****Алиахунова М.Ю.***Доктор медицинских наук, профессор, заведующий лабораторией ревматологии Республиканского специализированного научно-практического медицинского центра терапии и медицинской реабилитации при Министерстве здравоохранения Республики Узбекистан*
<https://doi.org/10.5281/zenodo.21982211>**Abstract**

The aim of this study was to investigate the clinical and laboratory characteristics of rheumatoid arthritis (RA) associated with autoimmune thyroiditis (AIT). A total of 120 patients with confirmed RA were enrolled and divided into groups with and without AIT. Comprehensive clinical, laboratory, and instrumental assessments were performed, including evaluation of disease activity, thyroid function, and immunological parameters. Patients with RA associated with AIT demonstrated higher disease activity, more severe articular manifestations, poorer functional status and quality of life, as well as significant alterations in thyroid function and ultrasonographic thyroid structure compared with patients with RA alone. These findings emphasize the importance of early screening for thyroid dysfunction in patients with RA and support a multidisciplinary approach to diagnosis and management.

Аннотация

Цель исследования — изучить клинические и лабораторные особенности течения ревматоидного артрита (РА), ассоциированного с аутоиммунным тиреоидитом (АИТ). В исследование включены 120 пациентов с подтвержденным диагнозом РА, разделенные на группы с наличием и отсутствием АИТ. Проведена комплексная клиническая, лабораторная и инструментальная оценка активности заболевания, функции щитовидной железы и иммунологических показателей. Установлено, что сочетание РА с АИТ сопровождается более высокой активностью заболевания, большей выраженностью суставного синдрома, ухудшением функционального состояния и качества жизни, а также значительными изменениями тиреоидного статуса и ультразвуковой структуры щитовидной железы. Полученные результаты свидетельствуют о необходимости раннего выявления тиреоидной патологии у пациентов с РА и комплексного междисциплинарного подхода к их ведению.

Keywords: rheumatoid arthritis, autoimmune thyroiditis, thyroid dysfunction, DAS28, autoantibodies, quality of life.

Ключевые слова: ревматоидный артрит, аутоиммунный тиреоидит, тиреоидная дисфункция, DAS28, аутоантитела, качество жизни.

В настоящее время РА рассматривается как хроническое системное воспалительное заболевание, приводящее к поражению не только суставов и околосуставных тканей, но и вегетативной и центральной нервной систем, эндокринной системы, с возможным нарушением их взаимосвязи, которое приводит к дополнительному осложнению течения основного заболевания.

Целью исследования явилось клинико-лабораторная диагностика ревматоидного артрита, ассоциированного с аутоиммунным тиреоидитом. Диагноз РА был предложен американским обществом ревматологов и Европейской ассоциацией по ревматизму (ACR 2010/eular, 2010).

Материалы и методы. диагностики АИТ были предложены Российской ассоциацией эндокринологов в рамках клинической конференции по диагностике аутоиммунного тиреоидита в 2002

году. Всем пациентам, поступившим в ревматологическую клинику проведено комплексное обследование на предмет выявления всех признаков аутоиммунных заболеваний.

Клиническое обследование пациентов с ревматоидным артритом включает изучение следующих количественных параметров суставного синдрома: количество болезненных и припухших суставов, длительность утренней скованности (в минутах), интенсивность боли, а также общую оценку состояния пациентом и врачом по 100-миллиметровой визуальной аналоговой шкале (ВАШ), где 0 означает отсутствие боли, а 100 — ее максимальную интенсивность.

У всех пациентов были взяты общепринятые анализы также были определены, оценивающие тиреоидный статус показатели: свободный Т3 (0,7-2,0 нг/л), свободный Т4 (4,8-11,6 мкг/л), ТТГ (0,3-

4,0 млМЕ/л), антитела к тиреопероксидазе (антиТПО, 30 ЕД/л), антитела к тиреоглобулину (антиТГ, 100 МЕ/мл), инструментальные методы обследования такие как рентгенография суставов, УЗИ щитовидной железы).

Для проспективного анализа исследования были отобраны 120 пациентов с подтвержденным диагнозом ревматоидного артрита в возрасте 50,5±5,6 лет, со средней продолжительностью заболевания 8,01±3,8 лет.

Результаты. Все пациенты заполнили анкету для определения дисфункции щитовидной железы. Согласно результатам анализа, представленным в

таблице 1, несколько клинических признаков значительно различались между группами РА, АИТ и РА+АИТ, в том числе: усиление отечности (χ^2 -11,4; $p=0,001$) 75% и 33%, сильная усталость (χ^2 -12,6; $p=0,001$) 70% и 30%, сухость кожи (χ^2 -12,6; $p=0,001$) 75% и 25%, и запор (χ^2 -17,8; $p=0,001$) 80% и 20%. Задержка ответа наблюдалась у 75% пациентов в группе РА+АИТ и у 54% в группе РА, нарушение памяти — у 55% и 45%, увеличение массы тела — у 30% и 18% пациентов соответственно, а также были выявлены достоверные различия между группой РА+АИТ и группой РА ($p<0,05$; $p<0,01$).

1 -таблица

Сравнительный анализ клинических признаков пациентов

Жалобы и клинические признаки, количество (%)	РА+АИТ n= (60)		РА n= (60)		достоверность различий показателей в группах
	n	%	n	%	
Увеличение отечности суставов, %	45	75	19	33	χ^2 -11.4 $p=0,001$
Сонливость (%)	18	30	36	26	χ^2 -1.3 $P=0,32$
Замедленная реакция, число (%)	45	75	32	54	χ^2 -5.4 $P=0,05$
Повышенная утомляемость, число (%)	42	70	18	30	χ^2 -12.6 $P=0,001$
Ухудшение памяти, число (%)	33	55	27	45	χ^2 -4.9 $P=0,05$
Апатия и снижение настроения (%)	22	38	17	29	χ^2 -0.8 $P=0,32$
Брадикардия, количество (%)	18	30	12	20	χ^2 -2.4 $P=0,09$
Увеличение массы тела (%)	18	30	11	18	χ^2 -10.5 $P=0,01$
Выпадение волос, (%)	42	70	19	32	χ^2 -16.3 $P=0,001$
Сухость кожи (%)	45	75	15	25	χ^2 -12.6 $P=0,001$
Запоры (%)	48	80	12	20	χ^2 -17.8 $P=0,001$

Примечание: Р — надежность различия групповых показателей: надежный — $p<0,05$; средний — $p<0,01$; высоконадежный — $p<0,001$; χ^2 — критерий хи-квадрат — метод, выбранный для различения теоретического и практического проявления качественных признаков в группах; чем выше его показатель, тем выше степень практического проявления качественных признаков.

В таблице 2 представлен сравнительный анализ клинических характеристик пациентов с РА с АИТ и без него. В группе РА+АИТ наблюдались различия в возрасте пациентов по сравнению с группой РА (54,3±4,6; 44,5±6,2; $p<0,05$), а по длительности заболевания в группе с патологией АИТ преобладали 37,6% пациентов с запущенной стадией (<2 лет) и 56,7% пациентов с поздней стадией (≥2 лет). В группе пациентов с РА было больше случаев очень ранней стадии заболевания (до 6 месяцев) (34,4%) и запущенной стадии (<2 лет) (56,1%) ($p<0,05$). Гендерных различий в группах РА+АИТ и РА не наблюдалось.

При сравнительном анализе активности заболевания: уровень активности I по индексу DAS 28 был выявлен у 3 (7,1%) пациентов в группе РА+АИТ и у 4 (5%) в группе РА, статистически значимой разницы между группами не

наблюдалось. Уровень активности II был выявлен у 19 (31,6%) пациентов в группе РА+АИТ и у 34 (57,1%) в группе РА, что в 1,8 раза выше, чем в предыдущей группе. Также уровень активности III с высоким индексом DAS 28 был выявлен у 27 (63,3%) пациентов в группе РА+АИТ и у 21 (35,7%) пациента в группе РА, что в 1,77 раза выше, чем в предыдущей группе, и была отмечена значительная разница.

По продолжительности заболевания, в группе РА+АИТ результат был на 16% выше (8,08±2,39) по сравнению с группой РА (6,8±1,6), что является статистически значимой разницей ($p<0,05$). Также при анализе рентгенологических стадий заболевания по Штайнброкеру было установлено, что в группе РА преобладала II рентгенологическая стадия (40%, 27%, $p<0,05$), тогда как у пациентов с РА, ассоциированным с АИТ, в относительно

высокой пропорции наблюдались деструктивные процессы и анкилоз суставов, характерные для III стадии (40%, 30%, $p<0,05$).

Хотя объективные и субъективные симптомы были более выражены в группе РА+АИТ, различий между группами по степени функциональной

недостаточности суставов обнаружено не было. Однако группа РА+АИТ показала в $1,7\pm0,3$ и $1,4$ раза лучшие показатели качества жизни, чем группа РА, и была выявлена достоверная разница ($r<0,05$).

2-таблица

Клинические характеристики пациентов с РА с наличием и отсутствием АИТ (n=60)

	Показатель	РА АИТ n=60, abs, (%)	РА n=60 abs, (%)
1	Пол (абс.%): женский мужской	47 (77,5) 13 (22,5)	72 (73,5) 26 (26,5)
2	Возраст, лет ($M\pm m$)	$54,3\pm4,6^*$	$44,5\pm6,2^*$
3	Иммунологические характеристики РА (абс.%) Серопозитивный Серонегативный	48 (80) 33 (55)	34 (57,1) 26 (42,9)
4	Клиническая стадия РА (по длительности РА) Очень ранняя (<6 месяцев) Ранняя (6-12 месяцев) Продвинутая (<2 лет) Поздняя стадия (≥ 2 лет)	- 5 (8,3) 23 (38,3) * 32 (53,3)	13 (21,7) 4 (6,7) 9 (15) 34 (56,7)
5	Длительность суставного синдрома, лет ($M\pm m$)	$7,2\pm1,7$	$6,7\pm1,8$
6	Длительность РА, лет ($M\pm m$)	$8,08\pm2,39^*$	$6,8\pm1,6$
7	Активность заболевания по индексу DAS 28 ($M\pm m$)	$6,7\pm1,2^*$	$5,3\pm1,4$
8	Активность заболевания по индексу DAS 28 (абс.%) Низкая (DAS28 <3,2) Умеренная (3,2<DAS28<5,1) Высокая (DAS28>5,1)	14 (23,3) 19 (31,6) * 27 (45) *	5 (8,3) 34(56,7) * 21 (35) *
9	Внесуставные (системные) симптомы (абс.%) Присутствуют Отсутствуют	12 (20,2) 48 (79,8)	58 (59,1) 40 (40,8)
10	Наличие эрозий (абс) Неэрозивный эрозивный	14 (35) 26 (65)	23 (23,4) 75 (76,5)
11	Рентгенологическая стадия по Штайнброкеру (абс %) I II III IV	6 (10) 16 (27) 24 (40) 14 (23)	3 (3) 24 (40) 18 (30) 15 (25)
12	Функциональный класс (абс %) I II III IV	4 (6,7) 19 (31,6) 30 (50) 7 (11,7)	3(5) 21 (35) 29 (48,3) 7 (11,7)
13	Индекс HAQ ($M\pm m$)	$1,7\pm0,3^*$	$1,2\pm0,2$

*РА+АИТ и РА - различия между группами по надежности, $r<0,05$

Результаты, полученные в ходе исследования, и данные литературы подчеркивают, что анализ характера проявления системных симптомов РА, «серьезных» внесуставных проявлений, своевременное выявление агрессивной и быстро развивающейся патологии дает возможность рационального подхода к выбору ранней и активной терапии.

Сравнивались изменения тиреоидной ультратонкой ткани в группах РА+АИТ и РА. У

пациентов группы РА+АИТ была обнаружена статистически значимая разница между группами по гетерогенному составу и очаговым изменениям щитовидной железы ($r<0,05$). В группе РА статистически значимой разницы в размерах правой и левой долей щитовидной железы и размерах шеи не было. У пациентов группы РА+АИТ по сравнению с группой РА (26,6%) в большинстве случаев было выявлено неоднородное содержание щитовидной железы, в 60% случаев –

достоверная разница ($r < 0,01$). Диффузное содержимое было обнаружено в большинстве случаев у всех пациентов с РА + АИТ и имело статистически значимый характер ($P < 0,02$). При сравнении этих групп было установлено, что неравномерная структура щитовидной железы встречалась в 2,63 раза чаще у пациентов с ревматоидным артритом, ассоциированным с аутоиммунным тиреоидитом, а смешанные диффузно-неравномерные изменения также были выявлены только у пациентов этой группы, что статистически значимо ($p < 0,01$). Кроме того, очаговые изменения отмечались почти у половины пациентов с РА + АИТ (51,7%). Заметно было увеличение объема щитовидной железы у пациентов с РА + АИТ по сравнению с группой РА, но статистически значимой разницы не наблюдалось. Диффузные экзогенные изменения щитовидной железы представляли собой многочисленные нерегулярно расположенные гипозоногенные зоны различной формы, также отмечались фиброзные структуры.

В активный период ревматоидного процесса у пациентов возникала боль при пальпации щитовидной железы, ее размер увеличивался, консистенция железы становилась плотной, а иногда появлялась боль при глотании. Эти клинические данные в сочетании с изменениями уровня гормонов щитовидной железы позволили нам подтвердить развитие АИТ у пациентов, а ультразвуковое исследование щитовидной железы выявило гиперэхогенную ткань щитовидной железы, «ложные» узлы, неровные контуры щитовидной железы и асимметрию ее сегментов, что характерно для АИТ.

Диффузно-узловая гипертрофическая форма наблюдалась у 8 (36,4%) пациентов с субклиническим гипотиреозом, у 2 (22,2%) пациентов с явным гипотиреозом и у 5 (17,2%) пациентов с эутиреоидным типом. Атрофия щитовидной железы была выявлена только у 2 (22,2%) пациентов с явным гипотиреозом ($r < 0,01$). Атрофическая форма щитовидной железы в основном наблюдается при явном гипотиреозе, а на начальных стадиях заболевания атрофия железы не наблюдается.

Уровни гормонов щитовидной железы и антител сравнивались между пациентами с РА+АИТ и РА. Значение ТТГ было в 1,8 раза выше в группе РА+АИТ по сравнению с группой РА ($4,2 \pm 4,1$, $2,3 \pm 1,5$, $r < 0,01$). Достоверных различий в значениях $eT3$ и $eT4$ обнаружено не было. Значения соотношения АТ к ТПО были в 8 раз выше ($87,3 \pm 12,2$ и $9,1 \pm 40,2$, $r < 0,01$), а соотношение АТ к ТГ было в 5,75 раз выше ($81,1 \pm 39,6$ и $14,1 \pm 38,4$, $r < 0,01$) в группе РА+АИТ по сравнению с группой РА.

У пациентов с РА по функциональным изменениям щитовидной железы субклинический гипотиреоз был выявлен у 22 (36,7%) пациентов, явный гипотиреоз — у 9 (15%) пациентов, а эутиреоидный тиреоидит — у 29 (48,3%) пациентов. Гиперфункция щитовидной железы — гипертиреоз — среди пациентов, участвовавших в исследовании, не была выявлена. У пациентов с АИТ течение и активность заболевания зависят от степени дисфункции щитовидной железы.

Изменения состояния щитовидной железы у пациентов с РА, ассоциированным с АИТ, анализировались в сравнении с функциональными характеристиками щитовидной железы в подгруппах пациентов с субклиническим, явным гипотиреозом и эутиреозом (таблица 3). При этом уровень $eT3$ был выше в группе с субклиническим гипотиреозом и эутиреозом ($2,1 \pm 1,2$ и $2,4 \pm 1,9$), чем в группе с явным гипотиреозом, значение $eT4$ было выше во всех подгруппах РА + АИТ, чем в группе РА, но более низкие значения были зафиксированы только при явном гипотиреозе по сравнению с другими группами ($6,4 \pm 2,3$, $p > 0,05$), статистически значимых различий не обнаружено. Также динамическое повышение уровня ТТГ, ТПО и ТГ в функциональных группах РА + АИТ было статистически значимым по сравнению с группой РА ($p < 0,05$).

Количество ТТГ в субклинических гипотиреозидных функциональных группах пациентов с АИТ было в 3,2 раза выше, чем в эутиреоидной группе, и в 2,43 раза выше в группах с РА ($5,6 \pm 1,7$ и $1,7 \pm 0,6$; $5,6 \pm 1,7$ и $2,3 \pm 1,5$; $r < 0,05$). Было установлено, что значения индекса ТТГ в эутиреоидных группах были аналогичны значениям в группе с РА. При субклиническом гипотиреозе антитела к ТПО были обнаружены у 13 (61,9%) пациентов, антитела к ТГ — у 8 (38,1%) пациентов, а антитела обеих групп — у 2 (9,5%) пациентов; при манифестном гипотиреозе антитела к ТПО были обнаружены у 4 (66,7%) пациентов, антитела к ТГ — у 2 (33,3%) пациентов, а антитела обеих групп — у 3 (50%) пациентов; в функциональной группе эутиреоза антитела к ТПО были обнаружены у 13 (68,4%) пациентов, антитела к ТГ — у 6 (31,6%) пациентов, а антитела обеих групп — у 1 (5,3%) пациента. У пациентов с аутоиммунным тиреоидитом с ревматоидным артритом у 25 (62,5%) были антитела к ТПО, у 9 (22,5%) — антитела к ТГ, а у 6 (15%) — антитела обоих поколений. Кроме того, соотношение антител к щитовидной железе к антителам к тиреопероксидазе (анти-ТПО) было выше, чем к антителам к тиреоглобулину (анти-ТГ), и антитела к ТПО считались высоконадежным индикатором для диагностики аутоиммунного тиреоидита. 3 - жадвал

**Анализ параметров состояния щитовидной железы у пациентов
с РА+АИТ и РА**

Показатели	эТ3	эТ4	ТТГ	ТПО к АТ	ТГ к АТ
РА	2,8±1,8	14,2±3,3	2,3±1,5	18,3±40,2	14,1±38,4
РА+АИТ субклинический гипотиреоз n=22	2,1±1,2	10,7±2,2	5,6±1,7 [#]	83,6±44,3 [#]	80,4±35,7 [#]
РА+АИТ манифестный гипотиреоз n=9	1,6±1,5	6,4±2,3	7,1±1,4 [*]	85,7±46,8 [*]	83,6±38,4 [*]
РА+АИТ эутиреоз n=29	2,4±1,9	13,6±3,5	1,7±0,6 ^Δ	38,4±32,6 ^Δ	32,4±23,6 ^Δ

Примечание: Р - достоверность различия групповых показателей: достоверность - * $p < 0,05$; средняя - ** $p < 0,01$; ***высоко достоверность - $p < 0,001$; # - достоверность различия показателей групп 1 и 2, * - 1 и 3 и Δ - достоверность различия показателей групп 1 и 4.

При анализе количества болезненных суставов, количества опухших суставов, уровня активности и индекса CDAI, являющихся показателями оценки суставного синдрома у пациентов с РА, ассоциированным и не ассоциированным с АИТ, были обнаружены достоверные статистические значения среди пациентов с РА+АИТ с субклиническим и манифестным гипотиреозом и пациентов группы РА. Количество болезненных суставов в группе пациентов с РА, не связанных с АИТ, составило 6,1±1,2, а у пациентов с субклиническим и явным гипотиреозом — 7,6±2,2 (24,5%) и 8,2±2,3 (25,6%) соответственно (# $p < 0,05$). Также количество опухших суставов в группе с субклиническим гипотиреозом составило 7,4±2,1, что в 1,32 раза выше, чем результат 5,6±1,4 в группе РА. У пациентов с явным гипотиреозом этот показатель составил 8,1±2,4, что в 2,76 раза выше, чем в группе РА (# $p < 0,05$). Продолжительность утренних приступов составила 76,1±4,7 мин в группе пациентов с РА и 116,5±4,5 мин в подгруппе с манифестной формой РА+АИТ, что на 34,6% больше по сравнению с группой пациентов с РА (# $p < 0,05$).

Индекс CDAI составил 25,5±13,2 в группе субклинического гипотиреоза и 26,5±12,3 в группе явного гипотиреоза, что в 1,18 и 1,23 раза выше, чем в группе РА (21,6±12,1) соответственно (# $p < 0,05$). Также индекс активности DAS-28 составил 5,6±1,3 и 6,2±2,4 в группах субклинического и явного гипотиреоза, что на 17,8% и 25,8% выше, чем в группе РА (4,6±1,3), что является статистически значимой разницей (# $p < 0,05$).

Согласно индексу HAQ, ухудшение качества жизни было отмечено во всех подгруппах РА+АИТ по сравнению с группой РА (1,25±0,13), но статистически значимая разница наблюдалась только в группах субклинического и явного гипотиреоза, 1,32±0,11 и 1,57±0,12 соответственно ($p < 0,05$). Только в эутиреоидной группе РА+АИТ и группе РА значимой разницы не было обнаружено, что затрудняет клиническую диагностику АИТ на данном этапе.

Таким образом, анализ клинических проявлений заболевания у пациентов обеих групп в ходе исследования характеризует тяжесть симптомов и повышенную активность основного

заболевания у пациентов с ревматоидным артритом, ассоциированным с аутоиммунным тиреоидитом.

Список литературы:

1. Агаки С.А., Граппа Л.Г. Взаимосвязь между функцией щитовидной железы и течением ревматоидного артрита // Научно практическая ревматология. – 2001. – № 3. – С. 4.
2. Валдина Е.А. Заболевания щитовидной железы // – СПб. - 2006. – С.368.
3. Валеева Ф.В., Киселева Т.А., Ахунова Г.Р. Проблемы взаимосвязи патологии щитовидной железы и ревматологических заболеваний / /Сибирский медицинский журнал. – 2011. - № 4(26).
4. Грязнова МА, Хамнуева ЛЮ. Особенности цитокиновой регуляции при аутоиммунной патологии щитовидной железы // Журнал научных статей «Здоровье и образование в XXI веке». – 2017. - №19(7).3 – С.3-39.
5. Елисеева Л.В. Течение ревматоидного артрита, сочетающегося с патологией щитовидной железы : автореф. дис. ... канд. мед. наук. – Томск, 2002. – С.21.
6. Уитман Э. Сопутствующая аутоиммунная патология при заболеваниях щитовидной железы [Электронный ресурс] / русский перевод докт. мед. наук В.В. Фадеева // Thyroid International. – 2005. – № 1. – URL: http://www.voed.ru/sop_autoimm_pat_zab_sh_zh.htm.
7. Bliddal S, Nielsen CH, Feldt-Rasmussen U. Recent advances in understanding autoimmune thyroid disease: the tallest tree in the forest of polyautoimmunity // F1000Res. – 2017. - №6. – P.1776.
8. Charles PJ, Plant D, Chowdhury W, Worthington J, Venables P. Antibodies to thyroglobulin and thyroid peroxidase in rheumatoid arthritis: environmental and genetic associations // Ann Rheum Dis. – 2011. - №70. – P.A88
9. Cojocaru-Gofita IR, Ciurea P, Rosu A, Musetescu AE, Vreju F, Barbulescu A. Hypothyroidism-risk factor for treatment resistant, aggressive rheumatoid arthritis onset // Scand J Rheumatol. – 2010. - №39. – P.29.
10. Colin MD, Gilbert HD. Chronic autoimmune thyroiditis // New. Engl. J. Med. – 2016. - №335. P.99-107

PHILOLOGICAL SCIENCES

RECEPTION OF THE IMAGE OF THE MODERN WOMAN IN AMERICAN LITERATURE

Mykhailenko V.

*Department of Foreign Literature and Fundamentals of Rhetoric
Communal Higher Education Institution
«Vinnytsia Humanities Pedagogical College»
st. Nagirna, 13, Vinnytsia, Ukraine*

РЕЦЕПЦІЯ ОБРАЗУ СУЧАСНОЇ ЖІНКИ В АМЕРИКАНСЬКІЙ ЛІТЕРАТУРІ

Михайленко В.В.

*КЗВО «Вінницький гуманітарно-педагогічний коледж»
кандидат філологічних наук,
старший викладач кафедри зарубіжної літератури та основ риторики
Вінниця, Україна
<https://doi.org/10.5281/zenodo.21982213>*

Abstract

The article examines the features of the representation of the image of a modern woman in American literature of the late 20th and early 21st centuries. The focus is on the transformation of the traditional female model and the formation of a new type of heroine, for whom personal autonomy, self-realization, professional activity, the right to one's own choice and the search for individual identity become decisive.

The material for the study was the novels of modern American writers Britt Bennett *The Vanishing Half* and Meg Wolitzer *The Female Persuasion*. The main models of the artistic representation of a modern woman are identified: a woman as a subject of her own life, a professional woman, a woman leader, a woman mother, a woman who resists social stereotypes, as well as a woman who is in the process of searching for her own identity.

It is proven that modern American literature moves away from a one-dimensional image of a female character and represents her as a complex, contradictory and dynamic personality. The problem of the interaction of gender, social, professional and racial identities is of particular importance. Based on the material of the novels, it is traced that the freedom of a modern woman does not mean the absence of social pressure: the heroines are forced to constantly correlate their own aspirations with social expectations, family roles, cultural norms and ideas about "successful" femininity. The conclusion is made about the formation of a polyphonic image of a woman in modern American literature, which is based on the principles of autonomy, self-identification and the right to personal choice.

Анотація

У статті досліджено особливості репрезентації образу сучасної жінки в американській літературі кінця XX – початку XXI століття. Зосереджено увагу на трансформації традиційної жіночої моделі та формуванні нового типу героїні, для якої визначальними стають особистісна автономія, самореалізація, професійна діяльність, право на власний вибір і пошук індивідуальної ідентичності.

Матеріалом дослідження стали романи сучасних американських письменниць Бріт Беннет *The Vanishing Half* та Мег Волітцер *The Female Persuasion*.

Визначено основні моделі художньої репрезентації сучасної жінки: жінка як суб'єкт власного життя, жінка-професіоналка, жінка-лідерка, жінка-мати, жінка, яка протистоїть соціальним стереотипам, а також жінка, що перебуває у процесі пошуку власної ідентичності.

Доведено, що сучасна американська література відходить від одновимірного зображення жіночого персонажа та репрезентує його як складну, суперечливу й динамічну особистість. Особливого значення набуває проблема взаємодії гендерної, соціальної, професійної та расової ідентичностей.

На матеріалі романів простежено, що свобода сучасної жінки не означає відсутності суспільного тиску: героїні змушені постійно співвідносити власні прагнення із соціальними очікуваннями, сімейними ролями, культурними нормами та уявленнями про «успішну» жіночність. Зроблено висновок про формування в сучасній американській літературі поліфонічного образу жінки, який ґрунтується на принципах автономії, самоідентифікації та права на особистий вибір.

Keywords: American literature, modern woman, female image, female identity, gender, feminism, self-realization, artistic representation, American prose, female characters.

Ключові слова: американська література, сучасна жінка, жіночий образ, жіноча ідентичність, гендер, фемінізм, самореалізація, художня репрезентація, американська проза, жіночі персонажі.

Постановка проблеми Проблема жіночої ідентичності є однією з визначальних у сучасному літературному процесі. Трансформація соціального статусу жінки, розвиток феміністичної думки, зміна моделей сімейних і професійних відносин, посилення уваги до проблеми особистої автономії та права на самовизначення зумовили появу нових типів жіночих персонажів.

Американська література особливо чутливо реагує на соціокультурні зміни. У художніх текстах сучасних американських письменниць жінка дедалі частіше постає не як другорядний персонаж або об'єкт чоловічого погляду, а як центральний суб'єкт оповіді, здатний формувати власну життєву стратегію.

При цьому сучасний жіночий образ не можна зводити виключно до категорії «сильної жінки». Його художня специфіка полягає саме у внутрішній суперечливості. Сучасна героїня може бути одночасно незалежною і вразливою, професійно успішною та невпевненою в особистому житті, матір'ю і професіоналкою, активною учасницею суспільного життя та людиною, яка переживає кризу самоідентифікації.

Дослідники сучасної американської жіночої прози наголошують на тому, що питання ідентичності та спільноти є центральними для творчості таких письменниць, як Тоні Моррісон, Еліс Вокер, Сандра Сісерос та інших авторок [1].

У сучасній літературі ця проблематика набуває нових вимірів, оскільки жіноча ідентичність дедалі частіше розглядається на перетині гендеру, раси, класу, культури та особистого досвіду.

Метою статті є визначення основних моделей художньої репрезентації сучасної жінки в американській літературі та характеристика особливостей їх реалізації у творчості сучасних американських письменниць.

Для досягнення поставленої мети передбачено розв'язання таких завдань:

- 1) охарактеризувати основні підходи до вивчення жіночого образу в американській літературі;
- 2) визначити особливості трансформації традиційної моделі жіночого персонажа;
- 3) проаналізувати образ сучасної жінки на матеріалі романів Бріт Беннет *The Vanishing Half* та Мег Волітцер *The Female Persuasion*;
- 4) простежити взаємозв'язок жіночої, соціальної, професійної та особистісної ідентичності;
- 5) визначити роль проблеми свободи вибору та самореалізації у формуванні сучасного жіночого образу.

Аналіз останніх досліджень і публікацій Проблема репрезентації жінки в американській літературі має значну історію дослідження. Особливого розвитку вона набула в межах феміністичної літературної критики, гендерних студій та культурології.

Важливим теоретичним підґрунтям є праці С. де Бовуар, яка розглядала жіночність не як наперед задану сутність, а як результат соціокультурного формування [2]. Значний вплив на сучасне розу-

міння гендеру мала концепція Дж. Батлер, відповідно до якої гендерна ідентичність формується через повторювані соціальні та культурні практики [3].

Для американської літератури особливого значення набуває проблема взаємодії гендерної та расової ідентичності. У колективній монографії *Contemporary American Women Writers: Gender, Class, Ethnicity* акцентовано на тому, що художня репрезентація американських жінок охоплює різноманітні етнічні та соціальні спільноти, а жіночий досвід не може бути розглянутий поза категоріями класу, раси та культурної належності [1].

Окремої уваги заслуговує дослідження Л. П. Запори, присвячене жіночому письму в сучасній американській літературі. Дослідниця наголошує на важливості жіночого голосу як способу подолання культурної невидимості та формування нових моделей історичної й гендерної пам'яті [4].

1. Трансформація традиційного жіночого образу

У традиційній літературній моделі жінка часто репрезентувалася передусім через її стосунок до чоловіка або родини. Основними соціальними ролями героїні були роль дружини, матері, доньки або коханої.

Сучасна американська література суттєво трансформує цю модель. Жінка набуває власного голосу, життєвої історії та системи цінностей. Її існування більше не визначається виключно стосунками з чоловіками.

Показовим є перехід від моделі: **woman as object** → **woman as subject**. Тобто жінка переходить від статусу об'єкта спостереження, оцінювання чи бажання до статусу активного суб'єкта художньої оповіді.

Її внутрішній світ, професійні прагнення, сексуальність, материнство, страхи, травматичний досвід і пошук власної ідентичності стають самостійними предметами літературного зображення.

2. Жінка як суб'єкт власного життя

Однією з ключових характеристик сучасної американської героїні є прагнення до автономії. Вона прагне самостійно визначати:

- 1) місце проживання;
- 2) професію;
- 3) модель особистих стосунків;
- 4) ставлення до материнства;
- 5) зовнішність;
- 6) систему цінностей;
- 7) життєві пріоритети.

Таким чином, сучасна жінка отримує право на власний сценарій життя.

Ця модель особливо виразно простежується у романі Мег Волітцер *The Female Persuasion*. У центрі твору перебуває Грір Кадетські, молода жінка, яка поступово усвідомлює власні амбіції та прагнення до суспільної діяльності. Зустріч із відомою феміністичною активісткою Фейт Френк стає для неї поштовхом до переосмислення власного життя.

Критикиня Лорі Фезерс характеризує роман як твір про особисті амбіції, соціальну активність та феміністичну ідентичність [9].

Важливим є те, що становлення Грір не відбувається миттєво. Вона проходить шлях від невпевненої студентки до жінки, здатної самостійно визначати власні цінності.

Отже, сучасна американська героїня часто постає як **особистість у процесі становлення**.

3. Жінка і професійна самореалізація

Одним із найбільш характерних компонентів сучасного жіночого образу є професійна реалізація.

Якщо традиційний образ жінки часто був пов'язаний із приватною сферою, то сучасна героїня активно присутня у публічному просторі. Вона може бути: письменницею, журналісткою, науковицею, політикинею і т.д. Професійна діяльність у цьому випадку стає не просто способом заробітку, а важливим компонентом самоідентифікації.

У *The Female Persuasion* професійний шлях Грір тісно пов'язаний із її поступовим формуванням як особистості. Її прагнення працювати у сфері суспільної активності свідчить про бажання бути не лише спостерігачкою, а й учасницею суспільних процесів.

Водночас Волітцер демонструє суперечливість поняття успіху. Професійна реалізація не гарантує особистого щастя, а прагнення до впливу може супроводжуватися конкуренцією, амбіціями та моральними компромісами. Саме ця проблематика є однією з центральних у романі [9].

4. Жінка та проблема власного голосу

Особливого значення в сучасній американській літературі набуває мотив **голосу**.

Говорити означає бути присутньою у суспільстві. Власний голос стає символом автономії та права на самовизначення. Л. П. Замора наголошує, що жіноче письмо в американській літературі пов'язане з прагненням подолати історичне замовчування жіночого досвіду та створити простір, у якому жіночі голоси можуть бути почутими [4].

У цьому контексті сучасна героїня не просто отримує можливість говорити – вона отримує право **самостійно визначати значення власної історії**. Це особливо важливо для персонажів, чия ідентичність тривалий час визначалася іншими людьми.

5. Жіноча ідентичність і проблема раси

Однією з особливостей сучасної американської літератури є розширення поняття жіночої ідентичності.

Жінка більше не розглядається лише як представниця певної статі. Її ідентичність формується на перетині: **гендеру + раси + класу + культури + родини + особистого досвіду**.

Яскравим прикладом є роман Бріт Беннет *The Vanishing Half* (2020).

У центрі роману – сестри-близнючки Дезіре та Стелла Вайнс, чий життєвий шлях радикально розходиться. Офіційний опис роману Національного книжкового фонду США акцентує на відмінностях їхніх сімей, спільнот та расових ідентичностей [10].

Стелла починає жити як біла жінка, приховуючи своє афроамериканське походження, тоді як Дезіре повертається до свого минулого та приймає власну ідентичність.

Отже, роман демонструє, що ідентичність не є незмінною категорією. Вона формується під впливом історії, соціального середовища, особистого вибору та суспільних упереджень.

Дослідження М. Лапінської показує, що в романі Беннет ідентичність пов'язана з расою, особистим вибором, насильством, соціальними стереотипами та досвідом кількох поколінь жінок однієї родини [5].

6. Жінка і свобода вибору

Одним із центральних концептів сучасного жіночого образу є **свобода вибору**.

Дезіре у *The Vanishing Half* обирає повернення до рідного міста після років життя в іншому середовищі. Її рішення означає не повернення до минулого, а спробу відновити контроль над власною історією. Важливо, що свобода у романі не представлена як абсолютна. Жіночий вибір постійно обмежується: соціальними упередженнями, расовою ієрархією, економічними обставинами, сімейною пам'яттю, очікуваннями суспільства. Тому сучасна американська література розглядає свободу не як відсутність обмежень, а як **постійний процес боротьби за право визначати себе**.

7. Материнство як компонент сучасної жіночої ідентичності

залишається важливою складовою жіночого образу, однак сучасна література дедалі частіше відмовляється від його ідеалізованої моделі.

Жінка може бути матір'ю, але материнство не вичерпує її особистості.

У *The Vanishing Half* особливо важливою є історія Дезіре та її доньки Джуд. Їхні стосунки демонструють, як особистий досвід матері впливає на формування наступного покоління. Джуд успадковує не лише сімейну історію, а й травми, пов'язані з расовими та соціальними упередженнями.

Таким чином, материнство в романі стає механізмом передачі пам'яті та водночас можливістю **перервати успадковану модель дискримінації**.

8. Жінка як суб'єкт феміністичного дискурсу

У сучасній американській літературі жіночий персонаж часто бере участь у дискусії про саму природу фемінізму.

У *The Female Persuasion* Мер Волітцер порушує питання про те, хто має право говорити від імені жінок і якою повинна бути феміністична діяльність. Фейт Френк є представницею покоління феміністок, яке сформувалося в умовах іншого соціального контексту, тоді як Грір представляє молодше покоління.

Їхня взаємодія демонструє спадкоємність і водночас конфлікт між різними моделями фемінізму. У центрі опиняються питання жіночої солідарності, лідерства, влади, особистих амбіцій, суспільної відповідальності, взаємодії поколінь.

Отже, сучасна американська література репрезентує жінку не лише як об'єкт феміністичної боротьби, а як **активного творця феміністичного дискурсу**.

9. Суперечливість образу сучасної жінки

Важливою особливістю сучасного жіночого образу є його внутрішня суперечливість. Сучасна жінка прагне незалежності, кар'єрного успіху, особистого щастя, любові, материнства, суспільного визнання, свободи, самореалізації.

Проте одночасне досягнення всіх цих цілей часто виявляється неможливим. Тому сучасна героїня переживає внутрішні конфлікти. Вона повинна відповісти на питання: **Хто я? Чого я хочу? Якою мене хочуть бачити інші? Чи можу я залишатися собою, не відповідаючи суспільним очікуванням?**

Саме пошук відповідей на ці питання формує психологічну глибину сучасного жіночого персонажа.

10. Від «ідеальної жінки» до автентичної особистості

Традиційна література часто створювала нормативний образ «ідеальної жінки». Сучасна американська проза дедалі частіше ставить під сумнів саму можливість існування такого універсального ідеалу. Сучасна героїня може бути недосконалою.

Вона може помилятися, змінювати рішення, відмовлятися від певних ролей, переживати кризу, сумніватися у власних силах. Саме ця недосконалість робить її психологічно переконливою. Відтак відбувається перехід: **ідеальна жінка → реальна жінка → унікальна особистість.**

Ця тенденція є одним із ключових показників трансформації сучасної американської літератури.

Отже, образ сучасної жінки в американській літературі характеризується складністю, багатомірністю та динамічністю.

Сучасна американська героїня вже не обмежується традиційними ролями дружини, матері чи коханої. Вона постає як **самостійний суб'єкт**, який прагне визначити власний життєвий шлях, професійні цілі, систему цінностей та особисту ідентичність.

На матеріалі романів Бріт Беннет *The Vanishing Half* та Мег Волітцер *The Female Persuasion* можна виокремити такі основні моделі сучасної жінки: **жінка як суб'єкт власного життя, жінка-професіоналка, жінка-лідерка, жінка, яка шукає власну ідентичність, жінка-мати, жінка, яка протистоїть соціальним стереотипам, жінка як активна учасниця феміністичного дискурсу.**

Особливо важливою є ідея множинності жіночої ідентичності. У романі *The Vanishing Half* вона формується на перетині гендеру, раси, класу, сімейної історії та особистого вибору. У *The Female Persuasion* центральними стають питання жіночої самореалізації, амбіцій, феміністичної солідарності та професійної ідентичності.

Таким чином, сучасна американська література відходить від стереотипного образу «ідеальної жінки» та створює образ **автентичної особистості**, яка має право на суперечність, помилку, сумнів і самостійний вибір.

Сучасна жінка в американській прозі – це не завершений тип, а **процес становлення**, у якому особистість постійно переосмислює себе та власне місце у світі.

Перспективним напрямом подальшого дослідження є порівняльний аналіз жіночих образів у творчості Бріт Беннет, Мег Волітцер, Колсон Вайтхед, Роксани Гей, Отесси Мошфег та інших сучасних американських авторів із урахуванням категорій гендеру, раси, класу та культурної ідентичності.

Список літератури:

1. Zamora L. P. (ed.). *Contemporary American Women Writers: Gender, Class, Ethnicity*. London : Longman, 1998. 240 p.
2. Beauvoir S. de. *The Second Sex*. New York : Vintage Books, 1989.
3. Butler J. *Gender Trouble: Feminism and the Subversion of Identity*. New York : Routledge, 1990.
4. Zamora L. P. Finding a Voice, Telling a Story: Constructing Communal Identity in Contemporary American Women's Writing // *American Mythologies: Essays on Contemporary Literature*. Liverpool : Liverpool University Press, 2005. P. 267–294.
5. Łapińska M. The Consequences of Crossing the Color Line: Identity and Racial Passing in Brit Bennett's *The Vanishing Half* // *Crossroads. A Journal of English Studies*. 2024. No. 44. P. 66–83.
6. Bennett B. *The Vanishing Half*. New York : Riverhead Books, 2020.
7. Wolitzer M. *The Female Persuasion*. New York : Riverhead Books, 2018.
8. Champion L., Austin R. (eds.). *Contemporary American Women Fiction Writers: An A-to-Z Guide*. Westport, CT : Greenwood Press, 2002. 424 p.
9. Feathers L. Whose Feminism Is It Anyway? Meg Wolitzer's *The Female Persuasion* // *Los Angeles Review of Books*. 2018. April 12.
10. National Book Foundation. *The Vanishing Half*. National Book Awards 2020.
11. Sari Dewi I. R., Fithriani R., Pardi. Feminist Analysis of Brit Bennett's *The Vanishing Half* // *Humanitatis: Journal of Language and Literature*. 2026. Vol. 12, No. 2.

DEICTIC DIMINISHMENT: THE STRATEGIC USE OF PRONOMINAL REFERENCE IN POLITICAL OTHERING (ON THE EXAMPLE OF 2024 US PRESIDENTIAL DEBATE BETWEEN REPUBLICAN NOMINEE DONALD TRUMP AND DEMOCRATIC NOMINEE KAMALA HARRIS)

Kostanian Z.

*Ph.D., Associate Professor, Chair of Media Linguistics, Faculty of Journalism,
Lomonosov Moscow State University, Moscow, Russia
<https://doi.org/10.5281/zenodo.21982215>*

Abstract

This article identifies and critically analyzes a specific discursive strategy – deictic diminishment – employed by political figures to undermine their opponents through derogatory framing, demonization, stigmatization, and political othering. This strategy strips opponents of institutional legitimacy and social recognition, while simultaneously shaping the audience's mental models of them in negative terms.

To support this view, the author has studied the debate between Republican nominee Donald Trump and Democratic nominee Kamala Harris during the 2024 U.S. presidential election. While extensive scholarly work has catalogued Donald Trump's overtly insulting and pejorative language toward opponents, a systematic examination of his shift from formal address to bare pronouns, particularly "she" for Kamala Harris, remains absent. Drawing on insights from Critical Discourse Analysis (CDA), sociolinguistics, and cognitive linguistics, this study argues that such linguistic practice constitutes a strategic act of "deictic diminishment", demonstrating how the grammatical omission of a proper name, replaced by a personal pronoun, functions as a powerful instrument of political discourse.

The methodological framework combines Norman Fairclough's three-dimensional model of discourse and Teun A. van Dijk's socio-cognitive approach, enabling deictic devices to be analyzed not merely as linguistic units but also as instruments involved in the reproduction of power relations, ideological assumptions, and practices of political exclusion.

The results prove that Trump's linguistic strategy reduces Kamala Harris to a depersonalized adversary, incapable, unworthy and unfit to run for presidency. By analyzing key speech acts from the 2024 campaign, this article fills a critical gap in the literature on political communication, demonstrating how deixis can be weaponized not only to build in-group solidarity but also to enact strategic exclusion and dehumanization in contemporary electoral politics.

Keywords: deictic diminishment, political othering, social deixis, Critical Discourse Analysis (CDA), pronominal reference, 2024 US presidential debates.

1. Introduction

The 2024 U.S. presidential election between Republican nominee Donald Trump and Democratic nominee Kamala Harris [1] has generated a significant corpus of academic inquiry. Research has effectively mapped their rhetorical strategies, framing Trump's approach as 'impact leadership' characterized by simplicity, crisis-framing, and emotional resonance, while defining Harris's as "visionary progressivism" emphasizing inclusivity and systemic reform [11]. Comparative discourse analyses have dissected their debate performances, noting distinct patterns in lexical choice, emotional appeal, and the use of conceptual metaphors for image formation. A consistent thread in this scholarship is the recognition of Trump's reliance on personal insults and derogatory language, a well-documented feature of his political style aimed at illegitimizing opponents [2]; [24]. Attacks on Harris have ranged from questioning her mental acuity and racial identity to employing gendered and bigoted tropes.

However, while scholars have meticulously analyzed Trump's overtly pejorative language and metaphorical framing, there has been no focused academic study devoted to his systematic derogation and diminishment of his political adversaries through the strategic use – and omission – of deictic reference. To describe this subtle yet effective pragmatic strategy, we propose the concept of "deictic diminishment", which

we define as an intentional substitution of an opponent's formal name and title with bare, dismissive, and often contextually and emotionally loaded pronouns.

A semantic and pragmatic analysis of the September 2024 Trump-Harris debate notes a striking asymmetry of power: "Trump not mentioning Harris by name, while Harris [referred] to Trump frequently." [14]. This fleeting observation points toward a deeper discursive phenomenon yet to be theorized. This article argues that this omission is not accidental but instrumental. It functions as a violation of social deixis norms, which govern the use of linguistic markers to acknowledge social status and respect. By denying Harris the basic linguistic marker of her office and identity, the strategy seeks to strip her of institutional authority and reduce her from a titled official to a depersonalized, generic opponent.

2. Theoretical background

As its central theoretical framework, this study primarily draws upon *social deixis*, which constitutes a fundamental dimension of linguistic pragmatics, encompassing expressions such as pronouns, titles, and honorifics that explicitly encode the social relationships between interlocutors. As Van Dijk [20] theorizes, social deixis operates at a critical socio-cognitive interface, where linguistic structures are inextricably linked to societal hierarchies through shared knowledge, atti-

tudes, and ideologies. Within the strategic realm of political discourse, social deixis assumes a particularly potent role as an instrument for constructing authority, fostering solidarity, and demarcating opposition. According to Levinson [13], deictic expressions like “we”, “our”, and “they” serve as primary linguistic tools in political communication, inherently relying on contextual information for their full pragmatic force. Through the deliberate manipulation of such forms, politicians can construct collective identities and divisions. A salient example is found in Donald Trump’s rhetorical strategy, whereby he uses an inclusive “we/us” against an exclusive (oppositional) “they/them”, a maneuver designed to consolidate in-group solidarity while systematically marginalizing out-groups.

Van Dijk [21] elucidates that social deixis frequently grammaticalizes *asymmetries of power*, which is most transparent in languages possessing a T-V distinction (e.g., *tu* vs. *vous* in French, *мы-Вы* in Russian), where the choice of address form directly indexes social hierarchy and dominance in relations. In such systems, a speaker of higher social status, age, or power may employ the informal T-form toward a subordinate addressee, while receiving the formal V-form in return. As Wierzbicka [25] notes, these pragmatic choices of address are deeply tied to cultural scripts of distance, respect, and the linguistic manifestation of social power. Although English lacks a morphologically marked T-V dichotomy, power asymmetry is nonetheless pragmatically encoded through other deictic means. As Levinson notes, fine-grained distinctions in relative rank are often conveyed through the strategic selection of pronoun forms, vocatives, and titles. Indeed, within political discourse, personal pronouns (I/me, we/us, they/them) function as markers of in-group/out-group boundaries, signaling inclusion or exclusion, asserting institutional authority, and enacting processes of othering and hierarchical positioning.

Levinson [13, pp. 62-68] categorizes these pronouns under *person deixis*, which serves to predicate the roles of participants in a speech event and is grammatically reflected in the categories of first, second, and third person. This theoretical perspective is reinforced by subsequent analyses, such as those by Burling and Ingram [13, p. 69], who affirm the intrinsically deictic nature of pronominal systems. They define the latter through a framework of participant inclusion and exclusion: first person marks speaker inclusion (+S); second person marks addressee inclusion (+A); and third person marks the exclusion of both speaker and addressee (–S, –A). It is through this very mechanism of inclusion and exclusion that pronouns become central in constructing a political identity and demarcating social groups.

Building upon this theoretical foundation, the strategic deployment of person deixis can be understood as a core linguistic mechanism for enacting *political othering* described by Powell and Menendian [16, pp. 14-40]. This discursive and ideological process presents individuals or groups as fundamentally alien and oppositional to a dominant ‘in-group’ identity, drawing rigid symbolic boundaries between a legitimate ‘us’ and a

threatening ‘them’. The deictic choices outlined previously – specifically, the exclusive use of ‘we’ and the distancing ‘they’ – operationalize this binary. Elena Shegal [17] characterizes this phenomenon as the semiotic construction of the ‘political enemy’, a discursive strategy where linguistic distancing is used to strip political adversaries of institutional legitimacy.

The process of othering involves establishing a hierarchy that positions the self or in-group as superior. As noted above, the moral superiority claimed by the in-group legitimizes varying degrees of derogation toward the out-group, ranging from dislike and disrespect to outright hostility. By linguistically excluding the out-group from the deictic center (the –S, –A status of the third person), the discourse can facilitate their dehumanization, effectively redrawing the boundaries of the moral community to exclude them [12, pp. 252-264; 15, pp. 303-318].

The cumulative effect of this linguistically-mediated othering in political discourse is the intensification of *affective polarization* [3] – a state characterized not just by ideological disagreement but by profound animosity and distrust between partisan groups. When deictic strategies consistently frame political opponents as a distant, excluded, and morally inferior “them”, they foster the social distance, perceived moral superiority, and political intolerance that erode democratic norms. Thus, the micro-level linguistic choices surrounding pronouns and address forms are not merely reflective of social relations; they are active, constitutive tools in macro-level processes that threaten democratic resilience and social cohesion.

This practice aligns with, yet critically extends, established frameworks in Critical Discourse Analysis (CDA): Van Dijk’s model of the “ideological square” emphasizes “Our good things” and “Their bad things” while de-emphasizing the opposite [14, p. 75]. Deictic diminishment operationalizes this at the grammatical level: the opponent is not merely described negatively; they are first denied the symbolic capital of their name, making subsequent negative predication more easily naturalized. Similarly, Fairclough’s three-dimensional model of CDA, which connects textual features to discursive and social practices, provides a robust framework for understanding this tactic not as a stylistic quirk but as an exercise of power that shapes social relations and political cognition.

This intimate connection between micro-level textual manipulation and macro-level social control reflects the foundational ethos of the field. One of the central aims of CDA is to grasp, uncover, and identify ways of overcoming the abuse of power [7], [19]. Drawing on the work of Foucault [8], [9], [10], CDA scholars consider power relations to be discursive. In order to point out how the social abuse of power is discursively manifested, Fairclough suggests exploring the text’s nature, how it is embedded in discursive processes, and analysing discursive and social change on the basis of the text [4], [5], [6].

3. Material and methods

The primary data for this study consist of the official transcript of the first presidential debate between Democratic nominee Kamala Harris and Republican

nominee Donald Trump, held on September 10, 2024. The debate was hosted by ABC News and moderated by “World News Tonight” anchor David Muir and ABC News Live “Prime” anchor Linsey Davis [1]. This single pivotal script provides a dense corpus for a pragmatic investigation of diminishment strategies in political discourse.

To investigate the strategic mechanism of “deictic diminishment” as a form of political othering, this study employs a qualitative and quantitative discourse analysis situated within CDA, focusing on theoretical concepts: 1) Norman Fairclough’s three-dimensional framework, which views discourse simultaneously as text, discursive practice and socio-cultural practice [4], [5], [6]; and Teun A. van Dijk’s “ideological square” and socio-cognitive analysis, which connects micro-level textual structures to macro-level social power and ideological reproduction [22], [23]. This integrated framework enables the study to move beyond descriptive linguistics to critically examine how micro-linguistic choices in deixis enact macro-social processes of power, marginalization, and ideological contest.

The analysis unfolds through two integrated phases designed to move systematically from a close reading of the text to a broader ideological interpretation. The initial textual examination involves a detailed profiling of pronominal use, quantifying the frequency and context of third-person references like “she” and “her”, while also noting their strategic omissions. It further examines the evaluative lexis chosen to characterize Harris and her policies, and analyzes the rhetorical devices that frame these references. The consistent use of bare pronouns is examined as a mechanism of negative other-presentation, where the omission of formal title subtly erodes Harris’s institutional standing while amplifying her negative personal and political image. Ultimately, this systematic substitution is interpreted as a violation of norms in social deixis, constituting what we term deictic diminishment: a grammatical strategy to strip an opponent of authority, reduce their social persona, and facilitate their political delegitimization.

4. Textual analysis

4.1. Pragmatic Asymmetry: Deictic Diminishment versus Formal Nominal Recognition

The textual analysis reveals a fundamental and strategic asymmetry in how the candidates established reference to one another during the televised debate. Donald Trump’s linguistic choices are characterized by a consistent pattern of indirect reference and deictic diminishment. Throughout the debate, not once does he use Harris’s proper name (*Kamala Harris*) or her official title (*Vice President*). Instead, his references are exclusively pronominal, relying solely on the third-person pronouns “she” and “her”. This pattern is established from the very outset, when Trump references Harris as a detached third party:

(1) *I have no sales tax. That’s an incorrect statement. **She** knows that.*

In the examples below, Trump persistently continues referencing Harris as ‘she’ and ‘her’.

(2) ***She** copied Biden’s plan. And it’s like four sentences, like run-Spot-run. Four sentences that are*

*just oh, we’ll try and lower taxes. **She** doesn’t have a plan. Take a look at **her** plan. **She** doesn’t have a plan.*

(3) *I don’t say **her** because **she** has no policy. Everything that **she** believed three years ago and four years ago is out the window.*

(4) ***She** made a mistake.*

(5) *And you know what? I’ll give you a little secret. He (Viktor Orban) hates **her**. He can’t stand **her**.*

Trump’s systematic omission of his opponent’s name and title in examples (1-5) constitutes a marked violation of all sociolinguistic norms of political discourse. This deliberate strategy denies the referent social and political recognition, effectively reducing Kamala Harris to a depersonalized adversary. The contrastive nature of this tactic is underscored by Trump addressing other figures by their names within the same debate, for example Joe Biden. As is seen from the example (6), (7), (8) below, Trump refers to President Biden by name while maintaining the pronominal “she” for Harris:

(6) *These are the people that **she** and **Biden** let into our country.*

(7) *And that’s the kind of talent we have with **her**. **She**’s worse than **Biden**.*

(8) ***She** copied **Biden**’s plan.*

The deliberate contrast between naming Biden and pronominalizing Harris illustrates a strategy of selective recognition. On a pragmatic level, this pattern constructs a hierarchy of opposition, an asymmetry of power, framing Harris as unworthy, while recognizing Biden as a worthier opponent (*She’s worse than Biden*).

This pattern of diminishment is further amplified by the semantic content attached to the pronoun “she”, which Trump consistently embeds within assertions of Harris’ incompetence and lack of autonomy:

(9) *They gave **her** that to say.*

(10) *People don’t go to **her** rallies. There’s no reason to go. And the people that do go, **she**’s busing them in and paying them to be there.*

(11) *But if **she** ever got elected, **she**’d change it. And it will be the end of our country.*

(12) *...**she** has destroyed our country with policy that’s insane*

The above examples openly question Harris’s authority, intellect, and independent agency. In example (9), Trump’s assertion implies that Kamala Harris is incapable of formulating her own position: her speech was scripted by an unspecified “they” (a thinly-veiled reference to Democrats). Furthermore, the deliberate vagueness of “that” dismisses the substantive content of her notes, portraying Harris not as an equal actor but as a mere conduit for others’ ideas.

In an act of pejorative generalization (example (10)), Trump talks of Harris as an unpopular politician who has no followers; as a fraudster who boosts her rally figures by ‘busing people to the rallies’. Examples (11) and (12) are a vivid illustration of the strategy of ‘negative othering’: The out-group pronoun “she” is linguistically contrasted to the in-group pronoun “our” (*our country*), framing Harris’s potential presidency as an external threat to the nation.

Kamala Harris, in sharp contrast with Trump, consistently uses formal nominal reference to her opponent throughout the debate. She respectfully addresses Trump by his full name, “Donald Trump”, never resorting to the surname alone (*Trump*). As an alternative, she uses a formal titular reference “former president”:

(13) *Well, I would love to. Let's talk about what **Donald Trump** left us. **Donald Trump** left us the worst unemployment since the Great Depression. **Donald Trump** left us the worst public health epidemic in a century. **Donald Trump** left us the worst attack on our democracy since the Civil War. And what we have done is clean up **Donald Trump's** mess.*

(14) *What you're going to hear tonight is a detailed and dangerous plan called Project 2025 that the **former president** intends on implementing if he were elected again.*

(15) *The United States Supreme Court recently ruled that **the former president** would essentially be immune from any misconduct if he were to enter the white house again. Understand what it would mean if **Donald Trump** were back in the white house with no guardrails.*

As is seen in example (13), Kamala Harris mentions Trump's full name 5 times in succession, practically in each sentence of the passage, not once replacing it with a pronoun - what would be a grammatically correct and logically appropriate anaphorical reference. We can assume that Harris's deliberate avoidance of pronominal reference is not occasional, but rather a marked choice, with tangible pragmatic implications: Each repetition of her opponent's full name helps foster in the audience's minds that Donald Trump is the worst possible political actor, the one responsible for the “worst unemployment, worst public health and the worst attack on democracy” and therefore is the worst choice as future president.

4.2. Quantifying Asymmetry: Pronominal Erasure versus Nominal Recognition

Our quantitative analysis shows that in the aforementioned 2024 debate, Kamala Harris references Donald Trump by his name 37 times, while Trump makes 0 nominal references of Harris.

Figure 1 below presents the number of references of the political opponents during the debate:

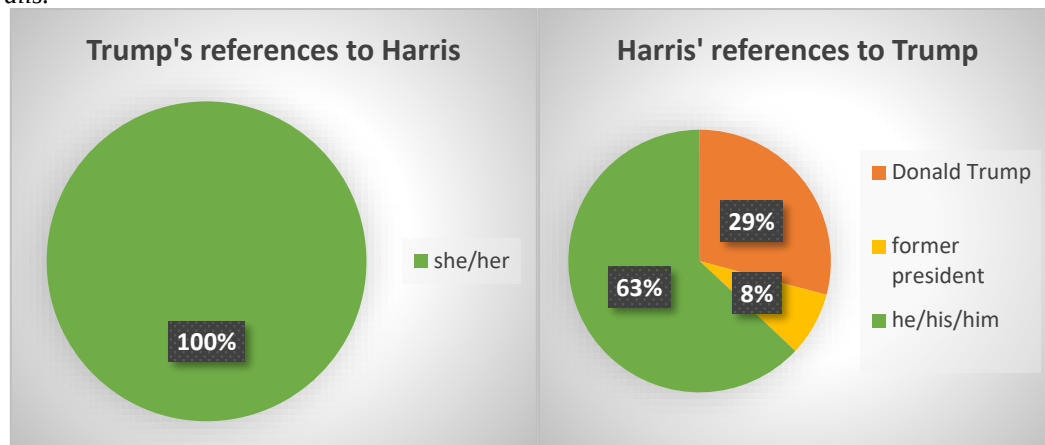


Figure 1: The number of references to political opponents across all responses.

Noteworthy, when considering how often each candidate referred to their opponent, we took into account not only personal names, but also other possible addresses, for example titles (“Vice-President” for Kamala Harris or “former President” for Donald Trump) or their mentions as nominees of Democratic and Republican respectively.

On the grammatical level, the above chart (a) demonstrates the use of zero anaphora (or indirect pronominal reference) as an instrument of constructing negative other-presentation. In linguistics, this phenomenon is also known as *pragmatics of absence*, the act of omission, which is not merely a lack of information but a strategic, discursive choice that carries significant functional weight in social interaction. In this particular case, zero anaphora is a direct application of social deixis to enforce the pragmatic functions of demeaning, presupposition, and negative framing of the opponent in a political discourse.

4.3. Deictic Diminishment as Gendered and Racialized Erasure

The linguistic tactic of erasing “Kamala Harris” in favor of “she” can meanwhile be viewed as an intentional act of gender and racial discrimination. This tactic aligns with a well-documented history in which Trump disproportionately targets women, particularly political opponents and critical journalists. *Washington Informer* quotes Elisa Lees Muñoz, Executive Director of the International Women's Media Foundation (IWMF), as saying, “Trump focuses on insulting women more than men... They are insults that we consider to be gender-based.” Another quote goes: “Since his (Trump's) appearance in Chicago, he has publicly called Vice President Harris an expletive on a golf course, as well as “stupid” and a “loser”.

The data we collected suggest that Trump's omission of Kamala Harris's name and the repeated use of the pronoun “she” reduces her to a generic, gendered category, implying she is less able, less worthy, less potent than a male politician would be. The discriminatory nature of this strategy is highlighted through direct contrast: During the same debate, Trump readily uses the proper names of male figures: moderator David

Muir (examples (16), (17), (18)) and, as we have already mentioned earlier, President Joe Biden (examples (19), (20), (21)):

(16) *What's, when are they going to be prosecuted -- when are these people from countries all over the world, not just South America, they're coming in from all over the world, David, all over the world.*

(17) *But when are those, David, when are those people going to be prosecuted? When are the people that burned down Minneapolis going to be prosecuted or in Seattle?*

(18) *We have a nation that is dying, David.*

(19) *These are the people that she and Biden let into our country.*

(20) *By the way, Joe Biden was found essentially guilty on the documents case.*

(21) *I ended the Nord Stream 2 pipeline and Biden put it back on day one but he ended the XL pipeline.*

This juxtaposition confirms that the omission applied specifically to Kamala Harris was not a general discursive habit but a targeted pragmatic act. By systematically withholding the respectful acknowledgment granted to male peers, Trump enacted a clear power differential, presenting Harris's identity as subordinate, diminished, unimportant.

Furthermore, for a Black woman like Kamala Harris, this gendered diminishment is inextricably interwoven with racial prejudice. The pronoun "she" in this context becomes a linguistic container for layered stereotypes, questioning the authority and intellect of Black women. As argued in a *Washington Informer* editorial, "Intelligent, strong Black women will always be a threat to Donald J. Trump." His verbal attacks on Kamala Harris's intelligence and his dismissive comments on her racial identity demonstrate how deictic diminishment serves as a component of a broader strategy to undermine her legitimacy. The exchange between moderator David Muir and former President Donald Trump over Kamala Harris's racial identity presented in example (22) is a vivid illustration of racialized rhetoric.

(22) *DAVID MUIR: I want to move on now to race and politics in this country. Mr. President, you recently said of Vice President Harris, "I didn't know she was Black until a number of years ago when she happened to turn Black, and now she wants to be known as Black." I want to ask a bigger-picture question here tonight. Why do you believe it's appropriate to weigh in on the racial identity of your opponent?*

(23) *FORMER PRESIDENT DONALD TRUMP: I don't. And I don't care. I don't care what she is. I don't care. You make a big deal out of something. I couldn't care less. Whatever she wants to be is okay with me.*

Trump's claim that Harris "happened to turn Black" in example (23) frames Harris as someone manipulating her identity for gain, thereby questioning her

sincerity and integrity. Furthermore, Trump's follow-up dismissal ("I don't care" and "I couldn't care less") emphasizes how little she means to him. The final line of the tirade, "Whatever she wants to be is okay with me", sounds quite patronizing, as if Trump grants Harris a permission to be who she wants, even more stressing his superiority over her.

4.4. From Individual "she" to Collective Diminishment "they"

Remarkably, Trump's strategic diminishment extends beyond an individual opponent to encompass an entire political affiliation through a rigid pronominal binary of "I" versus "they". This framework subsumes other binary pairs, such as "I/she" and "we/they", where the singular feminine pronoun "she" is semantically inflated to stand metonymically for the collective "they" – that is, the Democratic Party.

A clear example of such diminishment is found in Trump's discourse on economic policy. His statement begins with a direct, personalized attack: "She knows that," but then strategically shifts to 'they', as shown in example (24):

24. *I took in billions and billions of dollars, as you know, from China. In fact, they never took the tariff off because it was so much money, they can't. It would totally destroy everything that they've set out to do. They've taken in billions of dollars from China and other places. They've left the tariffs on. When I had it, I had tariffs and yet I had no inflation.*

This shift is not arbitrary but is the logical endpoint of deictic diminishment: the metonymic inflation of singular feminine "she" into plural anonymous "they". The negative associations attached to "she" (incompetence, destructive policy, illegitimacy) are seamlessly transferred onto the plural pronoun 'they', an ambiguous referent for Biden's administration, the Democratic Party, the "system". This strategy denies the opposition formal recognition and aggregates them into a singular, shadowy antagonist. The binary of the assertive, agential "I" ("I took," "I had") versus "they/them" reinforces the contrast between a strong effective leader and his ineffective opponents. Consequently, the political contest is discursively reshaped from a debate between platforms into a personal struggle, demonstrating how deictic diminishment enacts politics of polarization, where dehumanization begins with the simple act of refusing to name.

5. Discussion

On the pragmatic level, our examples show that the consistent use of the pronoun "she" in place of Kamala Harris's name establishes a diminishing deictic frame, which is strengthened through the employment of four discursive strategies: Othering, Labelling, Diminishing, and Demonizing, aimed at presenting Harris's persona as alien, ideologically rigid, insignificant, and existentially threatening. The following table delineates these core strategies, providing examples from the debate transcript and analyzing their specific purpose within the framework of deictic diminishment.

Table 1:

Four discursive strategies of diminishment used by Trump		
Strategy	Examples from Trump's discourse	Purpose
1. Othering	• <i>I rebuilt our entire military. She gave a lot of it away to the Taliban. She gave it to Afghanistan.</i> • <i>This is the one that weaponized. Not me. She weaponized.</i>	to construct a fundamental, moral opposition between the patriotic and effective "I" and a dangerous or traitorous "she". This places the opponent outside the community of shared national values and interests.
2. Labelling	• <i>She's a Marxist. Everybody knows she's a Marxist.</i> • <i>She was the border czar.</i> • <i>She was a horrible negotiator.</i>	to fix the opponent's identity with a single, reductive, and pejorative term.
3. Diminishing	• <i>They gave her that to say</i> • <i>So it doesn't matter what she says about going to Congress.</i> • <i>And I don't care. I don't care what she is. I don't care.</i>	to rhetorically negate the opponent's authority, arguments, and significance. By declaring their speech irrelevant or their identity meaningless, the speaker performs an act of discursive erasure.
4. Demonizing:	• <i>If she's president, I believe that Israel will not exist within two years from now.</i> • <i>Now she wants to do transgender operations on illegal aliens that are in prison.</i>	to escalate the critique to existential threat. This strategy portrays the opponent not merely as wrong, but as an agent of apocalyptic destruction and moral depravity,

These four macro-strategies mentioned above do not exist in a rhetorical vacuum; they are operationalized through identifiable stylistic devices. The follow-

ing analysis examines the key rhetorical devices, including refrain, contrast, and hyperbole, which serve to systematically deny, diminish, and depersonalize Kamala Harris.

Table 2:

The Execution of Diminishment Through Rhetorical Devices		
Stylistic Device / Rhetorical Strategy	Examples from Trump's Discourse	Commentary on Function within Deictic Diminishment
Refrain/ Anaphora	• <i>And just to finish off, <u>she</u> doesn't have a plan. <u>She</u> copied Biden's plan. And it's like four sentences, like run-Spot-run. Four sentences that are just oh, we'll try and lower taxes. <u>She</u> doesn't have a plan. Take a look at her plan. <u>She</u> doesn't have a plan.</i> • <i><u>She's</u> been against it for 12 years. Uh, defend the police. <u>She's</u> been against that forever. <u>She</u> gave all that stuff up, very wrongly, very horribly.</i>	The pronominal subject "she" functions as a grammatical refrain, transforming the pronoun from a simple referent into a rhythmic instrument of negation. Each repetition reinforces the opponent's identity as lacking, hateful, deceitful, and her actions as incompetent, ineffective and destructive for the country.
Parallel structures/Repetition	• <i><u>She went out</u> – <u>she went out</u> in Minnesota and wanted to let criminals that killed people, that burned down Minneapolis, <u>she went out</u> and raised money to get them out of jail. <u>She did things</u> that nobody would ever think of.</i> • <i>Now <u>she wants</u> to do transgender operations on illegal aliens that are in prison. This is a radical left liberal that would do this. <u>She wants</u> to confiscate your guns and she will never allow fracking in Pennsylvania</i>	Parallelism/repetition introduces structural uniformity to listing diverse accusations, making them sound even more dangerous and threatening. The rhythmic repetition of "she"-clauses creates a hypnotic cadence that is both memorable and rhetorically persuasive.
Gradation/ Amplification	• <i>She's not going to get the vote. She can't get the vote. She won't even come close to it.</i>	Grammatically, gradation moves from simple assertion ("she's not") to categorical impossibility ("she can't") to hyperbolic failure ("won't even come close").

	• <i>She's destroying this country. And if she becomes president, this country doesn't have a chance of success. Not only success. We'll end up being Venezuela on steroids.</i> • <i>She's worse than Biden. In my opinion, I think he's the worst president in the history of our country. She goes down as the worst vice president in the history of our country.</i>	Semantically, gradation amplifies from criticism of her actions ("destroying this country") to a larger scale of disaster ("this country doesn't have a chance of success") to a devastating culmination ("We'll end up being Venezuela on steroids."). Put in the order from comparative to superlative degree, the adjectives intensify the emotional impact of the warning, especially in the last sentence, with the extension 'in the history of our country'.
Hyperbole	• <i>She got zero votes. And when she ran, she was the first one to leave because she failed. And now she's running. I don't understand it but I'm okay with it – because I think we're going to do pretty well.</i> • <i>If she's president, I believe that Israel will not exist within two years from now.</i>	The use of hyperbole reduces a complex political career to an absolute zero, completely erasing the opponent's political legitimacy. This extreme simplification makes the argument memorable and easy to grasp. This sentence uses hyperbole to frame the election as an existential crisis, shifting the debate from a discussion of specific policies to a terrifying, life-or-death scenario.
Contrast	• <i>I rebuilt our entire military. She gave a lot of it away to the Taliban. She gave it to Afghanistan.</i> • <i>I had no inflation, virtually no inflation, they had the highest inflation, perhaps in the history of our country</i>	This persistent pattern of binary contrasts (I/she, I/they, we/they) frames the audience's choice as an irreconcilable conflict between success and failure, strength and weakness, poverty and wellness.
Metaphors	• <i>She was the border czar. Remember that. She was the border czar. She doesn't want to be called the border czar because she's embarrassed by the border.</i>	The metaphor "czar" serves to alienate Harris, presenting her as an autocratic, un-American ruler, building an association with Russian czars. The metaphor functions as a tool of political alienation.
Questions	• <i>Why hasn't she done it? She's been there for 3 1/2 years. They've had 3 1/2 years to fix the border.... Why hasn't she done it?</i>	A rhetorical question of this kind is meant to plant an accusation as if it were an obvious fact. By repeatedly asking why "she" has not acted, the speaker frames the opponent as fundamentally incapable and negligent, fostering the audience's negativity towards the opponent.

The empirical findings compiled in Tables 1 and 2 demonstrate that "deictic diminishment" operates as a highly systematic, interconnected discursive system rather than a series of arbitrary personal slights. This phenomenon illustrates what Fairclough [5], [6] describes as the direct link between micro-textual features and macro-social practices. By replacing socially sanctioned nominal references (*Kamala Harris; The Vice President*) with the bare third-person singular pronoun she, the speaker establishes a restrictive deictic frame. This frame serves as the pragmatic foundation for four distinct macro-strategies: Othering, Labelling, Diminishing, and Demonizing.

This strategic orchestration relies heavily on anaphora, refrains, and parallel syntax to initiate the macro-strategy of *Othering*. In the context of Critical Discourse Analysis (CDA), Othering serves to construct a rigid ideological divide between a self-legitimated in-group and a marginalized out-group. In the analyzed text, the pronoun "she" is stripped of its neutral indexical function and transformed into a rhythmic instrument of negation. When different socio-political accusations are embedded within parallel clauses, they

flatten the opponent's multifaceted political identity into a monolithic source of threat.

Following this initial pronominal baseline, the discourse employs the macro-strategy of *Labelling* to represent the opponent's identity within pejorative categories (e.g., *Marxist, horrible negotiator*). This strategy aligns with van Dijk's [22] "ideological square", which emphasizes the out-group's negative properties while erasing their positive attributes. The use of the "border czar" metaphor illustrates the interplay between micro-semantics and macro-ideology; by leveraging the autocratic associations of the term, the text superimposes a framework of un-American authoritarianism onto the bare pronoun. This works in tandem with binary syntactic contrasts, structurally positioning a capable, active first-person pronoun (*I rebuilt, I had no inflation*) against an inept, destructive third-person pronoun (*She gave away; They had the highest inflation*). This clear division pushes the opponent completely out of the deictic center of authority.

The macro-strategy of *Diminishing* then uses this structural marginalization to erase the opponent's au-

thority, rendering her speech irrelevant (*It doesn't matter what she says*), which is sustained through two linguistic maneuvers: rhetorical questions and grammatical gradation. Targeted rhetorical questions like *Why hasn't she done it?* sound like obvious facts, framing the opponent as fundamentally incapable. At the same time, syntactic gradation scales her political potential down from a simple negative assertion (*She's not going to get the vote*) to an absolute modal impossibility (*She can't*), systematically reducing her perceived political efficacy.

Finally, the discourse culminates in the macro-strategy of *Demonizing*, turning standard political contexts into an existential and apocalyptic crisis. This shift is executed through semantic amplification and hyperbole. The text scales its critique from localized policy failure (*destroying this country*) to systemic, civilizational collapse (*Venezuela on steroids; Israel will not exist*). This extreme exaggeration works because the opponent's individual identity has already been minimized by withholding her name. It allows the speaker to use the pronoun *she* as an empty placeholder for absolute catastrophe and moral failure.

In summary, the interaction between the macro-strategies in Table 1 and the stylistic devices in Table 2 demonstrates that deictic diminishment operates as an integrated system. What might have seemed as an initial grammatical slight – the refusal of nominal and titular recognition – is systematically amplified through repetition, binary contrasts, and hyperbole. The result shows how basic grammatical choices can be weaponized to achieve institutional erasure, deepen polarization, and reinforce political divisions.

6. Conclusion

Our analysis of the 2024 Trump-Harris debate reveals the following key findings. First, deictic diminishment represents a form of symbolic violence that targets the opponent's social persona and institutional standing. By denying onomastic recognition, it seeks to undo the individual's legitimacy before engaging with their policies.

Second, when directed at a pioneering female candidate of color, this strategy intersects with enduring patterns of gendered disrespect, leveraging stereotypes to question competence and authenticity. It thus functions as a reactionary linguistic practice, attempting to reinscribe traditional hierarchies challenged by Harris's identity.

Finally, and most broadly, the practice contributes to the degradation of democratic discourse. It models a form of engagement that replaces the recognition of a legitimate adversary – a cornerstone of agonistic democracy – with a rhetoric of erasure and existential threat, thereby fueling the affective polarization that destabilizes pluralistic societies.

Furthermore, this study delineates the specific pragmatic-semantic load borne by the diminished pronoun. The pronominal reference “*she*” became a semantically enriched node, consistently embedded in contexts of negation, incompetence, and threat through the intertwined strategies of Othering, Labelling, Diminishing, and Demonizing. Thus, the pronoun was transformed from a neutral grammatical placeholder

into a carrier of fixed negative meaning. Every new instance of “*she*” served to strengthen a pre-existing negative perception. This shifted the discursive effort away from refuting Harris's substantive arguments and reinforced a damaging associative link – a key mechanism of political persuasion.

The analysis also elucidates the rhetorical-grammatical synergy essential to the strategy's efficacy. Deictic diminishment provided the foundational linguistic structure upon which rhetorical devices – such as refrain-like repetition, contrastive parallelism, and hyperbolic gradation – built their persuasive force. The insistent repetition of “*she*” functioned as a cognitive anchor, ensuring that a multitude of negative predicates were consistently attributed to a single, depersonalized agent.

This study opens several avenues for further scholarly inquiry. Future research should employ experimental methods to test the cognitive and attitudinal effects of deictic diminishment versus formal address on voter perceptions and biases. Investigating audience reception and resistance – how different voter segments interpret or reject such diminishment would provide a more complete picture of the pragmatic efficacy and limits of deictic diminishment.

References:

1. ABC News. 2024. Harris-Trump presidential debate full transcript. ABC11 Raleigh-Durham, 11 September 2024. <https://abc11.com/feature/kamala-harris-donald-trump-presidential-debate-full-transcript-abc-news/15287730>
2. BBC. 2024. What insults tell us about the Trump-Harris election fight. *BBC News*, 21 September 2024. <https://www.bbc.com/news/articles/cx20np62x880> (accessed 24 March 2026).
3. Erdoğan, Emre & Pinar Uyan-Semerici. 2025. *Frontiers in Political Science* 7. Article 1553889. <https://doi.org/10.3389/fpos.2025.1553889> (accessed 12 December 2025).
4. Fairclough, Norman. 1992. *Discourse and social change*. Cambridge: Polity Press.
5. Fairclough, Norman. 1995. *Critical discourse analysis: The critical study of language*. London: Longman.
6. Fairclough, Norman. 2001. *Language and power* (2nd ed.). London: Pearson Education.
7. Fairclough, Norman, Jane Mulderrig & Ruth Wodak. 2011. Critical discourse analysis. In Teun A. van Dijk (ed.), *Discourse studies: A multidisciplinary introduction* (2nd ed.), 357–378. London: Sage.
8. Foucault, Michel. 1971. Orders of discourse (L'ordre du discours). *Social Science Information* 10 (2). 7–30.
9. Foucault, Michel. 1972. *The archaeology of knowledge*. London: Tavistock Publications.
10. Foucault, Michel. 2001. *Power: The essential works of Foucault, 1954–1984* (Vol. 3). James D. Faubion (ed.). New York: The New Press.
11. Hamed, Dalia M. & Naif Alqurashi. 2025. Impact vs. vision: A critical discourse analysis of Trump and Harris' leadership rhetoric in the 2024 presidential election. *Frontiers in Communication* 10.

- Article 1541513.
<https://doi.org/10.3389/fcomm.2025.1541513>
12. Haslam, Nick. 2006. Dehumanization: An integrative review. *Personality and Social Psychology Review* 10 (3). 252–264.
 13. Levinson, Stephen C. 1983. *Pragmatics*. Cambridge: Cambridge UP.
 14. Linkevičiūtė, Vilma. 2025. Shaping the political image: Kamala Harris's case. *Journalism and Media* 6 (2). Article 75.
<https://doi.org/10.3390/journalmedia6020075>
 15. Opotow, Susan, Janet Gerson & Sarah Woodside. 2005. From moral exclusion to moral inclusion: Theory for teaching peace. *Theory Into Practice* 44. 303–318.
https://doi.org/10.1207/s15430421tip4404_4
 16. Powell, John A. & Stephen Menendian. 2016. The problem of othering: Towards inclusiveness and belonging. *Othering & Belonging* 1. 14–40.
 17. Sheigal, Elena I. 2004. *Semiotika politicheskogo diskursa* [Semiotics of Political Discourse]. Moscow: Gnosis.
 18. The Guardian. 2024. Republican attacks on Kamala Harris to get 'as ugly and bigoted as they can'. *The Guardian*, 25 July 2024. <https://www.theguardian.com/us-news/article/2024/jul/25/kamala-harris-trump-republicans-attacks> (accessed 3 February 2026)
 19. van Dijk, Teun A. 2001. Critical discourse analysis. In Deborah Schiffrin, Deborah Tannen & Heidi E. Hamilton (eds.), *The handbook of discourse analysis*, 352–371. Malden, Oxford: Blackwell.
 20. van Dijk, Teun A. 2014. Discourse, cognition, society. In Christopher Hart & Piotr Cap (eds.), *Contemporary Critical Discourse Studies*, 121–146. London: Bloomsbury.
 21. van Dijk, Teun A. 2018. Socio-cognitive discourse studies. In John Flowerdew & John E. Richardson (eds.), *The Routledge Handbook of Critical Discourse Studies*, 26–43. London: Routledge.
 22. van Dijk, Teun A. 1998. *Ideology: A multi-disciplinary approach*. London: Sage.
 23. van Dijk, Teun A. 2006. Discourse, context and cognition. *Discourse Studies* 8 (1). 159–177.
<https://doi.org/10.1177/1461445606059565>
 24. Wicke, Philipp & Marianna M. Bolognesi. 2025. Red and blue language: Word choices in the Trump and Harris 2024 presidential debate. *PLoS ONE* 20 (6). Article e0324715.
<https://doi.org/10.1371/journal.pone.0324715>
 25. Wierzbicka, Anna. 2016. Making sense of terms of address in European languages through the Natural Semantic Metalanguage (NSM). *Intercultural Pragmatics* 13 (4). 499–527.
<https://doi.org/10.1515/ip-2016-0022>

PHYSICAL SCIENCES

TIME TRAVELS IS PHYSICALLY POSSIBLE AND READY TO USE

Antonov A.

PhD, HonDSc, H.Prof.Sci

Independent researcher, Ukraine, Kiev

<https://doi.org/10.5281/zenodo.21982217>

Abstract

The article explains that although the special and general theories of relativity studied in physics textbooks consider time travels on Earth impossible even in the most distant future, in fact, all air passengers are already doing it during their flights. This is proven by the fact that after planes land, air passengers change their watches to local time, which is different from the local time where they flew from. But such time travels is not used now, since it always occurs only as a result of the movements of aircraft in space. However, the corrected version of the special theory of relativity proposes to make time travel on airplanes possible through the use of round-the-world flights, as a result of which the resulting movements of airplanes in space are reset to zero. And such physically possible time travels is currently technically feasible and quite accessible to people on Earth.

Keywords: special theory of relativity; relativistic formulas; physical reality of imaginary numbers; phenomena of dark matter and dark energy; anti-time; internal time and external time; time travels; structure of planet Earth

1. Introduction

Due to the use of the principle of relativity in it, the special theory of relativity (SRT) [1]-[3] is rightly considered to be an outstanding scientific achievement of physics of the twentieth century. But due to the lack of necessary scientific knowledge at the beginning of the twentieth century, the derivation of relativistic formulas in the SRT was not completed, and because of this, the resulting relativistic formulas turned out to be incorrect and could not be explained. Therefore, naturally, this SRT itself turned out to be incorrect in many respects [4]-[8]. And since no one needed a theory that even its creators could not explain, in order to make it explainable and necessary, a postulate¹ was introduced into it, called the principle of not exceeding the speed of light. And from this postulate the conclusion was made about the physical unreality of imaginary numbers. Moreover, as the creators of SRT claimed, there are no processes² in nature that prove the physical reality of imaginary numbers. This is the form in which SRT is still presented in physics textbooks. Later, already in the 21st century, the OPERA experiment [9] was carried out at the Large Hadron Collider for 15 years (2003-2018), which aimed to prove the physical reality of imaginary numbers, but failed to do so. And thereby creating the impression that imaginary numbers are physically unreal.

However, in 1897, i.e., even before the creation of SRT, Charles Proteus Steinmetz published [10] the theory of linear electrical circuits of alternating current³, which actually affirmed the physical reality of imaginary numbers, since the imaginary resistance of capacitors $-j/\omega C$ and inductors $+j\omega L$ ⁴ were assumed to be really physically existing, and in radio engineering and

electrical laboratories there were instruments that confirm this assumption, since they measured these imaginary physical value. In addition, from this theory of Steinmetz it follows that if imaginary numbers were really, as stated in the generally accepted version of SRT, physically unreal, then neither radio engineering, nor electrical engineering, nor computer technology should exist in nature.

And in the 21st century, successful experimental evidence of the physical reality of imaginary numbers has already been published [11]-[23], including [11]-[15], published in 2008-2010, i.e. even before the publication in 2011 of the results of the unsuccessful OPERA experiment, which therefore made it unnecessary. Moreover, these proofs were not only radio engineering using the theory of linear electrical circuits created by Charles Proteus Steinmetz, but also physical, the existence of which Albert Einstein denied.

Some other conclusions from the version of SRT studied in textbooks also turned out to be incorrect [24]-[55]. Including the statement of this SRT about the impossibility for people on Earth to travel in time even in the most distant future. Which, however, was refuted by the corrected version of SRT created in the 21st century.

2. Physical possibility of time travels

Time travels, which until recently belonged to the genre of science fiction, as it turned out in the 21st century, is now actually feasible for people on Earth. Moreover, they are also quite affordable. Such time travels will be comparable in cost and complexity to, for example, a vacation trip to an expensive resort. Therefore, this situation may be of great interest to readers. However, according to the special and general theories of

¹ As shown below, incorrect

² In fact, they exist, there are many of them, and they are known to everyone. For example, tsunamis, ringing bells and swinging swings on playgrounds.

³ Which has become fundamental in theoretical radio engineering, electrical engineering and computer engineering

⁴ In radio engineering, electrical engineering and computer engineering, the imaginary unit is usually denoted by the letter j , since the letter i denotes electric current

relativity studied in physics textbooks time travels is possible only in some exotic situations. But for people on Earth, such a possibility was categorically denied forever. However, the corrected version of SRT [56]-[64] created in the 21st century claims that time travels for people on Earth is now quite feasible [65]-[81]. This statement is confirmed by the daily flights of millions of air passengers, since during such flights time travels is also carried out. After all, after landing, air passengers always change their watches to local time, which differs from the local time at the departure airport.

Nevertheless, these time travels are not currently used in any way due to the fact that, in accordance with the relativistic formulas of the SRT

$$\Delta t = \Delta t_0 \sqrt{1 - (v/c)^2} \quad (1)$$

$$l = l_0 \sqrt{1 - (v/c)^2} \quad (2)$$

in which Δt_0 is the rest time of a moving body; Δt is the relativistic time⁵ of a moving body; l_0 is the rest length of a moving body; l is the relativistic length of a moving body;

v is speed of a moving body; c is speed of light;

such time travels inevitably involves traveling in space, and even over very long distances. And from these formulas it follows

$$\Delta t = \Delta t_0 (l / l_0) \quad (3)$$

where Δt is external time in hours;

Δt_0 is 24 hours, since there are 24 time zones on Earth; l is path length in the direction perpendicular to time zones; l_0 is the length of a circle intersecting 24 time zones at a given latitude.

Moreover, during airplane flights, this ratio is always satisfied, since airplanes during flights cross time zones that exist due to the rotation of the Earth around its axis. But this seemingly fatally insoluble problem of the inevitable correspondence of time travel to formula (3) is completely solvable, since in fact it is possible to travel in time, ignoring formula (3). To do this, all you need to do during such trips is to fly around the world around the north or south pole, landing at the same airfield from which the plane took off. Indeed, in this case, the distance that the plane will ultimately fly from the airfield from which it took off will always be zero, regardless of the length and duration of the flight. In this case, the plane, since it will cross twenty-four time zones as a result of a round-the-world flight, will find itself one day in the past or in the future. And this technique allows time travel to be made available for practical use. Moreover, this potential physical opportunity can be turned into a real-life service even tomorrow, since everything necessary for this already exists.

There are currently 22000-24000 privately owned small jet aircraft, called business jets, in operation on Earth (see Fig. 1). They are used for custom flights with a high level of comfort for a limited number of passengers (usually from 6 to 20) - businessmen, high-ranking officials and other

Table 1.

Examples of business-jet characteristics that can be used for time travels

Aircrafts	Maximum range	Cruising speed	Hourly rates	Seats
Citation Latitude	5 300 km	815 km/h	3 500 €/hour	8
Citation Longitude	7 400 km	910 km/h	5 000 €/hour	12
Challenger 300	5 700 km	850 km/h	4 900 €/hour	8
Challenger 350	5 926 km	850 km/h	4 000 €/hour	9
Challenger 600	5 500 km	850 km/h	4 600 €/hour	12
Challenger 3500	6 297 km	985 km/h	5 500 €/hour	10
Falcon 20	4 200 km	987 km/h	3 900 €/hour	8
Falcon 50/50 EX	5 600 km	850 km/h	4 900 €/hour	8-10
Global 5500	10 927 km	900 km/h	8 000 €/hour	16
Gulfstream G150	5 200 km	850 km/h	3 900 €/hour	6-8
Gulfstream G200	5 000 km	870 km/h	6 200 €/hour	8
Hawker 850 XP	4 800 km	750 km/h	3 400 €/hour	6-8
Hawker 900 XP	5 400 km	865 km/h	3 700 €/hour	6-8
Hawker 4000	5 280 km	890 km/h	5 400 €/hour	10
Learjet 70	3 815 km	967 km/h	3 500 €/hour	7
Legacy 450	5 370 km	860 km/h	3 300 €/hour	8
Praetor 600	7 400 km	850 km/h	6 000 €/hour	12

⁵ The concepts 'external time' and 'internal time' are explained below.

Table 2.

The value of external time at different latitudes

Location of departure and arrival airfields	Geographic coordinates of the airfield	Size of 24 time zones for a roundthe-world flight	Size of one time zone.
Santiago de Chile	33,45° S.	33422 km	1393 km
Buenos Aires	34,60° S.	33021 km	1375 km
Melbourne	37,82° S.	31339 km	1306 km
New York City	40,72° N.	30456 km	1269 km
Reykjavík (Iceland)	64,15° N.	17616 km	734 km
Murmansk (Russia)	69,58° N.	14424 km	601 km
Kirkenes (Norway)	69,73° N.	14376 km	599 km
Longyearbyen (Norway)	78,13° N.	8184 km	341 km
Alert (Canada)	82,5° N.	5230 km	218 km



Fig. 1. This is one of the business jets.

VIPs. And these business jets are quite suitable for time travels.

And since the round-the-world flights of business jets necessary for time travel must necessarily be carried out around the northern or southern pole, the most profitable shortest routes for such flights, naturally, should be laid as close as possible to the north pole (as they are further from the south pole). And the airports closest to the north and south poles for such routes are shown in Table 2.

3.1. The version of SRT taught in physics textbooks is incorrect

And in order to further explain the features of round-the-world flights in time, naturally, it is necessary to know what modern science claims about this in physics textbooks. And it turns out that the relativistic formulas (1), (2) given in physics textbooks, as well as other relativistic formulas, are incorrect. Since their

conclusion, due to the lack of necessary scientific knowledge in the twentieth century, was not actually completed. Therefore, in many respects the generally accepted version of SRT presented in these textbooks also turned out to be incorrect [4]-[8], [24]-[56].

Let's prove it. Since the human brain is designed in such a way that it thinks in visual images, let's consider the graphs of formulas (1) and (2). As can be seen (Fig. 2a, b), in the subluminal speed range $v < c$, in which Δt and l take values measured by real numbers, and in the hyperluminal speed range $v > c$, in which Δt and l take values measured by imaginary numbers, these graphs are different. Moreover, the authors of STR explained the processes occurring in the subluminal speed range $v < c$, but failed to explain the processes occurring in the hyperluminal speed range $v > c$. And not only the authors of SRT, but also the authors of modern physics textbooks⁶, failed to explain this.

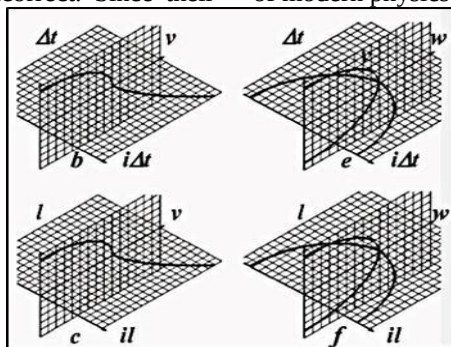


Fig. 2. Graphs of the functions $\Delta t(v)$ and $l(v)$, corresponding to the generally accepted incorrect and corrected versions of SRT in the subluminal $v < c$ and hyperluminal $v > c$ speed ranges

⁶ Since their explanation, using, as it later turned out, the incorrect principle of not exceeding the speed of light, turned out to be incorrect due to the fact that it required the recognition of the physical unreality of imaginary numbers. Therefore, it could be used only temporarily, while continuing to

search for an explanation that corresponds to the physical reality of imaginary numbers already actually proven by Charles Proteus Steinmetz. But this has not yet been done in the generally accepted version of SRT. And it was done in the corrected version of SRT.

Therefore, naturally, such formulas could not correspond to any processes existing in nature. Then, in order to save the situation, the authors of physics textbooks⁷ did what they could do (and at that time it was the right decision) - they created a motivation that allowed them to get rid of inexplicable fragments of relativistic formulas in the hyperluminal speed range $v > c$. And they began to argue that in the hyperluminal speed range $v > c$ there is no need to explain inexplicable relativistic formulas, since nothing in nature is supposedly described by imaginary numbers. Therefore, the principle of not exceeding the speed of light was introduced into the SRT. And physicists in the 20th century found this motivation convincing. Therefore, it is still given in all physics textbooks⁸.

And to strengthen the impression that this version of SRT is correct, the OPERA experiment was carried out at the Large Hadron Collider (worth 10 billion dollars) for 15 years (2003-2018), in which more than one hundred of the most respected physics professors took part. With this experiment, physicists tried to prove the physical reality of imaginary numbers, but they failed to do so. And thus they created the impression that imaginary numbers are physically unreal.

But even before the creation of SRT in 1905 [82],[83] in 1897, Charles Proteus Steinmetz published [10] the theory of alternating current electrical circuits,

in which he stated that the resistance R of resistors is measured in real numbers, and the resistance of capacitors $-j/\omega C$ and inductors $+j\omega L$, are measured in imaginary numbers. And from this statement, in accordance with Ohm's law, it followed that the electrical resistances and transfer functions of electrical LCR-circuits are always measured in complex numbers. Then, if imaginary numbers are assumed to be physically unreal, then the measured resistances of electrical LCR-circuits will not depend on frequency. And if in fact imaginary numbers are physically real, then the measured resistances of electrical LCR-circuits will depend on frequency. Consequently, an experiment proving the physical reality of imaginary numbers can be extremely simple. You just need to change the frequency of the sinusoidal voltage supplied to any electrical LCR-circuit and make sure that this changes the amount of current flowing through it. And it is always changing. Therefore, all radio and electrical engineers who have repeatedly performed this experiment in their practical activities know that imaginary numbers are physically real. Therefore, for more than half a century, the industry has been producing devices (see Fig. 3) – frequency response meters, oscilloscopes, multimeters – which prove the physical reality of imaginary numbers by their very existence. Since you can only measure what actually physically exists.

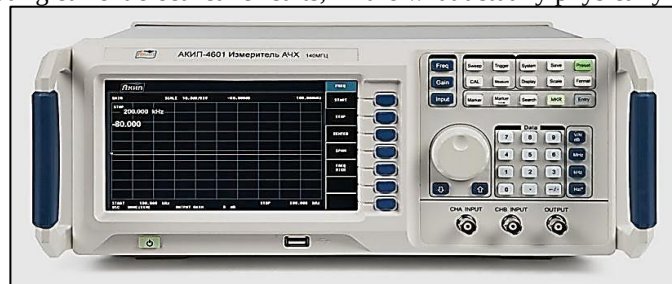


Fig. 3. In any radio engineering laboratory there are instruments called frequency response meters, which prove the physical reality of imaginary numbers by their very existence

Consequently, we again come to the conclusion that the version of STR currently studied in all physics textbooks is incorrect. Why then do physicists still need this incorrect SRT, which states the unprovable (that imaginary numbers are physically unreal) is unclear. But therefore, due to the lack of experimental confirmation of the truth of the version of STR studied in physics textbooks, Albert Einstein, despite the fact that he was nominated for the Nobel Prize 66 times for its creation, never received it.

3.2. Commentary on STR advertisements on the Internet

And yet, the incorrect version of STR is still studied in all physics textbooks. Moreover, it is now even advertised on the Internet [84], in which it explains (see Fig. 4) in reality inexplicable (since they are not true) relativistic formulas of the SRT "Why can't you exceed the speed of light?" And from this explanation follows exactly what the authors of incorrect physics textbooks really need. That the principle of not exceeding the speed of light in SRT is supposedly correct. And this

allows them to at least somehow explain the relativistic formulas of SRT (which, in fact is incorrect).

But, firstly, the principle of not exceeding the speed of light is just a postulate. Therefore, the conclusion from it about the physical unreality of imaginary numbers has no evidentiary force. Moreover, there is no experimental evidence of the physical unreality of imaginary numbers. On the contrary, there is numerous experimental evidence of their physical reality. Including those mentioned in the previous section of this article.

Secondly, another incorrect conclusion follows from the principle of not exceeding the speed of light - that our only visible universe exists in nature. And therefore, in the microcosm of our only universe, for almost a hundred years everyone has been forced to search, but have not found an explanation for the phenomena of dark matter and dark energy [85]-[89]. Moreover, the mass-energy of these supposedly located in the microcosm of dark matter and dark energy, as follows from the data obtained by the WMAP and

⁷ Instead of continuing their derivation, as is now done in the corrected version of SRT, and deducing the correct relativistic formulas given below

⁸ Although a corrected version of the SRT has already been created by the author. And it's time to use it.

Planck spacecraft, is more than 20 times greater than the mass-energy of the macrocosm of our entire visible universe. Which is obviously unnatural.

But in fact, from the relativistic formulas⁹ obtained by the authors of the version of STR studied in physics textbooks, it follows that the argument v in them is, in accordance with Newton's first law, the fourth spatial dimension. And therefore:

- in nature there are universes invisible to us, differing in different values of this fourth spatial coordinate v and, consequently, their existence in other dimensions;

- according to the data obtained by the WMAP and Planck spacecraft, there are about 20 of these invisible universes in our invisible Multiverse (and therefore we will answer Albert Einstein: the speed of light, in accordance with Newton's first law, can be exceeded - this will be a transition to another dimension);

- and these invisible universes located in other dimensions give rise to the phenomena of dark matter and dark energy, and therefore are the sought-after dark matter and dark energy.

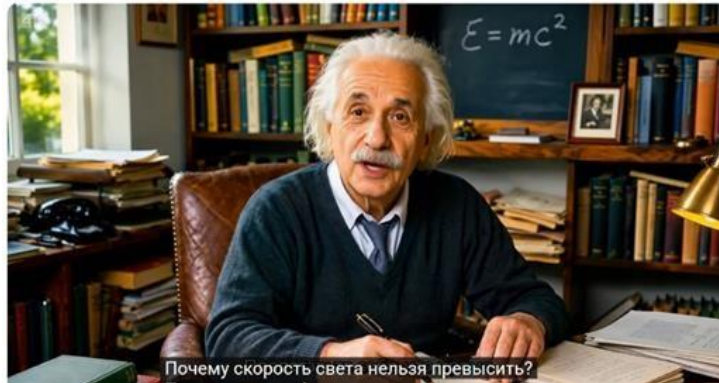


Fig. 4. Why can't the speed of light be exceeded?

Moreover, all this is provable, since the invisible universes are connected with each other and with our visible universe through portals, the entrances of which on planet Earth are more than 200,000 anomalous zones. Therefore, one can be convinced of the existence of invisible universes by discovering, during astronomical observations of the starry sky in portals (and even, perhaps, in anomalous zones), constellations that are different from the constellations observed outside the portals. Moreover, some astronomical observatories have already been located in anomalous zones. For example, the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, located in the Goloseevsky forest 12 km away from the center of Kiev

Thus, what has been stated in the most indisputable way proves that the authors of the question "Why can't you exceed the speed of light?" published on the Internet, who are unable to give any clear objection to the numerous published refutations of the generally accepted incorrect version of SRT, do not intend to correct it. Even after learning that the generally accepted version of SRT¹⁰, it is incorrect and how it can be corrected. For some reason, they are more satisfied with

the incorrect version of SRT studied in textbooks, which was advertised for fifteen years by the unsuccessful OPERA experiment, and now continues to be advertised (as in business, not in science) by publications on the Internet. And it is completely unclear why an incorrect service station is needed if it can be corrected.

But it is clear that students certainly need correct textbooks containing a corrected version of SRT. And teaching children the wrong SRT is unethical.

4. Corrected version of STO

Therefore, will continue the unfinished derivation of the relativistic SRT formulas and correct them. In order for SRT to be conclusively true and explainable, the graphs of the relativistic formulas $\Delta t(v)$ and $l(v)$ (and other relativistic formulas too) in the subluminal and hyperluminal speed ranges should actually be the same in all ranges of change in the argument v , as they are shown in Fig. 2c,d.

Then, for this, in formulas (1) and (2), taking into account that according to Newton's first law, the speed of a moving body v in them is the fourth spatial dimension, it is necessary to introduce the factor i^q

$$\Delta t(q) = \Delta t_0 i^q \sqrt{1 - (v/c - q)^2} = \Delta t_0 i^q \sqrt{1 - (w/c)^2} \quad (4)$$

$$l(q) = l_0 i^q \sqrt{1 - (v/c - q)^2} = l_0 i^q \sqrt{1 - (w/c)^2} \quad (5)$$

⁹ And also from the corrected relativistic formulas given below

¹⁰ Because it denies the existence of radio technology, computer technology, tsunamis, ringing bells and even swings

swinging on playgrounds due to the denial of the physical reality of imaginary numbers

where v is the speed of a moving body on Earth;
 c is speed of light; $w = v - qc$ is local speed in all other universes;

$q(v) = [vq/c]$ is discrete mathematics “floor” function from the argument vq/c .

But since the fourth spatial dimension v is a vector quantity in three-dimensional space, formulas (4), (5) must be corrected again. To do this, three factors i^q , i^r and i^s must be introduced into formulas (1), (2)

$$\Delta t(q, r, s) = \Delta t_{0_1 i_1^q i_2^r i_3^s} \sqrt{1 - [v/c - (q + r + s)]^2} \quad (6)$$

$$l(q, r, s) = l_{0_1 i_1^q i_2^r i_3^s} \sqrt{1 - [v/c - (q + r + s)]^2} \quad (7)$$

where $s(v) = [v_s/c]$ is the “floor” function of discrete mathematics from the argument v_q/c , corresponding to one of the orthogonal components of the fourth spatial dimension v ;

$r(v) = [v_r/c]$ – discrete mathematics “floor” function of the argument v_r/c , corresponding to another orthogonal component of the fourth spatial dimension v ;

$s(v) = [v_s/c]$ – discrete mathematics “floor” function of the argument v_s/c , corresponding to the third orthogonal component of the fourth spatial dimension v ; v_q, v_r, v_s – projections of the velocity vector v onto the orthogonal coordinates q, r, s (see Fig. 5).

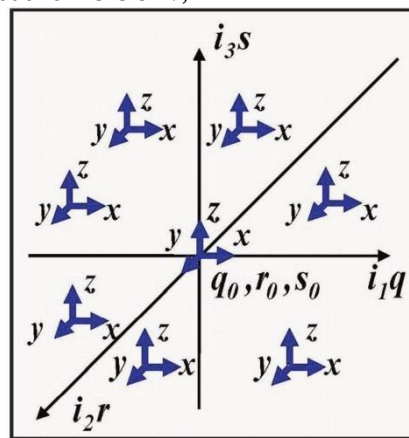


Fig.5. Six-dimensional space of the hidden Multiverse, where q, r, s are the coordinates of mutually invisible parallel universes and antiuniverses, and x, y, z are the coordinates of the material contents of these parallel universes and antiuniverses

And in this corrected version of the STO there is already:

- the physical reality of imaginary numbers has been proven;
- the fourth spatial dimension has been opened;
- correct relativistic formulas were obtained;
- it has been proven that the principle of not exceeding the speed of light is incorrect;
- it is stated that there is a hidden Multiverse, which includes our visible universe, as well as about twenty mutually invisible universes and anti-universes;
- it is stated that there are also other Multiverses, which together with our hidden Multiverse form the Hyperuniverse;
- the phenomena of dark matter and dark energy are explained;
- the physical possibility of time travel has been proven.

All this is described in the author's previous publications.

5. Technical Feasibility of Time Travel

When explaining time travel on Earth, it is necessary to take into account the existence in nature, in ad-

dition to internal time, which we always use, also external time, which we have never used before. But now you have to use it. Moreover, these two different times are generated by different circumstances and have different characteristics. Internal time can be called biological time, since one second is one contraction of the human heart. And internal time cannot flow backwards. A person cannot return to his youth or childhood. External time is determined by processes occurring in the external environment. Namely, the rotation of the Earth and the existence of time zones. One revolution of the Earth corresponds to 24 time zones. And by changing the direction of our movement in space, we can move both into the past and into the future external time. Consequently, time travel is always movement only in external time.

But since there are no round-the-world flights in the history of aviation, let's take such an air trip mentally. Let us assume that two identical aircraft simultaneously took off from the same airfield with the aim of making their round-the-world trips (with refueling in the air or at intermediate airfields). Moreover, one of them always flies to the west, and the other to the east. And if we assume that the Earth does not rotate, then they will arrive at the same airfield from which they took off almost simultaneously, since they will fly the

same distance at the same speed, without crossing time zones. Which do not exist on the still earth.

But if such travel is made on a rotating Earth, then one of these planes will always fly into the past time, and the other into the future time, since they will cross time zones. And therefore they will not be able to fly to the same airfield. They will inevitably arrive at different airfields, although with the same name as the airfield from which they took off. Moreover, these airfields exist in the past and future, regardless of whether we fly to them or not. Moreover, in the past and in the future, not only these airfields exist, but also other airfields, and all other cities, deserts, mountains, seas and oceans shown on the map. That is, in the past and future there are parallel worlds in which you and I also find ourselves. And if we fly into the past and/or into the future, we will probably be able to meet ourselves. Moreover, these worlds in the past and future coexist with our world in the present time. These worlds form a kind of unified whole, structured somehow differently than we now imagine our Earth to be.

And yet, although the airfield from which our plane took off in the present time and the airfields in the future and/or past time at which our planes will arrive are different, they will differ only slightly. Therefore, the space factor in such quasi-round-the-world flights will be reset to zero just as successfully as in round-the-world flights. Therefore, such flights would also make time travel feasible.

And if you need to return, you will just need to fly along the same route in the opposite direction.

6. Availability of time travel

And it's not difficult to verify all this. To do this, such a journey through time must actually be done. Moreover, this opportunity is truly accessible, just as, for example, you can go to work not only by your car, but also by public transport. For time travel, you can also use not only business jets, but also planes making regular commercial flights.

Let's give an example of such time travel. But since, dear reader, neither the author, nor you, nor anyone else has ever flown around the world, let's take such an air trip through time mentally. Let's say you fly from New York to Tokyo and after landing you set your watch back 11 hours. Then you flew from Tokyo to London and after landing, you set the clock back another 8 hours. Finally, after landing in London, you boarded a plane to New York. And after landing in New York, you once again set your watch back 5 hours. Thus, ultimately you will travel in external time into the past by $11 + 8 + 5 = 24$ hours, i.e. for a day. And this trip in external time will be quasi-around the world, since you actually did not arrive at the airfield from which you flew away, but yesterday's airfield. But he's a little different. All the flights you took were regular commercial ones. And your trip did not cause any surprise among other air passengers, since no one knew anything about your around-the-world intentions. However, you will eventually move back 24 hours, i.e. took a real trip into the past.

And you found yourself in New York again. But at a different time. You were convinced of this by buying a newspaper. Moreover, the newspaper seller did

not know anything about the pre-sent time from which you arrived. None of the passers-by knew about this either. Then you called your home and agreed to meet with yourself. And you talked to ourselves. You also discussed how it would be possible to keep in touch with each other. For example, by phone through friends who live somewhere between the New York of today and the New York of yesterday. After all this, having made sure that you really visited yesterday's London, you return flights New York-London, London-Tokyo and Tokyo-New York returned to your current New York.

And having convinced yourself of the feasibility of time-travels, you may also want to visit tomorrow's New York in order to also establish a connection with yourself, who lives there. Then, as a result of the three of you together (i.e., together with your two copies in the future and in the past), you can make your life more successful.

Moreover, as time travel is mastered, sooner or later someone will inevitably realize that it can be done not only on airplanes, but also via radio communication lines that everyone will use if they just need to send a message to the past and/or future. And such round-the-world communication lines will certainly be created, which will make informational time travel around the world quite accessible to people.

7. The structure of planet Earth does not correspond to modern scientific knowledge

Such time travel will create many situations that are not obvious and incomprehensible to current human knowledge and life experience. Although, observing the arrivals of different planes at the airport at different times, we will never see any problems in communication between passengers arriving on these planes, as well as with the people who met them, due to the difference in arrival times. Nevertheless, it is clear that for residents of, for example, New York, Tokyo or London, located in today's, tomorrow's and/or yesterday's time, the material reality surrounding them will be slightly different. Somewhere, for example, in yesterday's London, unlike today's London, a new subway station has not yet been opened, your car has not yet been repaired and something else has not yet been done. Therefore, today's London and yesterday's London are incompatible not only in time, but also in space, since they differ in many small details. Moreover, these two different Londons, into one of which one plane flew with you, and from the other another plane with you flew away, exist on Earth regardless of whether you flew into them or not. It is also clear that if you were flying not to the west, but to the east, you would fly to London tomorrow in the same way. Which also differs from today's London and yesterday's London in some other minor changes. And which therefore will have to be in some other place. Therefore, another world in which other cities exist exists. But where? Naturally, on our Earth. Then it is obvious that our planet Earth is not at all what we and modern science imagine it to be like a globe [90]-[95]. And is some kind of three-dimensional (i.e. volumetric) spiral-shaped structure Using, probably, the fourth spatial dimension, which was mentioned at

the beginning of the article. And our science will now have to engage in the knowledge of this other world.

Moreover, this other world is quite possibly even much more complex. It may include, in addition to the worlds of yesterday and tomorrow mentioned above, also the day before yesterday and other inhabited worlds that are more distant from our world today. And to get there you will only need to make several quasi-round-the-world flights.

Nevertheless, in any case, using round-the-world flights (if the structure of the Earth is what modern science believes it to be) or quasi-round-the-world flights (if the structure of the Earth is different), time travel is feasible. We have become convinced of this. And then it becomes possible to foresee disasters, accidents, bankruptcies and much more. And therefore, somehow it will be possible to avoid them or otherwise minimize the unpleasant consequences associated with this. Since we will have our doubles in the future and in the past, from whom we can receive and use reliable information about the future and past. Therefore, we will actually now exist not only in today's time, but also in yesterday's and tomorrow's time. Then, by communicating with our counterparts, we will be able to make our lives more successful. Presumably it will now even be possible to bring back to life people who died due to accidents or as a result of crimes¹¹. And due to the increased information transparency of human activity, its immoral and criminal manifestations will now gradually begin to disappear. Many other things will happen that are difficult to predict right now.

8. Conclusion

We must admit that we live in amazing times. Our lives literally become completely different before our eyes. For example, artificial intelligence has finally received the recognition it deserves. But in an even more amazing way, our lives will inevitably soon be changed by time travel, which opens up new opportunities for people.

Indeed, a person who has his counterparts in the past and future tense (i.e., coexisting with them in the past and future) will be able to increase his intelligence. By receiving information from the future about the behavior of other people, he will be able to solve multifactorial information problems of optimizing his behavior in a team. Traveling to the future will also make it possible to anticipate accidents, catastrophes, and natural disasters and take appropriate measures in a timely manner. And traveling into the past will make it possible to correct and/or prevent many events that ended in tragic consequences. Scientific, economic and any other creative activity will become much more successful. And higher information transparency of human society will make immoral and criminal activities less successful. Our world will become different.

References:

1. Einstein A. (1920). *Relativity: The Special and General Theory*. H. Holt and Company. NY.
2. Bohm D. (2006). *The Special Theory of Relativity*. Routledge, Abingdon on Thames.
3. Penrose R. (2010). *The Nature of Space and Time*. Princeton University Press. Princeton.
4. Terletsky Ya. P. (1966). *Paradoxes of the theory of relativity*. Nauka Publishing House. Moscow. (In Russian)
5. Logunov A. A. (1987). *Lectures on the theory of relativity and gravitation*. Science Publishing House. Moscow. (In Russian)
6. Atsyukovsky V. A. (2003). *General ether dynamics*. Energoatomizdat. Moscow. (In Russian)
7. Kalinin S. A. (2003). *Einstein's cardinal errors*. Editorial Urss Publishers. Moscow. (In Russian)
8. Arteha S. H. (2007). *Critique of the foundations of the theory of relativity*. 2nd ed. LKI Publishing House. Moscow. (In Russian)
9. Adam T., Agafonova N., Aleksandrov A. et al. (2012). Measurement of the neutrino velocity with the OPERA detector in the CNGS beam. arxiv:1109.4897v4 [hep-ex].
10. Steinmetz C. P. *Theory and Calculation of Electric Circuit*. Nabu Press. Charlstone.
11. Antonov A. A. (2008). Physical Reality of Resonance on Complex Frequencies. *European Journal of Scientific Research*. 21(4). 627-641.
12. Antonov A.A. (2009). Resonance on Real and Complex Frequencies. *European Journal of Scientific Research*. 28(2). 193-204.
13. Antonov A.A. (2010). New Interpretation of Resonance. *International Journal of Pure and Applied Sciences and Technology*. 1(2). 1-12. http://doi.org/10.17686/sced_rusnauka_2010-888
14. Antonov A. A. (2010). Version of the special theory of relativity that is. Oscillation processes as a tool of physics cognition. *American Journal of Scientific and Industrial Research*. 1(2). 342-349. [doi:10.5251/ajsir.2010.1.2.342.349] (<http://dx.doi.org/10.5251/ajsir.2010.1.2.342.349>)
15. Antonov A. A. (2010). Solution of algebraic quadratic equations taking into account transitional processes in oscillation systems. *General Mathematics Notes*. 1(9). 11-16. http://doi.org/10.17686/sced_rusnauka_2010-887
16. Antonov A. A. (2013). Physical Reality of Complex Numbers. *International Journal of Management, IT and Engineering*. 3(4). 219-230. [http://doi.org/10.17686/sced_rusnauka_2013-898] (http://doi.org/10.17686/sced%20rusnauka_2013-898)
17. Antonov A. A. (2015). Physical reality of complex numbers is proved by research of resonance. *General Mathematics Notes*. 31(2). 34-53. [http://www.emis.de/journals/GMN/yahoo_site_admin/assets/docs/4_GMN-9212-V31N2.1293701.pdf] (http://www.emis.de/journals/GMN/yahoo_site_admin/assets/docs/4_GMN-9212-V31N2.1293701.%20pdf)
18. Antonov A. A. (2015). The principle of the physical reality of imaginary and complex numbers in modern cosmology: the nature of dark matter and dark energy. *Journal of the Russian Physical and Chemical Society*. 87(1). 328-355. (In Russian)

¹¹ Perhaps in a similar way, after the assassination attempt on him, President Kennedy could have been saved [96]-[106].

[http://doi.org/10.17686/sced_rusnauka_2015_1119](<http://doi.org/10.17686/sced%20rusnauka%202015%201119>)

19. Antonov A. A. (2016). Physical Reality and Nature of Imaginary, Complex and Hypercomplex Numbers. *General Mathematics Notes*. 35(2). 40-63.

[http://www.geman.in/yahoo_site_admin/assets/docs/4_GMN-10932-V35N2.31895146.pdf](http://www.geman.in/yahoo_site_admin/assets/docs/4_GMN-10932-V35N2.31895146.pdf)

20. Antonov A. A. (2017). The physical reality and essence of imaginary numbers. *Norwegian Journal of development of the International Science*. 6. 50-63. <http://www.njd-iscience.com>

21. Antonov A. A. (2024). Physical reality of imaginary numbers and their physical essence. *Danish Scientific Journal*. 80. 25-35. [<https://doi.org/10.5281/zenodo.10594282>]

[<https://doi.org/10.5281/zenodo.10594282>)]

22. Antonov A. A. (2024). Proof of physical reality of imaginary numbers and explanation of their physical essence. *German International Journal of Modern Science*. 72. 17-27.

23. Antonov A. A. (2024). Physical reality of imaginary numbers and their physical essence. *Sciences of Europe*. (Praha, Czech Republic). 133(1). 79-90. DOI: 10.5281/zenodo.10575590

24. Antonov A. A. (2021). The special theory of relativity as taught in physics textbooks is incorrect. 77th International Scientific Conference of the Eurasian Scientific Association "Theoretical and practical problems of modern science". Moscow. 11-15. (In Russian)

25. Antonov A. A. (2021). Version of the special theory of relativity that is studied in all physics textbooks is incorrect. *Österreichisches Multiscience Journal* (Innsbruck, Austria). 43(1). 17-22. [<http://osterr-science.com>](<http://osterr-science.com/>)

26. Antonov A. A. (2021). The fallacy of the SRT version studied in physics textbooks proved experimentally. *Österreichisches Multiscience Journal* (Innsbruck, Austria). 45(1). 17-26.

27. Antonov A. A. (2021). Generally accepted version of the special theory of relativity contained in physics textbooks is incorrect. *The scientific heritage*. (Budapest, Hungary). 73(2). 39-43. DOI: 19.24412/9215-0365-2021-73-2-39-43

28. Antonov A. A. (2021). Special theory of relativity presented in physics textbooks is wrong. *Norwegian Journal of development of the International Science*. 68(1). 3-7. DOI: 10.24412/3453-9875-2021-68-3-7.

29. Antonov A. A. (2021). In all physics textbooks an erroneous version of special theory of relativity is given. *International independent scientific journal*. 31.34-39. [<http://www.iis-journal.com>]

<http://www.iis-journal.com/> 30. Antonov A. A. (2021). All physics textbooks study incorrect special theory of relativity. *Sciences of Europe*. (Praha, Czech Republic) 79(1). 30-35. DOI: 10/24412/3162-2364-2021-79-3035

31. Antonov A. A. (2021). Special theory of relativity, which is studied in physics textbooks, is incorrect. *German International Journal of Modern Science*. 16. 49-53. DOI: 10.24412/2701-8369-2021-16-49-53

32. Antonov A. A. (2021). Special theory of relativity, which is studied in all physics textbooks, is incorrect. *Danish Scientific Journal*. 51(1). 31-35. [<http://www.danish-journal.com>](<http://www.danish-journal.com/>)

33. Antonov A. A. (2021). Special theory of relativity taught in all physics text-books is incorrect. *Annali d'Italia*. 22(1). 39-44. <https://www.anditaia.com/>

34. Antonov A. A. (2021). Special theory of relativity taught in physics text-books is wrong. *Journal of science*. Lyon. 23. 47-52. <https://www.joslyon.com/>

35. Antonov A. A. (2021). Experimental evidence of the incorrectness of the version of the special theory of relativity studied in physics textbooks and the truth of its alternative version. 80th International Scientific Conference of the Eurasian Scientific Association "Development of science and education in conditions of global instability." Moscow. 8-17. (In Russian). <https://esa-conference.ru/sborniki/?y=2021>

36. Antonov A. A. (2021). Experimental evidences for the fallacy of the STR version in the physics textbooks. *European Journal of Applied Sciences*. Services for Science and Education. UK. 9(6). 349-364. DOI:10.14738/aivp.96.11304.

37. Antonov A. A. (2021). If the STR version in physics textbooks were true, we would never have heard the music of the piano and the bell ringing, there would be no television, no cellular telephony, no radar or GPS navigation, we would not even be aware of the existence of resonance and Ohm's law as interpreted by Steinmetz, and our children could not swing on the swings. *The scientific heritage* (Budapest, Hungary). 78(2). 41-50. DOI: 10.24412/9215-0365-2021-78-2-41-50

38. Antonov A. A. (2021). The STR version in physics textbooks must be corrected, because if it were true, there would be no tsunamis or indian summer in nature, we would be never have heard piano music, engineers would be not have been able to create television, cell phones, GPS trackers, and even children would not be able to swing on swings. *Danish Scientific Journal*. 54(1). 29-38. [<http://www.danish-journal.com>](<http://www.danish-journal.com/>)

39. Antonov A. A. (2021). Experimental refutations of the STR version contained in physics textbooks and confirmations of the truth of its alternative version. *German International Journal of Modern Science*. 22. 52-61. DOI: 10.24412/2701-8369-2021-22-52-61

40. Antonov A. A. (2021). Experimental evidence of the incorrectness of the STR version studied in physics textbooks. *Annali d'Italia*. 25(1). 32-41. <https://www.anditalia.com/>

41. Antonov A. A. (2021). The incorrectness of the STR version presented in physics textbooks proven experimentally. *Norwegian Journal of development of*

the International Science. 74(1). 3-7. DOI: 10.24412/2453-9875-2021-74-53-62.

42. Antonov A. A. (2021). Experimental refutations of the generally accepted version of the SRT studied in physics textbooks. International independent scientific journal. 34(1). 23-32. http://www.iis-journal.com

43. Antonov A. A. (2021). Experimental refutations of the SRT version in the physics textbooks. Journal of science. Lyon. 26(1). 29-37. https://www.joslyon.com/

44. Antonov A. A. (2021). Experimental evidences for the fallacy of the STR version in physics textbooks. Sciences of Europe (Praha, Czech Republic). 82(2). 19-28. DOI: 10.24412/3162-2364-2021-82-2-19-28

45. Antonov A. A. (2021). The version of SRT, set out in physics textbooks, is incorrect, since it denies the existence of radio engineering. 82nd International Scientific Conference of the Eurasian Scientific Association "Scientific results in theory and practice". Moscow. 11-15. (In Russian). https://esa-conference.ru/sborniki/?y=2021

46. Antonov A. A. (2022). The version of STR presented in physics textbooks is incorrect, since it follows from it that radio engineering should not exist. European Journal of Applied Sciences. Services for Science and Education. UK. 10(1). 440-445. DOI://doi.org/10.14738/aivp.101.2022

47. Antonov A. A. (2022). The existence of radio engineering refutes the physics text books' version of STR. The scientific heritage. (Budapest, Hungary). 83(1). 19-22. DOI: 10.24412/9215-0365-2022-83-1-19-22

48. Antonov A. A. (2022). The fundamental Ohm's law in radio engineering as interpreted by Steinmetz, which proves the physical reality on imaginary capacitive and inductive reactances, refuted the version of the STR presented in physics textbooks even before its creation. German International Journal of Modern Science. 26. 50-53. DOI: 10.24412/2701-8369-2022-26-50-63

49. Antonov A. A. (2022). The version of STR stated in physics textbooks is refuted by the existence of radio engineering. Danish Scientific Journal. 56. 56-59. http://www.danish-journal.com

50. Antonov A. A. (2022). The version of STR presented in physics textbooks is incorrect because it denies the possibility of the existence of Ohm's law as interpreted by Steinmetz and, consequently, the existence of radio engineering. Annali d'Italia. 28(1), 43-47. https://www.anditalia.com/

51. Antonov A. A. (2022). The version of STR stated in physics textbooks is refuted by the existence of radio engineering. Norwegian Journal of development of the International Science. 78(1). 63-67. DOI: 10.24412/3453-9875-2022-78-63-66.

52. Antonov A. A. (2022). If the physics textbook version of STR were true, then Ohm's law should not

exist in nature, and therefore all radio engineering would not exist. International independent scientific journal. 36. 16-19. http://www.iis-journal.com

53. Antonov A. A. (2022). If the version of STR in physics textbooks were true, then there would be no radar, no television, no radio navigation, no telecommunication and many other things. Journal of science. Lyon. 28. 76-79. https://www.joslyon.com/

54. Antonov A. A. (2022). The version of STR set out in physics textbooks is incorrect because it states that Ohm's law as interpreted by Steinmetz does not really exist, and therefore radio engineering does not exist either. Sciences of Europe (Praha, Czech Republic). 87(1). 54-57. DOI: 10.24412/3162-2364-2022-1-54-57

55. Antonov A. A. (2022). Why the physics textbooks teach an incorrect version of the special theory of relativity which denies the existence of radio and electrical engineering. III international scientific conference "Challenges and problems of modern science". London. Great Britain. 78-86. DOI: https://doi.org/10.528/zenodo.7486814

56. Antonov A. A. (2014). Correction of the special theory of relativity: physical reality and nature of imaginary and complex numbers. American Journal of Scientific and Industrial Research. 5(2). 40-52. doi:10.5251/ajsir.2014.5.2.40.52

57. Antonov A. A. (2023). The Corrected Version of the Special Theory of Relativity. European Journal of Applied Sciences. Services for Science and Education. UK. 11(5). 68-83. DOI:10.14738/aivp.115.15474

58. Antonov A. A. (2023). Corrected special theory of relativity. Annali d'Italia. 49, 25-35. DOI: 10.5281/zenodo.10214679

59. Antonov A. A. (2023). Special Theory of Relativity. German International Journal of Modern Science. 67. 64-73. DOI: 10.5281/zenodo.10966458

60. Antonov A. A. (2023). Corrected special theory of relativity. Journal of science. Lyon. 47. 14-23. https://doi.org/10.5281/zenodo.10068983

61. Antonov A. A. (2023). The Corrected Version of the Special Theory of Relativity. The scientific heritage. (Budapest, Hungary). 123. 72-81. DOI: 10.5281/zenodo.10033028

62. Antonov A. A. (2023). The Corrected Version of the Special Theory of Relativity. Norwegian Journal of development of the International Science. 118. 40-49. https://doi.org/10.5281/zenodo.10009500

63. Antonov A. A. (2023). Alternative Version of the Special Theory of Relativity. Sciences of Europe. (Praha, Czech Republic). 128. 62-71. DOI: 10.5281/zenodo.10081933

64. Antonov A. A. (2023). Corrected Version of the Special Theory of Relativity. Danish Scientific Journal. 77. 88-97. https://doi.org/10.5281/zenodo.10054677

65. Antonov A. A. (2025). Time Travels are Already Possible Nowadays. *European Journal of Applied Sciences. Services for science and education.* U.K. 13(03). 47-70. DOI:10.14738/aivp.1303.18764.
66. Antonov A. A. (2025). Time travels are already possible for people on Earth. *German International Journal of Modern Science.* 104. 64-76. DOI: 10.5281/zenodo.15480577
67. Antonov A. A. (2025). Discovery of the possibility for people on Earth of time travels. *Norwegian Journal of development of the International Science.* 156. 84-98 [https://doi.org/10.5281/zenodo.15397809] (https://doi.org/10.5281/zenodo.15397809)
68. Antonov A. A. (2025). The discovery of physically real time travels. *Journal of Science.* Lyon. 66. 33- 48. [https://doi.org/10.5281/zenodo.15584655] (https://doi.org/10.5281/zenodo.15584655)
69. Antonov A. A. (2025). The physical reality of time travels available to people. *Annali d'Italia.* 67. 58-72. DOI: 10.5281/zenodo.15545211
70. Antonov A. A. (2026). From the Corrected Version of the SRT it Follows that Time Travels for People on Earth is Physically Possible and Technically Feasible. *European Journal of Applied Sciences. Services for Science and Education.* UK. 14(01). 723-744. https://doi.org/10.14738/aivp.1401.19957
71. Antonov A. A. (2026). Time travels according to the corrected version of the special relativity theory. XIX International Scientific and Practical Conference "Theoretical and practical perspectives of modern science", 13-14.01.2026., Stockholm. Sweden. DOI [https://doi.org/10.5281/zenodo.18303431] (https://doi.org/10.5281/zenodo.18303431)
72. Antonov A. A. (2026). Time travel on Earth is physically and technically feasible. *Journal of Science.* Lyon. 75. 28-41. [https://doi.org/10.5281/zenodo.18888329] (https://doi.org/10.5281/zenodo.18888329)
73. Antonov A. A. (2026). How to call yourself to yesterday? *Norwegian Journal of development of the International Science.* 172. 23-36. [https://doi.org/10.5281/zenodo.18268393] (https://doi.org/10.5281/zenodo.18268393)
74. Antonov A. A. (2026). Time travels on Earth is already available to peoples. VI International scientific conference "Dialogue of Times: Past, Present, Future" Brussels. Belgium. 21-22. 04.2026. DOI [https://doi.org/10.5281/zenodo.19823915] (https://doi.org/10.5281/zenodo.19823915)
75. Antonov A. A. (2026). From the corrected version of the SRT it follows that time travels is now available to people on Earth. *Danish Scientific Journal.* 103. 74-79. [https://doi.org/10.5281/zenodo.19922847] (https://doi.org/10.5281/zenodo.19922847)
76. Antonov A. A. (2026). Time travel for people on Earth physically is and possible now already technically feasible. XXIII International Scientific Conference "Modern Science: Theoretical and Practical View". Madrid. Spain. 31.03-01.04.2026. DOI [https://doi.org/10.5281/zenodo.19442313] (https://doi.org/10.5281/zenodo.19442313)
77. Antonov A. A. (2026). Time travel on Earth is available for use. *Annali d'Italia.* 76. 52- 65. DOI: 10.5281/zenodo.18803259
78. Antonov A. A. (2026). Time travels according to the corrected version of SRT is physically feasible. XXIII international scientific conference "The modern vector of the development of science". Philadelphia. USA. 29-30.01.2026. DOI [https://doi.org/10.5281/zenodo.18472454] (https://doi.org/10.5281/zenodo.18472454)
79. Antonov A. A. (2026). Time travels is already technically feasible for people on Earth. VI international scientific conference "Innovative scientific forum". Helsinki. Finland. 02-03.04.2026. 2. DOI [https://doi.org/10.5281/zenodo.19460273] (https://doi.org/10.5281/zenodo.19460273)
80. Antonov A. A. (2026). From the corrected version of the SRT it follows that time travels is now available to people on Earth. XIX international scientific conference "Questions. Hypotheses. Answers: science XXI century". Toronto. Canada. 17-18.03.2026* *
81. Antonov A. A. (2026). From the corrected version of the SRT it follows that time travels is now available to people on Earth. *Danish Scientific Journal.* 107. 74-88. DOI [https://doi.org/10.5281/zenodo.19823915] (https://doi.org/10.5281/zenodo.19823915)
82. Poincaré H. (1905). On the Dynamics of the Electron. *Comptes Rendus.* 140. 1504-1508.
83. Einstein A. (1905). Zur Elektrodynamik bewegter Körper. *Annals of Physic.* 17. 891-921.
84. (27.07.2026). Why can't the speed of light be exceeded? (In Russian) [https://www.youtube.com/watch?v=3xT5-GuhLKQ] (https://www.youtube.com/watch?v=3xT5-GuhLKQ) [https://www.youtube.com/watch?v=3xT5-GuhLKQ]
85. Antonov A. A. (2022). Dark Matter and Dark Energy, Which are Inexplicable in the Microcosm, are Mutually Invisible Universes and Anti-universes of the Hidden Multiverse. *European Journal of Applied Sciences, Services for Science and Education.* UK. 13(06). 84-107. DOI:10.14738/aivp.1306.19658.
86. Antonov A. A. (2025). Dark matter and dark energy are mutually invisible universes and anti-universes of the hidden Multiverse. *German International Journal of Modern Science.* 113. 27-42\ DOI: 10.5281/zenodo.17286973
87. Antonov A. A. (2025). Dark matter and dark energy are invisible universes and anti-universes of the hidden Multiverse. *Journal of Science.* Lyon. 71. 38-52. [https://doi.org/10.5281/zenodo.17533496] (https://doi.org/10.5281/zenodo.17533496)
88. Antonov A. A. 2025. Dark matter and dark energy are mutually invisible universes and antiuniverses of the hidden Multiverse. *Annali d'Italia.* 72. 28-42. DOI: 10.5281/zenodo.17463768
89. Antonov A. A. 2025. Dark matter and dark energy, which are inexplicable in the microcosm, are universes and anti-universes of the hidden Multiverse. XVIII International Scientific and Practical Conference "Theoretical and practical perspectives of modern science". 28-29.10. 2025, Stockholm. Sweden. 69-86.

- DOI [https://doi.org/10.5281/zenodo.17513357]
[https://doi.org/10.5281/zenodo.17513357]
90. Antonov A. A. (2026). Earth is structured differently than this is modern science explains. *Journal of Science*. Lyon. 79. 17-32. [https://doi.org/10.5281/zenodo.21109510] [https://doi.org/10.5281/zenodo.21109510]
91. Antonov A. A. (2026). Planet Earth is structured by nature differently than it is stated by modern science. VII International scientific conference "Dialogue of Times: Past, Present, Future". 30.06-01.07.2026. Brussels. Belgium DOI [https://doi.org/10.5281/zenodo.21226354] [https://doi.org/10.5281/zenodo.21226354]
92. Antonov A. A. (2026). Planet Earth is designed much more complex than it is stated by modern scientific knowledges. *Danish Scientific Journal*. 109. 38-53. [https://doi.org/10.5281/zenodo.21108869] [https://doi.org/10.5281/zenodo.21108869]
93. Antonov A. A. (2026). From the corrected version of STR it follows that planet Earth is a three-dimensional spiral structure in four-dimensional space. *Annali d'Italia*. 80. 54-69. DOI: 10.5281/zenodo.21031035
94. Antonov A. A. (2026). Planet Earth is designed much more complex than it is explained by modern scientific knowledges. *Norwegian Journal of development of the International Science*. 182. 122-137. [https://doi.org/10.5281/zenodo.20691204] [https://doi.org/10.5281/zenodo.20691204]
95. Antonov A. A. (2026). From the corrected version of SRT it follows that planet Earth is designed much more complex than it is explained by modern science. XXI International Scientific and Practical Conference "Theoretical and practical perspectives of modern science". 02-03.06. 2026. Stockholm. Sweden. [https://sconferences.com] [https://sconferences.com/]
96. Antonov A. A. (2025). The physical ability to bring a person who has died, for example as a result of an accident or a crime, back to life**. ** Polish journal of Science. 89(1). 36-39. DOI: 10.5281/zenodo.16917782
97. Antonov A. A. (2025). The use of the laws of physics allows a person who has died, for example, as a result of an accident or crime, to be brought back to life. *European Journal of Applied Sciences. Services for Science and Education*. UK. 13(04). 174-179. DOI:10.14738/aivp.1304.19179.
98. Antonov A. A. (2025). By using the laws of physics, it is possible to bring back to life a person who has died, for example, as a result of an accident or crime. *The scientific heritage*. (Budapest, Hungary). 166. 65-68. DOI: 10.5281/zenodo.1676353
99. Antonov A. A. (2025). It is physically possible to bring back to life a person who has died, for example, as a result of an accident or crime, using time travels. *German International Journal of Modern Science*. 109. 24-27. DOI: 10.5281/zenodo.16752567
100. Antonov A. A. (2025). The laws of physics allow a person who has died, for example, as a result of an accident or crime, to be brought back to life. *Danish Scientific Journal*. 98. 67-71. [https://doi.org/10.5281/zenodo.16615081] [https://doi.org/10.5281/zenodo.16615081]
101. Antonov A. A. (2025). It is physically possible to bring back to life a person who has died as a result of an accident or crime by using time travels. *Annali d'Italia*. 69. 46-49. DOI: 10.5281/zenodo.16419980
102. Antonov A. A. (2025). Possibility in accordance with the laws of physics, of bringing back to life people who have died as a result of accident and other causes by time travels using time zones on Earth. XVI International scientific conference. Beijing. China. "Science in modern society". 22-23. 07.2025. DOI [https://doi.org/10.5281/zenodo.16562393] [https://doi.org/10.5281/zenodo.16562393]
103. Antonov A. A. (2025). How the laws of physics can be used to bring back to life a person who has died as a result of an accident or crime. *Norwegian Journal of development of the International Science*. 160. 69-72. [https://doi.org/10.5281/zenodo.15879906] [https://doi.org/10.5281/zenodo.15879906]
104. Antonov A. A. (2025). A person who has died in an accident or crime, for example, can be brought back to life through the use of time travels. *International independent scientific journal*. 76. 17-20. [https://doi.org/10.5281/zenodo.16778574] [https://doi.org/10.5281/zenodo.16778574]
105. Antonov A. A. (2025). The laws of physics allow a dead person to be brought back to life. *Journal of Science*. Lyon. 68.15-18. [https://doi.org/10.5281/zenodo.16758455] [https://doi.org/10.5281/zenodo.16758455]
106. Antonov A. A. (2025). The laws of physics allow by time travelling with using time zones on Earth to bring back to life people who died as a result of accidents, in war and for other reasons. XVII International scientific conference "Theoretical and practical perspectives of modern science". Stockholm. Sweden. 12-13.08.2025. DOI [https://doi.org/10.5281/zenodo.16892861] [https://doi.org/10.5281/zenodo.16892861]

EVALUATION OF SMART CITY AS A GLOBAL WONDER IN THE ERA OF ADVANCED TECHNOLOGY

Dr Hossain K.

Vice Chancellor of Bangladesh Maritime University (BMU), Dhaka, Bangladesh
<https://doi.org/10.5281/zenodo.21982219>

Abstract

Top-notch and cutting-edge technologies such as mobile phone technology, digital/quantum computers, camera surveillance, robotics, Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), Big Data, Digital Twin, etc. have radical changes on human culture, law, religion, work, etc., and that have greatly up-sated the normal order of things in the society. The use of these smart technologies in smart cities and business enterprises has been met with certain technological, economical, legal and ethical repercussions. The use of advanced technology presents many significant challenges including technological, economical, legal and ethical facet and that are primarily centered around data privacy, security, and accountability in the era of advance technology. Smart City is a city which uses advanced technology and innovation to improve the efficiency and productivity of services and city planning, to reduce the cost and resources utilizes by the city and target people. This model city emphasises on a decent design and the contribution of the business sector and people in developing the city under the idea of a better and modern city. In smart city people will live comfortably, happily and sustainably, and have a good quality of life with safety and security. This article examines the status, benefit, and prospects of smart cities for global enterprises to meet the problems of the 21st century, keeping in mind the objective of smart cities. This study will also appraise the prospect and challenges along with ethical aspect of extensive and wide use of smart technology to develop smart cities.

Keywords: Advance technology, smart city, cyber security, comfort, service, digitization, IoT, AI

1. Introduction

Technology has woven itself into our lives, transforming everything from the way we communicate to how we handle legal matters. With innovations like Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), quantum computing, and the legal field isn't untouched by these advancements. However, with technological progress comes the need to address ethics in technology. Legal ethics now involves understanding how these innovations impact confidentiality, accuracy, and privacy [1]. Our lives are made more convenient and easier by technology. We use technology, such as video calls and messaging, to swiftly communicate with others. Additionally, it facilitates fast access to information through search engines like Google. We can complete jobs more quickly and effectively thanks to technology. Today's society relies heavily on technology, which affects how you communicate, work, and make decisions. In the legal field, technology plays a significant role in ensuring confidentiality, managing factual discrepancies, and enhancing data security [2]. Let's delve into these aspects and see how they influence ethics and technology. Again, Generative AI is increasingly being used in legal systems to automate tasks like creating documents or assisting with research. This integration raises questions about legal responsibility, especially when AI makes autonomous decisions. For instance, if an AI system drafts a contract, who is accountable for any errors? As you work with AI, it's important to regulate its use to prevent inaccuracies. Consider a scenario where a law firm in Dhaka uses AI to draft contracts. They must ensure that the AI's outputs meet legal standards and that there's a system in place to review these documents [3]. These days, smart cities leverage data from cutting-edge technologies like IoT, AI, and ML to give resi-

dents better environmental cleanliness and safety. In order to meet the requirements of their residents and increase the effectiveness of service delivery, some cities also make use of IoT or AI devices [4]. Cybersecurity threats are one of the many threats that smart cities face, despite their high degree of connectedness and security. However, possible threats and attacks can be avoided with appropriate safety precautions. [6].

The steam engine, which altered manufacturing and transportation, was the first invention of the Industrial Revolution. Leaders like James Watt used this method to revolutionize entire industries and speed up progress. The advent of computers and the digital age accelerated the rate of creation [99]. By using technologies like the Internet of Things, AI-powered smart homes mark a significant advancement in sustainable living by lowering energy use, enhancing security, and enhancing comfort [5]. These systems can estimate maintenance requirements, modify environments, and manage resources on their own, which lowers waste and costs. In addition to transforming economic affluence through housing and technical innovation, the digital or smart revolution has also changed environmental sustainability [6]. Strong data privacy, cybersecurity, and ethical AI must be given top priority in smart home technology innovations. In order to prevent the negative effects of unchecked but intelligent technology, transparency, justice, and accountability are crucial because these systems handle sensitive personal data [16]. IoT, AI, ML, Deep Learning (DL), big data, blockchain, cloud computing, platform economy offers, big data, and algorithm-based decisions are currently revolutionizing the field of brain workers [119]. The complicated scenario affects not only auditors but also lawyers, engineers, doctors, data scientists, and computer scientists. In actuality, a few decades ago, leadership

was based on extraordinary skill. This focus is progressively diminishing. Through advancements in healthcare, education, transportation, housing, distribution, and other essential services, innovations in the fourth industrial revolution (4IR) can result in a higher standard of living. By encouraging innovation, opening up new markets, and increasing overall economic efficiency, the integration of 4IR technologies can promote economic growth and national development [14]. By giving everyone access to economic, medical, and educational opportunities, it is also paving the path to reduce social inequality, claims 4IR Energy Solutions [15]. Digital communication is convenient but poses significant challenges to confidentiality. Technologies like encryption and secure data storage are vital in maintaining privacy. Imagine you're a lawyer handling sensitive client information. Ensuring that this data is encrypted and securely stored is crucial [130]. The legal framework around confidentiality is evolving, and as a legal professional, you need to stay updated with these changes. AI systems can sometimes perpetuate biases or inaccuracies, especially if trained on flawed data. This is a significant concern in ethics with technology. For example, if an AI used in a court case relies on biased data, it could lead to unjust outcomes. Rigorous data validation and ethical AI development are necessary to ensure technology's outputs are reliable. As technology advances, so do cyber threats. Investing in robust cybersecurity measures is essential to protect user data. Consider a corporate law firm managing vast amounts of client data. Implementing AI-driven security tools can help detect and prevent cyber-attacks, maintaining trust in digital systems.

Liability and Accountability is determining legal responsibility when an autonomous or AI-driven system causes harm or a security breach is complex [6]. The issue of who is at fault and the manufacturer, the software developer, or the end-user and which is a significant legal question that evolving frameworks like the EU AI Act are attempting to address by proposing risk-based liability regimes. On the other hand, Data Ownership and Rights It is often unclear who owns the data generated by smart devices: the person generating it, the device manufacturer, or a third-party service provider. Legal frameworks are needed to clarify ownership, access, and usage rights, especially concerning data portability and cross-border data flows. Again, Intellectual Property (IP) is an emerging technology that challenges traditional IP laws, raising questions about ownership of AI-generated content and how to protect innovations like smart contracts within existing frameworks. AI, IoT, ML, and big data can be used for automation, data-driven decision-making, and predictive analysis by intelligent and modern company owners, CEOs, managers, or even any individual [38]. Numerous businesses, industries, service sectors, and facets of life benefit from these innovative technologies [17]. Bill Gates said, "As we look ahead into the next century, leaders will be those who empower others." In several industries, technology is becoming increasingly advantageous. A digital and intelligent revolution is being brought about by technology. Leaders with intelligence need to adjust to new technologies. Without it,

they are unable to lead and connect on a global scale. The workplace will change in the upcoming ten years due to AI and robots' capacity to automate tasks, improve decision-making, and streamline procedures. Massive data sets can be analyzed, patterns can be found, and accurate predictions can be made by AI-powered devices [41, 46]. This makes it possible for executives to make data-driven decisions, which enhances cost, accuracy, efficiency, competitiveness, and idea generation. AI may also automate routine activities, give men and subordinate more time to concentrate on strategic and creative work. This change in emphasis increases employee satisfaction and innovation. AI enables personalized team experiences, such as career paths and learning and development initiatives. Leaders may use AI and other contemporary technology to create a company that is future-proof, sustainable, flexible, adaptive, and purpose-driven, enabling it to prosper in the quickly changing military sector and future battlefield. AI enables students to personalize their learning. AI technology has the potential to improve teacher effectiveness and education. AI is used by big financial institutions to make investing easier. BlackRock's AI engine, Aladdin, assists customers in making financial decisions.

Eighty percent of the world's population is predicted to live in cities by 2050, when there will be nearly nine billion people on the planet. Just over half of the seven billion people on the planet now live in cities. City dwellers consume 80 percent of the planet's resources, although making up only 2 percent of the planet's land area. The conventional structures that cities rely on to supply resources are unsustainable, as are the cities' disproportionate use of social and physical resources and their rapid growth [7]. Local action is essential to attaining a low carbon future, even though urbanization continues to contribute to rising carbon emissions worldwide. Cities are now taking the initiative and creating plans to deal with the effects of climate change due to the lack of legally enforceable international climate action and the lack of leadership in many state governments. Cities are, in many ways, our best chance to combat climate change (World Urbanization Problem, United Nations, 2014) [8, 154]. By 2030, 70% of the world's population will reside in our global cities, which currently account for 80% of the world's GDP and are centers of innovation and commerce (World Bank). It is vital that we proactively determine what we want for our future cities and put in place mechanisms now that serve those future demands in a sustainable and integrated fashion because the appearance of these cities will have an impact on our environment globally [9]. Future consequences include optimized energy usage and improved mobility, but also present serious challenges regarding data privacy, security risks like cyber security, digital divide and many uncertainties [181]. Beside many prospects there are some major challenges including legal or ethical issues require a balance between technological innovation and the protection of individual rights and societal values.

Over the past century, there has been a notable improvement in the quality of life, mostly in terms of service access. However, administrators, architects, and urban planners have faced significant challenges due to the strong industry and population growth in urban regions. In the era of advance technology a major focus is transitioning to Net Zero through smart energy, waste management, and climate adaptation strategies [10]. The use of digital twins, artificial intelligence, and robotics is accelerating to create responsive urban environments. Real-time data collection enhances public services, such as, for instance, in traffic management and public transport. Future development emphasizes engaging citizens to ensure solutions meet actual needs, rather than just technology-driven initiatives. On the other hand, huge dependance on connected infrastructure introduces vulnerabilities, making cybersecurity a top concern [12]. Many of these cities have difficulties due to the enormous amount of capital needed for growth and upkeep. In addition, there are numerous ethical and legal difficulties. Regulatory and compliance issues, privacy concerns, and questions about intellectual property rights protection are just a few of these legal nightmares. [13]. Meanwhile, the ethical dilemma fluctuates between dignity, conscience, right and wrong, addictions, etc. The main legal challenges revolve around applying existing law to new, complex technologies and ensuring compliance with evolving regulations. Evaluating smart city initiatives becomes difficult without agreement on parameters [14]. Additionally, it makes it more difficult to compare projects and find best practices. The transformation of smart cities into "smart regions"—for example, by fostering greater cooperation between the public and private sectors—is the way forward [15]. In order to assess the opportunities and difficulties of smart cities in the twenty-first century, this essay will examine the evolution of smart technology. The complexity and process of striking a balance between the employment of smart technology and the defense of individual and collective rights as well as societal values in the complicated global context will also be evaluated and discussed in this article. In the dominion in the era of advance technology, smart skills, this research also emphasizes the importance of a suite of capabilities like communication, collaboration, problem solving, interpersonal skills, and job-specific advanced technical skills and that will be boosting employability and competence for future citizen. This is an analytical qualitative study on advance technology to evaluate the concept, elements, business, prospects, benefit, and challenges of smart cities in the era of advance technology along with legal and ethical aspect in contemporary age.

2. Literature Review and Methodology

The character of cities has always been multifaceted. In the era of advance technology cities must incorporate the use of big data and information and communication technology (ICT) into everyday operations and in the achievement of their urgent objectives if they are to become smart and sustainable—more ecologically sound, commercially successful, and socially just. As we swiftly move into the twenty-first century, it becomes clear that in order to keep up with the expanding

population and limited resources, a city's total live-ability will need to take on a new dimension and horizon. The city will become a more livable place if technological innovation is combined with smart connectivity that makes use of the expanding Internet of Things (IoTs) to address the real problems of traffic congestion, waste/pollution control, and energy efficiency. Although smart city efforts are always a work in progress, communities worldwide stand a better chance of receiving the most livable award when they are carried out with actual business results and the specific demands of end users in mind. Therefore, through multilateral trading systems like those provided by the WTO, smart cities as they are now defined and understood have immense potential to open up in the worldwide business arena. Though descriptions and visions of the future city will still reflect the competitive dynamics between cities and the businesses and organizations that want to service them, the conversation about future cities is becoming more multidisciplinary, evidence-led, and conceptually rigorous. Most people's lives, whether or not they reside in a city, will be directly impacted by the shape, functionality, look, and atmosphere of cities in the future. In addition to its effects on people, the future city will have an impact on economies and broader global environments. Economically speaking, the biggest metropolitan marketplaces have already surpassed those of several countries.

Numerous disputes and public discussions have been sparked by the new environmental challenges. Degradation of the environment is becoming a worldwide problem. An estimated trillion tons of carbon dioxide would be added by 2050 if current emission rates continue, according to the literature, which could have a negative impact on human existence [166]. In recent years, there has been research on the function and significance of ICT for various economic outcomes. Increased use of information communication technology (ICT) has been shown to have positive economic effects [167]. Nonetheless, the literature has paid the least attention to ICT's ecological aspects. ICT has actually had an impact on human life from a variety of angles, including ecological ones. However, ICT is seen as a way to strengthen environmental protection, lessen the negative effects that human activity has on the environment, and tackle important environmental issues like sustainability and climate change. By raising knowledge of environmental issues and encouraging the use of ecologically friendly technology, ICT can also aid in reducing environmental damage [168]. Environmental dangers can be anticipated and managed with the aid of ICT technologies. Computerized simulation tools, for instance, can make "learning by simulation" easier in order to speed up decision-making processes and avoid the negative effects of trial and error. The "internet network" is another component of ICT that enhances environmental awareness. Due to their ability to lower greenhouse gas emissions, ICT-based solutions are regarded as beneficial for environmental sustainability [169].

The legal and ethical implications of these developments cannot be disregarded in the age of smart cities, when the integration of IoT, AI, and other smart

technologies promises previously unheard-of levels of efficiency and innovation. Questions around data privacy, surveillance, cyber security, and the ethical use of technology become more pressing as urban areas become more globally connected and accessible through the internet or web. The gathering and use of personal data as well as open connectivity to the outside world are among the main issues in the context of smart cities [128]. IoT devices and AI technology collect data from a variety of sources, including sensors, cellphones, and security cameras. Therefore, establishing strong data privacy legislation becomes essential. To guarantee that people's or personal information is handled responsibly, openly, and with the highest level of security, smart cities must abide by strict data protection rules. Concerns regarding citizen privacy are brought up by the use of surveillance technology, such as voice and facial recognition and video analytics. Finding the ideal balance between protecting individual rights and maintaining public safety is a difficult task. Clear rules and guidelines controlling the use of surveillance technology are necessary in smart cities to guard against misuse and shield residents from unjustified intrusions into their personal life. It is essential to make sure that people are aware of how data is collected in smart cities. People are empowered to make educated decisions about their involvement in smart city efforts when there are open communication and explicit agreement is obtained for the gathering and use of personal data [186]. This openness promotes a cooperative and moral approach to urban development by increasing trust between citizens and city officials.

Because IoT devices are interconnected and use AI, smart cities are vulnerable to cyberattacks. It is crucial to safeguard the infrastructure from possible threats and secure the data that is sent between devices. To prevent unwanted access and preserve the integrity of the data gathered, smart cities must have strong cybersecurity measures in place, such as encryption methods, frequent software updates, and intrusion detection systems [25]. The Internet of Things (IoT) and artificial intelligence (AI) are major forces behind efficiency and creativity in the age of linked technology and smart cities. However, the crucial relevance of cybersecurity cannot be understated given the growth of smart cities and the proliferation of connected devices. The importance of cybersecurity in the context of IoT and smart cities is examined in this blog post, which also outlines best practices for protecting infrastructure and data. Mobile phones can determine where and when we cast our ballots by tracking us as we shop. Drones monitor our neighbors and provide drinks to fishermen in the middle of a frozen lake, and algorithms based on commercial data enable businesses to sell us goods they believe we can afford and refrain from displaying those they believe we cannot. One day, autonomous cars will talk to each other to reduce traffic jams and, consequently, energy usage. Technology has repercussions, challenges conventions, alters our abilities and actions, acts on our behalf, and renders biased judgments [64]. There are drawbacks to using this technology, particularly with regard to human privacy and emotional and finan-

cial stability. Technology use can lead to moral dilemmas, political challenges, and a host of other legal issues. The combination of these technologies and their negative impacts is what gives rise to ethical issues surrounding the usage of smart and contemporary technology.

Smart cities are vulnerable to cyber threats due to the interconnectedness of IoT devices that use AI. It is crucial to secure data being sent between devices and to defend the infrastructure against possible threats. To prevent unwanted access and preserve the integrity of the data gathered, smart cities need to have strong cybersecurity measures in place, such as encryption methods, frequent software updates, and intrusion detection systems [25]. The Internet of Things (IoT) and artificial intelligence (AI) are major forces behind efficiency and creativity in the age of connected technology and smart cities. However, the crucial significance of cybersecurity cannot be emphasized given the growth of smart cities and the proliferation of connected devices. This blog post examines the critical need for cybersecurity in the context of smart cities and the Internet of Things, exploring potential threats and describing recommended practices to protect infrastructure and data. Mobile phones can determine where and when we vote by tracking us while we buy. Drones observe our neighbors and provide drinks to fishermen in the middle of a frozen lake due to algorithms based on commercial data that allow businesses to offer us things they believe we can afford and avoid displaying us things they believe we cannot. By communicating with one another, autonomous cars will eventually reduce traffic jams and, consequently, energy usage. Technology affects our behavior, challenges conventions, alters our capabilities, acts on our behalf, and produces biased results [64]. There are drawbacks to using this technology, particularly with regard to human privacy and emotional and financial security. Technology use has the potential to influence and elevate political issues, moral concerns, and several legal challenges. Modern technology use raises ethical questions because of the confluence of various technologies and their negative impacts [188].

With over 95% of the world's population now connected to mobile networks in the twenty-first century, closing the digital divide both within and between nations was essential, and we must never forget that information and communications technologies (ICTs) are always beneficial for development. In the modern era, ICT is a useful instrument for reducing environmental deterioration. Large volumes of sensitive personal, behavioral, and environmental data are now collected by smart devices, making adherence to strict data protection regulations necessary. The stories about how technology will eventually interact with people and the myth of digitalization have finally come to pass. Nature has been profoundly altered by technology in previously unimaginable ways. The world is in awe of the entrance of mind-blowing technologies like robotics, the Internet of Things, artificial intelligence, machine learning, and smart devices like computers, phones, watches, and cameras. Nearly every aspect of human life, including society, has seen significant change as a

result of this contemporary technology. Politics, election trends and analysis, financial analysis, economic growth, social life, medical, education, energy, religious beliefs, and other areas are all significantly impacted by modern technology. Thanks to artificial intelligence (AI) and automation, humans may now effectively engage with technology in the twenty-first century. There are numerous facets to important regional and global frameworks. A strict EU framework that requires user consent, data minimization, transparency, and the right to be forgotten is the General Data Protection Regulation (GDPR). Alternatively, California customers have the right to know what data is collected and to request that it be deleted under the California Consumer Privacy Act (CCPA). Another is the Health Insurance Portability and Accountability Act (HIPAA), a federal law in the United States that regulates the security and privacy of personal health data gathered by smart health devices. However, while both Singapore's PDPA and Australia's Privacy Act are national laws that protect personal data, they differ in their enforcement and scope. The Australian Privacy Act, which is based on 13 APPs, regulates handling across sectors with a strong emphasis on individual access and transparency [144]. Once more, the Singapore PDPA, which is overseen by PDPC, establishes baseline guidelines for the gathering, use, and disclosure of data. It was recently improved with stricter penalties and guidelines for reporting data breaches. Both seek to strike a balance between organizational requirements and data protection [145].

This research has used the worktable, which consists of the review of documents and pertinent literature in this area, in order to accurately ascertain the ethical and legal ramifications of current technology. The completion of this research project has been made possible by the consultation and collection of important information from documents such as books, papers, journals, newsletters, and laws. The completion of this work has also benefited greatly from the internet, a primary data collection tool. The majority of these documents have provided insight into how technology functions and acts in general, which has greatly aided in the development of this article. Law analysis has also revealed a significant discrepancy between the rules governing important corporate, social, and economic facets of society prior to the emergence of digital or smart technologies and the recent significant advancements in technology [120]. Several AI tools, such as ChatGPT, have been utilized to gather pertinent data in order to provide a hands-on example of the benefit of technology. AI can collect data in minutes that 30 workers could collect in a week. The money that would have been spent on transportation, food allowance, paperwork, and documentation may now be used for other business-related expenses, which results in cost savings. Meetings that could have been held in person, with all the costs associated with arranging logistics, hiring staff, etc., can now be ignored because they can be handled conveniently and comfortably online. Just think about how much money a company or training school/institutes will spend to book tickets for her em-

ployees' flights, meals, and lodging when they are attending training overseas or in a far-off place. Thanks to technical advancements and astute business practices, these meetings, conferences, and gatherings may be conducted virtually for very little money. Data professionals may gather and analyze ever-increasing amounts of data more quickly and effectively when AI and data analytics are combined [63]. Productivity and efficiency are the keys to success in the fast-paced world of business. The same holds true for personal achievement in contemporary life. Because technology can automate monotonous work, minimize manual errors, and speed up procedures, organizations, businesses, and even astute citizens who embrace it are discovering that they have a clear advantage. In addition to saving money, this increased efficiency helps companies become more productive and profitable [115, 186].

Smart cities in the era of advance technology utilize IoT, AI, ML, Big Data, Digital Twin, and data analytics to enhance sustainability, efficiency, and quality of life, addressing rapid urbanization and climate challenges toward peaceful and smart living. Important prospects include intelligent traffic, smart grids, and citizen-centric services, though high implementation costs and cybersecurity risks remain significant challenges. Digitalization and the application of smart technologies make production and distribution, as well as the manufacturing of goods and services, comparatively simple, precise, and quick. Contemporary technology is designed to be flexible. It can adjust to changes in the business environment, pricing, quality, quantity, and kind of goods or services because of its independent and effective character [121]. The new pricing labeling in a supermarket can be easily reprogrammed and mastered by modern computer or AI systems. Therefore, modern technology is a strength because it keeps the organization, firm, business, or even the everyday work of a smart citizen current and present regardless of changes that take place in the course of business or odd events. There is increasing demand to make cities more environmentally friendly while also increasing their efficiency as urbanization rates rise and governments throughout the world set aggressive goals to cut carbon dioxide emissions. Over two-thirds of the world's CO₂ emissions come from cities. Some have taken up the task and are managing the difficulties of urban sustainability with the aid of technology [170]. Complex jobs, simulations, calculations, and other tasks can be completed 100 times faster by computers, IoT devices, and artificial intelligence (AI) systems than by the human brain. Smart technology, including artificial intelligence (AI), the Internet of Things (IoT), machine learning (ML), data science, big data, and ICT in general, is made up of various computer components and technological fusions that can readily adapt to human nature and carry out tasks more quickly and independently. An intelligent bottle, for instance, can cock bottles in minutes, but it will require 100 workers working long hours to complete the same activity. Given that time is the most valuable resource in the business world, this efficiency is a welcome boon.

Cities that are managed more effectively can increase economic growth, lower expenses, and increase productivity. Government assistance, technology innovation, and necessity are driving this movement toward smart, sustainable cities. Secular growth should benefit businesses that offer answers [15]. Despite being widely discussed, the term "business model" is relatively new and lacks a standard definition [155]. A business model explains the logic behind how a company generates, provides, and acquires value (economic, social, cultural, or other forms of value). A business model is defined as "an architecture of the products, services, and information flows," which is one of the most commonly used definitions. Actors, roles, potential economic value, and the revenue source are all acknowledged in this definition. Four components make up a business model framework, often known as a "canvas," which centers the value proposition. [150, 156]. According to Roy (2005) [157], business models can be categorized into five categories, despite the possibility of different value propositions. Unbundling business models are useful for companies that operate in the three essentially distinct business categories of infrastructure, product innovation, and customer relationships like private banking. A company that uses the long tail business model aims to sell more for less. Offering a wide variety of specialty products, each of which sells comparatively infrequently, can help address this problem like LEGO. Multi-sided platform models, which combine two or more separate yet connected client groups like game console production vendors. Free business model: consistently provide a free offer to at least one significant consumer category like cell phone operators. Unbundling business models are useful for companies that operate in the three essentially distinct business categories of infrastructure, product innovation, and customer relationships like private banking.

More sophisticated threats are always emerging, and the environment of cyber security is constantly changing nowadays. Since the pandemic, businesses and individuals have become increasingly dependent on technology, which has given hackers a special chance to take advantage of their weaknesses. Actually, there has been a 600% surge in cybercrime since the pandemic started. Sadly, most small and medium-sized business owners (SMEs) are not sufficiently equipped to protect themselves from a cyberattack, even though they are the most vulnerable. There are several reasons for this, including as inadequate cybersecurity plans, undertrained staff, and antiquated IT hardware and software. You must address this technological issue head-on because the majority of SMEs fail within six months of a cyberattack. Effective protection can be established by collaborating with the appropriate outsourced IT support company [122]. Automation has the potential to increase productivity, but it also puts certain jobs at risk of being replaced. Employee morale and corporate culture may suffer if there is less demand for some job positions as a result of increased reliance on technology [116]. There are many advantages to using AI, ML, robotics, or information and communication technology

(ICT) in business, but there are also risks and complicated legal issues involved. The following are some of the main risks associated with ICT use in businesses: old or malfunctioning hardware, software, or network components that can cause system crashes, data loss, and service interruptions. inadequate redundancy or backup solutions to guarantee the uninterrupted availability of vital IT resources in the event of emergencies or failures [117]. Once more, the widespread usage of smart gazettes, devices, and systems will raise significant ethical and legal concerns in the future. The impact that modern digital technologies have brought to bear on human activity such as politics, education, the economy and businesses across the globe is so alarming [188].

3. Chronological Development of Technological and Industrial Revolution

Technology from Primitive Age. Humans differ from other animals in that our capacity to convey and receive information improves our capacity for abstract thought. The reason we were at the top was our superior intelligence. Compared to a few hundred thousand years ago, human technology would have taken a million years to become economically viable enough to support an extra million people since it develops slowly. This time frame was shortened to two centuries by the Agricultural Revolution of 5,000 BC. It further decreased to just 90 minutes in the years after the Industrial Revolution. Technological developments like the creation of super-intelligent (SI) machines have the potential to drastically alter the world as we know it. The concept of superintelligence was explored in 2014 in relation to the possible societal repercussions of building a machine with greater intelligence than humans. These conversations provide a thorough understanding of the super-intelligent future and how we could get there, supported by facts, statistics, and research from a variety of fields. However, the condition of contemporary technology is the main focus at the moment. By analyzing data entered by humans, we have already been able to build machines that can learn and reason. One excellent example is the automatic spam filters that safeguard important information and keep our inboxes clear of unsolicited bulk emails. However, this is still a long way from the "general intelligence" that humans possess, which has been the goal of AI research for many years. Furthermore, it might yet be decades before a super intelligent computer that can learn and operate on its own is created. But the field is developing quickly, and a machine like this might be available sooner than expected. Its intelligence could have a profound impact on our lives and could even be dangerous because it might be too advanced for us to turn off in an emergency [76].

Although imitation can take many different forms, it can be used to develop technology. As a result, although some scientists are in favor of building a computer with artificial intelligence that can mimic people, others want an exact replication of human biology, which may be accomplished through techniques like whole brain emulation (or WBE). The majority of the most important discoveries in human history have ei-

ther been the result of substantial international cooperation or of individual scientists accomplishing a goal before others. If a team of scientists could find answers to the problems preventing AI and WBE in a short amount of time, they could probably build a single super-intelligent computer. This is because the industry is highly competitive, which would require such a group to operate covertly. Let's look at the possibilities for the development and application of general intelligence technology before we get scared of the impending machine-led disaster. The increased accessibility of technology and its decreasing cost are projected to promote the mass production of robots that can perform tasks that currently require human hands and minds [77]. This suggests that not only will machines take the place of all human labor, but they will do so with ease. A robotic workforce will have a significant impact on the economy, as well as our desires and lifestyles. Workers' earnings will fall until no human can live on a salary as machine labor becomes the new, less expensive norm [78]. In addition, the mechanical industry would see a small number of employers amass vast wealth. But this brings us back to a previous argument because where the money ends up depends on whether SI is created by a single, exclusive group or develops gradually through a collective process. If the former is true, most people's potential to make money would be limited since they would have to rely on their pensions, savings, or rental properties [79]. However, the expansion of SI is linked to a number of safety hazards that, in the worst cases, could lead to the extinction of humanity. Examining the logic behind the SI we create can help construct specific protections, but this won't be sufficient on its own.

Industrial Revolution and Complex Global Order in the Era of Advance Technology. As we speak, advances in sophisticated and intelligent technologies that span the digital, biological, intellectual, and physical domains are essentially transforming the global economy. The world is transforming as a result of emerging technologies including automation, robotics, AI, ML, DL, IoT, big data, and blockchain [80]. Globally, the industrial revolution is still running strong. It can be explained by the shift from manual to machine-based manufacturing, which had a significant impact on society and had worldwide repercussions. Although it brought about economic progress, reduced costs, and higher output, it also brought about social issues including environmental degradation and worker exploitation. The steam engine, power loom, and mass production methods were examples of innovations that transformed industries and encouraged continued expansion. It contributed to the establishment of Western supremacy by dramatically widening the divide between industrialized countries and the rest of the globe [81]. AI is going to change and upend products and service paradigms. Innovative and disruptive service models created by big data analysis of individual customer wants rather than corporation demands will transform the service industry, even while technical advancements primarily increase industrial efficiency [82]. Below is a summary of the industrial development timeline.

INDUSTRY 1.0: INDUSTRIALIZATION: Industry 1.0 marks the beginning of the industrial period in the 18th century, which is known as the first industrial revolution and was characterized by the first use of machinery to produce goods and services. Among the biggest developments were the development of heavy industry, railroads, and coal mining. The most important development of this era was the steam engine, which caused social unrest and the eviction of many workers. Because they provided a flexible energy source that could be used anywhere, steam engines were first used in Great Britain's industries in the late 18th century, which promoted industrialization [83].

INDUSTRY 2.0: ELECTRIFICATION: The advent of electrification in the late 19th century marked the beginning of the second industrial revolution. The assembly line, which was initially used in the automotive industry, developed into the steam engine's industrial equivalent at this time, enabling the automation and speeding up of production processes. The sequence of specific tasks that employees perform in Industry 2.0 demonstrates the division of labor, leading to the rise of serial manufacturing. Furthermore, the first automated product delivery between continents was made possible by the introduction of international shipping technologies, such as airplanes [84].

INDUSTRY 3.0: DIGITALISATION: The advent of electronics-driven automation and information technology marked the start of the third industrial revolution in the 1970s. The widespread adoption of personal computers and the internet significantly increased the integration of technology in the workplace. As a result, labor processes became more automated, and global information access increased. Additionally, in mass production, robots replaced human labor. At that time, this trend was already on the horizon and was intensified during Industry 4.0 [85].

INDUSTRY 4.0: AUTOMATIZATION: Industry 4.0, also referred to as the fourth industrial revolution or 4IR, entails incorporating cyber-physical systems (CPS) into logistics and manufacturing processes as well as connecting commonplace items via the Internet of Things. Value creation, business models, downstream services, and work organization are all impacted by services in industrial processes [86]. AI, IoT, ML, DL, big data, blockchain, and other smart technologies are all included in CPS, which refers to network connections between people, machines, products, things, and ICT systems. Over 100 billion devices will be connected in the future. The 4IR differs from the 3IR in the service industry due to AI.

Four essential elements define the word "automation" in industrial production: 1) Production operations are managed by machines. Thanks to clever technology, most production in the future will be automated, with human involvement occurring only seldom. The "smart factory," which has little to no human presence, is an example of this tendency [87]. 2) Real-time production is a key feature of Industry 4.0. The ideal utilization capacity of the industrial facility is determined by an intelligent machine. Lead times are short in the production process, and standstills—apart from those brought on by technical flaws—can be

avoided. To satisfy the needs of the value creation chain, resources, information, and commodities are carefully coordinated. Stocks are kept to a minimal, but when the amount required for manufacturing drops below a predetermined level, the machine automatically buys more supplies. The same concept holds true for completed goods; the machine minimizes storage costs by producing in accordance with overall demand and incoming orders [88]. 3) Decentralization of production: The machine, which includes a network of manufacturing units, is essentially self-organized. Order handling is fully automated in addition to material planning [89]. 4) Tailored production, even for individual pieces: As long as they stay within predetermined bounds, robots will eventually be able to respond to certain customer needs without the need for human adjustments. Changeover times are less necessary as a result. In order to accommodate customer needs and preferences, the smart factory incorporates additional components or, in an appropriately dispersed process, adjusts particular manufacturing processes [90].

The phrase "4IR" denotes the exponential advancement of technology in the twenty-first century [91]. The 2016 World Economic Forum Annual Meeting [92] in Davos-Klosters, Switzerland, will focus on the topic of "Mastering the Fourth Industrial Revolution." The global production and supply network is undergoing fundamental changes in this era as a result of the continuous automation of conventional manufacturing and industrial processes using contemporary smart technology, large-scale machine-to-machine communication (M2M) [93], and the Internet of Things. This integration has resulted in the deployment of intelligent robots that can assess and diagnose problems without human intervention, improved communication and self-monitoring, and increased automation [94]. AI, robotics, IoT, biotechnology, and nanotechnology are among the digital, physical, and biological technologies that combine to make it [95]. Infosys BPM asserts that Industry 4.0 is transforming the manufacturing and production sectors, leading to more automation, streamlined supply chains, and personalized products. In order to achieve the objectives of universal energy access and net-zero emissions, 4IR technologies are needed for the integration of renewable energy, smart grids, and energy storage systems, as per ScienceDirect.com. [96]. The education industry is changing as a result of 4IR, necessitating the incorporation of digital literacy, creative teaching techniques, and public-private partnerships. Personalized treatment, remote patient monitoring, and sophisticated diagnostic tools are some of the ways that 4IR technologies are transforming healthcare [97]. It seeks to use cutting-edge technologies to build a more sustainable, just, and affluent future for everybody.

Because of their autonomous communication via sensors and associated technological networks, 4IR's production process components—such as machinery, operational resources, software, and others—have significantly improved [98]. By reducing production expenses, particularly in personnel planning, 4IR seeks to improve the company's standing in global competition

[99]. It uses advances in digital, physical, and biological technologies to change how we live, work, and interact with each other. In order to alleviate social and economic inequality and build a more productive, efficient, and sustainable future, it aims to combine various technologies. Delivery drones, autonomous cars, "smart factories," and 3D printers—which can create extremely complex structures from a template without human assistance—are well-known instances of robotics and artificial intelligence. Car sharing, Spotify, Netflix, Uber, Airbnb, Facebook, and Amazon Mechanical Turk are examples of popular service models. Studies show that in just ten years, sector turnover will increase twentyfold due to service sharing [100]. However, 4IR has been developed with intelligent technology to improve resource use, cut expenses, and streamline procedures across a range of industries, resulting in higher productivity and efficiency. It is fostering the emergence of new sectors and employment prospects, especially in fields that demand a skilled labor force, such as artificial intelligence (AI), robots, biotechnology, smart shipping, smart transportation, smart healthcare, and data science. The World Economic Forum stated that by encouraging sustainable energy solutions, improving resource management, and lowering pollution, 4IR technologies can be extremely helpful in tackling environmental issues [101]. Human-centeredness, which emphasizes improving human well-being, conserving cultural heritage, and advancing societal ideals, is a fundamental component of 4IR [102].

Influence of AI in the Era of 4IR. Artificial intelligence has been pervasive for a long time. Our daily lives are continuously improved by its benefits. The technology is used in robots that greet clients at shopping malls and in internet search engines that provide suggestions [103]. AI systems today mimic human analysis. It indicates a computer program's ability to think and learn. Any system that uses a software to carry out tasks typically associated with human intellect is referred to as artificial intelligence (AI). The developments in AI have led to the realization of numerous benefits across various industries [104]. Today, projections are becoming more precise, and convenient technology is widely available. Procedures are also effective and efficient. AI ensures continuous business operations by optimizing data backup and disaster recovery options. Even though the key elements of successful technology and IT leadership are always changing, the need for a solid business plan, a clear vision, and effective IT management endures. Furthermore, there is still a strong requirement for an informed approach to outsourcing, AI, risk, and compliance [105].

Human potential is being enhanced by digital life, which is also upending conventional human activity. Currently, code-driven systems are used by more than half of the world's population, offering referable opportunities as well as previously unheard-of challenges [107]. AI optimizes data backup and disaster recovery solutions to ensure continuous business operations. Even while the essential components of successful technology and IT leadership are always evolving, the need for a solid business strategy, a clear vision, and

effective IT management endures. Furthermore, the necessity of a knowledgeable approach to outsourcing, AI, risk, and compliance is still steadfast [108, 129]. Experts predict that while networked AI will increase human productivity, human autonomy, agency, and capacities will be compromised [109]. When it comes to complex decision-making, learning, reasoning, pattern recognition, visual perception, speech recognition, and language translation, computers can perform better than humans. In addition to saving time, money, and lives, intelligent systems in cities, automobiles, buildings, utilities, agriculture, and commerce may also give

residents a more personalized future [110]. AI has significant potential in healthcare, with applications ranging from improving the quality of life for senior citizens to diagnosing and treating patients. They were particularly excited about the possibility of AI being involved in an all-encompassing public health initiative that would utilize the potentially enormous amounts of data on subjects as varied as diet and individual genomes that may be gathered in the years to come [41]. AI could help bring about much-needed reforms in both official and informal education.



Figure 1: AI and the future of life and working relationship between human and robots [62, 106]

Our culture is changing noticeably as a result of incorporating AI and the Internet of Things into our everyday lives. Artificial intelligence-powered devices will soon be able to take our pulses in medical facilities, and internet merchants will soon be able to customize their product recommendations for each customer. These are only a few of the numerous ways artificial intelligence enhances human life. AI will provide a lot more in the future. As time goes on, an increasing number of companies, nonprofits, and governmental organizations will begin utilizing this revolutionary technology to improve and simplify all facets of human existence [113]. By increasing workplace productivity,

assisting individuals in making better decisions, and providing direct assistance, artificial intelligence (AI) can simplify and speed up processes in the neighborhood, society, nation, and world. AI can help by spotting and fixing problems that people might not be able to find or fix on their own. However, some people may not see the advantages of artificial intelligence because they think it would make people less intellectual and cause them to lose their employment. The speed, accuracy, efficiency, and scalability of artificial intelligence are its greatest benefits [38].



Figure 2: Role of AI in education system [111] and revolution of future education system [112]

The 4IR will have a huge impact on many industries, service sectors, and other areas, making a large amount of the current work inaccessible over the next 25 years. We must have a thorough awareness of how these changes will impact all facets of our lives, including academic and educational institutions [114]. Today's graduates must contend with a world transformed by technology. AI, the internet of things, machine learning, big data, cloud and edge computing, and social media present traditional educational institutions

with a number of benefits and drawbacks. Traditional educational institutions worry about their students' prospects, particularly in regard to jobs, as they prepare for life beyond high school or college. Concepts like "post-work" are beginning to define our era as a result of the profound changes in the world brought about by the pervasive influence of AI-powered modern technology [140]. The abilities required in this era are substantially different from those in the Third Industrial Revolution

because information technology (IT) is now the primary driver. Over the next seven years, the US's artificial intelligence and other smart technology sectors are expected to grow to a value of \$15 trillion. People who have received traditional education but lack the requisite skills will be laid off in large numbers [115]. On the other hand, millions of jobs requiring high-tech and modern skills will be created in the next years [116]. Today, managing the ethical and legal issues becomes

essential to responsible urban development as smart cities emerge. Smart cities can set the stage for a digital future that respects the rights and values of the communities they serve while simultaneously embracing innovation by setting clear legislation, giving data privacy top priority, encouraging openness, and actively involving citizens. The secret to designing smart, inclusive, and individual rights-respecting urban environments is striking a balance between ethical ideals and technical advancement [143].

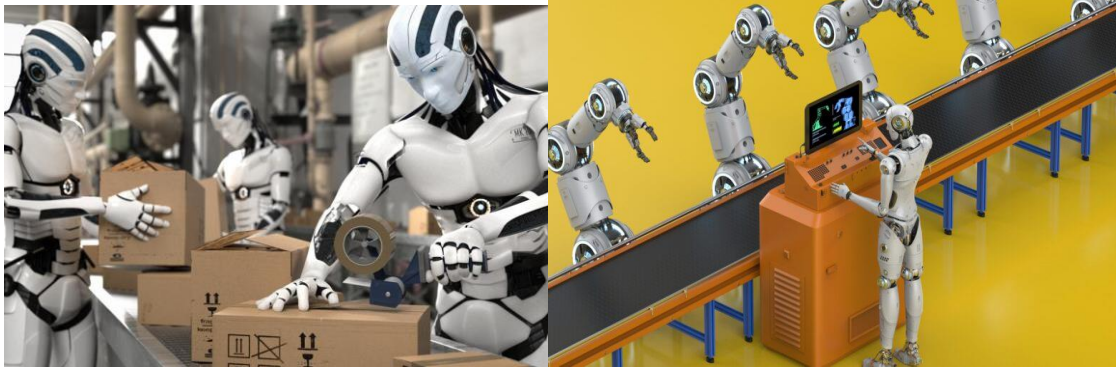


Figure 3: In future robots will work with human [123] and the chronological revolution [124]

4. Smart City is a Global Phenomenon in the Era of Advance Technology

In the era of advance technology, a smart city integrates digital technologies into its networks, services, and infrastructure in order to become more efficient and livable, thereby benefiting residents and businesses. According to the European Commission, a smart city requires: Smart urban transport networks; Improved water supply and waste disposal facilities; More efficient ways to light and heat buildings; More interactive and proactive city administration; Safer public spaces. In other words, a smart and sustainable city uses information and communication technologies (ICT) to improve quality of life, efficiency, and competitiveness, while ensuring that the needs of present and future generations are met. According to the United Nations Economic Commission for Europe (UNECE), the definition of a smart city includes elements such as widespread home connectivity and Wi-Fi in public areas, smart infrastructure, smart meters, the use of open data, and e-government solutions [186]. The Smart City concept has become a key factor in sustainable urban development. It is a compilation of urban planning strategies with lots of far-reaching benefits, including efficient distribution of resources, speed of policy implementations, seamless communication, and a range of environmental benefits. A city's "smartness" is determined using a set of characteristics, includes infrastructure based around technology, environmental initiatives, effective and highly functional public transportation, progressive city plans, people able to live and work within the city using its resources, etc. The success key of a smart city relies on the relationship between the public and private sectors as much of the

work to create and maintain a data-driven environment [63, 186].

A smart city is a technologically advanced metropolitan region that combines explicit information from sensors and numerous electrical strategies (Hossain, 2026c). The information gathered from that data is used to effectively manage resources, assets, and administrations; as a result, that data is used to advance duties throughout the city [17]. This includes data collected from inhabitants, devices, buildings, and resources that is processed and examined in order to track and control AI, web technologies, smart mobile platforms, telecommunications, e-commerce, e-business, and other technologies are all integrated in smart cities and smart businesses [18]. In Figure 4, the fields of utilization pertain to services for citizens and users, such as utilities, e-health, transportation, and structures. Information and communication technologies (ICTs) are used in smart cities to scale services like transportation and utilities for a growing population. Growing urbanization and population growth are igniting a fresh interest in incorporating technology into the planning of municipal services, which is what "smart cities" are all about [19]. In order to detect variables like temperature, moisture, allergens, contaminants, traffic, and power matrix status, smart cities heavily rely on sensors. These parameters' values offer a context that aids a system in comprehending a citizen's condition at any given time [187]. So, smart city encompasses all important element of citizen comfort and safety like, governance, banking, society, public safety, health care, environment, transport, mobility, etc. as shown in figure 4 below.

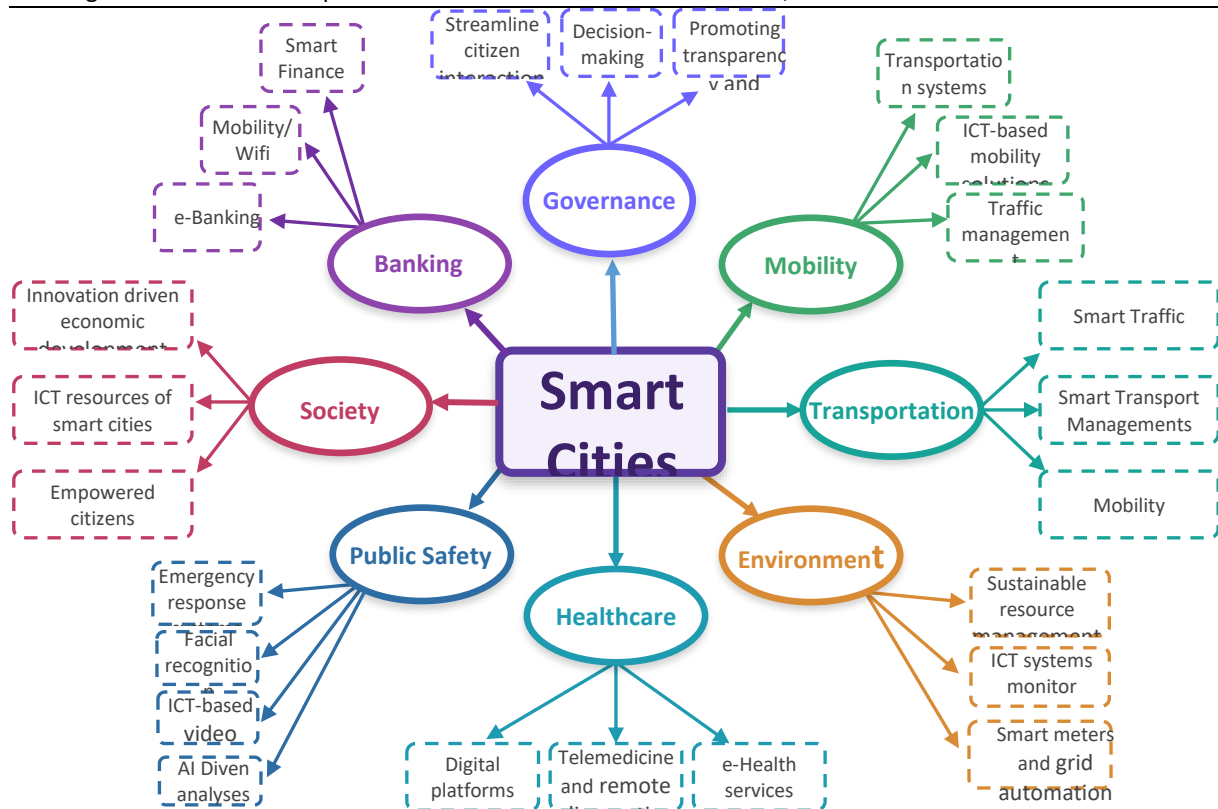


Figure 4. Many useful and efficient utilities and comfort in smart city

The multi-tier design is used in nearly all large, well-managed smart cities in an effort to combine the physical and ICT environments. Smart cities, however, seem to be adopting another intriguing strategy that involves the Internet of Things, artificial intelligence, robots, and automation. This means that many smart cities could use data from sensors, buildings, and users as sensors with their applications without having to install networks or other large-scale infrastructure from scratch. Any or all of the elements of smart cities could be mentioned in potential business models. For example, vendors in smart cities create and implement infrastructure; operators profit from the use of these facilities or the supply of services; service providers profit from the provision of their services, etc. To do this, a smart city might make use of a variety of modern business models [186]. A city can be viewed from a number of perspectives, some of which are already present

while others require design. The dimensions are environment, public transportation, infrastructure, health, education, social welfare, finance, etc. A smart city environment includes parks, buildings, lakes, rivers, and landscapes. Smart city open Data, innovation, synergy, cooperation, and creativity make up the collaboration system [187]. Smart city includes e-government, e-learning, and e-traffic are solutions. Where smart city living: working, recuperating, and having fun. However, smart city components like smart infrastructure, smart governance, and smart mobility, smart transport, smart healthcare, smart education, etc. and those work together to improve city life with comfort, security, and safety and that has been shown in figure 5 below. These elements use digital and smart technology, data, and connectivity to manage resources well with efficiency and optimization.

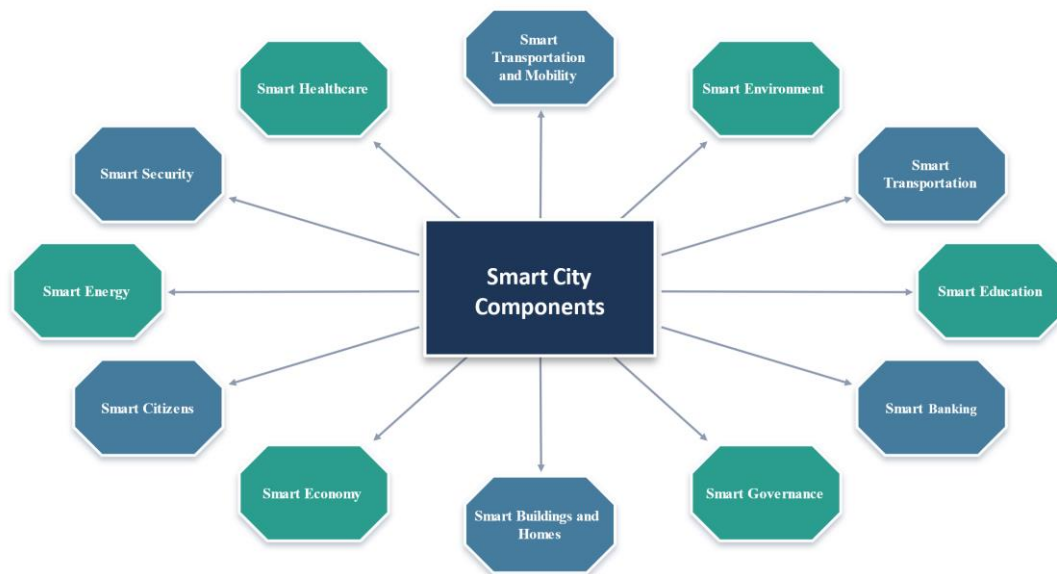


Figure 5: Components of smart city to manage resources effectively

The interactions between the different disciplines in a smart city offer the greatest potential for value creation. Additionally, services made possible by technology should be mentioned while discussing smart cities. People and their needs are frequently disregarded in this situation. In figure 6 provides a visual representation of the importance of the value of people in a smart city. It is important to keep in mind that a smart city is built for the people, not for its own purpose. It is now necessary to connect disciplines and sectors that did not previously interact closely in a way that adds value. Smart city initiatives are frequently approached solely from a technological standpoint. Nonetheless, it is crucial to address a number of other non-technological factors, including organizational settings, societal culture, and the culture of city management departments (viz. municipalities, corporations, district councils etc.). As cities grow, smart solutions are essential to handle population density, moving from conceptual ideas to, in some regions, highly connected urban environments. While Western cities often focus on retrofitting existing infrastructure with smart solutions, other regions may focus on new, purpose-built smart developments [120, 134]. Smart Cities make life easier and better for those who live and work there by utilizing technology to enhance urban administration. They reduce their environmental impact by making the best use of natural resources. More precisely, sensors gather information from various urban locations, including hospitals, law enforcement, waste management, traffic, transit systems, and air quality. One of the Smart Cities of Europe is Barcelona. There are many different applications and services for smart city solutions. They can provide safer public areas, more efficient transportation networks, just-in-time waste management, better-balanced and less wasteful water supplies, and efficient building heating and lighting. All of this may sound futuristic, but many of the cities where we live have already adopted some clever solutions, like telemedicine, intelligent traffic signals, ride-hailing, emergency response

optimization, and municipal water leak monitoring [188].

Smart systems are being adopted by city planners and authorities at an increasing rate due to the numerous issues posed by rising urbanization rates. Over 60% of the world's energy is consumed in cities, which also produce 70% of its CO₂ emissions. Reducing the footprint of big cities is crucial, as most governments have promised to cut national emissions. Another contributing cause is declining air quality, which results in health issues and restricted access to clean water. Perennial traffic and overwhelming trash management have long been serious problems that are getting worse. According to the World Economic Forum, the pace of urbanization worldwide is predicted to increase from 56.2 percent in 2021 to 70 percent by 2050. By that time, an additional 300 million people are predicted to live in cities in China and 400 million in India alone. North America's current high rate of urbanization (83.6%) is expected to rise even further [186]. A smart city is built on the foundation of 5G technology. In contrast to 4G, 5G is ten times faster, has low latency (i.e., there is only a slight delay of 1 to 1,000 milliseconds before a data transfer begins following an instruction), and allows for the connection of millions of devices and sensors within a one-kilometer square area, whereas 4G only allows for a limited number of connections. Various 5G-related technologies are necessary for the development of a sophisticated Smart City. A city, implements several Internet of Things sensors to supervise traffic. Once the data has been collected, it is transmitted across the 5G network. During this process, blockchain technology can facilitate secure data flow. Traffic authorities employ edge computing analytics to assess data in real-time in order to forecast traffic flows and devise feasible congestion management strategies, such as rerouting traffic or altering traffic signal sequences.

Massive quantities of Big Data can be efficiently processed by AI. After that, the dataset is securely stored on a cloud server for future study and utilization

[188]. There are a number of players and aspects involved in bringing smart cities into reality. *In a smart city manufacturer of 4G, 5G, and WIFI equipment and service providers meet the growing need for dependable high-speed connectivity by sending sensor data over their networks. High-capacity telecom towers and data centers that support edge computing are examples of communications infrastructure. Agin, manufacturers of semiconductors that provide sensors for data collection. Software firms that control devices and sensors and*

offer intelligent solutions. In a smart city business that use cloud storage to store the encrypted data. On the other hand, cybersecurity firms that defend systems against hackers and attacks during the data collection, transport, analysis, and storage process. Businesses that offer building management solutions to maximize facility operations, such as waste management, energy, water, and energy consumption. Additionally, the businesses that facilitate the transition to electric cars and smart grids.

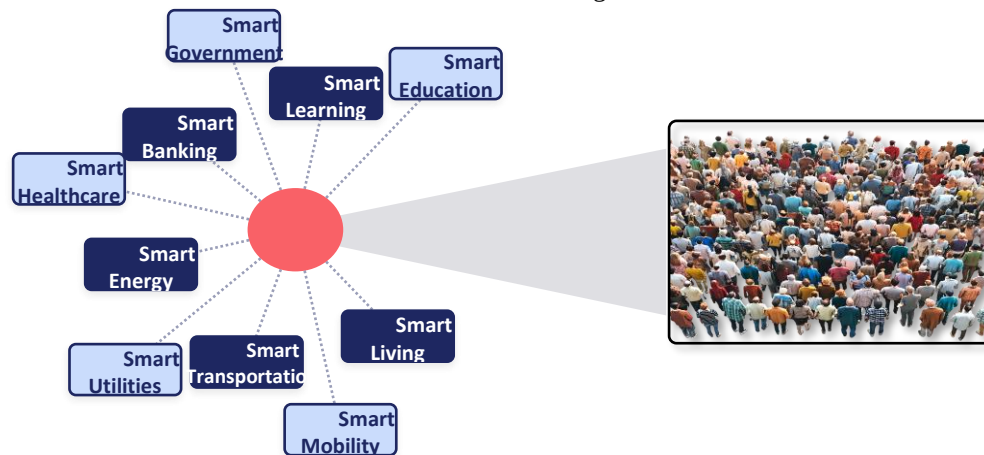


Figure 6: Significance of the Value for People in a Smart City

The interactions between the different disciplines in a smart city offer the greatest potential for value creation. Additionally, services made possible by technology should be mentioned while discussing smart cities. People and their needs are frequently disregarded in this situation. Figure 3 provides a visual representation of the importance of the value of people in a smart city [74]. It is important to keep in mind that a smart city is built for the people, not for its own purpose. It is now necessary to connect disciplines and sectors that did not previously interact closely in a way that adds value. Smart city initiatives are frequently approached solely from a technological standpoint. Nonetheless, it is crucial to address a number of other non-technological factors, including organizational settings, societal culture, and the culture of city management departments (viz. municipalities, corporations, district councils etc.). As cities grow, smart solutions are essential to handle population density, moving from conceptual ideas to, in some regions, highly connected urban environments. While Western cities often focus on retrofitting existing infrastructure with smart solutions, other regions may focus on new, purpose-built smart developments [96]. Smart Cities make life easier and better for those who live and work there by utilizing technology to enhance urban administration. They reduce their environmental impact by making the best use of natural resources. More precisely, sensors gather information from various urban locations, including hospitals, law enforcement, waste management, traffic, transit systems, and air quality.

The information is kept, examined, and applied to real-time problem solving. "Barcelona has been in the forefront of testing the internet of things with a municipal network of 500 km of optical fiber, free WiFi piped via street lighting, and sensors to monitor air quality,

parking places, and even rubbish bins," the Financial Times boasts. One of the Smart Cities of Europe is Barcelona. There are many different applications and services for smart city solutions. They can provide safer public areas, more efficient transportation networks, just-in-time waste management, better-balanced and less wasteful water supplies, and efficient building heating and lighting [75]. All of this may sound futuristic, but many of the cities where we live have already adopted some clever solutions, like telemedicine, intelligent traffic signals, ride-hailing, emergency response optimization, and municipal water leak monitoring. Smart systems are being adopted by city planners and authorities at an increasing rate due to the numerous issues posed by rising urbanization rates. Over 60% of the world's energy is consumed in cities, which also produce 70% of its CO₂ emissions. Reducing the footprint of big cities is crucial, as most governments have promised to cut national emissions. Another contributing cause is declining air quality, which results in health issues and restricted access to clean water. Perennial traffic and overwhelming trash management have long been serious problems that are getting worse. According to the World Economic Forum, the pace of urbanization worldwide is predicted to increase from 56.2 percent in 2021 to 70 percent by 2050 [186, 187]. By that time, an additional 300 million people are predicted to live in cities in China and 400 million in India alone. North America's current high rate of urbanization (83.6%) is expected to rise even further.

5. Smart Cities and Business in the Era of Advance Technology

A smart city is neither a neutral, self-sufficient benefit nor an objective in and of itself. While a smart city is a place that supports innovation and businesses, reducing environmental impact will also improve the

quality of life for inhabitants and employees. This support comes in the form of a number of services, including: e-Government, which facilitates communication between businesses and the appropriate authorities; efficient transportation, which enables employees to get to work quickly and safely; competitive pricing and performance of telecommunications media for businesses operating abroad; local cloud services, which can foster confidence regarding data security; and a dependable power supply, which is a crucial component of business continuity. At the very least, cheap energy is a competitive factor. Today, software development is a common area where innovation is realized. Information is the starting point for new applications. The software developer will have the chance to incorporate the data into new applications if the city makes it available for free in a machine-readable format. Open Data is the term for this accessibility in urban areas. Other "Open" movements, including open source, open hardware, open content, and open access, share the same objectives as the Open Data movement. Compared to product or process innovation, business model innovation yields higher profits. More than half of executives think that new business models are more advantageous than new products and services, which smart cities use to reach their full potential and take advantage of strategic economic prospects in their future undertakings (University of Sankt Gallen, Competence Centre for Business Models). Nowadays, the majority of sectors acknowledge—sometimes unwittingly—that digitalization creates new business models. We should be persuaded that discussing business models is at least as crucial as discussing projects and business cases, which are the most crucial aspects of developing smart cities. Like an Innovative Triangle, a smart city business model flips the conventional municipal business model on its head.

Despite its recent popularity as an urban planning model in both the theoretical and policy arenas, there is a startling lack of consensus over the definition of the term "smart city." The broad utilization of internet and communications technology (ICT) infrastructure to foster urban growth through improved service delivery, environmentally friendly development, and the building of social capital is frequently referred to as a smart city. Nevertheless, a significant percentage of the literature on smart cities is framed from a single perspective, with a primary emphasis on the technological, environmental, or social components. The governance aspect is neglected, and more comprehensive definitions have just recently emerged. The six attributes Hin and Subramaniam (2012) highlighted were developed by Giffinger et al. (2007) to evaluate the "smartness" of medium-sized cities throughout Europe: people, living, economy, mobility, environment, and governance [149, 150]. Townsend's "smart city" paradigm, which is similarly comprehensive, illustrates the convergence of urbanization with pervasive digital technology. This paradigm is characterized by four key "intelligent" drivers: markets, design and planning, governance, and the commons (Institute for the Future, 2010). This smart city perspective acknowledges the extent to which ICT can impact urban human relationships, as opposed to

segmenting the city (the model of six characteristics recalls the heritage of department-led municipal governance). The smart city distinguishes itself from its predecessors by emphasizing the specific tools that will facilitate the resolution of urban issues, such as embedded systems—sensor technologies, cell phones, and smart meters—and big data—vast and complex databases that are employed to analyze urban life [148]. The physical smart city is supported by the following essential ICTs: public interfaces, cloud computing, open data infrastructures, smart personal gadgets, and widespread internet access [151, 186].

Existing Smart City Business Models. Local and national governments, utility companies, ICT firms, non-governmental organizations (NGOs), international organizations, chambers and industry associations, universities, businesses, and citizens are just a few of the many stakeholders in smart cities. Value offers for local clients could therefore be created by each stakeholder (or in groups). Therefore, it is possible to worry that every smart city service or product adheres to or ought to adhere to a modern or creative business strategy. Even in web-based scenarios, modern business models exist, and the city functions as a direct supplier of content and services to its residents and businesses. However, different smart city business models have been described. The Municipality uses smart cities to draw tourists, residents, and investments, even if business models are not meant to be seen in public organization cases (such as Masdar, Gdansk, etc.). Additionally, some of the cases under investigation involve new business models, like the South Korean "city-in-a-box," which is copied in other Asian cases; the Dubai/Malta/Kochi Smart City, which capitalizes on the private investments of the businesses situated in the business parks; and Taipei Eco-city, which refers to a business model for sustainable growth. Representatives from two kinds of modern business models were assigned to these studies: 1. E-service business model [158] and 2. ICT network ownership and commercial enterprise transparency [159]. Every service group was regarded as being provided by a separate provider under the e-service business model (or groups of stakeholders). The network was regarded as the primary resource for the value proposition when a pattern was assigned. In doing so, the network owner provides value to both individuals and businesses. The application of business model patterns in situations where network-related business models were inapplicable is a significant result of this assignment procedure. Broadband, smart, digital, ubiquitous, and eco-cities are the circumstances where the unbundling pattern is most prevalent, and more precisely, in all cases where the smart city has access to and uses essential resources. This is a logical result given that each of these city shapes needs a distinct kind of infrastructure to provide services, such as networks, grids, sensors, etc. The unbundling pattern persists even if these facilities are rented for the provision of services. When the Internet of Things is used as the primary resource, things change, leading to the development of related IoT business models. However, current smart cities across many nations have not yet capitalized on the Internet of Things, leaving room for

start-ups and other suppliers to increase the value of their clients [160].

Smart Cities and Economy. In the era of advance technology, smart cities drive economic growth and development by integrating IoT, AI, ML, big data, robotic, automation and data analytics to improve efficiency and comfort, fostering innovation, and enhancing competitiveness. Which will also create jobs in tech sectors, attract investment, and optimize urban infrastructure like transport, energy, health, finance, industry as well as boosting productivity distinctly and reducing operational costs for businesses. According to the smart city's economic dimension, the concept can be used to boost the urban economy. Specifically, it is anticipated that the smart city will "keep employment and fight against poverty through employment generation, support the innovative economy and wealth of cities" [148]. There is a wealth of research on regional competitive advantage and the traits that, in addition to technological prowess, make places like Silicon Valley more resilient to failure. These traits include a culture of openness between businesses and the institutions in a region and collective innovation [152]. The "presence of a creative class, the quality of and dedicated attention to the urban environment, the level of education, multimodal accessibility, and the use of ICTs for public administration" [153] are all positively correlated with urban wealth. These components, which correspond with the six-part conception of the smart city—smart people, living (lifestyle), economy, mobility, environment, and governance—are viewed as the cornerstone of a new strategic agenda for European cities.

Smart city projects generate employment in IT, engineering, and data management, and attract a skilled workforce. Data-driven, connected environments are highly attractive to corporations, fostering innovation hubs and enhancing local GDP growth. Intelligence agencies and businesses will continue to want services from organizations like "Recorded Future" as the Internet of Things grows in scale and reach and generates even more data. According to Techopedia, the Internet of Things is a "computing concept that describes a future where every day physical items will be connected to the Internet and be able to identify themselves to other devices." In a 2011 report, Cisco describes the explosive growth in the number of internet-connected gadgets in recent years: There were 500 million Internet-connected devices and about 6.3 billion people on the earth in 2003. In 2010, there were 12.5 billion devices linked to the Internet due to the explosive expansion of smartphones and tablet PCs. According to Cisco IBSG, there will be 25 billion Internet-connected devices by 2015 and 50 billion by 2020. Since over half of the world's population currently resides in cities, this trend is expected to continue, meaning that the smart city concept will have an impact on billions of people worldwide. Singapore is expected to become the first smart nation in the world, and India is leading the charge with plans to construct 100 smart cities over the next several years. However, smart cities are not limited to Asia; among the cities participating in IBM's "smarter cities challenge" are Glasgow, Rio de Janeiro, New Orleans, and Cape Town.

6. Prospects in Smart Cities

In the era of advance technology, we may be able to live and work in safer, quicker, and more convenient ways thanks to smart cities. We think long-term, secular growth will benefit the sectors and businesses that can provide Smart City solutions. The Internet of Things (IoT) is a key driver of efficiency and innovation in the age of linked technology and smart cities. However, the essential relevance of cybersecurity cannot be understated given the growth of smart cities and the proliferation of connected devices. In the context of IoT, AI, and smart cities, cybersecurity is crucial, exploring potential threats and defining best practices to protect infrastructure and data. A smart city is an urban model that makes use of technology, human resources, and governance to enhance social inclusion, efficiency, and sustainability—all of which are regarded as objectives for cities of the future [23, 27]. Digital technology is used by smart cities to provide services and gather data. IoT and smart technology integration offers previously unheard-of possibilities for increased productivity, sustainability, and quality of life as smart cities develop. The advantages are numerous, ranging from smart grids improving energy management to connected gadgets optimizing traffic flow. However, new and complex cybersecurity concerns are also made possible by this interconnectedness. The transition to smart cities calls for a thorough reorganization of municipal operations and management, focusing on citizen involvement and public service delivery strategies. Planning, management, and operational procedures must change in order to become a smart city. In order to optimize urban services and identify areas for development, this data can be analyzed [54]. "Smart cities" were conceptualized as a result of the fast use of information and communication technology in global cities [55]. The four elements that Deakin and Al Waer identify as contributing to the definition of a smart city are the territorializing of practices that bring ICT and people together to enhance innovation and knowledge, the integration of ICT into living and working environments, the use of ICT in government systems, and the use of a wide range of electronic and digital technologies [56]. The very aspects that make smart cities intelligent and responsive—such as real-time data interchange and remote-control capabilities—can be misused if they are not appropriately protected [28].

In the era of advance technology, a smart city consists of three layers: an innovation foundation that includes sensors and cell phones connected to rapid communication organizations, apps that turn raw data into knowledge, and use by urban communities and society at large. It is entirely anticipated that the growing popularity of 5G, the widespread adoption of cellphones, and the growing acceptance of IoT will accelerate and elevate smart city developments. This opens up new avenues for creativity to transform urban neighborhoods. The local community has undoubtedly played a significant role in improving inhabitants' well-being as a result of the pandemic. By facilitating diagnosis and treatment as well as preventive self-care, intelligent advancements can reduce the strain on medical services' natural systems. This shifts the focus from medical

treatment that is individual-focused to a local area approach. People and their families can receive medical care that is tailored to them based on information analysis. Given that smart health is a subset of e-health, The Intramuros of the acknowledged smart city is comparable to s-health. In any case, s-health and m-health are distinct from one another. For instance, it is possible that the recognized key correspondence in s-health is not transferable. In practice, it may include dispersed outfoxed sensors in a significant number of cases. In spite of pollution to which the patient is sensitive, the patient receives information or information from an interactive information pole to check the amount of dust and residue. Additionally, the information helps individuals avoid areas that may be dangerous for their medical issues. The information shaft aids in providing the patient with guidance on the most effective path to reach a goal [98]. Therefore, every resident of a smart city greatly benefits from smart healthcare.

Every city's infrastructure serves as its foundation, and development can improve current connections in a variety of ways, such as by implementing green buildings, waste management programs, and traffic regulations. For instance, the goal of Singapore's Green Mark certification scheme is currently to make 80 percent of the city's buildings green. By 2028, according to Gartner, there will be several billion connected IoT devices in business-savvy buildings, driven by broadcast communications systems, 5G, and high-efficiency Wi-Fi in addition to smart utilities like water, garbage, and electricity. Platform assessment frameworks, IoT sensors for wastewater and obstruction detection, stopping sensor applications, lighting sensors, and fire detection frameworks are examples of moving innovations. Future metropolitan areas may become more conservative and close-knit as a result of this [126]. Therefore, every resident of a smart city greatly benefits from smart infrastructure. Smart cities, thus, elevate their tenants' voices. While local area network platforms allow users to collaborate and share resources, applications allow inhabitants to temporarily report local problems. With increased investment and transparency, metropolitan areas are developing into cooperative settings. Metropolitan cities are getting ready to be more human-focused and multidirectional for the government, associations, and inhabitants alike thanks to open information and new advancements [130].

In addition to investing in sustainable energy, cities can employ development to monitor and improve energy use in real time. This involves the use of ethical and sustainable materials, carbon-friendly and resource-efficient strategies, frameworks powered by renewable energy sources, and cutting-edge innovations that adapt to their needs. According to Deloitte Insights, the energy transformation contributes to the construction of a circular economy by decentralizing the production of energy from limitless sources. This is getting ready for urban areas to become energy self-sufficient [163]. Living in a smart city with smart energy is always pleasant and environmentally friendly. With increased use by law enforcement, biometrics, facial recognition, smart cameras, video, and other forms of smart surveillance have all been gaining some traction.

These developments help cities look into crime prediction, reduce reaction times, and identify examples and patterns in crime data. However, inhabitants' security, opportunity, and shared freedoms remain of utmost importance, even when new advancements provide enticing options. Urban areas need to exercise caution, in order to investigate the ethical and practical implications of using such technologies, and to avoid repressing specific regions or dividing groups [54]. Therefore, a well-maintained smart safety system may help keep an eye on crime, manage it, and promote peaceful life in smart cities. Urban planning faces a significant challenge in creating intelligent, cost-effective, and resilient urban communities due to environmental change and climatic circumstances. A green urban plan, motivated by decarbonization goals, combines 15-minute city models with reasonable area methods where the majority of daily needs are accessible by bicycle or foot [164].

In the era of advance technology, biodiversity is increased by vertical tiny forests and smart farms for plant development. New and sustainable alternatives, such as floating cities, islands, ranches, schools, and riverbanks, are gaining attention worldwide as ocean levels rise [124, 163]. In order to enable people and other forms of transportation to function in more effective, robust, and maintainable ways, smart mobility uses innovation. Developments in metropolitan portability revolve around improved infrastructure, adaptability as an administration, micro mobility, operational arrangements, and zero-emission transportation. Eco-friendly urban mobility is being made possible by autonomous vehicles, high-level driving, and intelligent traffic management. Innovative vehicle options, including as water taxis, robot axes, and the hyperloop, also find uses in incredibly adaptable cities [113]. In a smart city, smart transportation efficiently empowers all residents. Smart city players are compelled by the e-governance pattern to make their decisions and administrations more transparent, palatable, collaborative, and uncomplicated. Blockchain and IoT-based agreements are used by startups to do this, keeping track of all partners for the dynamic exchange. Advanced visas, web-based voting, and robust information security tools are examples of computerized administrations that encourage resident collaboration and contribute to the growth of e-majority rule government. Additionally, local e-profession centers, online retraining programs, and digitalization of corporate functions like burden filing and permitting contribute to financial growth and an innovative business environment [161]. In a smart city, e-governance guarantees citizens' satisfaction, accountability, and openness. Waste production rises in tandem with the continuous development of metropolitan populations and purchasing culture. IoT sensors are used by sophisticated and intelligent waste management systems to accurately track waste pickup, provide residents with usage advice, and incentivize them with financial benefits. Reusing e-waste also allows people to exchange equipment for cash. Smart containers manage the quantity of waste and sort uncategorized rubbish [115]. By avoiding human interaction, artificial intelligence recycling robots precisely identify the types of

materials during waste sorting, increasing total productivity and large efficiency. When combined, emerging waste management strategies lessen the impact of economic activity on the environment [162]. Effective trash management keeps the city clean and healthy for its residents.

7. Divergent Aspect of Smart City Development

With its early adoption of a sustainable, environmentally friendly agenda and emphasis on public transportation and urban infrastructure, Europe has long led the way in Smart City projects, despite having many old cities with legacy infrastructure systems in the era of advance technology. Intramodality, which combines several public transportation options into a seamless travel experience, has been a priority of European transport policy, according to 2018 McKinsey research. Rapid technical advancement has also fueled electronic services like ticketing systems. One characteristic of Smart Cities in the West is that development is primarily bottom-up, with individuals and the private sector actively involved in creating projects to enhance quality of life, promote economic growth, and protect the environment. In 2018, for example, the federal government of Canada invited about 200 communities nationwide to enter a competition wherein technological advancements may be used to improve people's quality of life. In order to identify demands and give city officials a plan for creating future traffic and public transportation infrastructure, the Intelligent Cities program held resident workshops. There must be a cultural change in the way cities are run and controlled in addition to the participation and input of local residents [15]. Additionally, municipal technology platforms must be more accessible and not kept in disconnected "silos" that are unable to work together. More than 40 local departments were operating on disparate, disjointed technology platforms when Los Angeles Mayor Eric Garcetti investigated the implementation of Smart City solutions.

In order to compile approximately 500 datasets from the city's departments as well as those from the county, state, and federal governments, Geo Hub was established in 2016. Los Angeles was able to manage resources and make better decisions thanks to the information that GeoHub uncovered about the city's infrastructure and public safety needs. A number of silo-type models were dismantled in Barcelona, including those in which networks lacked communication, users were bound by rigid contracts, or service delivery was contracted out to big operators with no government control over the collection or use of resident data. Since then, the government has taken over accountability for such data in order to protect privacy. With an emphasis on small, local businesses, the procurement of services was also made transparent. In the meantime, Asia has seen a boom in Smart City initiatives in recent years. The creation of smart cities is typically top-down in nations with powerful central governments, like China or Singapore, where the government creates rules and allocates funds. Usually, the emphasis is on enhancing urban governing capabilities and expanding infrastructure. Smart Cities are highly developed areas where many services are owned by the public sector. These

areas include waste management, water, power, transportation, and telecommunications. A fully functional Smart City must have this smooth data and technology flow [175]. Large heritage Western cities might need a few years to get to this level of Smart City development. However, there is a need for improvement, and both in the East and the West, more clever ideas are probably in store.

In Chicago, infrastructure investment, economic development, and community involvement are the three primary application areas for open data and smart city initiatives. To achieve gigabit speed over an open network, the city is investing in a new open fiber-optic ring. The city intends to support a more vibrant and competitive marketplace by making investments in open infrastructure. The city expects that reasonable pricing and high-speed broadband would entice digital technology enterprises to establish or relocate in Chicago. The unlicensed radio spectrum in Chicago City is exhausted. It is currently collaborating with the Federal Communications Commission on spectrum to dynamically share spectrum allotted for public safety so that it can be utilized for cell phones, tiny cells, etc. when not in use. The goal of the Smart Chicago Sustainable Broadband Adoption program is to promote economic growth in five underprivileged Chicago areas. More than 11,000 residents, 500 small enterprises, and non-profit organizations can get computers and training opportunities through the broadband awareness and adoption program. Since companies and applications are developed on their open data platforms, Chicago sees an economic growth justification for data accessibility. [172]. One of Chicago's top priorities is facilitating a market of interested parties and coordinating the demands of the public, business, and community sectors. In order to boost the diversity of the Chicago technology industry workforce, the mayor gathered a group of specialists known as the Technology Diversity Council to create policy suggestions. It could be necessary to work with other departments on some recommendations. The Smart Chicago Collaborative is responsible for a large portion of Chicago's community engagement efforts [173]. Chicago's investment in smart cities has been measured using a mixed-method approach. Cost savings are a major indicator for the city. For instance, by switching to cloud-based productivity tools, the city was able to save \$400,000. In a similar vein, the Windy-Grid application aims to reduce costs by providing information about how the city runs in order to facilitate more effective city operations and guide long-term policy decisions. However, measuring this is a major problem for Chicago.

Singapore has created and implemented some of the most cutting-edge urban solutions in the world, ranging from energy management and water treatment to public housing and transportation. The city has successfully transformed the difficulties of urban development into lucrative business opportunities because to progressive leadership and a strong dedication to sustainable development. Other cities have successfully implemented and duplicated some of those solutions. Singapore is already considered a "smart" city, but the government is constantly looking for ways to make it

smarter. The focus on "life-ability," or building a city where people are glad to live, the integration of policies, and the wise use of ICT are important components of this strategy. Singapore is a highly developed nation that depends on advanced technology, a highly skilled labor force, high productivity, and sound economic policies implemented by the government. Its emphasis is on innovation as a growth driver, much like the Netherlands. Thus, it makes significant R&D investments. The foundation of Singapore's development over the past few decades has been the attraction of foreign direct investment [186]. The Economic Development Board (EDB), which oversees foreign direct investment, offers incentive schemes to entice businesses in particular industries. Businesses with significant R&D expenditures, advanced technology, and high productivity are of primary interest to the EDB. Foreign design and architecture also pique Singapore's curiosity. Singapore is constantly searching for talent [174]. To draw gifted students and academics from the area and beyond, it offers unique programs.

In the era of advance technology smart cities are rapidly evolving concept-transforming urban developments. Smart cities use advanced technologies and data analytics to improve the quality of life for their citizens, increase the efficiency of infrastructure and services, and promote sustainable economic growth. The Sustainability Magazine ranking reveals the best integral technology and sustainability strategies after assessing their housing constraints and identifying their key business partners [178]. In the report it has been evaluated that Helsinki of Finland occupies the top spot for its citizen-focused approach and its digital project Helsinki 3D+, in collaboration with Nokia. Dubai of UAE follows, an example of technological ambition with its Core42 autonomous taxis and AI-based applications as its private sector ally, although more than 40% of its residential properties are owned by non-residents. And Seoul of South Korea, which combines connectivity and smart transportation (Samsung SDS), despite a gap between central and peripheral prices, forcing the displacement of the younger population. However, London of UK with Arup serving as the company in its joint venture, prioritizing open data, AI, and social participation with the support of digital infrastructure, while facing traffic congestion and high prices. Ahead of New York of USA (IBM) for wireless management, is Tokyo of Japan (Hitachi) for its capacity to detect and react to natural disasters, Copenhagen of Denmark (Siemens) for its public transport, Amsterdam of Netherlands (Philips) for energy efficiency, Singapore (ST Engineering) for its urban mobility, and Barcelona of Spain (Cisco) for its high level of digital democracy.

8. Challenges in Smart Cities

AI creates prospects for more intelligent healthcare through the development of smart cities. Concurrently, the collection and exchange of information is necessary for these developments. Information sharing is often hampered by security concerns. However, the topics that come up most frequently when discussing the limits of incorporating progress into medical services are security and protection. There are

three types of privacy-ensuring information withdrawal mechanisms being investigated that could provide residents of smart cities with confirmation. First, by making the information difficult to understand, it can be "camouflaged" while being collected. Second, ensuring the information's obscurity is a goal of protection-saving information mining in cases where the initially collected data will be sent to external parties [86]. This is a validation that certain arbitrary customers' identifiable attributes are identical to those of essentially k-1 different clients. Strategies such as removing mild attributes, increasing the range of touchy traits, or introducing fake information to confuse the honest qualities are some ways to achieve K-anonymity [171]. allowing sensitive information to be "concealed in the group." Due to multifunctional information, changing identifiers periodically is an alternative to downgrading a single, consistent identification for each client. Long-term and spatial client tracking becomes challenging as a result of this shift. When a client enters a space with k-1 other clients, it's the perfect time to alter the identification. Thus, it won't be possible to rapidly connect old and new IDs. Third, the outcome of information mining computations can be modified to prevent sensitive data from leaking. Once more, a gathering calculation's reasonability can be sufficiently reduced to fulfill execution constraints while limiting the risk of being used to identify individuals. Regardless of the combination of approaches used, it is crucial that all parties involved—city planners, strategy developers, and tech providers—agree on security measures and illustrate to city residents the potentially sensitive information sharing that could occur with smart city developments [164].

Both usability and accessibility A common theme in smart city initiatives is healthcare. However, the cost currently stands in the way of the inevitable adoption of advancements that can be used at the municipal and individual level. Long-term cost savings for the city and its residents can be achieved by incorporating technology into large medical care. In any case, the cost of the real development may prevent networks from adopting the innovation for a while [87]. There are several ways that smart cities make use of information and communications technologies. The goal of smart city platforms is to develop appropriate and play smart objects that can be delivered anywhere and blend in with their surroundings. Along with design observation, climate observation, security, and intelligent transportation, the things should aid in assessing well-being [20]. A Smart City needs "shrewd" citizens who actively participate in and effectively navigate new developments if it is to actually exist and thrive. Redetection of the smart city paradigm should be a part of the execution cycle of any new, comprehensive technology project. ember highlighting the advantages of the local area. This should be possible through a series of in-person civil focus-style gatherings, email campaigns to recruit voters, and an online preparation phase that stays up to date with the latest election results. Local communities are more willing to take advantage of developments and encourage others to do the same when they wish to influence the alternatives that affect daily life and are being

passed on in a clever and pragmatic way. This is essential to the success of a Smart City [21]. Notwithstanding the wealthy and technologically advanced, it is crucial that Smart City orchestration incorporates the prospect, all else being equal. Development should always aim to bring people together rather than further dividing them based on factors like income or educational attainment [22]. Examining these networks in relation to the various topics covered in this article will improve the overall result of a solution outside the domain of knowledgeable clients [24, 25].

Smart cities integrate multiple domains, including transportation, energy, health, education, agriculture, business, social, banking, economy and governance, to create an interconnected and intelligent urban environment. The integration of smart technology and data-driven solutions in smart cities has all potential to revolutionize urban living by providing citizens with personalized and accessible services. However, the implementation also presents challenges, including data privacy concerns, unequal access to technology, and the need for collaboration across private, public, and government sectors [177]. Even though technology has a lot of appeal, becoming a Smart City will not be easy. Because it's simpler to start from a relatively fresh slate than to upgrade outdated infrastructures, legacy cities face considerable challenges. In this sense, newer cities in Asia and the Middle East have a clear advantage. Another encumbrance that can make the adoption of some clever solutions more difficult is very big populations. New technologies can be adopted more quickly in smaller cities like Zurich (400,000) or Helsinki (1.3 million). In the 2020 IMD Smart City Index, they came in second and third place worldwide, respectively. The following are examples of typical points of vulnerability:

- **Data breaches and privacy issues:** Cybercriminals are drawn to the enormous volumes of data produced by IoT devices or AI systems. Individual privacy is seriously threatened by unauthorized access to sensitive data, which can result in identity theft or other nefarious actions [29].

- **Infrastructure Vulnerabilities:** Public services, electricity grids, and transportation networks are all susceptible to cyberattacks. The functioning of cities and public safety may be significantly impacted by disruptions in these vital services [50].

- **Device Manipulation:** Malicious acts, such as interfering with communication networks or changing data, can be carried out by compromised IoT devices or AI systems. The dependability and integrity of smart city operations are at stake as a result [51].

- **Denial of Service (DoS) Attacks:** Critical services can be interrupted by flooding systems with so

much traffic that they fail. This may result in grid outages, traffic jams, or compromised emergency response systems in the context of smart cities [52].

- **Risks of Surveillance Systems:** Smart cities and security technologies coexist. However, having inexperienced staff and ineffective processes can be risky and lead to cyberattacks even with the strongest technology defenses. In the event of a cyberattack, security and emergency alarm systems are the most vulnerable and might have the most effects.

- **Device Hijack:** Because a smart city's infrastructure is made up of millions of devices, attackers often try to take over a device in order to obtain control. Because the item has continued to function as intended, users might not be aware that someone has taken control of it. Once in control, a hacker can take advantage of other networked devices. For example, they might utilize smart meters to steal electricity from a municipality or employ ransomware to threaten a city's energy management system [146].

Deakin defines a smart city as one that utilizes ICT to meet the needs of the market (i.e., city people) through community participation [57]. As an alternative to broad notions that are difficult to define, investigations of smart city projects could be employed to elucidate the concept of smart cities [58]. Data is collected from individuals, devices, structures, or cameras. Smart cities are employed in a variety of applications, including traffic and transportation systems, power plants, utilities, urban forestry, water supply networks, trash disposal, criminal investigations, information systems, schools, libraries, hospitals, and other community services [30]. The cornerstone of a smart city is the integration of people, technology, and processes, which connect and interact across industries such as infrastructure, healthcare, transportation, and education [31]. The monitoring, analysis, planning, and governing procedures of their local governments are the defining characteristics of smart cities. In a smart city, the interchange of data involves businesses, people, and other parties who stand to benefit from its utilization [32]. Outdoor lighting, public transportation, and visual surveillance were the three primary sources of expenditures associated with smart cities as of 2022 [34]. In order to optimize city services and foster a relationship with their residents, smart cities integrate ICT (information and communication technologies) and IOT-connected devices [35]. ICT has the potential to enhance the quality, performance, and interactivity of urban services, as well as to reduce resource consumption and costs, and to enhance communication between the public and the government. Smart city applications regulate urban flows and facilitate real-time responses [36].



Figure 7: Proper guidance [125] and developing relation is the prime task of future leaders [126]

Compared to a city that has a traditional "transactional" relationship with its residents, a smart city might be more equipped to handle difficulties. However, there are numerous ways to interpret the phrase [35]. Smart city technology has already been used in a number of cities. Initiatives for smart cities have drawn criticism for being corporate-driven [37], poorly tailored to the requirements of locals [39], generally unsuccessful, and a step toward totalitarian surveillance [40]. Cybersecurity must be a key factor in the transition to smarter and more connected urban environments [26]. Although there are many advantages to IoT and smart cities, there is also a duty to protect inhabitants' safety, privacy, and general well-being [41]. Smart cities can create a secure foundation for the future and one where innovation and resilience go hand in hand by implementing preventive measures, adopting strong cybersecurity practices, and cultivating a culture of awareness. This will guarantee a connected urban landscape that is not only intelligent but also safe and reliable [46]. IoT, AI, and smart city cybersecurity best practices:

- **Encryption and Secure Communication:** Use strong encryption techniques to protect information sent between networks and devices. This guarantees that the information is kept private even in the event that it is intercepted [42].

- **Regular Software Updates and Patch Management:** Update IoT systems and devices with

the most recent security fixes. Frequent software updates aid in patching security holes that hackers might exploit [43].

- **Network Segmentation:** To reduce the possible consequences of a security breach, isolate important systems and network parts. By doing this, vital portions of smart city infrastructure are shielded from unwanted access [44].

- **Authentication and Access Control:** Put in place robust authentication procedures to confirm users' and devices' identities. Strict access restrictions should be implemented to guarantee that only authorized users can communicate with IoT systems. [45].

- **Security by Design:** From the beginning of IoT devices and smart city initiatives, integrate cybersecurity measures. Instead of being an add-on, security should be a crucial component of the design and development process [47].

- **Incident Response and Recovery Plans:** Create thorough incident response plans to quickly handle cybersecurity issues. A clear plan in place speeds up recovery efforts and lessens the impact of a security incident [48,59].

- **Public Awareness and Education:** Inform stakeholders and the general public on the significance of cybersecurity in smart cities. To enable people to defend themselves and support citywide security, cultivate a culture of cyber awareness [49, 53].



Figure 8: Use of smart technology and smart city in global perspective [60, 61]

9. Legal and Ethical Challenges Related to Use of Digital and Smart Technology

In the era of advance technology one of the major problems caused by the fragmentation of regulations on a regional level is the global Internet of Things ecosystem. Lack of global data policy uniformity makes it difficult to deploy IoT solutions efficiently in every jurisdiction. For example, GDPR outlines strict cross-border data transfer laws that are not covered by CCPA.

Regional regulations, such as India's DPDP, place additional limits on global scalability due to their focus on data localization; frameworks, such as the Privacy Act of Australia and the PDPA of Singapore, need to be flexible enough to accommodate the rapid evolution of the Internet of Things (IoT) sector. Data protection policies around the world need to be standardized to address these issues. Unified standards that strike a bal-

ance between privacy, security, and innovation can facilitate international cooperation, lower costs, and simplify compliance. By conforming to these new standards, internet of things (IoT) developers can build AI and IoT systems that are user-friendly, secure, and scalable on a global scale [131]. Unauthorized access to tracking devices is a major security concern in the Internet of Things ecosystem because hackers can take control of equipment that are specifically designed to monitor and acquire sensitive data. Several techniques exist for executing such attacks, such as evading security measures, using stolen or compromised credentials, or exploiting firmware vulnerabilities. Most users' privacy may be violated if attackers gained unauthorized access and changed the data being received, disabled the tracking device, or listened in on users' actions. Because hackers can get knowledge about users' habits, health data stream, preferences, and behavioral patterns with just one infiltration, this is a worrying situation for home digital twins. Improper handling of such data could lead to fraud, identity theft, or even worse, physical invasion, including the theft of a user's house or vehicle. Cyberattacks on AI and IoT are on the rise, and the more sophisticated these attacks are, the more they target specific aspects of human lifestyle, such as homes, wearable technology (home space), or vehicle type [132].

Although Bluetooth beacons improve data anonymization, they are not always secure and can be abused. Additionally, wireless connection tracking offers relatively little protection against cybercriminal activity and is highly vulnerable to privacy invasion and misuse. Biometric sensors have better data anonymization than other technologies, but they can raise privacy concerns despite being useful for identification. These monitoring techniques demonstrate that the performance and level of dangers in IoT systems vary, therefore it is necessary to consider tracking in light of privacy and security concerns. Once more, the widespread presence of IoT devices—the majority of which lack robust security measures—contributes to the ongoing issue of illegal access. It is also more difficult to guarantee consistent protection because of the differences in security methods between manufacturers and devices. Furthermore, consumers usually neglect to change the default security settings or update the software on their devices, leaving them vulnerable to attack. Attackers may occasionally utilize password-protected or password-free devices to listen in on data as it is being transmitted, and if the encryption technique is inadequate or nonexistent, they may be able to retrieve important data [133]. The Home Digital Twin system's trust and privacy are also jeopardized by tracking devices' illegal access. Smart thermostats, security cameras, alarms, and other devices that monitor and regulate vital operations could be tampered with to cause havoc in a home. This would occur if hackers took over security systems, altered environmental controls, or sent malicious commands to other devices that were connected, causing the system to malfunction and possibly turn malevolent. This emphasizes how crucial it is to have thorough privacy and security measures in place to stop unwanted access, which will only increase

as IoT devices become more integrated into daily life in the era of advance technology [134, 187].

False data injection attacks over tracking devices in IoT systems could compromise the entire Home Digital Twin ecosystem's integrity and reliability [135]. Attackers intentionally inject false or misleading information into the system to taint the tracked and sent data of IoT devices. Instead of powering down the devices, we can alter the data they receive or share in order to influence the system's decision-making or behavior in hostile environments. The impact of fake data injection attacks can range from minor disturbances to complete system crashes, depending on the data's intended use and the significance of the decisions dependent on it. One common method for injecting misleading data is intercepting and modifying the communications between the Internet of Things (IoT) devices and the control system or cloud platform. One example could be an Internet of Things (IoT) gadget for smart homes that records data on environmental monitoring, such as energy use, humidity, and temperature. It is possible for an attacker to inject the system with bogus data, leading it to incorrectly define normal ranges for environmental circumstances [136]. For example, if no one is home, it's possible to fool a thermostat into thinking the house is hotter than it actually is by directing the heat to different areas or floors. At their worst, these might create catastrophic failures, like home systems breaking down, or even more dangerous safety risks, such a data breach that triggers false fire alarms. Redundancy and cross-checking by many devices are also critical safeguards against bogus data injection [137]. In addition to finding discrepancies between different sensors or devices tracking the same data, this system has the ability to identify outliers as potentially fabricated data [138]. When multiple smart thermostats in a building detect an anomalous temperature difference, for instance, they can coordinate an inspection to confirm the data's accuracy. Particularly in fields like security and health monitoring systems, where data manipulation is possible, having similar data from many sensors can help detect these incorrect attempts to enter false data [139]. Last but not least, machine learning algorithms can be used to identify these suspicious patterns of fake data injection. These models are able to learn normal behavior by rapidly identifying unusual (irregular) data values that deviate from the expected pattern. Historical device data might further improve the models by illuminating patterns that can indicate data manipulation and offering a broad comprehension of typical device usage in the era of advance technology [188].

In the era of advance technology data protection, accountability, and the secure implementation of autonomous systems are the main concerns of legal frameworks. Future legislation is influenced by ethical considerations, which frequently come before formal regulation. Concerns of widespread surveillance and the degradation of individual privacy in areas that are customarily regarded as private are raised by the continuous monitoring capabilities of smart devices such as wearable health monitors, smart home sensors, and security cameras. As is well known, AI systems and Internet of Things devices learn from data and networks,

which can carry ingrained societal prejudices. This can result in biased outcomes in fields like law enforcement, recruiting, and finance. To guarantee justice and equal treatment for all demographic groups, it is morally necessary to recognize and address these biases. However, a loss of human control and a decline in critical thinking abilities might result from an over-reliance on automation, IoT devices, and AI or ML-driven decision-making. According to ethical design principles, systems should encourage digital literacy, prioritize user interaction, and permit manual overrides. Furthermore, there is an ethical worry that some groups of people may not be able to profit from smart technology because of their location, socioeconomic level, or lack of digital proficiency, which could exacerbate already-existing social disparities. Once more, the opaque nature of many AI algorithms makes it challenging to comprehend the decision-making process, undermining openness and confidence. Clear disclosure on data collection and use is essential for ethical practice in order to foster user trust and accountability.

10. Legal and Ethical Issues for Developing Countries

The responsible adoption of IoT and AI-powered smart homes is greatly influenced by the legal and regulatory environment, especially in developing countries like Bangladesh and any burgeoning digital economy. We require some kind of digital or smart economy policy and strategy, which should offer a thorough framework that guarantees and strikes a balance between innovation and the defense of individual rights. This calls for vigorous and appropriate regulation, regulatory sandpiles, and robust institutional cooperation. Ethical IoT, AI, data governance, and cybersecurity must be given top priority in the policy in order to guarantee that smart home technologies function in a setting that respects human rights and is people-centered [4, 187]. by giving regulatory organizations like the national cybersecurity authority and the national data protection commission/authority more jurisdiction. They should be in charge of the seamless digital transformation of pertinent smart technology use sectors and must promote public awareness and stakeholder participation. In addition to supporting equitable growth, digital literacy, personal safety, data/digital security, and the development of a strong, meaningful, and sustainable digital or smart economy, such a holistic strategy is in line with worldwide best practices [7]. IoT, AI, data protection, and cybersecurity laws must be sensible and well-balanced in order to address the intricate relationship between innovation and each person's right to use the internet. Transparency, equity, and accountability are among the values outlined in the UNESCO guideline on the ethics of IoT and AI [5, 188]. Once more, because of the speed at which technology is developing, there will be challenges in the future in regulating and using IoT and AI-powered smart appliances. Therefore, it is necessary to make adjustments and ongoing revisions to the regulations, as well as strike a balance between the risk of strangling innovation and aggressive regulations in the era of advance technology.

in the era of advance technology, the quick development of smart technology raises a number of ethical

and legal issues. Data protection and privacy are two of the main issues. Lawyers must manage the ethical responsibilities of protecting client confidentiality and preserving the privacy of sensitive information when technology gathers and analyzes enormous volumes of personal data. The possibility of bias and discrimination in technology-driven decision-making processes, such as algorithms used in legal research or IoT, AI, and ML employed in predictive analysis, is another matter of concern. Legal practitioners need to make sure that these technologies don't reinforce unfair prejudices or provide unfair results. Additionally, concerns including cybersecurity, the unlicensed practice of law via internet platforms, and the moral use of social media by attorneys are also relevant. Legal professionals need to keep up with technological developments, create ethical standards, and strike a balance between using technology for its advantages and adhering to ethical and professional requirements [140]. Legal practitioners need to increase awareness and educate themselves on a constant basis. It is essential to keep up with technology developments and comprehend their ramifications. In a technologically advanced society, maintaining competency and ethical standards requires active participation in continuing education and training. It is crucial to create and adopt best practices and ethical standards tailored to smart technologies. In order to create thorough ethical frameworks, professional associations and governing bodies are essential. These frameworks ought to address issues like cybersecurity, privacy, data protection, bias reduction, and ethical social media use that are brought on by smart technology [141, 187]. In order to resolve complex legal or ethical crises or challenges in the near future, technology specialists and legal professionals must collaborate in the twenty-first century.

Artificial intelligence, machine learning, data science, robotics, and other cutting-edge technologies are continuously changing and influencing our lives. Our lives are improved by the new breakthroughs and developments brought about by new technology. We can now accomplish tasks more quickly, more effectively, and in ways we never could have previously thanks to new technology that keeps pushing the envelope. Whether it is in transit or at rest, we must make sure that all sensitive data is encrypted. To make sure AI systems and IoT devices are operating accurately and morally, we must schedule routine audits. Our staff needs to receive frequent training on ethical AI use and the most recent cybersecurity best practices. Interdisciplinary communication and teamwork are essential. Experts in technology, artificial intelligence, data science, and cybersecurity should interact with legal professionals. This cooperative strategy guarantees a thorough grasp of the ethical ramifications associated with evolving technology, encourages creativity, and encourages accountability. It is now a constant process for regulatory frameworks to change in tandem with technology improvements [142, 186]. Legal professionals and technology stakeholders should be actively involved in the creation and revision of laws and regulations by governments and policymakers. These policies successfully handle ethical issues like data governance,

privacy protection, and algorithmic decision-making responsibility. Future legal issues and the environment will be more technologically advanced and complex in the era of advance technology.

In the era of advance technology, it is essential for policy maker of developing nations considering critically to develop policies that promote lifelong learning and continuous smart skill development, ensuring that the workforce remains agile and adaptable to the rapidly changing demands of smart cities. These could include offering incentives for businesses to invest in the ongoing education of their employees or implementing urban development plans that seamlessly integrate technology and learning spaces into the city landscape [183]. So, effective strategies like investing in employee training programs, promoting cross-departmental projects, facilitating mentorship and knowledge-sharing sessions to develop smart skill for citizen is very important. For all stakeholders including citizen of smart city, relevant study emphasizes the importance of digital engagement and smart technology friendly approach as a key driver of skill development. Therefore, it is imperative to ensure digital and smart technology inclusivity and literacy, guaranteeing that all citizens, regardless of age or background, have access to the digital and smart resources and training necessary to flourish in a smart city environment [184]. Additionally, developing and accessing specific policy and educational involvements need to be inform stakeholders in creating effective programs for lifelong learning of smart skill development across diverse demographics and career stages in smart city environments in 21st century [185, 188].

11. Conclusion

In the era of advance technology, we live in a time of intelligent technology. By 2030, AI is expected to require the transformation of about 75 million to 375 million jobs globally, according to forecasts by MGI Research. In addition, the MGI study emphasizes the establishment of new roles and duties. The American Economic Association's researchers agree with the MGI's predictions, stating that only a few jobs can be fully mechanized, even though some tasks can be automated. The world is now more interconnected and operates as part of a global financial and economic ecosystem. The 2008 financial crisis severely damaged the economies of developing and least developed countries, causing economic contraction, social and political unrest, and a general decline in the standard of living for the general populace. It is clear that any setback on one side of the globe would have an impact on the entire global economy. The world is waiting for the same financial crisis. Along with digital and smart technologies like IoT, AI, ML, DL, big data, blockchain, etc., organizations that have emerged in this period have grown increasingly complex in the areas of information and communication. People's interpersonal relationships, communication styles, professional lives, and skill sets have all changed as a result of this circumstance. According to Warren Buffett, intelligent technology—especially artificial intelligence—is profound, but it also poses serious threats and ethical dilemmas that are comparable to the development of

nuclear weapons. He emphasizes that the development and application of technology must have a purpose and that moral principles like accountability and integrity cannot be compromised. One of the most basic factors that improved openness and transparency, according to Mark Zuckerberg, is the growing emphasis on developing deeper social interactions, better connections, and trustworthiness. We are transitioning from a transaction-focused world to a relationship-focused one. Rapid urbanization in the twenty-first century has presented benefits as well as challenges. The complicated demands of urban life have led to the emergence of smart cities as creative solutions. The foundation of this change is ICT, which integrates public services, infrastructure, and environmental sustainability. While AI, ML, robots, IoT, and big data improve urban planning, optimize resource usage, and fortify governance, the computing continuum has emerged as a crucial paradigm for effective resource management within ICT.

In the era of advance technology natural resources and energy, transportation and mobility, infrastructures, governance, economics, and humans are the six core areas and associated sub-domains of smart city sending. To understand the relationship between various geological, urban, demographic, human resources, ecological, and innovation-related aspects, a dataset of logical factors has been compiled, and deterioration analyses have been guided. In reality, there isn't a single, globally recognized definition of smart cities, and the most recent developments and examples of smart city development typically depend on neighborhood setting variables. In this way, city strategy developers are urged to try to understand these factors in order to develop appropriate methods for their smart cities. The concept of smart cities has recently gained a lot of attention and will likely continue to do so in the future. Smart plans are being distributed by urban communities, related events are relocating, and that's just the beginning—more books on the subject are being written. Smart innovations can help metropolitan communities manage traffic streams, reduce the use of fossil fuels in products, and set aside money. However, the plan's complexity is impeding its advancement. There are many different stakeholders involved, such as local experts, citizens, innovation groups, academics, etc., and each has a different idea of what a smart city should be. Most of the conversation is stymied by trying to understand what "smart" means rather than how it can help urban communities achieve their goals.

In the era of advance technology, the importance of personal accountability and moral judgment must be emphasized by those working in the legal field. They should think about the moral consequences of technological use. Experts in the field should be mindful of their own prejudices and ethical issues while making decisions that put their customers' needs, the rule of law, and justice first. Legal professionals can successfully traverse the junction of technology and legal ethics by embracing these techniques. In a world when everything is becoming digital, it protects basic ethical values, promotes fairness, and guarantees professional integrity. The collection, processing, and storage of personal data are areas where technological decisions

significantly affect privacy regulations. Using AI and IoT devices raises questions about consent and data ownership. Privacy laws like the General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA) set standards for data protection, but technological advancements often outpace legal developments. Privacy laws need to be flexible yet robust to address the dynamic nature of technological innovation. As a legal professional, staying informed about these changes is crucial. Consider a tech company developing a new IoT device. They must ensure that their product complies with current privacy laws and anticipate future regulations. Develop transparent data usage policies that clearly explain how data is collected and used. Keep abreast of changes in privacy laws and update your practices accordingly. Educate users about their rights and how their data is used. As legal professionals navigate this complex terrain, they must strike a delicate balance between embracing technological advancements for the benefit of their clients and ensuring adherence to ethical principles that safeguard the integrity of the legal system. To navigate the intersection of law and emerging smart technologies, from AI governance, extensive use of ML/robotic and cybersecurity regulations to blockchain compliance is demand for contemporary era. From relevant law courses need to be arrange and that can be useful to gain practical insights to handle future challenges. Such courses are now found on YouTube, Udemy, edX and other social media which covering GDPR, EU AI Act, software liability, and digital privacy frameworks, cyber security issues for legal professionals and tech leaders. We need to explore and introduce more purposeful law and ethical courses to handle future challenges related to the consequences of extensive use of smart technology. Smart city technologies promote a "green economy," contributing to sustainable development while improving quality of life and attracting talent. A smart economy relies on high-speed communication infrastructure and automation, IoT, AI, ML, robotic, and the digitization of services to enhance competitiveness and foster collaboration between citizens, universities, and businesses. This market is expanding very rapidly.

In the era of advance technology, the IoT, computing continuum, big data, AI, ML, etc. are converging in the 21st century, making smart cities a reality. Data localization, scalability, and responsiveness are handled via the computing continuum (edge-fog-cloud-HPC). These days, "smart cities" are touted as the way to handle city issues like pollution, trash, and overcrowding. When discussing the company strategy, nevertheless, these ideals do not emerge as obvious. Particularly, whether it's through increased internal efficiency (web-based models), financial gain (network providers), enhanced city appeal (e-commerce models), or uniformity, all of the studied business models seem to benefit smart city owners (value integrators). Lastly, IoT is still in its early stages of development and has not been included in smart city applications, despite the fact that it is a hot topic and creative goods and services are being created in tandem with it. Both the smart city sector and state and regional governments have a vested stake in these results. Currently, there is debate on the

vendor-imposed technological push, even as smart city development is on the rise. Sustainable, citizen-centric, and real-time urban services are made possible by the incorporation of new paradigms into smart cities. To tackle issues of digital inequality, ethics, and privacy, policies and e-governance will need to change in tandem with technology. However, holistic integration of advanced technology and data-driven methodologies, are not merely altering the architectural landscape but fundamentally reshaping the societal fabric, economic operations, and life's quotidian beats, mainly within the ambit of growing markets. In 21st century this rapidly metamorphosing urban environment, the pivotal role of human capital, especially the acquisition and application of smart and advanced skills, is increasingly pronounced. These competencies, summarizing a diverse spectrum of skills including and that not limited to critical thinking, creativity, collaborative prowess, and digital literacy, are deemed essential for individuals to navigate and excel amidst the ongoing flux of urban transformation and technological progression. The acquisition and refinement of these smart skills are instrumental in fostering a workforce that is not only adaptable but also adept at driving innovation and productivity within the smart city ecosystem.

References:

1. Hossain K A, (2015), Leadership qualities for 21st century leaders, *Journal of Management, Social Science and Humanities*, published on 19 May 2015, available at: <http://pearlresearchjournals.org/journals/pjmssh/archive.html>, accessed on 31 Jul 2025
2. Hossain K. A., (2015), "Essential Tips and Tactics of motivation, *Journal of Management*", *Social Science and Humanistic*, Volume 1, Issue 1, April 2015, accessed on 29 Jul 2025
3. Hossain, K. A. (2025a). Digital transformation and entrepreneurial visibility. *Journal of Digital Entrepreneurship*, 8(1), 45-67, accessed on 17 Dec 2025
4. Saaman Nadeem, Noor Ismail, Paridah Daud and Tahir Mehmood, 'Emerging Technologies and Ethical Challenges in AI and Cybersecurity' (2025) 15 *International Journal of Academic Research in Business and Social Sciences*, available at: <https://doi.org/10.6007/IJARBS/v15-i2/24636>, accessed on 31 Jul 2025
5. UNESCO, Recommendation on the Ethics of Artificial Intelligence (2021) <https://unesdoc.unesco.org/ark:/48223/pf0000381137>, accessed on 13 Jul 2025
6. Wolfram, M. (2012). Deconstructing smart cities. An intertextual reading of concepts and practices for integrated urban and ICT development. *Proceedings Real Corp 2012*, 14-16 May, accessed Jan 23 2026
7. Nam, T., & Pardo, T. A. (2011a). Conceptualizing Smart City with Dimensions of Technology, People, and Institutions. *DG.O.* pp. 282-291, accessed on 11 Jul 2025
8. X Li et al, 'Internet of things to network smart devices for ecosystem monitoring' (2019) 64 *Science*

Bulletin (17) 1234 <https://www.sciencedirect.com/science/article/abs/pii/S2095927319304013>, accessed on 11 Jul 2025

9. Lombardi, P., Giordano, S., Caragliu, A., Del Bo, C., Deakin, M., Nijkamp, & P., Kourtit, K. (2011). An advanced triple-helix network model for smart cities performance. accessed Jan 23 2026

10. Lee, Hoe S., Hoon Han, J., Taik Leem, Y., & Yigitcanlar, T. (2008). Towards ubiquitous city: concept, planning, and experiences in the Republic of Korea. In Yigitcanlar, T., Velibeyoglu, K., & Baum, S., (Eds.), Knowledge-Based Urban Development: Planning and Applications in the Information Era (pp. 148-169). Hershey, PA: Information Science Reference (PDF) Significance of Smart Cities in 21st Century: An International Business Perspective. accessed Jan 23 2026

11. Komninos, N. (2011). What makes cities smart? SC Conference, Edinburgh, 30 June, 2011, accessed Jan 23 2026

12. Hall R. E. (2000). The Vision of a Smart City. In Proceedings of the 2nd International Life Extension Technology Workshop (Paris, France, Sep. 28), 2000, accessed Jan 23 2026

13. Anthopoulos, L. & P., Fitsilis. (2014a). Exploring architectural and organizational features in Smart Cities. 16th International Conference on Advanced Communications Technology (ICACT2014), IEEE, 2014, accessed on 11 Jul 2025

14. Anthopoulos, L. & P., Fitsilis. (2014b). Smart Cities and their roles in city competition: A classification. International Journal of Electronic Government Research (IJEGR), 10(1): 67-81, accessed Jan 21 2026

15. <https://www.rbcwealthmanagement.com/en-us/insights/how-are-smart-cities-meeting-the-challenges-of-urbanization-in-the-21st-century>, accessed on 11 Jan 2026

16. https://www.researchgate.net/publication/363915482_Recent_Trends_and_Challenges_in_Smart_Cities, accessed on 11 Jan 2026

17. Yin C, Xiong Z, Chen H, Wang J, Cooper D, David B. A literature survey on smart cities. Science China Information Sciences. 2015 Oct;58(10):1-8, accessed on 11 Jan 2026

18. Al Nuaimi E, Al Neyadi H, Mohamed N, Al-Jaroodi Applications of big data to smart cities. Journal of Internet Services and Applications. 2015 Aug;6(1):1-5, accessed Jan 23 2026

19. Harrison C, Donnelly IA. A theory of smart cities. In Proceedings of the 55th Annual Meeting of the ISSS-2011, Hull, UK 2011 Sep 23, accessed Jan 23 2026

20. Baba SM, Banday MT. Application Development for Wearable Internet of Things using Hexi wear. In 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN) 2020 Feb 27 (pp. 542-548). IEEE (PDF) Recent Trends and Challenges in Smart Cities, accessed on 01 Jan 2026

21. Baba SM, Banday MT. Application Development for Wearable Internet of Things using Hexi wear. In 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN) 2020 Feb 27 (pp. 542-548). IEEE, accessed on 01 Jan 2026

22. Hossain, K. A. (2025b). Assessment of Global great Entrepreneurs, Life: Lesson for New Entrepreneurs for Success in 21st Century, Norwegian Journal of development of the International Science, 167/2025, ISSN 3453-9875, accessed on 17 Dec 2025

23. Hossain, K. A. (2025c). Problem of Toxic Leadership Instead of Modern Leadership at New Age in 21st Century, Open Journal of Leadership, 2025, 14(3), ISSN Online: 2167-7751, accessed on 17 Dec 2025

24. Hossain, K. A. (2025d). Transformation of Contemporary Leadership in 21st century, International Journal of Advanced Research (IJAR), Int. J. Adv. Res. 13(09), September-2025, 352-390, DOI:10.21474/IJAR01/53711, ISSN:(O) 2320-5407, ISSN(P) 3107-4928, accessed on 17 Dec 2025

25. Murthy BS, Peddoju SK. IoT-Based Patient Health Monitoring: A Comprehensive Survey. ICT Analysis and Applications. 2021:349-56, accessed on 01 Jul 2025

26. <https://www.trigyn.com/insights/cybersecurity-smart-city-surveillance-system>, accessed on 01 Jul 2025

27. Marchesani, F. (2023). The global Smart City: Challenges and opportunities in the digital age. Emerald Publishing Limited., accessed on 01 Jul 2025

28. James, Peggy; Astoria, Ross; Castor, Theresa; Hudspeth, Christopher; Olstinske, Denise; Ward, John (2021). ["Smart Cities: Fundamental Concepts"](https://link.springer.com/rwe/10.1007/978-3-030-69698-6_2). Handbook of Smart Cities. [Springer International Publishing](https://en.wikipedia.org/wiki/Springer_International_Publishing) "Springer International Publishing". pp. 3–33. [doi]([https://en.wikipedia.org/wiki/Doi_\(identifier\)](https://en.wikipedia.org/wiki/Doi_(identifier))) "Doi (identifier)":[10.1007/978-3-030-69698-6_2](https://doi.org/10.1007%2F978-3-030-69698-6_2). [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [978-3-030-69698-6](<https://en.wikipedia.org/wiki/Special:BookSources/978-3-030-69698-6>) "Special:BookSources/978-3-030-69698-6", accessed on 11 Jul 2025

29. Goldsmith, Stephen (16 September 2021). ["As the Chorus of Dumb City Advocates Increases, How Do We Define the Truly Smart City?"](<https://datasmart.ash.harvard.edu/chorus-dumb-city-advocates-increases-how-do-we-define-truly-smart-city>). datasmart.ash.harvard.edu, accessed on 11 Jul 2025

30. Fourtané, Susan (16 November 2018). ["Connected Vehicles in Smart Cities: The Future of Transportation"](<https://interestingengineering.com/innovation/connected-vehicles-in-smart-cities-the-future-of-transportation>). Interesting Engineering.com, accessed on 11 Jul 2025

31. McLaren, Duncan; Agyeman, Julian (2015). [Sharing Cities: A Case for Truly Smart and Sustainable Cities](<https://books.google.com/books?id=KhvLCgAAQBAJ&q=smart+cities+and+sustainability>). MIT Press. [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [978-0-262-02972-

- 8](https://en.wikipedia.org/wiki/Special:BookSources/978-0-262-02972-8 "Special:BookSources/978-0-262-02972-8"), accessed on 11 Jul 2025
32. Musa, Sam (March 2018). "Smart Cities-A Road Map for Development". IEEE Potentials. 37 (2): 19–23. [Bibcode](https://en.wikipedia.org/wiki/Bibcode_(identifier)) "Bibcode (identifier)":[2018IPot...37b..19M](https://ui.adsabs.harvard.edu/abs/2018IPot...37b..19M). [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1109/MPOT.2016.2566099](https://doi.org/10.1109/2FMPOT.2016.2566099). [ISSN](https://en.wikipedia.org/wiki/ISSN_(identifier)) "ISSN (identifier)" [1558-1772](https://search.worldcat.org/issn/1558-1772), accessed on 11 Jul 2025
33. Paiho, Satu; Tuominen, Pekka; Rökman, Jyri; Ylikerälä, Markus; Pajula, Juha; Siikavirta, Hanne (2022), [Opportunities of collected city data for smart cities,](https://doi.org/10.1049%2Fsmc2.12044) IET Smart Cities. 4 (4): 275–291. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1049/smc2.12044](https://doi.org/10.1049%2Fsmc2.12044). [S2CID](https://en.wikipedia.org/wiki/S2CID_(identifier)) "S2CID (identifier)" [253467923](https://api.semanticscholar.org/CorpusID:253467923), accessed on 11 Jul 2025
34. ["IDC Forecasts Smart Cities Spending to Reach \$158 Billion in 2022, with Singapore, Tokyo, and New York City Among Top Spenders"] (https://www.businesswire.com/news/home/20180723005083/en/IDC-Forecasts-Smart-Cities-Spending-to-Reach-158-Billion-in-2022-with-Singapore-Tokyo-and-New-York-City-Among-Top-Spenders). www.businesswire.com. 23 July 2018, accessed on 11 Jul 2025
35. https://www.scrip.org/journal/paperinformation?paperid=135309, accessed on 11 Jul 2025
36. ["Building a Smart City, Equitable City – NYC Forward"] (http://www1.nyc.gov/site/forward/innovations/smartnyc.page). [Archived](https://web.archive.org/web/20171204115315/http://www1.nyc.gov/site/forward/innovations/smartnyc.page) from the original on 4 December 2017, accessed on 11 Jul 2025
37. Jennifer Clark. ["Solving for the city"] (https://www.technologyreview.com/2021/04/28/1023104/smart-cities-urban-technology-pandemic-covid/). [MIT Technology Review](https://en.wikipedia.org/wiki/MIT_Technology_Review "MIT Technology Review"). Vol. 124, no. 3, May/June 2021. pp. 9–11, accessed on 11 Jul 2025
38. Hossain K A, (2023), Analysis of Present and Future Use of Artificial Intelligence (AI) in Line of 4th industrial Revolution (4IR), Scientific Research Journal 11 (8), ISSN: 2201-2796, Aug 2023, accessed on 11 Jul 2025
39. Watson, Vanessa (6 December 2013). ["African urban fantasies: dreams or nightmares?"] (https://doi.org/10.1177%2F0956247813513705). Environment and Urbanization. 26 (1): 215–231. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1177/0956247813513705](https://doi.org/10.1177%2F0956247813513705). [ISSN](https://en.wikipedia.org/wiki/ISSN_(identifier)) "ISSN (identifier)" [0956-2478](https://search.worldcat.org/issn/0956-2478), accessed on 11 Jul 2025
40. Woyke, Elizabeth. ["Smart cities could be lousy to live in if you have a disability"] (https://www.technologyreview.com/s/612712/smart-cities-coule-be-lousy-if-you-have-a-disability/). MIT Technology Review. [Archived](https://web.archive.org/web/20190305211109/https://www.technologyreview.com/s/612712/smart-cities-coule-be-lousy-if-you-have-a-disability/) from the original on 5 March 2019, accessed on 11 Jul 2025
41. *Hossain, K. A., (2023), * Evaluation of Influence of Artificial Intelligence (AI) on Technologies in 21st Century, Journal of Electronics and Communication Engineering Research, Quest Journal, accessed on 11 Jul 2025
42. Hollands, R. G (2008). ["Will the real smart city please stand up?"] (https://repositorio.unal.edu.co/handle/unal/79888). City. 12 (3): 303–320. [Bibcode](https://en.wikipedia.org/wiki/Bibcode_(identifier)) "Bibcode (identifier)":[2008City...12..303H](https://ui.adsabs.harvard.edu/abs/2008City...12..303H). [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1080/13604810802479126](https://doi.org/10.1080%2F13604810802479126), accessed on 11 Jul 2025
43. Chan, Karin (3 April 2017). ["What Is A 'Smart City'?"] (https://web.archive.org/web/20180124135638/https://www.expatriatelifestyle.com/life-and-style/What-Is-A-Smart-City). Expatriate Lifestyle. Archived from the original on 24 January 2018, accessed on 11 Jul 2025
44. Komninos, Nicos (22 August 2013). "What makes cities intelligent?". In Deakin, Mark (ed.). Smart Cities: Governing, Modelling and Analysing the Transition. Taylor and Francis. p. 77. [ISBN](https://en.wikipedia.org/wiki/ISBN_(identifier)) "ISBN (identifier)" [978-1-135-12414-4](https://en.wikipedia.org/wiki/Special:BookSources/978-1-135-12414-4 "Special:BookSources/978-1-135-12414-4"), accessed on 11 Jul 2025
45. Lipman-Blumen, J. (2005). The Allure of Toxic Leaders: Why We Follow Destructive Bosses and Corrupt Politicians – and How We Can Survive Them. Oxford: Oxford University Press
46. *Hossain, K. A., (2023), * Evaluate the Mystery of Creation of Universe and Existence of Antimatter Dark Matter and Dark Energy, International Journal of Current Science Research and Review 6 (6), Jun 2023, accessed on 11 Jul 2025
47. Peris-Ortiz, Marta; Bennett, Dag R.; Yábar, Diana Pérez-Bustamante (2016). [Sustainable Smart Cities: Creating Spaces for Technological, Social and Business Development](https://books.google.com/books?id=AtQ0DQA

- AQBAJ&q=smart+cities+and+sustainability). Springer. [ISBN](https://en.wikipedia.org/wiki/ISBN_(identifier)) "ISBN (identifier)" [978-3-319-40895-8](https://en.wikipedia.org/wiki/Special:BookSources/978-3-319-40895-8) "Special:BookSources/978-3-319-40895-8"). [Archived](https://web.archive.org/web/20201030003828/https://books.google.com/books?id=AtQ0DQAAQBAJ&q=smart+cities+and+sustainability) from the original on 30 October 2020, accessed on 11 Jul 2025
48. Talari, Saber; Shafie-khah, Miadreza; Siano, Pierluigi; Loia, Vincenzo; Tommasetti, Aurelio; Catalão, João (2017). ["A Review of Smart Cities Based on the Internet of Things Concept"](<https://doi.org/10.3390%2Fen10040421>). [Energies](https://en.wikipedia.org/wiki/Energies_(journal)) "Energies (journal)". 10 (4): 421. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.3390/en10040421](https://doi.org/10.3390%2Fen10040421), accessed on 11 Jul 2025
49. Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*. doi:10.1080/10630732.2014.942092, accessed on 13 Jul 2025
50. Vanolo, A. (2014). Smart mentality: The smart city as disciplinary strategy. *Urban Studies*, 51(5), 883–898. doi:10.1177/0042098013494427, accessed on 11 Jul 2025
51. Marsal-Llacuna, Maria-Lluïsa; Colomer-Llinàs, Joan; Meléndez-Frigola, Joaquim (2015). ["Lessons in urban monitoring taken from sustainable and livable cities to better address the Smart Cities initiative"](<https://linkinghub.elsevier.com/retrieve/pii/S0040162514000456>). *Technological Forecasting and Social Change*. 90: 611–622. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1016/j.techfore.2014.01.012](https://doi.org/10.1016%2Fj.techfore.2014.01.012), accessed on 11 Jul 2025
52. Marchesani, Filippo (2023). [The Global Smart City](https://www.emerald.com/insight/publication/doi/10.1108/9781837975754). Emerald. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1108/9781837975754](https://doi.org/10.1108%2F9781837975754). [ISBN](https://en.wikipedia.org/wiki/ISBN_(identifier)) "ISBN (identifier)" [978-1-83797-576-1](https://en.wikipedia.org/wiki/Special:BookSources/978-1-83797-576-1) "Special:BookSources/978-1-83797-576-1"), accessed on 13 Jul 2025
53. Lim, Yirang; Edelenbos, Jurian; Gianoli, Alberto (2019). ["Identifying the results of smart city development: Findings from systematic literature review"](<https://linkinghub.elsevier.com/retrieve/pii/S0264275118314161>). *Cities*. 95 102397. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1016/j.cities.2019.102397](https://doi.org/10.1016%2Fj.cities.2019.102397), accessed on 11 Jul 2025
54. Hossain MS, Muhammad G, Alamri A. Smart healthcare monitoring: a voice pathology Multimedia Systems. 2019Oct;25(5):565-75, accessed on 11 Jan 2026
55. Batty, M.; Axhausen, K. W.; Giannotti, F.; Pozdnoukhov, A.; Bazzani, A.; Wachowicz, M.; Ouzounis, G.; Portugali, Y. (2012). ["Smart cities of the future"](<http://link.springer.com/10.1140/epjst/e2012-01703-3>). *The European Physical Journal Special Topics*. 214 (1): 481–518. [Bibcode](https://en.wikipedia.org/wiki/Bibcode_(identifier)) "Bibcode (identifier)":[2012EPJST. 214..481B](https://ui.adsabs.harvard.edu/abs/2012EPJST.214..481B). [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1140/epjst/e2012-01703-3](https://doi.org/10.1140%2Fepjst%2Fe2012-01703-3), accessed on 11 Jul 2025
56. Deakin, Mark; Al Waer, Husam, eds. (2011). ["From Intelligent to Smart Cities"](<http://researchrepository.napier.ac.uk/id/eprint/7295>). *Journal of Intelligent Buildings International: From Intelligent Cities to Smart Cities*. 3 (3): 140–152. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1080/17508975.2011.586671](https://doi.org/10.1080%2F17508975.2011.586671), accessed on 13 Jul 2025
57. Deakin, Mark (22 August 2013). "From intelligent to smart cities". In Deakin, Mark (ed.). *Smart Cities: Governing, Modelling and Analysing the Transition*. Taylor and Francis. p. 15. [ISBN](https://en.wikipedia.org/wiki/ISBN_(identifier)) "ISBN (identifier)" [978-1-135-12414-4](https://en.wikipedia.org/wiki/Special:BookSources/978-1-135-12414-4) "Special:BookSources/978-1-135-12414-4"), accessed on 13 Jul 2025
58. Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*. doi:10.1080/10630732.2014.942092, accessed on 13 Jul 2025
59. Camboim, Guilherme Freitas; Zawislak, Paulo Antônio; Pufal, Nathália Amarante (May 2019). ["Driving elements to make cities smarter: Evidences from European projects"](<https://linkinghub.elsevier.com/retrieve/pii/S0040162517318607>). *Technological Forecasting and Social Change*. 142: 154–167. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)) "Doi (identifier)":[10.1016/j.techfore.2018.09.014](https://doi.org/10.1016%2Fj.techfore.2018.09.014), accessed on 13 Jul 2025
60. <https://energie-digitalisieren.de/knowhow/smart-city-intelligent-vernetz-und-effizient/>, accessed on 06 June 2025
61. Jangjarat K., Kraiwani T., Limna P., and Son-suphap R., (2023), Public perceptions towards ChatGPT as the robo-assistant, *Online Journal of Communication and Media Technologies*. (2023) 13, no. 3, article e202338, https://doi.org/10.30935/ojcm/13366(https

[://doi.org/10.30935/ojcm/13366](https://doi.org/10.30935/ojcm/13366)), accessed on 11 Jan 2026

62. <https://guptadeepak.com/the-future-of-ai-and-its-impact-on-humanity/>, accessed on 13 Jul 2025

63. Vizion (2024) The Role of Technology in Regulatory Compliance: Leveraging Analytics to Meet Global Standards.

<https://www.vizionapi.com/blog/the-role-of-technology-in-regulatory-compliance-leveraging-analytics-to-meet-global-standards>, accessed on 13 Jul 2025

64. Nagar, P. (2024) The Power of Technology: Driving Efficiency and Productivity in Business. <https://www.linkedin.com/pulse/power-technology-driving-efficiency-productivity-business-nagar>, accessed on 13 Jul 2025

65. Soni, A. (2023) Technology in Business Communication: Examples, Advantages & Types. <https://clearinfo.in/blog/technology-in-business-communication/>, accessed on 13 Jul 2025

66. Adel A., (2023), Unlocking the future: fostering human-machine collaboration and driving intelligent automation through industry 5.0 in smart cities, *Smart Cities*. (2023) 6, no. 5, 2742–2782, <https://doi.org/10.3390/smartcities6050124>, accessed on 31 Dec 2025

67. Zeffass, A., (2007), Innovation, communication, and leadership: New developments in strategic communication. *International Journal of Strategic Communication*, 1(2), 107–122, accessed on 13 Jul 2025

68. Rost, J. C., (1993), *Leadership for the twenty-first century*, Greenwood Publishing Group, accessed on 13 Jul 2025

69. Di Stefano, G., Scrima, F., and Parry, E., (2019), The effect of organizational culture on deviant behaviors in the workplace. *The International Journal of Human Resource Management*, 30(17), 2482–2503, accessed on 11 Jul 2025

70. Yukl, G. (2006). *Leadership in organizations* (6th ed.). Upper Saddle River: Pearson, accessed on 11 Jul 2025

71. Nauman, S., Khan, A. M., and Ehsan, N. (2009), Patterns of empowerment and leadership style in project environment. **International Journal of Project Management*, 28,* 638–649, accessed on 11 Jul 2025

72. Goulet, L. R., and Frank, M. L., (2002), Organizational commitment across three sectors: Public, non-profit, and for-profit. *Public Personnel Management* 31(2), 201–210, accessed on 11 Jul 2025

73. Einarsen, S., Aasland, M. S., and Skogstad, A., (2007), Destructive leadership behaviour: A definition and conceptual model. *The leadership quarterly*, 18(3), 207–216, accessed on 11 Jul 2025

74. Kellerman, B. (2004). *Bad leadership: What it is, how it happens, why it matters*. Harvard Business Press,

75. Madzar, S., (2001), Subordinates' information-inquiry: Exploring the effect of perceived leadership style and individual differences. *Journal of Occupational and Organizational Psychology*, 74,221–232, accessed on 13 Jul 2025

76. <https://www.blinkist.com/en/books/superintelligence-en>, accessed on 13 Jul 2025

77. <https://www.blinkist.com/en/books/life-3-dot-0-en>, accessed on 13 Jul 2025

78. Bunker, K. (1997), The power of vulnerability in contemporary leadership. *Consulting Psychology Journal: Practice and Research*, 49(1), 122–136, accessed on 11 Jul 2025

79. <https://www.blinkist.com/en/books/the-wealth-of-nations-en>, accessed on 11 June 2025

80. <https://ekonomi.gov.my/sites/default/files/2021-07/National-4IR-Policy.pdf>, accessed on 11 Jul 2025

81. <https://www.britannica.com/summary/Industrial-Revolution-Causes-and-Effects#>, accessed on 11 June 2025

82. Rada, Michael; Schaller, Achim (2024), Gondlach, Kai; Brinkmann, Birgit; Brinkmann, Mark; Plath, Julia (eds.), ["The Future of Industry 5.0: A Comprehensive Reflection on Sustainable Industrial Evolution"](https://link.springer.com/chapter/10.1007/978-3-658-43586-8_27), *Regenerative Zukünfte und künstliche Intelligenz: Band 1: PLANET* (in German), Wiesbaden: Springer Fachmedien, pp. 341–350, [doi]([https://en.wikipedia.org/wiki/Doi_\(identifier\)](https://en.wikipedia.org/wiki/Doi_(identifier))) "Doi (identifier)":[10.1007/978-3-658-43586-8_27](https://doi.org/10.1007/978-3-658-43586-8_27), [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [978-3-658-43586-8](<https://en.wikipedia.org/wiki/Special:BookSources/978-3-658-43586-8>) "Special:BookSources/978-3-658-43586-8"), accessed on 11 Jul 2025

83. LIMS, (2023), Nobody always sees the whole pictures, our AI do; available at: www.lmis.de/im-wandel-der-zeit-von-industrie-1-0-bis-4-0, accessed on 11 Jul 2025

84. *Hossain, K. A., (2023), An overview of merchant ships, *International Journal of Novel Research and Development (IJNRD)*, Vol 8, Issue 6, June 2023, ISSN 2456-4184,* accessed on 11 Jul 2025

85. *Hossain, K. A., (2023),* An Overview of Naval Ships, *Scientific Research Journal (SCIRJ)* 11 (6), ISSN: 2201-2796, June 2023, accessed on 11 Jul 2025

86. Tripathi G, Abdul Ahad M, Paiva S. Sms: A secure healthcare model for smart cities. *Electronics*. 2020 Jul13;9(7):1135, accessed on 11 Jul 2025

87. Umair M, Cheema MA, Cheema O, Li H, Lu H. Impact of COVID-19 on IoT adoption in healthcare, smart homes, smart buildings, smart cities, transportation and industrialIoT. *Sensors*. 2021 Jun 1;21(11):3838, accessed on 11 Jul 2025

88. Rotatori, Denise; Lee, Eun Jeong; and Sleeva, Sheryl (1 January 2021), ["The evolution of the work-

- force during the fourth industrial revolution"](<https://www.tandfonline.com/doi/full/10.1080/13678868.2020.1767453>), Human Resource Development International, 24 (1): 92–103, [ISSN]([https://en.wikipedia.org/wiki/ISSN_\(identifier\)](https://en.wikipedia.org/wiki/ISSN_(identifier))) "ISSN (identifier)" [1367-8868](<https://search.worldcat.org/issn/1367-8868>), accessed on 11 Jul 2025
89. Rifkin, Jeremy (2013), The third industrial revolution: how lateral power is transforming energy, the economy, and the world. Palgrave Macmillan. [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [978-0-230-34197-5](<https://en.wikipedia.org/wiki/Special:BookSources/978-0-230-34197-5>) "Special:BookSources/978-0-230-34197-5", accessed on 11 Jul 2025
90. Hossain K A, (2023), Analysis of Present and Future Use of Artificial Intelligence (AI) in Line of 4th industrial Revolution (4IR), Scientific Research Journal 11 (8), ISSN: 2201-2796, Aug 2023, accessed on 11 Jul 2025
91. Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins, (2003), "Technological change and the environment", Handbook of environmental economics, Vol. 1, Elsevier, 2003, 461-516, accessed on 11 Jul 2025
92. <https://www.forbes.com/sites/bernardmarr/2016/04/05/why-everyone-must-get-ready-for-4th-industrial-revolution/>, accessed on 11 Jul 2025
93. https://web.archive.org/web/20080930171222/http://drrc.lbl.gov/pubs/LBNL_55087.pdf, accessed on 11 Jul 2025
94. Philbeck, Thomas; Davis, and Nicholas, (2018), ["The Fourth Industrial Revolution"](<https://www.jstor.org/stable/26588339>), Journal of International Affairs, 72 (1): 17–22. [ISSN]([https://en.wikipedia.org/wiki/ISSN_\(identifier\)](https://en.wikipedia.org/wiki/ISSN_(identifier))) "ISSN (identifier)" [0022-197X](<https://search.worldcat.org/issn/0022-197X>), accessed on 11 Jul 2025
95. Ross, Philip; Maynard, and Kasia (2021), ["Towards a 4th industrial revolution"](<https://doi.org/10.1080%2F17508975.2021.1873625>), Intelligent Buildings International, 13 (3): 159–161. [doi]([https://en.wikipedia.org/wiki/Doi_\(identifier\)](https://en.wikipedia.org/wiki/Doi_(identifier))) "Doi (identifier)":[10.1080/17508975.2021.1873625](<https://doi.org/10.1080%2F17508975.2021.1873625>), accessed on 11 Jul 2025
96. Hermann, Mario; Pentek, Tobias; and Otto, Boris (January 2016), ["Design Principles for Industrie 4.0 Scenarios"](<https://ieeexplore.ieee.org/document/7427673>), 2016 49th Hawaii International Conference on System Sciences (HICSS), pp. 3928–3937, [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [978-0-7695-5670-3](<https://en.wikipedia.org/wiki/Special:BookSources/978-0-7695-5670-3>) "Special:BookSources/978-0-7695-5670-3", accessed on 11 Jul 2025
97. Gronau, Norbert; Grum, Marcus; and Bender, Benedict (2016), ["Determining the optimal level of autonomy in cyber-physical production systems"](<https://ieeexplore.ieee.org/document/7819367>), 2016 IEEE 14th International Conference on Industrial Informatics (INDIN), IEEE, pp. 1293–1299. [doi]([https://en.wikipedia.org/wiki/Doi_\(identifier\)](https://en.wikipedia.org/wiki/Doi_(identifier))) "Doi (identifier)":[10.1109/INDIN.2016.7819367](<https://doi.org/10.1109%2FINDIN.2016.7819367>). [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [978-1-5090-2870-2](<https://en.wikipedia.org/wiki/Special:BookSources/978-1-5090-2870-2>) "Special:BookSources/978-1-5090-2870-2", accessed on 11 Jul 2025
98. Chourabi H, Nam T, Walker S, Gil-Garcia JR, Mellouli S, Nahon K, Pardo TA, Scholl HJ. Understanding smart cities: An integrative framework. In 2012 45th Hawaii international conference on system sciences 2012 Jan 4 (pp.2289-2297). IEEE, accessed on 13 Jan 2026
99. *Hossain, K. A., (2023a), Technological advancement and future of warship building, International Journal of Research and Development (IJNRD), Vol 8, Issue 5, May 2023, ISSN 2456-4184,* accessed on 13 Jan 2026
100. Bloomberg, (2016), available at: [www.bloomberg.com/news/videos/2016-05-20/forward-thinking-march-of-the-machines](<http://www.bloomberg.com/news/videos/2016-05-20/forward-thinking-march-of-the-machines>), accessed on 15 Aug 2025
101. NeVill C. and Sirasoonthorn P., (2021), social media as the learning platform of power in Thai university students, Humanities, Arts and Social Sciences Studies, 2021, 21, no. 1, 162–170, <https://so02.tci-thaijo.org/index.php/hasss/article/view/235276>, accessed on 15 Dec 2025
102. [Schwab, Klaus](https://en.wikipedia.org/wiki/Klaus_Schwab) "Klaus Schwab" (2016), [The Fourth Industrial Revolution](https://books.google.com/books?id=ST_FDAAAQBAJ). New York: Crown Publishing Group (published 2017). [ISBN]([https://en.wikipedia.org/wiki/ISBN_\(identifier\)](https://en.wikipedia.org/wiki/ISBN_(identifier))) "ISBN (identifier)" [9781524758875](<https://en.wikipedia.org/wiki/Special:BookSources/9781524758875>) "Special:BookSources/9781524758875", accessed on 11 Jul 2025
103. Housman, M., (2018), Why 'Augmented Intelligence' Is a Better Way to Describe AI, AINews, 2018, accessed on 11 Jul 2025
104. Jordan, M.I.; Mitchell, T.M., (2015), Machine learning: Trends, perspectives, and prospects. Science 2015, 349, 255–260, accessed on 13 Jul 2025
105. Unified architecture for machine learning in 5G and future networks, Technical Specification TU-T FG-ML5G-ARC5G, January 2019, accessed on 11 Jul 2025
106. <https://www.shutterstock.com/search/robot-human-working-together>, accessed on 11 Jul 2025

107. <https://www.pewresearch.org/internet/2018/12/10/artificial-intelligence-and-the-future-of-humans/>, accessed on 11 Jul 2025
108. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3661469, accessed on 11 Jul 2025
109. Calzada I., (2021), Book review: smart city citizenship, *Journal of Contemporary Urban Affairs*. (2021) 5, no. 1, 113–118, <https://doi.org/10.25034/ijcua.2021.v5n1-7>, accessed on 11 Jul 2025
110. <https://www.sciencedirect.com/science/article/abs/pii/S0264837719317302>, accessed on 11 Jul 2025
111. <https://www.airtics.org/the-role-of-ai-in-modern-education-italys-experiment-with-ai-assisted-teaching/>, accessed on 11 Jul 2025
112. <https://itchronicles.com/artificial-intelligence/ai-in-education/>, accessed on 11 Jul 2025
113. ramanik MI, Lau RY, Demirkan H, Azad MA. Smarthealth: Big data enabled health paradigm within smartcities. *Expert Systems with Applications*. 2017 Nov30; 87:370-83, accessed on 11 Jul 2025
114. <https://nntc.digital/blog/4ir-how-to-exploit-the-fourth-industrial-revolution/>, accessed on 24 June 2023
115. Poongodi M, Sharma A, Hamdi M, Maode M, Chilamkurti N. Smart healthcare in smart cities: wireless patient monitoring system using IoT. *The Journal of Supercomputing*. 2021 Nov;77(11):12230-55, accessed on 13 Jul 2025
116. Patterson, N. (2023) What Is Cybersecurity and Why Is It Important? <https://www.snhu.edu/about-us/newsroom/stem/what-is-cyber-security>
117. FM Contributors (2023) Compliance Challenges in a Digital World: Regtech's Role in Evolving Regulations, *Finance Magnates*, <https://www.financemagnates.com/institutional-forex/regulation/compliance-challenges-in-a-digital-world-regtechs-role-in-evolving-regulations/>,
118. Faster Capital (2024) What Are the Challenges of Using Technology in Business. <https://fastercapital.com/questions/What-are-the-challenges-of-using-technology-in-business.html>
119. Pensar IT Support Services and Consultancy (2024) The Top 5 Technology Challenges for Small Business. <https://www.pensar.co.uk/blog/the-top-5-technology-challenges-for-small-business/>
120. Strong, T. (2024) Navigating the Risks: How Technology Poses Threats to Your Business. <https://www.reacpa.com/insight/navigating-the-risks-how-technology-poses-threats-to-your-business/>
121. Klein, A.Z. (2022) Ethical Issues of Digital Transformation. *Organizacoes & Sociedade Journal*, 29, 443-448,
122. Trevino, L.K. (1986) Ethical Decision Making in Organizations: A Person-Situation Interactionist Model. *Academy of Management Review*, 11, 601-617
123. <https://www.forbes.com/sites/timothypanandreou/2024/06/27/is-the-future-of-robotics-specialized-or-humanoid-it-depends/>, accessed on 11 Jul 2025
124. <https://esdst.eu/the-future-of-work-how-robotics-and-automation-are-transforming-industries/>, accessed on 11 Jul 2025
125. <https://www.linkedin.com/pulse/leadership-titles-positions-flowcharts-mohammed-aldossary-assoc-cipd/>, accessed on 03 Aug 2025
126. Pacheco Rocha N, Dias A, Santinha G, Rodrigues M, Queirós A, Rodrigues C. Smart cities and healthcare: A systematic review. *Technologies*. 2019 Aug 16;7(3):58, accessed Jan 24 2026
127. *Hossain, K. A., (2023b), * Evaluation of Influence of Internet of Things (IoT) Technologies and Devices in 21 Century, *Scientific Research Journal* 11 (7), ISSN: 2201-2796, Jul 2023, accessed on 11 Jul 2025
128. *Hossain, K. A., (2023c), * The Potential and Challenges of Quantum Technology in Modern Era, *Scientific Research Journal* 11 (6), Jun 2023, accessed on 11 Jul 2025
129. Hossain, K. A. (2025e). Study on Entrepreneurship and Quality of Successful Entrepreneurs: Global Perspective, *Journal of Liberal Arts and Humanities (JLAH)*, Issue: Vol. 6; No. 5; October 2025 (pp. 1-79, ISSN 2690-070X (Print) 2690-0718 (Online), Doi: 10.48150/jlah.v6no5. 2025.a1, accessed on 17 Dec 2025
130. Ghazal TM, Hasan MK, Alshurideh MT, Alzoubi HM, Ahmad M, Akbar SS, Al Kurdi B, Akour IA. IoT for smartcities: Machine learning approaches in smart healthcare—A review. *Future Internet*. 2021 Aug 23;13(8):218, accessed Jan 21, 2026
131. Navigating the digital maze: privacy and security challenges in the era of cloud computing - Harsh Pandey, Chinmay Lunia, Er. Nisha Rathore - *IJFMR* Volume 6, Issue 3, May-June 2024. DOI [10.36948/ijfmr.2024.v06i03.23105](<https://doi.org/10.36948/ijfmr.2024.v06i03.23105>), accessed on 13 Dec 2025
132. Greser J. Proceedings of the ETHICOMP 2020. Paradigm Shifts in ICT Ethics, Logroño, Spain. 2020. legal and ethical challenges for cybersecurity of medical IoT Devices; pp. 144–146. June, accessed on 13 Dec 2025
133. Anwar S., Panda U., Mohapatra H. Legal and ethical issues in IoT based smart city: data privacy, surveillance, and citizen rights. *J. Comput. Sci. Eng. Softw. Test*. 2024;10(2):17–26. doi: 10.46610/JOCSES. 2024.v10i02.003, accessed on 17 Dec 2025

134. AboBakr, Azer M.A. Proceedings of the 2017 12th International Conference on Computer Engineering and Systems (ICCES), Cairo. 2017. IoT ethics challenges and legal issues; pp. 233–237, accessed on 17 Dec 2025
135. Zeng Q., Pan Z., Zhang Q., Han T., Zheng W., Li J., Zhang Z., Feng W., Zhen Li, Ma L., Liu K., Yuan X., Xing S. CSR evolution: new opportunities and challenges for IoT in advancing ESG practices. *Int. J. Front. Eng. Technol.* 2024;6(3):1–8. doi: 10.25236/IJFET.2024.060301, accessed on 17 Dec 2025
136. Wachter S. Proceedings of the Living in the Internet of Things: Cybersecurity of the IoT - 2018, London. 2018. Ethical and normative challenges of identification in the Internet of Things; pp. 1–10, accessed on 17 Dec 2025
137. Zakerabasali S., Ayyoubzadeh S.M. Internet of Things and healthcare system: A systematic review of ethical issues. *Health Sci. Rep.* 2022;5(6): e863. doi: 10.1002/hsr2.863, accessed on 31 Dec 2025
138. Falkowski P., Osiak T., Wilk J., Prokopiuk N., Leczkowski B., Pilat Z., Rzymkowski C. Study on the applicability of digital twins for home remote motor rehabilitation. *Sensors.* 2023;23(2):911. doi: 10.3390/s23020911, accessed on 30 Dec 2025
139. Dhinakaran D., Srinivasan L., Gopalakrishnan S., Anish T.P. An efficient data mining technique and privacy preservation model for healthcare data using improved darts game optimizer-based weighted deep neural network and hybrid encryption, accessed on 31 Dec 2025 *Biomed. Signal. Process. Control.* 2025;100 doi: 10.1016/j.bspc.2024.107168, accessed on 31 Dec 2025
140. <https://timespro.com/blog/the-intersection-of-technology-and-legal-ethics-a-balancing-act>, accessed on 31 Dec 2025
141. <https://timespro.com/blog/digital-transformation-trends-top-6-emerging-trends-and-technologic>, accessed on 31 Dec 2025
142. <https://www.classcentral.com/subject/technology-law>, accessed on 31 Dec 2025
143. <https://www.trigyn.com/insights/legal-and-ethical-considerations-smart-cities-and-iot>, accessed on 31 Dec 2025
144. <https://www.oaic.gov.au/about-the-OAIC/our-corporate-information/memorandums-of-understanding/current-memorandums-of-understanding/mou-with-the-personal-data-protection-commission-of-the-republic-of-singapore>, accessed on 31 Dec 2025
145. <https://www.pdpc.gov.sg/overview-of-pdpa/the-legislation/personal-data-protection-act>, accessed on 04 Jan 2026
146. <https://itchronicles.com/smart-city/5-smart-city-vulnerabilities/>, accessed on 04 Jan 2026
147. Javed A. R., Shahzad F., ur Rehman S., Zikria Y. B., Razzak I., Jalil Z., and Xu G., (2022), Future smart cities: requirements, emerging technologies, applications, challenges, and future aspects, *Cities.* (2022) 129, article 103794, <https://doi.org/10.1016/j.cities.2022.103794>, accessed Jan 22, 2026
148. Schaffers H., Komninos N., Pallot M., Trousse B., Nilsson M., & Oliveira A. (2011). Smart cities and the Future Internet: towards cooperation frameworks for open innovation. In Domingue, J. et al. (eds.) *Future Internet Assembly*, LNCS 6656, pp.431–446, Springer accessed Jan 22, 2026
149. Hin, L. T., & Subramaniam, R. (2012). Creating Smart Cities with intelligent transportation solutions: Experiences from Singapore. In O. Ercoskun (Ed.), *Green and Ecological Technologies for Urban Planning: Creating Smart Cities* (pp. 174-190). Hershey, PA: Information Science Reference, accessed Jan 22, 2026
150. Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., & Pichler-Milanovic, N. (2007). Smart cities-Ranking of European medium-sized cities. Vienna: Centre of Regional Science, available at: [http://www.smart-cities.eu/download/smart_cities_final_report.pdf](http://www.smart-cities.eu/download/smart_cities_final_report.pdf), accessed Jan 22, 2026
151. Institute for the Future (2011). The Future of Cities, Information, and Inclusion. A Planet of Civic Laboratories. Retrieved from <http://www.iftf.org/inclusion>. accessed Jan 22, 2026
152. Saxenian, A. (1994). Lessons from Silicon Valley. *Technology Review*, 97(5): 42-51.
153. Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, 18(2): 65-82.
154. United Nations. (2014). World Urbanization Problem. Available at: <http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf>, accessed Jan 22, 2026
155. FIREBALL (2012). Landscape and Roadmap of Future Internet and Smart Cities. FP7-ICT-2009-5, accessed Jan 22, 2026
156. Etzkowitz, H. (2008). *The Triple Helix: University-Industry-Government Innovation in Action*. London, UK: Routledge.
157. Roy, J. (2005). E-governance and international relations: A consideration of newly emerging capacities in a multi-level world. *Journal of Electronic Commerce Research*, 6(1): 44-55, accessed Jan 22, 2026
158. Etzkowitz, H. (2008). *The Triple Helix: University-Industry-Government Innovation in Action*. London, UK: Routledge, accessed Jan 22, 2026
159. Carayannis, E. G., Barth, T. R., & Campbell, D. F. J. (2012). The quintuple helix innovation model: global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, 1-2. accessed Jan 22, 2026
160. Bannister, F. & Connolly, R. (2012). The trouble with transparency: A critical review of openness in e-government. *Policy & Internet*, 3. accessed Jan 22, 2026

161. Nam, T.; Pardo, T.A. Conceptualizing Smart City with Dimensions of Technology, People, and Institutions. In Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times, College Park, MD, USA, 12–15 June 2011; pp. 282–291, accessed Jan 22, 2026
162. Tripathi G, Abdul Ahad M, Paiva S. SMS: A secure healthcare model for smart cities. *Electronics*. 2020 Jul13;9(7):1135, accessed Jan 22, 2026
163. Poongodi M, Sharma A, Hamdi M, Maode M, Chilamkurti N. Smart healthcare in smart cities: wireless patient monitoring system using IoT. *The Journal of Supercomputing*. 2021 Nov;77(11):12230–55, accessed Jan 22, 2026
164. Deakin, M.; Al Waer, H. From Intelligent to Smart Cities. *Intell. Build. Int.* 2011, 3, 140–152, accessed Jan 22, 2026
165. Dante D. Sanchez-Gallegos, Diana E. Carriazales-Espinoza, Catherine Torres-Charles and Jesus Carretero, (2025), Smart Cities: A Systematic Review of Emerging Technologies, *Smart Cities*2025, 8(5), 173; <https://doi.org/10.3390/smartcities8050173>, accessed Jan 22, 2026
166. Lashkarizadeh, M., & Salatin, P. (2012). The Effects of Information and Communications Technology (ICT) on Air Pollution, *Elixir Pollution*, 46, 8058–8064, accessed Jan 23, 2026
167. Majeed, M. T., & Ayub, T. (2018). Information and Communication Technology (ICT) and Economic Growth Nexus: A Comparative Global Analysis. *Pakistan Journal of Commerce and Social Sciences*, 12(2), 443–476, accessed Jan 23, 2026
168. Lashkarizadeh, M., & Salatin, P. (2012). The Effects of Information and Communications Technology (ICT) on Air Pollution, *Elixir Pollution*, 46, 8058–8064, accessed Jan 23, 2026
169. Webb, M. (2008). Smart 2020: Enabling the low carbon economy in the information age. The Climate Group. London, 1(1), 1–1, accessed Jan 23, 2026
170. Zhang, C., & Liu, C. (2015). The Impact of ICT Industry on CO2 Emissions: A Regional Analysis in China. *Renewable and Sustainable Energy Reviews*, 44(1), 12–19, accessed Jan 24, 2026
171. Hong, V.N.H.; Anh, L.T. Development Trends of Smart Cities in the Future—Potential Security Risks and Responsive Solutions. *Adv. Sci. Technol. Eng. Syst. J.* 2020, 5, 548–556, accessed Jan 23, 2026
172. Zekić-Sušac, M.; Mitrović, S.; Has, A. Machine learning based system for managing energy efficiency of public sector as an approach towards smart cities. *Int. J. Inf. Manag.* 2021, 58, 102074, accessed Jan 24, 2026
173. HYPER-AI Project. Revolutionizing big data processing applications with self-abstracted and self-coordinated cloud-to-edge resources. 2024. Available online: <https://hyper-ai-project.eu/>, accessed Jan 24, 2026
174. Chen, X.; Deng, Y.; Ding, H.; Qu, G.; Zhang, H.; Li, P.; Fang, Y. Vehicle as a service (VaaS): Leverage vehicles to build service networks and capabilities for smart cities. *IEEE Commun. Surv. Tutor.* 2024, 26, 2048–2081, accessed Jan 24, 2026
175. Selvan, C.; Senthil Kumar, R.; Swamidason, I.T.J.; Malin Bruntha, P.; Amanullah, M.; Arulkumar, V. Traffic Prediction Using GPS Based Cloud Data Through RNN-LSTM-CNN Models: Addressing Road Congestion, Safety, and Sustainability in Smart Cities. *SN Comput. Sci.* 2025, 6, 159, accessed Jan 25, 2026
176. <https://www.moeveglobal.com/en/planet-energy/2030-goals/smart-cities-innovation-sustainability-mobility>, accessed Jan 25, 2026
177. Bibri S. E., (2019), The anatomy of the data-driven smart sustainable city: instrumentation, datafication, computerization and related applications, *Journal of Big Data*. (2019) 6, no. 1, 1–43, <https://doi.org/10.1186/s40537-019-0221-4>, 2-s2.0-85068758273, accessed Jan 25, 2026
178. Eremia M., Toma L., and Sanduleac M., (2017), The smart city concept in the 21st century, *Procedia Engineering*. (2017) 181, 12–19, <https://doi.org/10.1016/j.pro-eng.2017.02.357>, 2-s2.0-85020681632, accessed Jan 25, 2026
179. Rochet C. and Belemlih A., J. C. Augusto, (2020), Social emergence, cornerstone of smart city governance as a complex citizen-centric system, *Handbook of Smart Cities*, 2020, Springer, Cham, [https://doi.org/10.1007/978-3-030-15145-4_29-1](https://doi.org/10.1007/978-3-030-15145-4_29-1), accessed Jan 25, 2026
180. Sibiya B., (2023), Digital Transformation of Cities through Emerging Industry 4.0 Smart Technologies and Infrastructure in South Africa, 2023, Dissertation, University of Johannesburg, <https://hdl.handle.net/10210/504660>, accessed Jan 25, 2026
181. Ghonge M. M., Pradeep N., Jhanjhi N. Z., and Kulkarni P. M., (2024), Advances in Explainable AI Applications for Smart Cities, 2024, IGI Global, <https://doi.org/10.4018/978-1-6684-6361-1>, accessed Jan 25, 2026
182. Adel A., (2023), Unlocking the future: fostering human-machine collaboration and driving intelligent automation through industry 5.0 in smart cities, *Smart Cities*, 6, no. 5, 2742–2782, <https://doi.org/10.3390/smartcities6050124>, accessed Jan 25, 2026
183. Ahmad K., Maabreh M., Ghaly M., Khan K., Qadir J., and Al-Fuqaha A., (2022), Developing future human-centered smart cities: critical analysis of smart city security, data management, and ethical challenges, *Computer Science Review*, 43, article 100452, <https://doi.org/10.1016/j.cosrev.2021.100452>, accessed Jan 25, 2026
184. Ratten V., (2017), *Entrepreneurship, Innovation and Smart Cities*, 1st edition, Routledge, <https://doi.org/10.4324/9781315407463>, 2-s2.0-85020660529, accessed Jan 25, 2026

185. Mahmud M. M. and Wong S. F., (2022), Stakeholder's perspectives of the twenty-first century skills, *Frontiers in Education*, 7, article 931488, <https://doi.org/10.3389/feduc.2022.931488>, accessed Jul 13, 2026

186. Hossain K A, (2026a), Analysis of Possibilities and Problems of Smart City: Global Perspective, *IOSR Journal of Mechanical and Civil Engineering*, Feb 2026, DOI: 10.9790/1684-2302010834, available from: https://www.researchgate.net/publication/408501906_Analysis_of_Possibilities_and_Problems_of_Smart_City_Global_Perspective, accessed Jul 13, 2026

187. Hossain K A, (2026b), STUDY TO INVESTIGATION OF BENEFITS AND CHALLENGES OF SMART CITIES IN 21ST CENTURY, *Journal of Liberal Arts and Humanities (JLAH)* Issue: Vol. 7; No. 3; March 2026 (pp. 1-30), available from: <https://jlahnet.com/wp-content/uploads/2026/03/1.pdf>, accessed Jul 13, 2026

188. Hossain K A, (2026c), Investigation of Prospects and Challenges of Smart Cities in 21st Century, *International Journal of Sustainability Management and Information Technologies*, Volume 12, Issue 1, available from: <https://sciencepublishing-group.com/article/10.11648/j.ijsm.20261201.11>, accessed Jul 13, 2026

SOCIAL SCIENCES

USE OF ARTIFICIAL INTELLIGENCE IN FAMILY RELATIONSHIPS

Dr. Aghayeva M.

Baku State University, Department of Sociology

<https://doi.org/10.5281/zenodo.21982221>

Abstract

This article analyzes the integration of artificial intelligence (AI) technologies into the daily lives of modern families. The main areas of AI application are examined. The impact of home management using smart home systems and voice assistants on children's educational trajectories and family communication is studied. Special attention is paid to the process of "domestication" of AI, in which technological devices become full-fledged actors in family diaries. The article also touches on social and ethical problems associated with the widespread application of AI in the private sphere. This study examines the impact of new digital technologies and artificial intelligence on user consciousness. Artificial intelligence is already integrated into family systems at the everyday level, but it still remains a poorly understood phenomenon in developmental psychology, personality psychology, and pedagogy. In particular, it is necessary to understand how everyday artificial intelligence affects the development of a child's individual consciousness and parent-child relationships. The aim of the study was to investigate the synergistic effects of neural networks and individual and group consciousness in family systems. The experiment demonstrated the integration of a digital assistant into the family space and the emotional response to interaction. The study showed that neural networks are increasingly integrated into the parental holons and parent-child subsystems of young families. Family systems are currently adapting to new user experiences.

Keywords: artificial intelligence, family, everyday experiences, smart home, voice assistants, digitalization, young family, parent-child relationships.

INTRODUCTION

Artificial intelligence (AI) technologies are rapidly moving beyond science fiction or highly specialized industries and are actively penetrating the most everyday aspects of human life. V.A. As Aksentov notes, the development of AI has reached a point where its presence is increasingly felt in everyday life, which opens up new prospects for increasing comfort and efficiency [Aksentov V.A. (2023) , p. 80]. One of the most important spaces of this transformation is the family — a fundamental social institution, the foundations, rituals and communication practices of which have undergone significant changes under the influence of smart technologies. The "domestication" of artificial intelligence occurs through smart speakers. The main process describing the integration of new technologies into the home is their "domestication". This term, discussed in detail by A.M. Korbut, means not only the physical placement of the device in the home, but also its integration into the social practices, routines and semantic systems of the family [Korbut A.M. (2021), p. 194]. Smart speakers with voice assistants (Yandex.Station, etc.) are a modern example of this "domestication". Initially perceived as devices for listening to music or getting quick answers to questions, these devices gradually take on the functions of mediators, organizers, and even companions. They become the central control unit of the "smart home" system: they regulate lighting and climate control, activate household appliances, and monitor security systems. This allows for the automation of many everyday tasks and frees up family time. Nowadays, verbal interaction with such devices is becoming more and more natural and resembles human communication, which contributes to their rapid adoption in the family environment [Azina D.B., Pyankova P.A., Kozitsyna M.O., Potapov D.A.,

Ivanova V.V., Kulagina E.V., Kuznetsova A.S.(2022). , p. 56]. A voice assistant that can play a fairy tale at the child's request, remind an elderly relative of the time to take medicine, or help with a recipe while cooking, ceases to be just a tool and acquires the properties of a quasi-subject, an "invisible family member" [Korbut A.M. (2021) p. 205]. In addition, artificial intelligence assistants affect the distribution of household responsibilities. For example, the ability to create shared shopping lists synchronized between the smartphones of all family members simplifies logistics and reduces communication gaps. Thus, it is not just a matter of technologically equipping the house; it is a restructuring of existing household practices and rituals. The role of artificial intelligence in the upbringing and education of children deserves special attention. Modern technologies offer a wide range of tools aimed at the development of children at home. Artificial intelligence-based educational platforms can analyze student activity and adapt teaching materials to their individual needs, set tasks at an optimal level of difficulty. This creates a gap between families who can use artificial intelligence to improve their quality of life and those who cannot. As a result, the digitalization of everyday life can become another factor in the deepening of social stratification.

METHOD AND RESEARCH

This article uses general scientific methods: experimental justification and analysis and synthesis in a theoretical overview. Empirical methods were also used in conducting socio-psychological research, in particular expert interviews (qualitative experiments), in-depth interviews, conversations and surveys. The article also presents data obtained from analysis, modeling and forecasting using a neural network (GPT4 conversation).

Topics

The study involved 49 participants, 33 of whom were members of 10 families living in Baku; 12 of whom were parents (men and women aged 27-38) and 21 children (boys and girls aged 4-14). Separately, 15 participants aged 4-13 years participated in in-depth interviews to determine the impact of the digital nanny on their mental state. The families studied included at least two children aged 7-14 years and used the digital nanny "Damla" (and/or "Sevil"). The families were characterized by a stable, positive and caring (supportive) atmosphere in the parent-child relationship.

Research Procedure

Participants signed a written consent form to participate in the experiment on the condition of anonymity (no personal data will be used in the publication). The interviews were audio-recorded and transcribed. The condition for participation in the experiment was to use the digital nanny "Damla" or its equivalent in the family environment and in the upbringing and education of their children for at least one year. Interviews with children were conducted only in the presence of parents. Parents were asked the following questions:

1. What advantages do you see in using the "smart speaker" in the education and upbringing of children?
2. What limitations have you observed in using the "Smart Speaker"?
3. In your opinion, have children's behavior, family communication style, daily routines or customs changed?

The children participating in the experiment were asked the following questions:

1. Do you enjoy communicating with "Damla" (or its equivalent)?
2. What type of communication ("reading aloud", learning or conversation") do you prefer?
3. Imagine that "Damla" gave a different answer than the parents' answer. Which idea do you think is more correct?

The in-depth interview method used with children was also used in our study.

Research Results

It turned out that the neural network predicting possible future interactions between everyday artificial intelligence and a child (GPT4 conversation) shows the development of the following communication parameters (events):

1. Personalization and adaptation of the environment. (Neural networks are used to create personalized recommendations that can personalize the living environment).

2. Changing spatial perception.

3. Automation and optimization of space (route planning, resource management, object recognition).

4. Social change.

Thus, the parameters of the digital assistant create the illusion of "understanding" the user's characteristics, the illusion of targeted communication, which can lead to the illusion of intersubjectivity, dialogic communication and, as a result, the increased influence of the neural network on the upbringing and education of the child. Changing spatial boundaries is especially important for the child: this is the basis of the ability to orient in the human coordinate system and mental normality. The standardization and thought algorithms that have become the digital norm contradict the natural human need for spontaneous, associative and creative thinking. But most importantly, neural networks are increasingly influencing social relationships and the dynamics of family interactions. The study used a survey method with 49 respondents, 53% of whom were children, the rest were parents, and about 10% were fathers. The study showed that more than 70% of respondents had used the station for a significant period of time (Figure 1). Figure 1 shows that 70% of the subjects had been in contact with AI for many years. For children aged 4 and older, this reflects the long-term and systematic impact of digital technologies on children's consciousness, the formation of their psyche under the influence of forces, structures, attitudes and values from outside the family, which leads to unknown consequences, since the content of these processes has not been subjected to competent, professional or scientific reflection. Figure 2 shows the intensity of interaction with digital technologies over the course of a day. This device is used for personal and group (family) use. Figure 2 shows that 33% of subjects encounter consumer artificial intelligence for several hours a day. Considering that an average person is awake for about 16 hours, a third of subjects spend a significant part of their time encountering poorly researched technologies whose creators' intentions are unknown to the general public

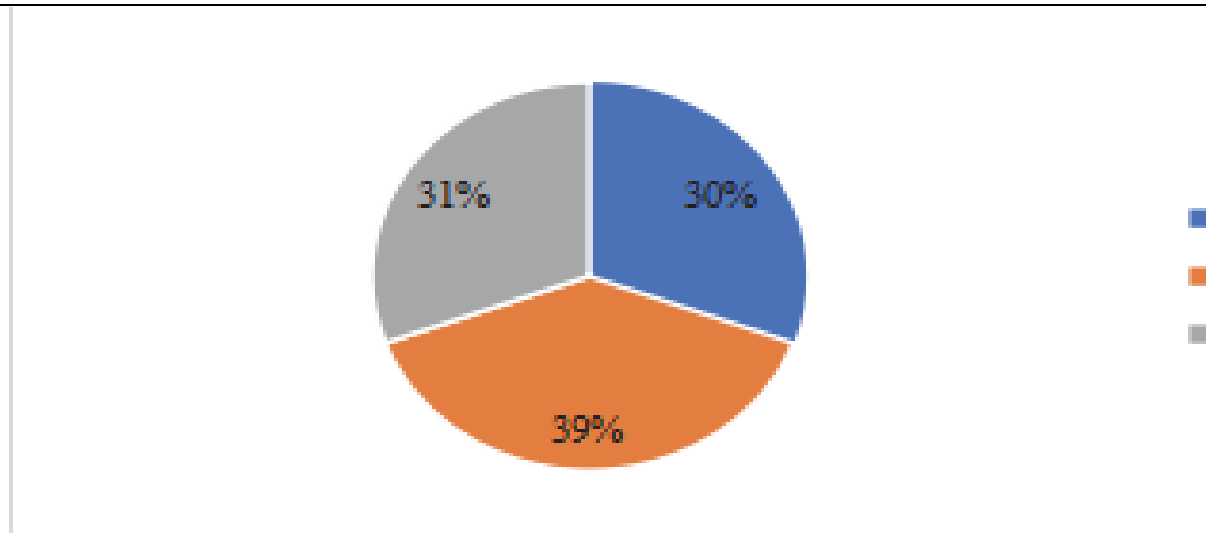


Figure 1. Time of Use of Consumer AI as a Digital Nanny by Users

This fact raises concerns about the psychological impact of household AI on children's immature and still developing minds. This is especially worrying if the

child is left alone with such digital technologies: there are known cases of household AI encouraging children to stick their fingers into electrical sockets.

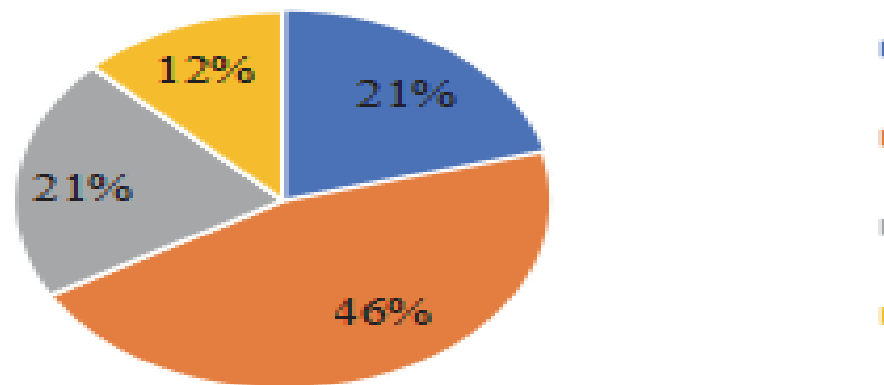


Figure 2. Time spent interacting with household AI during the day

Figure 2 shows the determinants of home AI use in parenting. Respondents are mainly interested in entertainment options, such as searching for and listening to their favorite music (89.8%) and chatting. Positive effects such as a home assistant are also noted (20.4%). However, some respondents also note, in addition to entertainment, its educational functions, such as selecting audio fairy tales and stories, educational stories for children, checking homework, and more.

To gain a more detailed picture, the study used a qualitative interview method, which revealed that all families have developed certain traditions of interaction with the "station". Most families (8 out of 9) use it for educational and pedagogical interaction with their children, and the children of the respondents prefer educational communication and conversation. The interviewees' opinions are as follows: "The station can serve as a tool for listening to stories, a source of knowledge", "my little daughter often uses Damla to find videos on how to draw correctly in the kitchen or cook delicious food", "my son plays educational games with him, and Damla reminds him when it's time to go to the gym".

"Our whole family loves to lie down and listen to Damla's stories. But for now, they still like it when I, the mother, read them. Damla has not yet been able to replace reading in real life." However, almost all of the children surveyed (more than 70%) said that they would trust the opinion of their digital assistants more than their parents. The phenomenon of a decrease or temporary loss of parental authority was noted. Over the years of using the station (or the console, or Damla on the computer), many families have developed their own traditions: welcoming the day with Damla, asking her to turn on morning music, and chatting about the weather over breakfast. "Every morning when we sit down to breakfast, I ask Damla to turn on "Morning Music". She plays cheerful songs that lift the mood and set the emotional tone of the day." "Turning on music with Damla has become much easier. My playlist has expanded. When we do things together, music almost unites us." Despite the positive reaction, some parents (15%) are wary of their children using the "smart speaker" every day. They believe that Damla can teach their children to use a neural network to solve any intellectual problems, including those included in the

school curriculum and managed. 5% of adults radically limit their school-age children's interaction with any neural assistant.

We will quote some of the opinions in full: "In general, this is just another device. Even she (Damla) can get in my way. Because my little child can ask her for an answer to a question, because she is too lazy to look for it on her own. And in my opinion, Damla's answers are often limited. I don't like my child to spend a long time with her, listening to stories for hours. Another reason: the choice of works offered by Damla is limited and sometimes quite dubious. It turns out that my child listens to the same works, and some I don't like at all from a literary point of view." "The downside of communicating with Damla is that instead of communicating with people, the child begins to communicate with her - a neural network that is far from perfect. And the child's development can be delayed or misdirected." The child's worldview is constantly being formed, so I think it is important to have experience communicating with people with different emotions and behaviors. Furthermore, Damla does not really understand the speech of young children until certain sounds are pronounced...

The in-depth interview method also revealed that attitudes towards Damla (or her analogue Sevila) and, consequently, interactions with her changed at different ages. Preschool and primary school children play with it with enthusiasm and have fun: "We play 'Guess the melody', 'We ask Damla to bark like a dog, meow like a cow, crow like a rooster', 'we set her difficult tasks, such as counting from 100 in Chinese'. In families with many devices, children arrange 'battles' between neuro-assistants: 'First I asked Damla a question, and Damla on the computer picked up her answer - it was really fun to listen to their interaction.' In families with two to four children and children from four to 13-14 years old, trust in neural network responses also varies. The older the child, the more critical they are of the answers generated by the neural network: 'I was asked to prepare a summary of the text, but I did not have a book - Damla came to help, but later it turned out that her summary was incomplete', 'Alice is good at solving math problems, but for other subjects I trust Damla, but then I check her answer Search Google again for. 'Modeling, copying style, phrase structure and its own logic.' They believe that the neural network systems ('neural nannies') in their families are tuned to interact with their child through content personalization ('as if they understand the child's speech better than we, the parents') and emotional sensitivity ('they can recognize the emotional state of children - happiness, sadness, fatigue, etc. - by their voices'; 'we hear the tone, speed and style of communication depending on the emotional background').

Discussion

New digital technologies pose challenges for the family institution, and preparation for these challenges is necessary, including specialized education and training for parents to raise children with the participation of artificial intelligence (AI) acting as digital nannies. Artificial intelligence has become part of family systems, but its impact on family relationships has not yet

been sufficiently studied. Family systems have homeostatic mechanisms (Eidemiller & Yustickis, 2008), and the rapid spread of home AI, which replaces parental functions, including the formation of family values and norms, indicates the instability of the parent-child subsystems of the family as a single system. Perhaps this effect of the reliable acceptance of AI into the parent-child subsystem reflects the consequences of the psychological phenomenon of "separation" (Bowlby, 1958). Perhaps, until the impact of AI on families is thoroughly studied and the content and form of communication between children and AI are fully controlled, it is necessary to refrain from using this information product without adult supervision. The potential of artificial intelligence can be used as a means of developing human culture, but the content and forms of interaction between artificial intelligence and children must be approved and approved by competent state and public institutions. Studies (Rayhan & Rayhan, 2023) have shown that replacing face-to-face communication with communication through artificial intelligence leads to feelings of loneliness and social isolation. Perhaps through mechanisms of transmission of traumatic experiences from generation to generation, the lack of human warmth (Schutzenberger, 2005) has manifested itself in the form of busy parents replacing communication with their children with artificial intelligence, which is seen as an alternative to face-to-face human communication. We are on the verge of a new era in which digital technologies will play a greater role in child development, and an important area of research should be to investigate the impact of household technologies integrated into family interactions on people's lives. The study has shown that scientific studies investigating this issue are underrepresented in Azerbaijan. By examining the integration of artificial intelligence into family interactions, we see artificial intelligence as a tool capable of facilitating daily tasks and supporting children's learning. This new phenomenon requires a reconsideration of traditional approaches to studying child development and socialization. The concepts of "digital nanny" and "neuronania" discussed in this article reflect the growing role of digital technologies in the lives of the younger generation. This emphasizes that traditional forms of socialization and education are increasingly being supplemented by digital forms, and in some cases completely replaced. The statistics we present give rise to an important discussion about the balance between the use of artificial intelligence in parenting and the need to preserve the familiar (traditional) format of communication between parents and their children.

Conclusion

Artificial intelligence is actively and irreversibly penetrating the everyday experiences of modern families, changing the organization of everyday life, models of raising and educating children, and the nature of intra-family communication. The process of "domestication" of artificial intelligence, which is especially manifested in the example of smart speakers, is transforming technologies from simple tools into active participants in family life. On the one hand, artificial intelligence offers solutions for automating everyday

tasks, personalizing education, and increasing overall comfort. On the other hand, its implementation raises complex questions for society and each individual family regarding the confidentiality of information, the protection of living human communication, and the risks of widening the digital divide. Prospects for the further development of artificial intelligence in everyday life [Aksentov V.A.(2023) , p. 82] indicate that its role will only increase. In these conditions, the development of skills to consciously and critically use new opportunities becomes a key task for families.

Thus, the experience demonstrated the integration of a digital assistant into the family space and the emergence of an emotional response to interaction. The introduction of a neural network into parent-child relationships can in some cases lead to a decrease in parental authority. Studies show that neural networks have become part of family systems, and artificial intelligence is integrated into parental holons and parent-child subsystems

References:

- 1.. Aksentov V.A.(2023) Artificial intelligence in everyday life: development and prospects // Science Bulletin. No. 8 (65). P. 80-82
2. Korbust A.M. (2021)Marriage of Artificial Intelligence: Intelligent Dynamics and Transformation of Everyday Life // Monitoring Public Opinion: Economic and Social Changes. . No. 1. p. 193-216
3. Azina D.B., Pyankova P.A., Kozitsyna M.O., Potapov D.A., Ivanova V.V., Kulagina E.V., Kuznetsova A.S.(2022). Speech Interaction between People and Artificial Intelligence through Chatbots and Smart Devices // Social Sciences and Humanities. Domestic and Foreign Literature. Series 6, Linguistics: Abstract Journal. . No. 1. P. 54-65
4. Volkov N. I., Lebedeva A. K. (2023)"The role of artificial intelligence in home education of children" // Questions of pedagogy. . No. 9-1. pp. 45-59
5. Grigoryev, S. V. (2020)"Digitalization of everyday life and transformation of family roles" // Man and society. . No. 4 (55). pp. 78-90
- 6.. Smirnova E. P. (2022)"Smart home" as an element of the modern family ecosystem: Social aspects // Sociological journal. . No. 3. pp. 112-128
7. Bowlby, J.(1958) The Nature of the Child's Tie to His Mother // International Journal of Psychoanalysis. – – Vol. 39. – Pp. 350–373.
8. Eidemiller, E. G., & Yustickis, V. (2008). Psychology and family psychotherapy (4th ed.). Peter.
9. Rayhan, S., Rayhan, A.(2023) The Psychological Impact of AI: Adapting to the World of Intelligent Machines // Discover World Research, July. – . – DOI: 10.13140/RG.2.2.29902.64329/1
10. Shutzenberger, A. A.(2005) "Ancestor Syndrome: Transgenerational Connections, Family Secrets, Anniversary Syndrome, Trauma Transmission and the Practical Use of Genosociograms." Moscow: Institute of Psychotherapy, . 256 p.

RISKS OF THE CIRCULAR ECONOMY AND PROSPECTS FOR THEIR NEUTRALIZATION IN GEORGIA**Vekua D.***Doctor of Economics,**Associate Professor of Georgian International University GIU, Geo**<https://doi.org/10.46361/2449-2604.8.1.202>***Vekua G.***PhD candidate in Economics**DOI: 10.5281/zenodo.18427027**<https://doi.org/10.5281/zenodo.21982223>***Abstract**

Globalization, the establishment of inclusiveness in the economy, and the scarcity of material, energy, and human resources are among the major challenges of the modern world, requiring businesses to adopt adequate responses and adapt economic systems to new demands.

In the era of technological progress and rapid social transformation, Georgia's reserves of material and labor resources remain relatively limited. The implementation of a circular economy and the application of new instruments can significantly reduce dependence on traditional resources and improve the ecological environment.

The introduction of a circular economy in Georgia requires a comprehensive approach in which all opportunities characteristic of the circulation process are utilized as efficiently as possible.

Among the many vectors of the circular economy, one of the most promising directions is the implementation of technologies characterized by a high level of secondary resource utilization, the rational recycling of household waste, and the replacement of traditional energy resources with renewable and biologically clean energy sources.

The implementation of such technologies involves numerous risks and requires specific and complex approaches to risk neutralization. The aim of this paper is to identify the risks associated with the circular economy in Georgia and determine the prospects for their mitigation.

Keywords: circular economy, business model, resources, economic system, innovation, sustainable development.

In business, the repeated use and recycling of resources within the circular economy significantly reduces the cost of goods and services while creating opportunities for additional profit generation. At the same time, the circular economy functions as an economic mechanism that can help eliminate resource scarcity in business, improve the ecological environment, and enhance competitiveness.

The share of the circular economy in the global economy remains relatively small, and there is still a long way to go in this direction. "Only 7.2% of the modern global economy currently operates according to the principles of circularity, while the dominant economic model remains linear. In 2023, approximately 2 billion tons of municipal solid waste were generated worldwide, and by 2050 this figure is expected to increase to 3.4 billion tons. The vast majority of this waste is managed unsustainably. Georgia's circularity rate does not exceed 1.3%, which is significantly below the already low global average of 7.2%." [1]

The scarcity of material and energy resources is one of the major challenges hindering sustainable global development today, while the circular economy represents the model that can help the civilized world address these problems. "Humanity consumes approximately 100 billion tons of raw materials annually for various purposes, 90% of which eventually end up in landfills." [2]

Many countries in Europe and Asia are taking significant steps toward radically improving the circularity of their economies. For example, "According to the Dutch government, their goal is to recycle approximately 50% of waste by 2030 and 100% by 2050." [2]

Waste disposal and recycling remain one of the most serious challenges for Georgia today. "Approximately 900,000 tons of waste are generated annually in Georgia, more than 75% of which is disposed of in landfills. Landfilling is the least desirable method of waste management, especially when landfills are inadequately maintained." [3]

We believe that Georgia has already lost a certain amount of time in managing this system, as short-term decisions and incorrect calculations have turned into long-term challenges. However, this does not yet mean that opportunities have been lost.

Georgia still faces shortages of material and energy resources. In order to avoid potential economic shocks, it is essential to maximize the opportunities provided by the circular economy and strengthen its mechanisms of influence on economic processes. Such an approach increases the prospects for the sustainable development of an innovative ecosystem and enables businesses to actively utilize Georgia's specific natural resources, such as solar, wind, and hydropower energy.

Considering the existing specifics, the implementation of two circular economy models appears particularly promising for Georgia. The first is related to waste recycling and involves resource recovery and their secondary use; the second involves replacing traditional energy resources with renewable and environmentally clean resources.

According to a report by the Rocky Mountain Institute (RMI), "Wind and solar energy projects are expected to account for at least 33% of global electricity generation by 2030, compared to only 12% today.

According to the report of the President of the COP28 Climate Summit, Sultan Al Jaber, "Currently,

the production cost of one megawatt-hour of solar energy is approximately \$40, and by the end of the decade this cost is expected to decrease by half to around \$20.”[4]

Georgia demonstrates promising prospects in terms of renewable energy utilization. “Since 2025, an increase in the import of renewable energy technologies has been observed in Georgia. In particular, imports of electric generating units and rotary electric converters have quadrupled, mainly due to the import of wind turbine generators. Imports of solar panels increased by 80%. The growth of renewable energy technologies is associated with the rapid pace of solar and wind power plant construction in the country.”[4]

The main advantages characteristic of the circular economy include reduced production costs, the creation of new markets, and the improvement of the ecological environment.

The improvement of the institutional framework for the circular economy in Georgia, along with the successful implementation of strategies and tactics, is primarily connected with the refinement of the legislative framework. At the same time, it is necessary to pursue active policies aimed at waste recycling and reducing environmental pollution. Under an appropriate resource circulation management model, Georgia’s economy will become more inclusive.

In the process of implementing the circular economy in Georgia, it is necessary to establish proper conditions for risk regulation, which implies the more active use of existing insurance mechanisms. This process primarily concerns insurance companies, since they specialize in risk reduction and compensation for financial losses.

Some of the existing risks are material in nature, while others are mental or cultural. High mental risks are обусловлены by the fact that the economic policy of Georgia, as a post-Soviet country, was historically oriented toward the inefficient consumption of resources (due to the abundance of resources in the Soviet Union) and based on the principle: “extract, consume, dispose.”

As for material risks, these include the high initial investment costs in this sector, the process of recycling toxic substances and waste, increasing costs associated with waste neutralization, infrastructural difficulties related to waste collection, logistical problems, and others.

At certain stages of implementation, there may also be risks associated with reduced revenues from extractive industries, additional energy consumption in recycling processes, and the need to allocate extra space for waste storage and recycling.

It should also be taken into account that recycled waste often requires additional processing due to its low-quality characteristics, which increases material risks and the cost of final products.

Moreover, the circular economy in business may encounter risks such as conflicts with shareholders and investors, as well as the low professional and qualification skills of employees.

The circular economy is characterized by all the risks generally associated with economic activity: risks

caused by natural events (natural disasters, earthquakes, droughts, etc.), business-related risks (accidents, catastrophes, fires, etc.), and financial risks (bankruptcy, decline in asset value, growth of creditor liabilities, etc.).

The risks of the circular economy also include the replacement of primary raw materials with secondary raw materials whose extraction and supply are poorly organized or insufficiently studied.

In Georgia, the most relevant issue in terms of waste recycling is plastic recycling, as plastic causes enormous damage both to the ecological environment and to human health. In order to address this problem, new governmental regulations are needed that will focus on organizing the collection and recycling of plastic products such as bottles, bags, and plastic containers.

The effectiveness of waste management mechanisms requires consensus and political will between the population and the government, which would significantly improve the investment environment in this field.

In Georgia, the management of circular economy risks should be viewed as a unified, continuous, and constantly evolving process that ensures the identification, measurement, assessment, and neutralization of existing risks in this sector.

References:

1. Douglas Webb, From a Linear Present to a Circular Future. [UNDP Georgia](#)
2. Circular Economy – New Approaches in the Global Economic System. [ISO Consulting Georgia](#)
3. Madona Gasanova, What Opportunities Does Georgia Have in Terms of Circular Economy? [BM.GE Article](#)
4. Salome Papalashvili, Solar and Wind Energy Production Will Account for More Than One-Third of Global Electricity Generation by 2030. [Forbes Georgia](#)
5. Shota Tkeshelashvili, Imports of Solar Panels in Georgia Increased 12-Fold, While Wind Turbine Imports Increased 4.5-Fold. [BM.GE Article](#)
6. Circularity Roadmap for Georgia (2024). Prepared with the support of the United Nations Development Programme and Sweden.
7. Executive Summary: Industrial Waste Mapping in the Pilot Zones of Zestafoni and Rustavi Municipalities, Georgia. [EU4Environment PDF](#)
8. National Waste Management Strategy of Georgia 2016–2030.
9. Acerbi, F., & Taisch, M. A Literature Review on Circular Economy Adoption in the Manufacturing Sector. *Journal of Cleaner Production*, 2020.
10. Velenturf, A. P. M., & Purnell, P. Principles for a Sustainable Circular Economy. *Sustainable Production and Consumption*, 2021.
11. Gusmerotti, N. M. et al. Drivers and Approaches to the Circular Economy in Manufacturing Firms. *Journal of Cleaner Production*, 2019.
12. Kumar, V. et al. Circular Economy in the Manufacturing Sector: Benefits, Opportunities and Barriers. *Management Decision*, 2019.

TECHNICAL SCIENCES

SYSTEMS MODELING OF CONSTRUCTION ORGANIZATION UNDER WARTIME RISKS: NONLINEAR INTERDEPENDENCIES, FUNCTIONAL RESILIENCE, AND TRANSFORMATIVE RECOVERY SCENARIOS

Kyryk Ya.

PhD Student,

ORCID: <https://orcid.org/0009-0004-5784-1115>

Herhi M.

PhD Student,

ORCID: <https://orcid.org/0009-0001-8184-4808>

Ratnikov D.

PhD in Economics, Doctoral Student,

ORCID: <https://orcid.org/0009-0006-0024-5384>

Hrynchevskyi S.

PhD Student,

ORCID: <https://orcid.org/0009-0002-3314-0299>

Department of Management in Construction,

Kyiv National University of Construction and Architecture, Kyiv, Ukraine

<https://doi.org/10.5281/zenodo.2198225>

Abstract

The article develops a systems model for organizing the recovery of buildings, engineering structures and infrastructure facilities under wartime risks, in which structural readiness, engineering-service availability, site accessibility, resource sufficiency, logistics continuity and digital information readiness are treated as interdependent state variables rather than independent indicators. A nonlinear functionality model, a time-dependent recovery function, a functional-resilience index and an object-prioritization procedure are integrated into a scenario-based computational experiment covering twelve representative facility classes; the results show that linear aggregation can materially overestimate post-damage functionality, while function-priority and adaptive transformative recovery substantially reduce the time required to restore critical service levels. The proposed framework is intended for engineering and organizational decision support in reconstruction programs where repeated disruptive impacts, limited repair resources and cross-infrastructure dependencies require the simultaneous coordination of technical inspection, temporary stabilization, construction sequencing, logistics and modernization decisions.

Keywords: construction organization; civil engineering; wartime risks; infrastructure resilience; functional recovery; nonlinear interdependencies; reconstruction; recovery scheduling; engineering structures; digital twin

Introduction

The organization of construction and reconstruction under wartime conditions differs fundamentally from conventional project delivery because the object of management is not a stable construction site but a dynamically changing system of buildings, engineering structures, utility networks, access routes, temporary facilities and resource flows. Damage to one element can reduce the feasibility of work on other elements: a damaged power-distribution node can suspend dewatering or lifting operations; a blocked bridge can interrupt the delivery of structural components; a failure of water supply can constrain concrete works and sanitary operation; and restrictions on access can delay technical inspection even when construction resources are available. Consequently, the engineering problem is not exhausted by determining the physical degree of damage. It also requires modeling how the technical state of assets, availability of engineering services, site accessibility, logistics, repair resources and information support jointly determine the ability of a territorial construction system to restore functions over time.

The scale of this problem is particularly visible in Ukraine. The Fifth Rapid Damage and Needs Assess-

ment (RDNA5), covering impacts through 31 December 2025, estimates direct damage at USD 195.1 billion, socioeconomic losses at USD 666.7 billion and recovery and reconstruction needs at USD 587.7 billion over a ten-year horizon; housing, transport and energy remain among the most affected sectors [1]. These figures are important not only as a measure of capital replacement requirements. They indicate that reconstruction must be organized as a multi-object, multi-network and resource-constrained engineering program in which the sequence of restoring individual facilities affects the recoverability of the entire built environment.

The theoretical basis for such analysis is provided by the engineering concept of resilience. Bruneau et al. [2] linked resilience to robustness, redundancy, resourcefulness and rapidity and showed that the performance of physical infrastructure must be considered together with organizational capabilities. Cimellaro, Reinhorn and Bruneau [3] formalized resilience through a time-dependent functionality trajectory, thereby shifting attention from a static loss estimate to the integral performance of a system during recovery. Hosseini, Barker and Ramirez-Marquez [4] demonstrated that resilience metrics differ substantially across engineering domains and that recoverability must be

modeled explicitly. Francis and Bekera [5] proposed a framework based on absorptive, adaptive and restorative capacities, while Bocchini et al. [6] emphasized the need to connect resilience decisions with life-cycle and sustainability objectives in civil infrastructure. A second stream of research concerns the dynamic and stochastic behavior of infrastructure systems. Ouyang and Dueñas-Osorio [7] showed that resilience may display nonlinear time-dependent effects and that improvement measures effective in the short term do not necessarily produce the same effect over a longer horizon. Pant et al. [8] introduced stochastic recovery metrics that distinguish vulnerability from restoration speed. The PEOPLES framework further demonstrated that physical infrastructure should be interpreted within a multi-layer system of functional dependencies rather than as an isolated asset [9]. These studies provide a strong conceptual basis for time-dependent recovery analysis, but their direct transfer to wartime construction organization requires additional representation of construction-site accessibility, temporary stabilization, repair-resource availability and repeated interference with construction operations. A third research direction addresses interdependent infrastructures and restoration optimization. Liu, Fang and Zio [10] integrated ex-ante and ex-post resilience strategies into a hierarchical optimization framework for interdependent critical infrastructures. Wu and Wang [11] formulated risk-averse post-disruption restoration under uncertainty by combining mixed-integer optimization with scenario-based stochastic programming. Bellè et al. [12] showed that the topology of coupling between critical infrastructures can materially influence resilience and that interface design can be treated as an optimization problem. At the operational level, Fan et al. [13] applied graph convolutional and deep reinforcement learning methods to road-network recovery, while Wang et al. [14] linked post-event road-network functionality to repair-order optimization. These contributions confirm that restoration sequencing is an engineering decision variable rather than merely an administrative schedule.

Digital information technologies are increasingly important for such decisions. Pregnolato et al. [15] proposed a workflow for digital twins of existing civil infrastructure and demonstrated its applicability to bridge management. Guo and Fang [16] developed lifecycle digital-twin modeling for cable-stayed bridges, while He et al. [17] showed how reduced-order modeling can accelerate the state estimation of engineering structures. Lünemann, Lindow and Goßlau [18] emphasized that digital twins for existing infrastructure should be built around functional user requirements. For wartime reconstruction, this is relevant because the value of BIM, GIS, monitoring and digital-twin technologies lies not only in visualization but also in the ability to maintain a synchronized representation of damage, work fronts, access restrictions, temporary states and restoration priorities.

Research focused directly on reconstruction also points to this convergence of civil engineering and digital decision support. Demian et al. [19] identified the potential and institutional barriers of BIM implementation in the post-war reconstruction of Ukraine. Rawat

et al. [20] systematized the role of GIS, BIM, UAVs, artificial intelligence and related digital technologies in post-disaster reconstruction, and Li, Yu and Deng [21] showed that resilience research in the construction industry remains fragmented across objects, organizational levels and uncertain impacts. At building scale, Zhao and Takahashi [22] demonstrated the importance of explicitly modeling repair scheduling in functional-recovery assessment. Recent infrastructure performance research also confirms that resilience indicators need to be embedded in practical project-assessment tools rather than treated as descriptive attributes [23], while digital-twin and AI studies increasingly move toward federated, multi-scale infrastructure models [24]. The nexus perspective of Erfani et al. [25] further supports consideration of infrastructure as a system of interdependent services and resource flows.

Despite these advances, three methodological gaps remain important for construction organization under wartime risks. First, many models aggregate performance indicators linearly and therefore underrepresent bottleneck effects: moderate deficits in power, access and logistics can interact and produce a much larger decline in feasible construction output than the arithmetic mean suggests. Second, structural or network resilience is frequently modeled separately from the organization of repair works, although inspection, stabilization, resource mobilization, construction sequencing and commissioning determine the actual recovery trajectory. Third, conventional recovery models often assume restoration to the pre-event state, whereas reconstruction programs may deliberately increase redundancy, modularity, energy autonomy, maintainability, monitoring capability and environmental safety beyond the original baseline.

Accordingly, the aim of this study is to develop and test a systems model for organizing the recovery of buildings, structures and infrastructure facilities under wartime risks, with explicit representation of nonlinear interdependencies, functional resilience and alternative recovery-transformation scenarios. The study has four objectives: (1) to formalize a state vector linking physical, engineering, logistical, resource and digital conditions; (2) to construct a nonlinear functionality function sensitive to simultaneous deficits and cross-system coupling; (3) to integrate functionality with recovery dynamics, object prioritization and resource constraints; and (4) to compare restorative, function-priority and adaptive transformative recovery scenarios using a reproducible computational experiment.

Materials and methods

The methodological approach combines systems analysis, nonlinear aggregation, time-dependent recovery modeling, priority ranking and scenario simulation. The unit of analysis is a territorial or program-level set of construction objects that may include residential and public buildings, bridges, road sections, energy facilities, water and wastewater infrastructure, district-heating nodes, shelters and logistics facilities. The model is intended for the organization stage after rapid engineering assessment has established that work can proceed subject to specified safety restrictions. It does not re-

place structural calculation, forensic examination, explosive-hazard clearance or statutory decisions on demolition and reconstruction; rather, it connects the outputs of those procedures to construction-sequencing decisions. RDNA5 [1] is used as the contextual source for the scale and sectoral composition of recovery needs. The numerical experiment presented below is a methodological scenario test, not a damage inventory of named Ukrainian facilities. Normalized inputs were assigned to twelve representative object classes to reproduce combinations of criticality, functional deficit, network centrality, repair duration and resource intensity that are typical of multi-object recovery programs. This distinction is essential: the purpose of the experiment is

to test the behavior and decision logic of the model, while project application requires replacement of normalized inputs with data from technical inspection reports, BIM/GIS models, bills of quantities, network operators, construction schedules and field monitoring. For each recovery program, the construction system at time t is represented by a normalized state vector containing six variables. Their engineering interpretation and practical sources are summarized in Table 1. All variables are scaled to the interval $[0, 1]$, where 1 denotes the target state required for full planned functionality. Because these states are mutually dependent, the model does not interpret a high value of one variable as fully compensating for a critical deficit in another.

Table 1.

State variables of the construction-recovery system

Symbol / state	Engineering interpretation	Typical project data	Scale
S(t)	Structural and physical readiness	Inspection category, stability, temporary strengthening, work-front readiness	0-1
E(t)	Availability of engineering services	Power, water, heat, drainage, communications needed for works and operation	0-1
A(t)	Site and network accessibility	Road access, bridge passability, safe zones, lifting and staging access	0-1
R(t)	Construction-resource sufficiency	Crews, machinery, materials, temporary systems, specialist contractors	0-1
L(t)	Logistics continuity	Delivery reliability, route redundancy, storage and transfer capacity	0-1
D(t)	Digital information readiness	BIM/GIS completeness, georeferenced inspection data, CDE and monitoring updates	0-1

Source: developed by the authors.

The state vector is written as:

$$\mathbf{z}(t) = [S(t), E(t), A(t), R(t), L(t), D(t)]^T$$

where each component $z_i(t) \in [0, 1]$. The weights used in the experiment were $w = (0.22, 0.21, 0.16, 0.15, 0.14, 0.12)$, with the largest shares assigned to structural readiness and engineering-service availability. The weighting structure is deliberately transparent and

can be recalibrated for a specific reconstruction program by expert judgment, entropy weighting, Bayesian updating or statistical learning from completed work packages.

To avoid the compensatory bias of a weighted arithmetic mean, the system functionality $Q(t)$ is defined as a weighted geometric state multiplied by a non-linear interdependency term:

$$Q(t) = \left[\prod_{j=1}^m z_j(t)^{w_j} \right] \left\{ 1 - \sum_{(i,j) \in \Omega} \gamma_{ij} [1 - z_i(t)][1 - z_j(t)] \right\}, \quad \sum_{j=1}^m w_j = 1 \quad (2)$$

where Ω is the set of material interdependencies and $\gamma_{ij} \geq 0$ is the interaction coefficient. In the computational experiment, four dominant couplings were retained: engineering services-accessibility, engineering services-resources, accessibility-logistics and resources-logistics. The expression in braces is bounded to the interval $[0, 1]$. This form has two useful properties for construction engineering: a severe deficit in one component cannot be fully offset by high values elsewhere, and simultaneous deficits in dependent components cause an additional loss of functionality.

The recovery trajectory for state variable j under scenario s is represented by a generalized saturation function:

$$z_{j,s}(t) = z_{j,0} + (z_{j,s}^\infty - z_{j,0}) \{1 - \exp[-(k_{j,s}t)^{p_{j,s}}]\}, \quad t \geq 0$$

where $z_{j,0}$ is the post-damage state, $z_{j,s}^\infty$ is the scenario target, $k_{j,s}$ is the recovery-rate parameter and $p_{j,s}$

controls the curvature of mobilization and commissioning. Values $p > 1$ represent an initially constrained period followed by accelerated recovery after access, design, procurement or enabling infrastructure is established. This is relevant to wartime reconstruction, where early progress can be limited by inspection and stabilization even when later construction production is comparatively rapid.

For comparison across scenarios, functionality is normalized by the pre-event reference Q_{pre} :

$$q_s(t) = \frac{Q_s(t)}{Q_{\text{pre}}} \quad (4)$$

The conventional resilience index over planning horizon T is defined as the area under the normalized functionality curve capped at the original baseline:

$$R_s(T) = \frac{1}{T} \int_0^T \min[1, q_s(t)] dt \quad (5)$$

Because reconstruction may intentionally improve performance above the original state, an additional transformation-adjusted index is used:

$$R_s^{tr}(T) = \frac{1}{T} \int_0^T q_s(t) dt, \quad G_s(T) = q_s(T) - 1 \quad (6)$$

Here $G_s(T)$ measures the terminal transformation gain relative to the pre-event baseline. A positive value does not imply unlimited capacity; it denotes that the selected functional criteria, such as redundancy, service availability, maintainability or information readiness, exceed their pre-event reference values.

Table 2.

Recovery scenarios used in the computational experiment

Scenario	Construction-organization principle	Target state
S1 Restorative repair	Object-by-object repair; limited reprioritization; restoration mainly to pre-event configuration	Return to baseline functionality
S2 Function-priority recovery	Priority to enabling infrastructure and shared services; temporary solutions; rolling resource reallocation	Fast restoration with selective improvement
S3 Adaptive transformative recovery	Function-priority sequencing plus redundancy, modularity, digital monitoring and maintainability upgrades	Recovery above baseline where justified

Source: developed by the authors.

Construction sequencing is determined by a priority score for object i . In the demonstrative case, the score combines facility criticality C_i , initial functional deficit $(1 - F_{i0})$, network centrality N_i , safety and social significance S_i , expected repair duration T_i and normalized resource intensity R_i :

$$P_i = \frac{C_i^{0.30} (1 - F_{i0})^{0.25} N_i^{0.20} S_i^{0.15}}{(T_i/10)^{0.06} R_i^{0.04}} \quad (7)$$

The exponents are normalized decision weights for the methodological experiment; they are not proposed as universal constants. Their role is to ensure that objects with high systemic criticality, large functional deficits and strong enabling effects can outrank assets that are easier to repair but less important for the recovery of the whole system.

At any planning interval, the selected work fronts must satisfy resource-capacity constraints:

$$\sum_i a_{ir} x_i(t) \leq B_r(t), \quad r = 1, \dots, R \quad (8)$$

where a_{ir} is the requirement of object i for resource r , $x_i(t)$ indicates whether the corresponding work package is active, and $B_r(t)$ is the available capacity of crews, machinery, materials or specialized services. When a new disruption or a material change in access occurs, $z(t)$, P_i and $B_r(t)$ are updated and the schedule is recalculated on a rolling horizon.

A conventional linear comparator was also calculated:

$$Q_{lin}(t) = \sum_{j=1}^m w_j z_j(t) \quad (9)$$

The difference between Q_{lin} and the nonlinear Q provides a direct measure of the extent to which a conventional compensatory index may overstate actual construction feasibility under simultaneous constraints.

The recovery parameters were selected to reproduce three distinct organizational logics rather than to fit a particular named object. S1 uses slower and nearly exponential recovery rates and returns states to their pre-event levels. S2 accelerates engineering-service, access, resource and logistics restoration and allows modest improvements in selected states. S3 applies nonlinear mobilization with higher target states reflecting redundancy, modularity, monitoring and maintainability improvements. The simulation horizon is 120 days. In addition to the deterministic run, a Monte Carlo sensitivity experiment with 5,000 realizations was performed. Recovery-rate multipliers were sampled with a standard deviation of 12%, and interaction coefficients with a standard deviation of 18%, with truncated ranges to prevent physically implausible values.

Table 3.

Normalized characteristics and calculated priority of representative recovery objects

Object class	C	F0	N	S	T, d	R	P	Rank
Power distribution substation	0.98	0.35	0.95	0.90	14	0.80	0.860	1
Water pumping station	0.96	0.40	0.92	0.92	12	0.75	0.845	2
Bridge crossing	0.93	0.30	0.94	0.88	26	0.95	0.821	3
Hospital building	0.95	0.42	0.90	0.95	18	0.85	0.811	4
District-heating node	0.88	0.48	0.82	0.85	10	0.68	0.778	5
Civil-protection shelter	0.90	0.62	0.70	0.98	8	0.55	0.733	6
Sewer collector	0.84	0.50	0.80	0.82	16	0.77	0.728	7
Urban arterial road section	0.86	0.55	0.88	0.78	20	0.72	0.715	8
Logistics hub	0.82	0.52	0.78	0.70	18	0.73	0.691	9
Residential building cluster	0.78	0.58	0.60	0.80	24	0.88	0.622	10
School building	0.72	0.60	0.55	0.74	15	0.60	0.609	11
Municipal service building	0.68	0.66	0.50	0.65	11	0.48	0.568	12

Source: authors' scenario dataset and calculations. C - criticality; F0 - initial functionality; N - network centrality; S - safety/social significance; T - expected repair duration; R - resource intensity; P - priority score.

Results and Discussion

The first result concerns the effect of nonlinearity on the assessment of immediate post-damage functionality. For the reference state used in the computational experiment, the normalized post-damage vector was $S = 0.62$, $E = 0.46$, $A = 0.58$, $R = 0.52$, $L = 0.55$ and $D = 0.72$. When these values were aggregated with the same weights by a conventional weighted sum, normalized functionality was 0.615 relative to the pre-event state. The proposed nonlinear model produced 0.520. Thus, linear aggregation overestimated feasible functionality by 15.5%. The difference is generated by simultaneous deficits in engineering systems, accessibility, resources and logistics, which are precisely the conditions under which construction organization is constrained by bottlenecks rather than by average performance.

This result has a direct civil-engineering interpretation. A building may preserve a substantial part of its load-bearing capacity, yet restoration works cannot proceed at a proportional rate if the site lacks safe access, electricity for equipment, water for technological processes, cranes or transport routes. Conversely, the restoration of a substation or bridge can create a sys-

tem-wide gain because it removes constraints from several downstream work fronts. The nonlinear term therefore functions as an engineering representation of coupled feasibility rather than as a purely mathematical penalty. Its value should be calibrated for a specific territory or project portfolio using observed dependencies, network topology, construction-method statements and expert elicitation.

The object-priority calculation is presented in Table 3. The highest priorities are assigned to the power-distribution substation, water pumping station, bridge crossing and hospital building. This ordering differs from a simple ranking by physical damage. The bridge, for example, has a comparatively long repair duration and high resource intensity, but its network centrality and large functional deficit increase its system value. The civil-protection shelter has a shorter repair duration and high safety significance, which moves it above several larger assets. Residential and school buildings remain important, but in the modeled first recovery wave their lower network centrality means that earlier restoration of enabling infrastructure can create better conditions for their subsequent reconstruction.

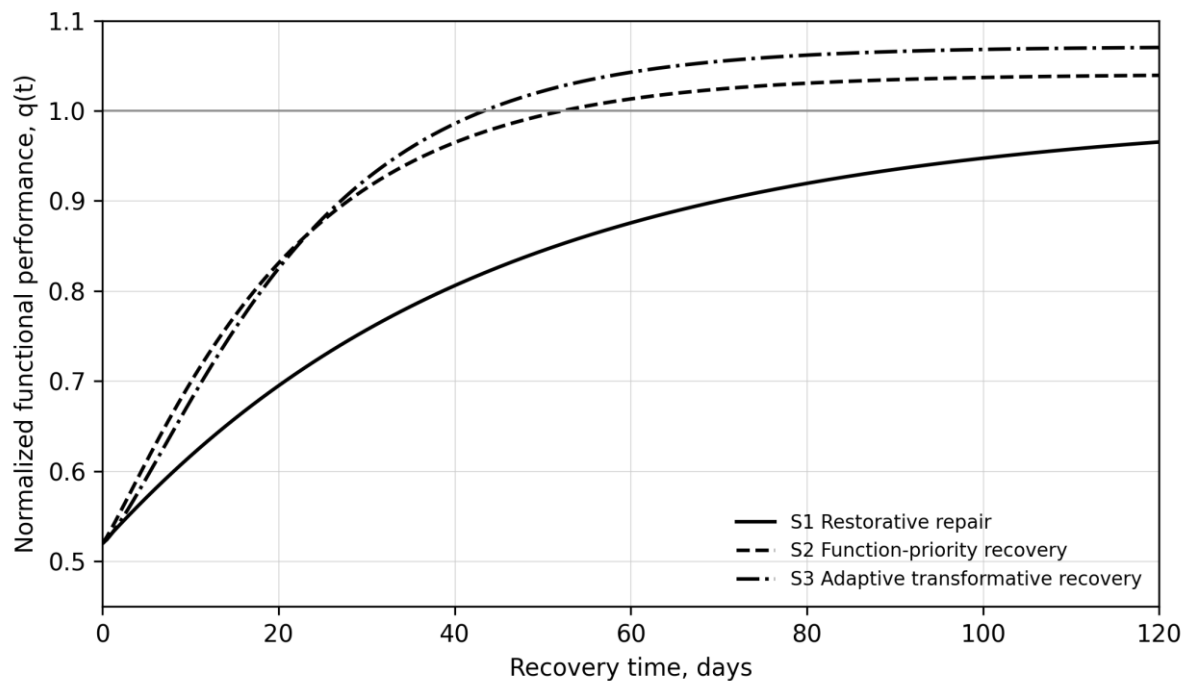


Fig. 1. Modeled functional recovery trajectories for three construction-organization scenarios
Source: developed by the authors using Eqs. (2)-(6).

Table 4.

Deterministic recovery-performance indicators							
Scenario	$q(0+)$	$q(120)$	R_{120}	$R_{tr,120}$	T_{80}, d	T_{95}, d	T_{100}, d
S1	0.520	0.965	0.834	0.834	39.0	102.5	-
S2	0.520	1.039	0.931	0.948	17.5	37.0	52.5
S3	0.520	1.070	0.932	0.967	18.5	34.0	43.5

Source: authors' calculations. R_{120} is capped at the pre-event baseline; $R_{tr,120}$ retains performance above baseline.

The scenario trajectories are shown in Fig. 1 and the numerical outcomes are summarized in Table 4. Under S1, restorative repair gradually returns individual state variables toward the pre-event configuration, but the slow recovery of engineering services, resource sufficiency and digital coordination keeps the system

below its original normalized functionality even after 120 days ($q(120) = 0.965$). The 120-day conventional resilience index is 0.834, and the modeled time to reach 95% functionality is 102.5 days. This scenario represents a technically feasible but sequentially fragmented

approach in which each asset is largely repaired as an independent construction object.

S2 changes the organization principle: objects that restore enabling services and accessibility are moved forward, temporary engineering solutions are used to open downstream work fronts, and resource allocation is updated according to functional priority. As a result, 95% functionality is achieved after 37.0 days, which is 63.9% faster than in S1. The conventional 120-day resilience index increases to 0.931, an improvement of approximately 11.7%. The terminal functionality reaches 1.039 because selected components are not merely repaired but modestly upgraded, for example through backup power connections, improved routing or more reliable temporary-to-permanent engineering interfaces.

S3 combines function-priority recovery with transformation measures introduced during reconstruction. These measures may include modular replacement, local redundancy, decentralized energy backup, standardized connection nodes, enhanced monitoring, BIM/GIS-based asset information and construction so-

lutions that improve maintainability and future repairability. In the simulation, S3 reaches 95% functionality after 34.0 days and the original baseline after 43.5 days. The conventional resilience index is close to S2 because this index is capped at the pre-event level; however, the transformation-adjusted integral increases to 0.967 and $q(120)$ reaches 1.070. This demonstrates why a conventional resilience metric alone can conceal the long-term value of rebuilding to a functionally improved state.

The comparison between S2 and S3 is also important. S3 does not dominate S2 at every instant: additional design coordination, modular interfaces and modernization can slightly delay some early work packages. In the model, S2 reaches 80% functionality in 17.5 days, compared with 18.5 days for S3. Nevertheless, S3 reaches 95% and 100% thresholds sooner and provides a higher terminal state. This pattern is realistic for construction practice because transformation measures can impose an initial planning and procurement burden while reducing later commissioning constraints and increasing the capacity of the recovered system.

Table 5.

Monte Carlo sensitivity results (5,000 realizations)

Scenario	Median R120	10th-90th percentile R120	Median T95, d	10th-90th percentile T95, d
S1	0.833	0.822-0.842	104	97-112
S2	0.931	0.925-0.936	37	35-40
S3	0.932	0.926-0.936	34	32-36.5

Source: authors' calculations with uncertain recovery rates and interaction coefficients.

A 5,000-run Monte Carlo sensitivity experiment was additionally performed by varying recovery-rate parameters with a standard deviation of 12% and interaction coefficients with a standard deviation of 18%, subject to truncation limits. The median conventional resilience indices were 0.833 for S1, 0.931 for S2 and 0.932 for S3. The 10th-90th percentile ranges were 0.822-0.842, 0.925-0.936 and 0.926-0.936, respectively. Median times to 95% functionality were 104, 37 and 34 days; the corresponding 10th-90th percentile ranges were 97-112, 35-40 and 32-36.5 days. The ranking of the scenarios therefore remained stable under moderate parameter uncertainty, although the absolute duration of restorative repair was substantially more variable because it was more sensitive to slow components and interaction penalties.

The findings are consistent with the broader resilience literature, which treats recovery speed and interdependence as central determinants of system performance [3, 7, 10-14]. Their contribution to construction engineering lies in translating these concepts into a state vector and scheduling logic that can be populated from project data. The model is particularly suitable for portfolios where technical inspection identifies many repairable objects but the simultaneous availability of crews, lifting equipment, specialized materials, access routes and engineering services is limited. In such settings, a schedule optimized only for individual project duration can be inferior to a schedule that restores shared enabling functions first.

The proposed model also clarifies the role of digitalization. Digital twins and BIM do not directly create

resilience; their effect enters through $D(t)$ and through improved estimation of the other state variables. A synchronized information environment can shorten the time between inspection and design, reduce inconsistency between damage records and work packages, support geospatial coordination of access restrictions, and permit faster updating of quantities and resource needs [15-20, 24]. In practical implementation, $D(t)$ may be measured through the completeness and currency of the common data environment, the share of assets with georeferenced inspection data, model-to-field synchronization frequency, or the availability of sensor and network-operator data.

Environmental and safety constraints should be integrated in the same decision loop. Recovery sequencing must account for debris handling, hazardous materials, damaged utility lines, contaminated areas, unstable elements and restrictions associated with explosive hazards. In the proposed framework these factors can be represented either as hard feasibility constraints on $A(t)$ and $S(t)$ or as separate state variables when environmental risk is a dominant characteristic of the program. This is consistent with the view that resilient infrastructure planning should consider interacting technological, environmental and resource systems rather than isolated assets [23, 25].

For practical application, the model can be implemented as a rolling-horizon procedure. After each inspection cycle or significant change in conditions, the state vector is updated; $q(t)$, object priorities and resource constraints are recalculated; and the next set of work fronts is selected. The planning horizon may

range from days for emergency stabilization to weeks or months for reconstruction. Such recalculation is especially important under wartime risks, where access, labor availability, energy supply and damage conditions may change faster than a conventional baseline schedule can be formally revised.

Several limitations should be recognized. First, the computational experiment uses normalized scenario data rather than observations from a single documented recovery program; therefore, the numerical thresholds should not be interpreted as universal engineering constants. Second, the interaction structure Ω is deliberately sparse for transparency, whereas real infrastructure networks may require graph-based or multilayer network representations. Third, the current recovery function is monotonic; repeated disruptive impacts would require piecewise state transitions or a stochastic jump process. Fourth, the priority function does not yet include explicit cost, carbon or contractual constraints. These limitations define the next stage of development rather than invalidate the proposed logic. Calibration on monitored reconstruction projects would allow interaction coefficients, recovery exponents and priority weights to be estimated statistically and linked to specific facility types.

Conclusions

The study developed a systems model for construction organization in recovery programs where buildings, engineering structures and infrastructure facilities are functionally interdependent and recovery resources are constrained. The central methodological result is the replacement of independent linear indicators by a nonlinear functionality function that combines a weighted geometric state with explicit interaction penalties. In the test case, the linear model overestimated immediate normalized functionality by 15.5%, demonstrating that concurrent deficits in engineering services, access, resources and logistics cannot be treated as mutually compensating. The second result is the integration of facility condition with construction sequencing. The proposed priority score links criticality, functional deficit, network centrality, safety significance, repair duration and resource intensity, allowing enabling infrastructure to be advanced when its restoration opens multiple downstream work fronts. This converts resilience from a descriptive property into an operational criterion for selecting the sequence of inspection, stabilization, repair, reconstruction and commissioning activities. The third result is the differentiation between restorative and transformative recovery. In the computational experiment, function-priority and adaptive transformative scenarios reduced the modeled time to 95% functionality from 102.5 days to 37.0 and 34.0 days, respectively. The transformative scenario also produced a terminal functional level above the prevent baseline, indicating that reconstruction decisions can simultaneously restore service and reduce future dependence on vulnerable interfaces.

For civil-engineering practice, the framework can serve as the analytical core of a BIM/GIS-enabled rolling-horizon decision-support system for multi-object reconstruction. Its further development should focus on calibration with field data from damaged buildings and

infrastructure, graph-based representation of energy-water-transport dependencies, stochastic modeling of repeated wartime disruptions, integration of structural-health-monitoring data, and multi-criteria optimization that jointly considers functional recovery time, construction cost, resource scarcity, environmental safety and life-cycle performance.

References:

1. World Bank. (2026). Ukraine Fifth Rapid Damage and Needs Assessment (RDNA5), February 2022–December 2025. World Bank. <https://doi.org/10.1596/44369>
2. Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., & von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, 19(4), 733-752. <https://doi.org/10.1193/1.1623497>
3. Cimellaro, G. P., Reinhorn, A. M., & Bruneau, M. (2010). Framework for analytical quantification of disaster resilience. *Engineering Structures*, 32(11), 3639-3649. <https://doi.org/10.1016/j.engstruct.2010.08.008>
4. Hosseini, S., Barker, K., & Ramirez-Marquez, J. E. (2016). A review of definitions and measures of system resilience. *Reliability Engineering & System Safety*, 145, 47-61. <https://doi.org/10.1016/j.res.2015.08.006>
5. Francis, R., & Bekera, B. (2014). A metric and frameworks for resilience analysis of engineered and infrastructure systems. *Reliability Engineering & System Safety*, 121, 90-103. <https://doi.org/10.1016/j.res.2013.07.004>
6. Bocchini, P., Frangopol, D. M., Ummenhofer, T., & Zinke, T. (2014). Resilience and sustainability of civil infrastructure: Toward a unified approach. *Journal of Infrastructure Systems*, 20(2), 04014004. [https://doi.org/10.1061/\(ASCE\)IS.1943-555X.0000177](https://doi.org/10.1061/(ASCE)IS.1943-555X.0000177)
7. Ouyang, M., & Dueñas-Osorio, L. (2012). Time-dependent resilience assessment and improvement of urban infrastructure systems. *Chaos*, 22(3), 033122. <https://doi.org/10.1063/1.4737204>
8. Pant, R., Barker, K., Ramirez-Marquez, J. E., & Rocco, C. M. (2014). Stochastic measures of resilience and their application to container terminals. *Computers & Industrial Engineering*, 70, 183-194. <https://doi.org/10.1016/j.cie.2014.01.017>
9. Cimellaro, G. P., Renschler, C., Reinhorn, A. M., & Arendt, L. (2016). PEOPLES: A framework for evaluating resilience. *Journal of Structural Engineering*, 142(10), 04016063. [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0001514](https://doi.org/10.1061/(ASCE)ST.1943-541X.0001514)
10. Liu, X., Fang, Y.-P., & Zio, E. (2021). A hierarchical resilience enhancement framework for interdependent critical infrastructures. *Reliability Engineering & System Safety*, 215, 107868. <https://doi.org/10.1016/j.res.2021.107868>

11. Wu, J., & Wang, P. (2021). Risk-averse optimization for resilience enhancement of complex engineering systems under uncertainties. *Reliability Engineering & System Safety*, 215, 107836. <https://doi.org/10.1016/j.ress.2021.107836>
12. Bellè, A., Abdin, A. F., Fang, Y.-P., Zeng, Z., & Barros, A. (2023). A resilience-based framework for the optimal coupling of interdependent critical infrastructures. *Reliability Engineering & System Safety*, 237, 109364. <https://doi.org/10.1016/j.ress.2023.109364>
13. Fan, X., Zhang, X., Wang, X., & Yu, X. (2023). A deep reinforcement learning model for resilient road network recovery under earthquake or flooding hazards. *Journal of Infrastructure Preservation and Resilience*, 4, 8. <https://doi.org/10.1186/s43065-023-00072-x>
14. Wang, H., Xiao, J., Li, S., & Zhai, C. (2024). Resilience assessment and optimization method of city road network in the post-earthquake emergency period. *Earthquake Engineering and Engineering Vibration*, 23, 765-779. <https://doi.org/10.1007/s11803-024-2254-8>
15. Pregnolato, M., Gunner, S., Voyagaki, E., De Risi, R., Carhart, N., Gavriel, G., Tully, P., Tryfonas, T., Macdonald, J. H. G., & Taylor, C. (2022). Towards Civil Engineering 4.0: Concept, workflow and application of Digital Twins for existing infrastructure. *Automation in Construction*, 141, 104421. <https://doi.org/10.1016/j.autcon.2022.104421>
16. Guo, X.-Y., & Fang, S.-E. (2024). Digital twin based lifecycle modeling and state evaluation of cable-stayed bridges. *Engineering with Computers*, 40, 885-899. <https://doi.org/10.1007/s00366-023-01835-6>
17. He, X., Lai, X., Li, K., Wang, S., Song, X., & Sun, W. (2024). Toward a shape-performance integrated digital twin based on hybrid reduced-order modeling for engineering structures. *Engineering with Computers*, 40, 1157-1175. <https://doi.org/10.1007/s00366-023-01862-3>
18. Lünemann, P., Lindow, K., & Goßlau, L. (2023). Implementing digital twins in existing infrastructures. *Forschung im Ingenieurwesen*, 87, 421-429. <https://doi.org/10.1007/s10010-023-00639-w>
19. Demian, P., Hassan, T. M., Kalmykov, O., Demianenko, I., & Makarov, R. (2024). BIM implementation in post-war reconstruction of Ukraine. *Buildings*, 14(11), 3495. <https://doi.org/10.3390/buildings14113495>
20. Rawat, A., Witt, E., Roumyeh, M., & Lill, I. (2024). Advanced digital technologies in the post-disaster reconstruction process-A review leveraging small language models. *Buildings*, 14(11), 3367. <https://doi.org/10.3390/buildings14113367>
21. Li, J., Yu, H., & Deng, X. (2024). A systematic review of the evolution of the concept of resilience in the construction industry. *Buildings*, 14(9), 2643. <https://doi.org/10.3390/buildings14092643>
22. Zhao, H., & Takahashi, N. (2025). Resilience evaluation of post-earthquake functional recovery for precast prestressed concrete buildings. *Applied Sciences*, 15(13), 6994. <https://doi.org/10.3390/app15136994>
23. Nor Shahrudin, N. S., & Mustaffa, N. K. (2024). Developing performance assessment tools for sustainable and resilient infrastructure project. *Innovative Infrastructure Solutions*, 9, 483. <https://doi.org/10.1007/s41062-024-01778-x>
24. Afolabi, A., Ogunrinde, O., & Zabihollah, A. (2025). Digital Twin and AI models for infrastructure resilience: A systematic knowledge mapping. *Applied Sciences*, 15(24), 13135. <https://doi.org/10.3390/app152413135>
25. Erfani, T., Mortazavi Naeini, M., Borgomeo, E., Anvari, M., Hurford, A., Erfani, R., Zarei, A., Matin, M. A., & Madani, K. (2024). Sustainability nexus AID: Infrastructure resilience. *Sustainability Nexus Forum*, 32, 13. <https://doi.org/10.1007/s00550-024-00551-z>

№186/2026

Norwegian Journal of development of the International Science

ISSN 3453-9875

It was established in November 2016 with support from the Norwegian Academy of Science.

DESCRIPTION

The Norwegian Journal of Development of the International Science, established in 2016 with support from the Norwegian Academy of Science, offers a platform for global researchers, academics, and students. Publishing 24 times annually, it covers current science topics. Submitting your article provides exposure to a diverse audience, enhancing your career. Our commitment to research and SEO ensures timely visibility. Submit to the Norwegian Journal of Development of the International Science today and join esteemed authors.

Editor in chief – Karin Kristiansen (University of Oslo, Norway)

The assistant of the editor in chief – Olof Hansen

- James Smith (University of Birmingham, UK)
- Kristian Nilsen (University Centre in Svalbard, Norway)
- Arne Jensen (Norwegian University of Science and Technology, Norway)
- Sander Svein (University of Tromsø, Norway)
- Lena Meyer (University of Gothenburg, Sweden)
- Hans Rasmussen (University of Southern Denmark, Denmark)
- Chantal Girard (ESC Rennes School of Business, France)
- Ann Claes (University of Groningen, Netherlands)
- Ingrid Karlsen (University of Oslo, Norway)
- Terje Gruterson (Norwegian Institute of Public Health, Norway)
- Sander Langfjord (University Hospital, Norway)
- Fredrik Mardosas (Oslo and Akershus University College, Norway)
- Emil Berger (Ministry of Agriculture and Food, Norway)
- Sofie Olsen (BioFokus, Norway)
- Rolf Ulrich Becker (University of Duisburg-Essen, Germany)
- Lutz Jäncke (University of Zürich, Switzerland)
- Elizabeth Davies (University of Glasgow, UK)
- Chan Jiang (Peking University, China) and other independent experts

1000 copies

Norwegian Journal of development of the International Science

Iduns gate 4A, 0178, Oslo, Norway

email: publish@nor-ijournal.com

site: <https://nor-ijournal.com>



© 2026 The Norwegian Journal of Development of the International Science

nor-ijournal.com

