Petroleum-Gas
University of Ploiești
Faculty of Economic
Sciences

PROCEEDINGS
of the 4th International Conference

CREATIVITY AND INNOVATION
IN
DIGITAL ECONOMY



Editors:

Mirela Panait,
Irina Rădulescu,
Bogdan Tudorică,
Cătălin Popescu,
Marian Cătălin Voica,
Marius Nica

CIDE 2025

Petroleum-Gas University of Ploiești

Faculty of Economic Sciences

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Chairs of the conference

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- ✓ Scholars, freelance researchers, and PhD. candidates are invited to submit their abstracts related to the topics of the conference and development economics in general to be considered for presentation at the annual conference of the Faculty of Economic Sciences from Petroleum-Gas University of Ploiești, Romania.

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- ✓ Innovative open business models and platforms (*Section 1*)
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Beyond the Norm: Education for Sustainability as an Innovation Ecosystem

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Abstract: *The global ecological transition and the growing socio-environmental complexity require a radical redefinition of educational and legal systems. Education for sustainability (EfS) is no longer a peripheral issue, but a transversal epistemological paradigm that integrates law, pedagogy and active citizenship. This article analyzes the convergence between multilevel regulatory frameworks — from the 2030 Agenda to the Paris Agreement, from the European Green Deal to Italian constitutional reforms — and educational innovations oriented towards systemic competences, critical thinking and intergenerational justice. Through a theoretical and regulatory review, a model of adaptive school-territory ecosystem is proposed, capable of transforming legislative prescriptions into meaningful educational practices. The contribution highlights how sustainability, understood as a strategic investment, can strengthen democratic resilience and planetary stewardship, overcoming the risk of symbolic implementations (greenwishing) and promoting a culture of shared responsibility.*

Keywords: *education for sustainability; ecological citizenship; 2030 Agenda; pedagogical innovation; transdisciplinarity; intergenerational justice; multi-level governance; democratic resilience; green transition; educational policies.*

JEL Classification: *I20, 121, 128, Q01, Q56, K32, 035*

1. Introduction

The ecological transition and the growing socio-environmental complexity have accelerated a redefinition of the relationship between education, law and civic responsibility. Sustainability is no longer a sectoral issue, but a transversal epistemological paradigm that reorganizes the meaning and purpose of education as a public good and infrastructure of substantial democracy. In this perspective, Education for Sustainability (EfS) abandons a merely informational approach to configure itself as a training device oriented towards systemic skills, critical thinking, civic agency and intergenerational justice.

At the global and supranational level, the 2030 Agenda and the 17 Sustainable Development Goals (SDGs) set measurable goals for sustainable development and recognize the role of school as a transformative lever (United Nations General Assembly, 2015). These guidelines have been further corroborated by the international climate framework defined by the Paris Agreement (UNFCCC, 2015) and by European policies which, with the Green Deal (European Commission, 2019) and the Council Recommendation on "learning for the green transition" (Council of the European Union, 2022), explicitly link regulatory obligations and pedagogical innovation.

In Italy, a progressive legislative trajectory — Law 92/2019 on civic education; the constitutional reform of Articles 9 and 41 (2022), which strengthen the protection of the environment, biodiversity and ecosystems also in the interest of future generations; the new *National Guidelines 2025* — has reshaped the mandate of the school as a laboratory of ecological citizenship and culture of sustainability (Italy, 2019; MIM, 2025). This paper critically analyzes this convergence, illustrating how law can act as a catalyst and enabling framework for high-impact teaching practices, such as those

that emerged in the national **#IosonoAmbiente program** and in the initiatives promoted by UNESCO's **Greening Education Hub** (cf. Sirleto, 2024; UNESCO references in Sirleto).
The aim of the article is to propose a transdisciplinary reconfiguration of educational and legal systems as adaptive ecosystems capable of transmitting complexity and interdependence of global challenges, promoting a shift from normative prescription to cultural transformation.

2. Literature Review

This review examines, on the one hand, the theoretical developments that support EfS as transversal knowledge and, on the other hand, the regulatory evolution that has enabled its curricular implementation.

2.1. Theoretical Review — Epistemological and Pedagogical Foundations

The literature on EfS shows a shift from "additive" approaches (thematic units on the environment) to "integrative" paradigms (sustainability as a curriculum organizing principle). In this transition, four epistemological assumptions are central:

- **Transdisciplinarity and systems thinking.** Sustainability requires going beyond disciplinary boundaries to read causal links, feedback, and tradeoffs between ecological, economic, social, and institutional dimensions (United Nations General Assembly, 2015).
- **Agency and ecological citizenship.** Learning is not limited to the acquisition of knowledge but enables the capacity for informed action and civic participation oriented towards the common good (Council of the European Union, 2022).
- **Intergenerational justice.** Present choices must reflect responsibility towards future generations, in line with the evolution of the Italian Constitution (Articles 9 and 41) and the principle *of no significant harm* of European policies (European Commission, 2019).
- **Transformative learning.** Authentic, inquiry-based experiences and service-learning support lasting changes in attitudes and behaviors (Sirleto, 2024; Valleriani, 2014).
  At the educational level, international convergence emphasizes key competences: sustainability literacy (knowledge and data), critical thinking, complex problem solving, collaboration, design imagination (*design futures*), and the ethical-civic dimension (Council of the European Union, 2022; European Commission, 2019).

Table 1. Four conceptual pillars of EfS and educational implications

Pillar	Description	Educational implications	References
Transdisciplinarity	Integration of disciplinary knowledge in a systemic perspective	Interdisciplinary units, reality tasks, system maps	UN General Assembly (2015)
Ecological citizenship	Agency and participation for the common good	Service learning, civic projects, deliberation	EU Council (2022)
Intergenerational justice	Responsibility towards the future	Impact assessments, scenarios, public ethics	European Commission (2019)
Transformative learning	Change of mindset and practices	Inquiry, critical reflection, *capstone* community	Sirleto (2024); Valleriani (2014)

2.2. Theoretical Review - Multi-level regulatory framework and governance

The normative dimension is the *sine qua non* for generalizing EfS in education systems.

- **Global picture.** The 2030 Agenda sets educational targets (SDG 4.7) to acquire knowledge and skills relevant to sustainable development (United Nations General Assembly, 2015). The Paris Agreement commits States to enhancing education, training and public awareness on climate change (Art. 12) (UNFCCC, 2015).
- **European framework.** The European Green Deal sets out the trajectory of climate neutrality by 2050, linking the green transition and investment in human capital and skills (European Commission, 2019). The Council Recommendation (2022/C 243/01) introduces a competence framework for learning about the green transition, promoting whole school approaches and territorial partnerships (Council of the European Union, 2022).
- **Italian framework.** Law 92/2019 institutionalizes civic education (at least 33 hours per year), including the environment and sustainable development among the founding axes; the reform of Articles 9 and 41 of the Constitution enhances environmental protection and the economic and social sustainability of production initiatives; the *National Guidelines 2025* reorient the curriculum towards ecological citizenship skills and integrated knowledge (Italy, 2019; MIM, 2025).

Table 2. Matrix of alignment between regulatory tools and teaching practices

Level	Instrument/Act	Normative device	Curriculum/Practical Implications	References
Global	Agenda 2030 (SDG 4.7)	Sustainability skills target	Transversal modules, EfS skills rubrics	UN General Assembly (2015)
Global	Paris Agreement (Art. 12)	Education, training, awareness	Climate education, citizen science	UNFCCC (2015)
EU	Green Deal	Neutrality 2050, *do no significant harm*	Green STEAM projects, "green" PCTOs	European Commission (2019)
EU	2022 Council Recommendation	Competence Framework & Wholeschool	School governance, partnerships, ESD	EU Council (2022)
EN	Law 92/2019	Civic education (33 h/year)	Vertical curriculum, skills assessment	Italy (2019)
EN	Indications 2025	Curriculum for ecological citizenship	Interdisciplinary units and service learning	MIM (2025)

3. Discussion

3.1. From prescription to transformation: the role of law as an "enabler"

The law, often perceived as a prescriptive apparatus, plays an enabling function in the context of the EfS: it defines common standards, legitimizes educational innovations and guarantees equity in access. The 2030 Agenda and the Paris Agreement provide the value and teleological grammar of sustainability; EU instruments translate these principles into investment and skills policies; the Italian framework institutionalizes them in curricula and learning outcomes (United Nations General Assembly, 2015; UNFCCC, 2015; European Commission, 2019; Council of the European Union,

2022; Italy, 2019; MIM, 2025).

3.2. Curricular design and skills: a strategic axis

Schools that adopt *wholeschool* approaches achieve consistency between governance, teaching, spaces and communities. EfS skills — systemic, critical, design, civic — require active methodologies (inquiry, *project-based*, service learning) with evaluation rubrics that combine knowledge, processes and social/environmental impact (Council of the European Union, 2022; Valleriani, 2014). The *2025 Guidelines* offer the opportunity to stabilize such practices in the vertical curriculum (MIM, 2025).

3.3. Multi-level governance: alignment and capacity building

Multilevel convergence is effective only if accompanied by *capacity building* (teacher training, widespread leadership, territorial networks) and monitoring mechanisms. Programs such as **#IosonoAmbiente** and the **Greening Education Hub** (dissemination of resources, *toolkits*, communities of practice) show how policy can radiate into concrete practices, promoting scalability and local adaptation (Sirleto, 2024).

3.4. Challenges and risks: avoiding greenwishing

Risks of symbolic implementation (*greenwishing*) persist: fragmentation, curricular overload, asymmetric assessment of skills, territorial inequalities. Strategies are needed:

- **Essential curricula** with integrated and measurable EfS objectives (SDG 4.7 alignment).
- **Structural training** for managers and teachers on internal/external design of the curriculum.
- **Stable partnerships** with local authorities, responsible companies, the third sector.
- **Monitoring** of learning outcomes and environmental impacts of the school (carbon literacy, energy audits, *student led sustainability councils*).

  These guidelines reduce the distance between norm and practice and nurture democratic resilience (European Commission, 2019; Council of the European Union, 2022).

3.5. An operational model: "adaptive ecosystems" school-territory

We offer a model in three layers:1) **Strategic regulation** (objectives, standards, accountability); 2) **Curricular-methodological** (interdisciplinary units, rubrics, authentic assessment); 3) **Community-impact** (service learning, community educational pacts, dissemination). Exchanges between layers (feedback) guarantee organizational learning and scalability, in line with the logic of *policy learning* and with the transdisciplinarity EfS (United Nations General Assembly, 2015; MIM, 2025).

4. Conclusions

Education for sustainability today is configured as transversal and practical knowledge, oriented towards skills for the twenty-first century and an informed ecological citizenship. The literature and the multilevel regulatory framework converge in qualifying schools as nodes of adaptive ecosystems capable of addressing complexity through transdisciplinarity, participatory planning and public accountability.

The main contribution of this article is twofold: (i) to show the role of law as an enabling infrastructure for systemic educational innovations; (ii) outline an operating model that integrates policy, curriculum and community. Priorities for the implementation phase include: continuous staff training, assessment tools for EfS skills, *wholeschool* governance, territorial partnerships, and impact monitoring. The critical shift is from regulatory compliance to cultural transformation: a strategic investment for

democratic resilience and care for the planet.

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The link between online universities and sustainability: benefits and trade-offs in the Italian context

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Abstract: *Humanity is experiencing an extremely challenging period of widespread degradation, characterized by the crossing of numerous planetary boundaries, the increased presence of climate-altering gases in the atmosphere, the rising extinction rates of numerous species, the increase in anthropogenic biogeochemical pollution, and the illogical and indiscriminate use of non-renewable resources and the unsustainable use of renewable resources (i.e. without waiting for natural regeneration rates).*
If we add to all this the demographic increase predicted by the United Nations (the world population is forecast to continue growing, reaching approximately 9.7 billion by 2050), it is easy to see how all relevant sectors must intervene to halt this negative spiral.
Many sectors are facing significant challenges, think of energy or agri-food for example, but one sector that is too often overlooked is education; this paper aims to investigate how online universities in the Italian context can contribute to decarbonization and inclusiveness and, more generally, can provide important boosts for holistically addressing all the key ESG aspects of (nowadays inflated) sustainability. It should be noted immediately that sustainability, to be truly effective and transformative, must develop in all its facets, without limiting itself to environmental sustainability, as unfortunately often occurs by focusing only on factors like energy savings or the reduction of total polluting emissions. Issues such as social sustainability, for example, are fundamental, and without them, the foundations of a fair and just transition are likely to crumble.

Keywords: *Online universities; Green transition; Distance learning; Emissions reduction; Sustainable development.*

JEL Classification: *I23; O33; L86*

1. Introduction

It is important to start from the definition of online universities and then to provide a brief introduction to the Italian online universities' regulatory framework and to the general overview of those already active in the Italian context. Online universities are institutions that enable the delivery of teaching remotely wherever permitted (either by government regulations or practical considerations). This systematically facilitates students' access to lectures and exams, allowing them to easily complete tasks from home that once required travel, logistical arrangements, and expense. In the Italian context, digital universities represent a flexible and effective alternative to traditional models, which allow students to attend lectures and access course materials remotely via their advanced digital platforms. Furthermore, for online universities recognized by the Italian Ministry of University and Research (MUR), the qualifications awarded are equivalent to those awarded by traditional universities, ensuring a high standard of quality.
Before analysing its advantages and disadvantages in detail, it is essential to provide a regulatory framework and a detailed overview of its specific characteristics, starting with the fact that Italian online universities currently offer approximately 300-degree programs and over 250,000 enrolled students. These figures demonstrate exponential growth over the last decade (with numbers quadrupling using the 2021/2022 academic year as a benchmark), undeniable proof of a growing phenomenon that, for various reasons, is increasingly taking root within the Italian student community. The Italian online university community is experiencing significant growth: in the first half of 2025, enrolment in online degree programs increased by 51% compared to 2024, and by a whopping 113% compared to 2023. This change

is particularly affecting younger students (the number of students under 25 has grown by 78% in just one year, reaching 34.5% of the entire online university population, reflecting a progressive decline in the average age: more than one in three students now choose distance learning as their primary option for their studies; at the same time, there has been growth among students over 56, who have increased by 89.2% compared to 2024).

Since the 2000s (the first, the Guglielmo Marconi Telematic University, was founded in 2004), online universities have also been introduced in Italy. These offer e-learning courses for all three cycles of higher education, with the requirement that only final exams and thesis defences be held in person.

Regarding the regulatory framework at the European level, on July 13, 2001, the Council of Ministers of Education of the European Union issued a resolution on e-learning (European Union 2001/C 204/02), encouraging Member States to experiment with new learning methods and approaches and in turn, the European Parliament (Decision No 2318/2003/EC) and the Council, decided to support EU Member States' initiatives in the field of distance learning with specific resources, prioritizing the university sector as the priority area for intervention. Remaining within the geographical scope of interest, namely Italy, it is worth mentioning the 2003 budget law[1], which, among the initiatives accompanying the actual financial provisions, in Article 26, paragraph 5, established that the Minister for Innovation and Technology may, by decree, determine the criteria and procedures for accrediting distance learning university courses, which were then established by subsequent inter-ministerial decrees (based on these, the Ministry of Education, University and Research subsequently issued individual recognition decrees for eleven online universities); online universities in Italy were therefore officially established in 2003 with the Decree of 17 April 2003 (Ministero dell'Istruzione, dell'Università e della Ricerca), signed by Minister of Education Letizia Moratti (this decree established online universities to offer new opportunities for higher education accessible remotely via online platforms, thus responding to a growing demand for flexibility, especially among students who work or have other personal commitments and allowing students to balance study and work or private life, making it possible to earn a degree through distance learning, which indeed allows students to follow lessons anytime and anywhere). It is also interesting to note that on September 27, 2013, the Minister of Education Maria Chiara Carrozza signed the decree on the three-year 2013-2015 university planning, containing a ban on the opening of new state and online universities (except for mergers).

The regulatory framework for Italian online universities was recently updated with Ministerial Decree no. 1835 of December 6, 2024, signed by the Minister of Universities and Research, Anna Maria Bernini, which aims to align the quality standards of online teaching with those of traditional universities. The main regulatory features envisaged include, for example, the requirement to take all exams, including final exams, in person at accredited institutions (except in exceptional cases); a guarantee that at least 20% of teaching will be delivered synchronously (live) to encourage direct interaction between students and teachers; the necessity of quality checks on teaching and the organization of the institutions provided by the National Agency for the Evaluation of the University and Research System (ANVUR); the requirement that each student will be assigned an individual tutor for support and monitoring; mandatory continuing education for teachers (these rules apply to all universities, both online and traditional, that offer online courses); increased attention to the student-teacher ratio for online courses (where an adequate number of tenured teachers is required to maintain high quality standards); and minimum limits on the ratio of teachers to enrolled students. This regulation is part of an evolving framework aimed at ensuring quality, transparency, and a better online learning experience for Italian students. The accreditation of online universities is managed by the Ministry of University and Research (MUR) and, specifically, 11 Italian online universities are recognized as being able to award degrees with legal value equal to those of traditional universities (all privately owned, one of which is somewhat unique, being promoted exclusively by public bodies that are entirely non-profit but also non-state-owned): IUL Telematic University, e-Campus Telematic University, Giustino Fortunato Telematic University, Guglielmo Marconi Telematic University, Uninettuno International Online University, Leonardo da Vinci Telematic University, Niccolò Cusano Telematic University, Pegaso Telematic University, San Raffaele Telematic University, UNITELMA Sapienza Telematic University , and Universitas Mercatorum Telematic University. The table below provides the specifics for Italy's eleven online universities.

[1] In this case, it is expressly stated that the recognition of online universities will occur without cost to the State.

Table 1. List of online universities recognized by the Italian Ministry of University and Research (MUR)

University name and logo	Year of foundation	University headquarters	# online degree courses	# online post degree courses	Ownership	# students enrolled (Year 2025)	Level – Judgment ANVUR[2] (Year 2025)
IUL Telematic University	2005	Florence	6	8	Public Non-State	1.767	Dtel – Conditioned
e-Campus Telematic University	2006	Novedrate (Como)	62	100+	Private	42.604	Ctel – Satisfying
Giustino Fortunato Telematic University	2006	Benevento	10	7	Private	2.189	Ctel – Satisfying
Guglielmo Marconi Telematic University	2004	Rome	44	60+	Private	18.787	Ctel – Satisfying
International Telematic University Uninettuno	2005	Rome	34	12	Private	16.908	Btel – Fully Satisfying
Telematic University Leonardo da Vinci	2004	Torrevecchia Teatina (Chieti)	3	9	Private	314	Dtel – Conditioned
Telematic University Niccolò Cusano	2006	Rome	49	100+	Private	18.400	Ctel – Satisfying
Telematic University Pegaso	2006	Naples	25	100+	Private	94.801	Ctel – Satisfying
Telematic University San Raffaele	2006	Rome	17	50+	Private	12.673	Ctel – Satisfying

[2] If the final score is over 7,5, the level is "Atel" and the judgment is "very positive", if the final score is between 6,5 and 7,5, the level is "Btel" and the judgment is "fully satisfying", if the final score is between 5,5 and 6,5, the level is "Ctel" and the judgment is "satisfying", if the final score is between 5,5 and 4, the level is "Dtel" and the judgment is "conditioned", if the final score is under 4, the level is "Etel" and the judgment is "unsatisfactory".

Telematic University UNITELMA Sapienza	2004	Rome	24	50+	Private	3.553	Ctel – Satisfying
Telematic University Universitas Mercatorum	2006	Rome	35	30+	Private	54.879	Ctel – Satisfying

Source: author's elaboration

There is also an additional ANVUR ranking to take into consideration, namely the one relating to the results of the VQR (Research Quality Evaluation): in April 2022, the results for the period 2015-2019 were released, which highlight the excellent result for the San Raffaele Telematic University of Rome, ranked first for research quality among online universities and fifth among the entire national university system. For the most recent period, 2020-2024, the evaluation of scientific products, case studies, and the infrastructure involved will take place during 2025 and 2026, with the publication of the results expected in March 2026 and the final report by May 2026. If we were to classify them according to different criteria, we should highlight the San Raffaele Telematic University of Rome for the quality of its research as mentioned above (according to VQR provided by ANVUR), the Uninettuno International Online University (according to the levels of ANVUR), the Guglielmo Marconi Telematic University for its quality/price ratio (the most affordable annual fees start from €1500/year), and finally the e-Campus Telematic University for the variety of its educational offerings, offering more than 60 degree courses; to rank them according to their preference among students, it is interesting to report the results of the survey conducted by Unitelematiche.it[3], which drew up the ranking[4] of the best online universities based on the opinions and level of satisfaction of enrolled and graduated students: in first place is Pegaso Telematic University, followed by Universitas Mercatorum Telematic University, San Raffaele Telematic University, Uninettuno International Telematic University, IUL Telematic University, Giustino Fortunato Telematic University, UNITELMA Sapienza Telematic University, Niccolò Cusano Telematic University, e-Campus Telematic University, Leonardo da Vinci Telematic University. Special mention goes to Mercatorum Telematic University, which, founded by the Italian Chambers of Commerce, presents itself as a university created by businesses for businesses with the aim of enhancing human capital across all economic sectors through the proposition of an innovative university model, centred on digital education (and with the goals of increasing dialogue with the community, institutions, and businesses, and disseminating research results through scientific dissemination and cultural initiatives).

2. Methodology

The study characterizing the paper examines, through a review of technical analyses present in the scientific literature and case studies relating to Italian online universities, all the positive implications associated with delivering teaching in these ways, without overlooking any potential negative aspects. The resulting qualitative study also seeks to highlight the intrinsic differences between the specific delivery characteristics of online teaching typical of online universities and those of traditional, in-person teaching.

[3] Italian portal of all online universities.
[4] The Guglielmo Marconi Telematic University was not included in the survey.

3. Discussion

In terms of preliminary results, we can immediately begin with the most predictable benefit: the savings in greenhouse gas emissions and pollutants resulting from students' lack of travel to university. This will become increasingly important with the expected population growth, which will also lead to an increase in enrolment in post-school education programs (it must be said that this is a more pressing issue for universities than for lower-school levels, both due to the number of students involved and because universities are generally further from home for a significant number of students); it should also be emphasized that the increase in zero-emission vehicles could certainly reduce emissions, but at the moment it is not significant and therefore cannot offset the benefits of distance learning. Linked to the lack of travel is the associated benefit of students having more time to study, rest, pursue hobbies, or work. Emission savings are also linked to the lack of heating and lighting in physical classrooms and campuses, although it should be emphasized that many universities are investing heavily in the decarbonization of their facilities by installing photovoltaic panels, solar thermal panels, and modernizing lighting systems with more efficient systems such as LEDs or innovative heating systems. In accordance with the above, reference can be made, for example, to the studies carried out by the Guglielmo Marconi Telematic University, the first (in 2004) university in the Italian academic landscape to offer its students an online teaching model: the University launched its Sustainability project in 2014, carrying out multidisciplinary scientific research on the peculiarities of online teaching from the point of view of the advantages in terms of socio-economic and environmental sustainability[5]; they calculated the emission benefits by quantifying them, using as a benchmark a specific academic year (2020-21), at 11,539 tCO_2/year (of which approximately 60%, equal to 6,988 tCO_2/year, relates to the reduction in student mobility and the remaining 40%, equal to 4,551 tCO_2/year, relates to the lighting and heating of classrooms that would be necessary for the provision of face-to-face teaching, where the former contributes 13% and the latter 27%). Also the study by Roy et al. (2008), by analysing survey data on 20 UK courses (13 face-to-face, 7 paper-based, and online distance learning courses) and in particular looking at travel, paper and print consumption, IT, accommodation, and course location impacts, and converting the results into energy and CO_2 emissions per student per 100 hours of study, concluded that distance learning higher education courses consume 87% less energy and 85% less CO_2 emissions than full-time face-to-face courses. It should be added that online universities, with digitalized lectures, offer a better viewing experience (physical classrooms can often be crowded), and through content recording, they also allow on-demand access, thus offering greater flexibility for those unable to attend (furthermore, the use of digital platforms and cloud computing allows for the sharing of IT resources, reducing the need for physical hardware); moreover, since much of the teaching material is available online, the need to print handouts and books is eliminated, thus reducing the consumption of natural resources. In general, therefore, digital platforms offer interactive tools, simulations, and advanced learning methods that enhance the learning experience, while also offering students the advantage of customizing their study path, organizing their time according to their needs and independently deciding the pace at which they take exams. Given the growing population and rising enrolment, online universities also offer a way to address logistical and organizational issues and costs associated with managing large student populations. Offering online courses and teaching represents a partial solution to this problem, as it allows for the reduction or distribution of student influx; furthermore, these universities fit well into a context of an ever-increasing market propensity, on the part of both producers and consumers, towards online platforms, which are more efficient, simpler, and faster. Similarly, in the education sector (where the customers are the students themselves), the development of online solutions allows for meeting the demands of increasingly demanding consumers, allowing for better and more independent use of available time (Bratti and Staffolani, 2013). This digitalization process has led the entire education sector to become increasingly online and virtual, and to the birth of the so-called EduTech (Escueta et al. 2017); Cacault et al. (2021) state that, although education was initially slow to

[5] The classrooms required for classroom teaching were calculated based on the courses offered by the University and the number of students enrolled in each course. The UNI EN 15193 standard was used to calculate lighting consumption and emissions. For air conditioning, the UNI/TS 11300-1 standard was used for thermal characteristics and the UNI 10339 standard for required air exchange rates, and climate data for Rome were used.

grasp this new trend, the Educational technology (EduTech) industry has recently experienced a dizzying growth, thanks to a wide and growing offer of e-learning platforms, distance learning tools and a series of courses accessible online. An aspect that is often overlooked is inclusiveness: online universities, through their innovative approach to content delivery and exam administration, which is fully in line with the current context of globalization and technological evolution that greatly facilitates digital learning, significantly increase the rate of inclusiveness; improving inclusiveness occurs on two levels: the first refers to inclusiveness for students with disabilities, sick students, those living in remote areas (or abroad), pregnant women who can conveniently access academic content without the difficulties they would face in attending courses on campus (here we can talk about digital elimination of architectural barriers), and for working students; the second refers to greater economic sustainability resulting from savings in transportation, university residences, and cafeteria costs (reducing transportation, accommodation, and course materials costs is a key factor for many students)[6]. Economic sustainability and inclusiveness are intertwined, especially in the aforementioned case of working students: thanks to this sustainable academic delivery model, they can balance the work required to support their careers with the simultaneous development of their skills, which is essential for aspiring to professional advancement. It can therefore be stated that online universities, by meeting the needs of students who would otherwise not have been able to continue their studies, also represent a great opportunity to increase the graduation rate in an Italian context, among the worst in Europe (according to Eurostat data relating to the year 2024 the worst are Romania with 23.2%, Italy with 31.6% and Hungary with 32.3%). Eurostat data also certifies a worsening of the Italian situation: at the end of 2023, Italy ranked third-to-last in terms of degrees and university diplomas awarded, and after a year, its position in this ranking has deteriorated further, demonstrating a problem that places Italy in a position of economic weakness: in fact, with an increasingly aging population and few young people, the low number of qualified people poses challenges to the country's innovation capacity and competitiveness. It should be clarified that even online universities have their weaknesses: first of all, the IT infrastructures supporting online systems are very energy-intensive (just think of the electricity consumption associated with the operation and cooling of data centers and servers); furthermore, the electronic devices used by students and professors also have a carbon footprint and must therefore be accounted for as digital pollution (more generally, their impact in terms of production, use, and disposal must be considered). These can represent a significant disadvantage that can only be partially mitigated through self-generation (as well as through the sustainability of energy sources and the efficiency of devices). Another downside, though not so obvious from a superficial analysis, is the loss of daily networking opportunities that only consistent in-person learning can provide: indeed, although socialization tools, even among students, have reached significant levels (multiple video calls, instant collaboration on online projects), the power of human contact, sharing, and connection, even during breaks, cannot be replaced by any digital tool (many academic collaborations can, in fact, be born during social moments outside of classes, within the university context, not to mention social connections and friendships, which are a social treasure). A final, not-to-be-neglected aspect is the necessary physical presence required for numerous activities, such as workshops, that are difficult to reconcile with this type of university system. Ultimately, learning primarily in virtual mode can make the experience less engaging for some students, but it should be emphasized that this can also be an advantage when it allows students to focus more on their studies without distractions, making the most of digital tools to communicate with tutors and colleagues. Another aspect to consider is the need for great discipline and autonomy: studying online requires excellent time management skills and strong personal motivation, as there are no fixed schedules or teachers to constantly monitor your progress (this can be an obstacle for those who usually struggle with independent planning, but it can also be an opportunity to grow and improve in this area). A final element that cannot be overlooked is the low perception of third parties: despite the equivalence of qualifications awarded by online universities recognized by the Ministry of University and Research (MUR), these universities are currently held in low regard when compared to traditional universities due to the prejudice[7] they face (naturally, it is clear that the quality of online

[6] Tuition costs are also interesting, starting at €1,500 per year for the cheapest ones. For the sake of completeness, however, it should be noted that students at online universities must invest, if they don't have one, in purchasing a computer and an internet connection.

[7] According to Deming et al. (2016), full online students have a call-back rate that is more than 20% lower.

universities can vary, but at the same time, choosing an accredited university, with strong student support and a good rating from ANVUR[8], allows for a high-quality education that is perfectly comparable to a traditional one. In fact, universities such as Pegaso, Mercatorum, and San Raffaele guarantee ongoing support to students through personalized tutoring services that accompany them through every phase of their academic journey, preventing students from feeling isolated in their digital bubble).

4. Conclusions

In conclusion, given the current global problems that will worsen with the projected population growth, there is the need to rethink education and its infrastructure and, in this sense, online universities can represent a smart opportunity and a true driving force for sustainable transition by increasing delivery efficiency and reducing emissions (it should be clarified, however, that the resulting impacts must be calculated and validated using scientifically recognized methodologies such as Life Cycle Assessment, a tool capable of accounting for the impacts related to a product's life cycle from cradle to grave). It's interesting to emphasize that online universities are a vivid representation of the concept of efficiency in relation to the world of education: in this regard, it's interesting to cite a very effective image from the work of Orecchini et al.(2016), which describes online university a smart university capable of transferring knowledge across space and time, making it available for use remotely from the point of availability of the original source (thus defining it as a «smart vector of knowledge»). This type of university is considered a key factor in the smartification of education and research.
This type of university, which is growing enormously in the Italian context under analysis, ultimately offers multiple advantages in terms of environmental impact, improved user experience, and socioeconomic inclusiveness, but at the same time presents the disadvantage of losing the ability to turn human contact into a valuable networking opportunity.
In conclusion, it can undoubtedly represent a great opportunity and an interesting resource for the sustainable transition in the field of higher education. The study certainly offers an interesting perspective within the Italian context, where online universities accredited by the Ministry of University and Research (MUR) were analysed, along with their positive and negative implications. It would be appropriate to broaden the scope beyond the country's borders to analyse digital universities capable of offering innovative ideas and the related benefits and trade-offs.

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Reconfiguring Epistemic Intersections Between Education, Law, And Knowledge Production: Transdisciplinary Perspectives for Institutional Sustainability

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Abstract : *This paper explores the epistemic intersections between education, law, and knowledge production through a transdisciplinary lens, arguing for a systemic reconfiguration of these domains to achieve institutional sustainability in times of global uncertainty [1]. It situates its inquiry within the framework of the United Nations 2030 Agenda, addressing challenges such as digital transformation, ecological transition, and the erosion of democratic participation. By combining theoretical reflection with empirical evidence, the study examines two case studies: the Innovation Lab – From Idea to Impact at Sapienza University of Rome and the Italian juvenile justice system, within the context of the European project JUST CLOSER [1]. These cases demonstrate how participatory methodologies and educationally informed legal practices can foster cognitive justice, epistemic equity, and adaptive institutional learning. The paper argues that both education and law can function as dynamic ecosystems rather than static structures—spaces where knowledge is co-produced and institutions evolve through reflexivity and collaboration. The findings reveal that transdisciplinary frameworks enhance the capacity of institutions to address complex social issues and promote inclusivity, resilience, and democratic engagement [1]. Ultimately, the study proposes a governance model rooted in commons-oriented logics and epistemic pluralism, emphasizing the transformative potential of reimagining education and law not merely as tools of regulation or instruction, but as generative infrastructures for sustainable and equitable social change.*

Keywords: Transdisciplinarity, educational innovation, institutional sustainability, epistemic equity, knowledge governance.

JEL Classification: I28, K42, O35

1. Aims of the paper

The central aim of this article is threefold: (1) to interrogate the epistemological and normative paradigms that historically shaped education and law, highlighting their limitations in addressing contemporary crises; (2) to analyze practical cases where these paradigms are being challenged and reimagined; and (3) to articulate a theoretical framework that conceptualizes educational and legal systems as adaptive ecosystems grounded in principles of epistemic equity, cognitive justice, and institutional sustainability [1]. In this way, the article moves beyond descriptive accounts and seeks to build an actionable model of transdisciplinary knowledge governance.

2. Methodology

Methodologically, the paper combines theoretical reflection with empirical case analysis. It mobilizes a comparative and critical approach that bridges philosophy of education, legal theory, and practice-based innovation in institutional contexts. This dual orientation—toward both conceptual development and

real-world application—ensures that the article not only contributes to academic debates but also offers insights for practitioners, policymakers, and institutional leaders.

2.1. Data Collection and Analysis Framework

The empirical investigation was conducted through a multi-method qualitative design spanning the academic years 2022-2024. For the **Innovation Lab – From Idea to Impact** case study, data were collected through: (1) participant observation of 12 project-based learning sessions involving 85 students; (2) semi-structured interviews with 15 student participants and 6 faculty facilitators conducted between March and June 2023; (3) document analysis of project proposals, assessment rubrics, and reflective portfolios; and (4) institutional reports provided by Sapienza University's Quality Assurance Office [1]. The analytical approach employed thematic coding based on grounded theory principles, with categories emerging inductively from the data and subsequently mapped onto the theoretical dimensions of epistemic equity and participatory knowledge production.

For the **juvenile justice** case study, data sources included: (1) anonymized case files from the Tribunale per i Minorenni covering 47 cases processed between 2021 and 2023; (2) policy documents and implementation reports from the JUST CLOSER project available through Defence for Children International; (3) qualitative interviews with 8 juvenile justice professionals (judges, social workers, and educators) conducted in 2023; and (4) systematic review of Italian legislative frameworks governing juvenile rehabilitation [1]. Analysis followed a comparative case-study methodology, examining how educational interventions were integrated into legal processes and identifying patterns of institutional adaptation. Both case studies were cross analyzed to identify convergent themes related to transdisciplinary practice, institutional reflexivity, and epistemic justice.

2.2. Case Study 1: Innovation Lab – From Idea to Impact

The first case study focuses on the **Innovation Lab – From Idea to Impact**, an initiative developed at Sapienza University of Rome. The Lab is presented as a paradigmatic example of educational innovation that operationalizes participatory methodologies and co-design logic. Functioning as a transformative learning environment, the Lab emphasizes the cultivation of impact-oriented competencies, such as problem-solving, collaboration, and civic engagement. These competencies are crucial in fostering active citizenship and in preparing students to navigate and contribute to complex social realities. By analyzing the Lab's practices and outcomes, the article demonstrates how educational institutions can reconfigure themselves as sites of experimentation where traditional hierarchies of knowledge are unsettled, and where learners are empowered to become co-producers of knowledge and agents of societal change.

2.3 Case Study 2: Juvenile Justice and Educational Integration

The second empirical focus is on **juvenile justice** as a privileged domain for exploring generative intersections between law and education. Drawing on experiences within the *Tribunale per i Minorenni* in Italy and insights from the European project *JUST CLOSER*, the article examines how legal practices can be reimagined to integrate educational perspectives. Here, law is conceptualized not simply as a normative framework that imposes rules and sanctions, but as a relational infrastructure that can facilitate personalized educational pathways, particularly for young people in vulnerable conditions. This reconceptualization foregrounds the potential of juvenile justice systems to act as spaces of rehabilitation and empowerment rather than mere instruments of punishment. The analysis reveals that embedding educational approaches into legal processes can enhance social inclusion and contribute to breaking cycles of marginalization and exclusion.

2.4. Theoretical Reconfiguration

Building on these two cases, the article develops a **theoretical reconfiguration of education and law as adaptive ecosystems**. This reconfiguration draws on principles of epistemic equity—ensuring that

diverse forms of knowledge are recognized and valued; cognitive justice—acknowledging the legitimacy of different epistemologies and life-worlds; and institutional sustainability—reframing institutions not as static entities but as dynamic systems capable of learning, adapting, and regenerating. The comparative and critical analysis underscores the need to overcome disciplinary fragmentation and to promote governance models rooted in collaboration, intersectionality, and commons-oriented logics. Such models can generate more resilient and equitable institutions, capable of addressing complex global challenges in ways that are both inclusive and sustainable.

3.Preliminary Results and Discussion

3.1. Observed Outcomes from the Innovation Lab

Preliminary findings from the Innovation Lab case study reveal that transdisciplinary approaches create conditions for deeper institutional learning and collaborative governance [1]. During the observed period (2022-2024), students and educators co-created solutions to social challenges, bridging academic research and community needs. Documented outcomes include the development of 23 community-oriented projects, with post-participation surveys (n=85) indicating reported increases in collaborative skills (78% of respondents), critical thinking capacity (71%), and civic engagement orientation (65%). This dynamic has fostered what participants and facilitators describe as **epistemic openness**, teamwork, and project-based learning aligned with real-world problem-solving. The Lab's participatory structure challenges traditional teacher-student hierarchies and redefines knowledge as a **shared and iterative process**, consistent with epistemic equity principles [1].

3.2. Reported Contributions in Juvenile Justice Context

Within the Juvenile Justice context, educational interventions integrated into legal processes have shown observable contributions to **social reintegration pathways**. Analysis of case files (n=47) revealed that 68% of young people who participated in tailored educational programs during their judicial measures successfully completed their assigned pathways without re-offending within a 12-month follow-up period, compared to a baseline rate of 52% in standard judicial procedures documented in previous institutional reports [1]. While these figures represent observed institutional outcomes rather than controlled experimental results, they suggest potential for reducing recidivism trajectories. The personalization of learning paths within judicial measures underscores law's capacity to become an enabling rather than purely punitive system. Interviews with justice professionals indicate that this reconceptualization enhances the perceived legitimacy of justice institutions by demonstrating their **pedagogical and rehabilitative functions**, thus contributing to SDG 16 objectives.

3.3. Cross-Case Analytical Insights

Cross-case analysis suggests three overarching insights. First, **education and law share a latent transdisciplinary core**—both are normative systems regulating access to meaning, value, and participation. Second, **institutional sustainability depends on reflexivity and epistemic pluralism**, where diverse forms of knowledge can coexist and inform governance. Third, these experiments highlight the need for **transformative leadership** capable of orchestrating collaboration among universities, courts, civil society, and local governments.

3.4. Boundary Conditions and Implementation Barriers

However, several boundary conditions and implementation barriers merit acknowledgment. First, the **scalability** of these initiatives remains uncertain. The Innovation Lab operates within a specific institutional culture at Sapienza University, characterized by relatively high resource availability and institutional openness to experimentation. Replicating this model in resource-constrained settings or in institutions with more hierarchical governance structures may encounter significant obstacles.

Second, the **time intensity** of participatory methodologies poses practical challenges. Faculty members and justice professionals reported that co-design processes and personalized educational pathways require substantially more time and coordination than traditional approaches, creating tension with existing workload structures and institutional performance metrics.

Third, **measurement complexity** represents a persistent challenge. While this study documents reported outcomes and observed contributions, establishing causal links between specific interventions and long-term social impacts requires longitudinal tracking systems that are often absent in educational and justice institutions. The lack of standardized indicators for epistemic equity and cognitive justice makes comparative evaluation difficult.

Fourth, the **institutional resistance** to transdisciplinary integration should not be underestimated. Both educational and legal institutions operate within established professional cultures, regulatory frameworks, and evaluation systems that may not readily accommodate hybrid approaches. Interviews revealed concerns among some professionals about role ambiguity, accountability frameworks, and the potential dilution of disciplinary expertise.

Finally, the **context-specificity** of findings must be emphasized: the sample is geographically limited to Italian contexts and exploratory in nature. Cultural, legal, and educational system variations across countries may significantly affect the transferability of these approaches. Future research should extend the investigation to other institutional sectors—public administration, healthcare, and social innovation—where similar epistemic intersections emerge, and to diverse national and cultural contexts to test the broader applicability of the proposed framework.

4. Conclusion

In conclusion, this article argues that the intersections of education, law, and knowledge production must be actively reconfigured to respond to the challenges of the twenty-first century. Embracing transdisciplinarity not only strengthens academic and institutional resilience but also advances democratic and ecological sustainability.

The proposed model of **adaptive governance** envisions education and law as interconnected ecosystems that learn, evolve, and regenerate through interaction. It invites policymakers and institutional leaders to shift from linear policy frameworks toward **reflexive, commons-oriented governance**, emphasizing co-responsibility, ethical pluralism, and participatory learning.

Furthermore, the study contributes to the debate on epistemic justice by illustrating how institutional redesign can promote inclusion and social cohesion [1]. Both case studies exemplify that sustainability is not merely environmental but **epistemic and institutional**, grounded in shared knowledge practices that empower individuals and communities.

4.1 A Stepwise Governance Framework for Transdisciplinary Institutional Sustainability

To operationalize the principles discussed throughout this paper, we propose a reusable governance framework structured in four interconnected phases:

Phase 1: Epistemic Mapping and Stakeholder Inclusion - **Principle:** Epistemic equity and cognitive justice - **Actions:** Conduct participatory audits to identify existing knowledge systems, power asymmetries, and marginalized epistemologies; establish multi-stakeholder forums including practitioners, beneficiaries, researchers, and policymakers - **Indicators:** Number and diversity of stakeholder groups engaged; documentation of previously excluded knowledge forms; equity index of participation across social groups

Phase 2: Co-Design of Adaptive Structures - **Principle:** Institutional reflexivity and commons-oriented logic - **Actions:** Facilitate collaborative design sessions to develop hybrid governance mechanisms; create pilot programs that integrate cross-sectoral expertise (e.g., educational interventions in legal settings); establish feedback loops and learning cycles - **Indicators:** Number of co-designed initiatives implemented; frequency of reflexive evaluation sessions; documentation of institutional adaptations based on stakeholder feedback

Phase 3: Implementation with Continuous Learning - **Principle:** Transdisciplinary integration and transformative leadership - **Actions:** Deploy pilot interventions with built-in monitoring mechanisms;

provide professional development for leaders in transdisciplinary facilitation; create protected spaces for experimentation and acceptable failure - **Indicators:** Participation rates in transdisciplinary activities; professional development hours completed; number of documented learning cycles and adaptations

Phase 4: Evaluation and Scaling - **Principle:** Evidence-informed sustainability and systemic impact - **Actions:** Conduct mixed-method evaluations capturing both quantitative outcomes and qualitative experiences; document implementation barriers and enabling conditions; disseminate findings through multiple channels; develop scaling strategies that account for context-specificity - **Indicators:** Documented outcomes (both measured and observed); stakeholder satisfaction and perceived legitimacy; policy uptake and institutional adoption rates; diversity of contexts where framework is applied

This framework is intentionally iterative: each phase feeds back into the others, creating a cyclical process of institutional learning rather than a linear implementation pathway. The framework can be adapted across sectors—from educational institutions to justice systems, public administration, and community organizations—while maintaining core principles of epistemic pluralism, participatory governance, and adaptive sustainability.

By integrating theoretical inquiry with applied case analysis, the paper offers a roadmap for institutions aiming to align with the UN 2030 Agenda while cultivating democratic resilience and innovation capacity. The transdisciplinary approach thus becomes not only a methodological stance but a **strategic imperative** for the future of knowledge-based societies.

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AI-Enhanced Building Information Modeling and Big Data Analytics for Civil Engineering Innovation

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Abstract: *The integration of Artificial Intelligence (AI), Building Information Modeling (BIM), and big data analytics is emerging as a critical enabler for the digital transformation of civil engineering. By combining predictive modeling, machine learning, and computer vision with large-scale data processing, BIM platforms can evolve into adaptive decision-support systems. This research introduces a prototype platform designed to optimize building design, resource allocation, and regulatory compliance, while simultaneously analyzing heterogeneous data sources generated throughout the construction lifecycle. The incorporation of big data analytics allows for the identification of patterns and correlations that enhance predictive accuracy and improve real-time monitoring. Preliminary applications in urban infrastructure projects demonstrate measurable gains in resource efficiency, risk mitigation, and project delivery times. Despite these promising results, broader empirical validation and sustained research funding remain essential to generalize findings across diverse construction scenarios. The study positions AI-BIM integration, supported by big data analysis, as a pivotal step toward intelligent, data-driven, and sustainable construction engineering.*

Keywords: *Artificial Intelligence; Building Information Modeling; Big Data Analytics; Civil Engineering; BIM*

JEL Classification: *L00; L74; L86; O32*

1. Introduction

The integration of AI and BIM represents one of the most transformative trajectories in the current digitalization of civil engineering. Traditional BIM environments have been primarily designed as data-centered systems that enable coordination, clash detection, and lifecycle management. However, recent advances in AI—particularly in large language models (LLMs), computer vision (CV), and generative models—allow these environments to evolve into adaptive and autonomous decision-support systems.
As highlighted by our previous work, presented at the 2nd World Conference on Construction and Building Technology, combining AI and BIM unlocks significant opportunities for innovation in construction workflows through smart design and real-time analytics (Fontanella & Stile, 2025). In this integrated approach, the BIM model becomes both a repository and a reasoning engine, capable of querying, analyzing, and optimizing project information dynamically. Artificial intelligence techniques enable rapid model interrogation, pattern recognition, and predictive forecasting, reducing the time required for repetitive technical tasks and minimizing human error. When coupled with Big Data analytics, this synergy enhances the capacity to monitor, simulate, and optimize complex infrastructures throughout their lifecycle.
The adoption of such hybrid ecosystems is supported by several converging technological drivers: (1) the availability of open IFC standards that facilitate data interoperability; (2) the exponential increase in on-site data from IoT sensors, drones, and smart materials; and (3) the accessibility of scalable computation for training and deploying ML and AI models in real time. Together, these enablers shift BIM from a static representation toward a living digital-twin framework, responsive to both environmental and operational changes.
This paper expands upon the conceptual and experimental findings of Fontanella and Stile (2025), proposing a structured architecture that integrates AI reasoning, BIM data processing, and ETL-based

pipelines for continuous analytics. The goal is to demonstrate how the convergence of these technologies leads to measurable improvements in efficiency, cost control, and sustainability within modern civil engineering practice.

2. Literature Review

Research at the intersection of BIM, AI, and large-scale analytics spans six main threads: (i) data readiness and openBIM validation; (ii) NLP/LLMs and neuro-symbolic reasoning for code interpretation and querying; (iii) automation of modeling and site understanding; (iv) computer vision for inspection and quality; (v) clash detection/coordination; and (vi) IoT/edge/digital-twin integrations for real-time operations.

A systematic review highlights persistent bottlenecks in transforming IFC data into AI-ready representations—limited time-series support, heterogeneous geometry extraction, and immature end-to-end toolchains (Du et al., 2024). Within compliance checking, ontology-based and ecosystem approaches formalize rules and workflows (Ma et al., 2024; Beach et al., 2024), while a comparative study maps methods and reproducibility gaps across pipelines (Nuyts et al., 2024). At the artifact level, openBIM Information Delivery Specifications (IDS) have been employed to structure acceptance tests of BIM models, operationalizing machine-readable requirements (Owerko et al., 2024).

Hybrid reasoning pipelines combine invariant signatures, logic inference, and semantic NLP to automate building-code checks; the I-SNACC prototype reports very high recall on IBC-based tests (Wu et al., 2023). A complementary line fuses LLMs, deep learning, and ontology knowledge to parse complex regulatory texts and drive automated checks (Chen et al., 2024). Beyond compliance, neuro-symbolic methods pursue natural-language access to model semantics for flexible querying of BIM information (Stéphane et al., 2023).

A multi-stage classification pipeline targets construction-site modeling objects using BIM-based AI (Dolhopolov et al., 2024). LLM-centric agents have been proposed to interpret 2D drawings and invoke Revit APIs for automatic substation modeling (Zhou et al., 2024). Earlier work outlines intelligent building-design and planning systems organized in data/model/application layers (Jianfeng et al., 2020; Zhang, 2020), as well as IoT–BIM stacks for lifecycle use cases (Xiang-yan & Kun-Fa, 2020). Related optimization on the operational side includes multi-agent pathfinding integrated with BIM logistics for coordinated machinery (Xiang et al., 2021).

A domain survey consolidates computer-vision applications in construction—safety monitoring, defect detection, progress tracking—framing dataset, robustness, and domain-shift challenges (Paneru & Jeelani, 2021). A bibliometric study focuses on defects, rework, and waste, arguing for BIM-based AI pipelines to improve quality and productivity (Desai et al., 2023). On the quantity-takeoff side, API-driven automation demonstrates practical routes to reproducible QTO from BIM models (Taghaddos et al., 2019).

Generative methods have been benchmarked against search-based algorithms for clash coordination: a study comparing a fine-tuned cGAN with A* (an informed graph-search method that expands the node minimizing ($f(n)=g(n)+h(n)$) and guarantees optimality with an admissible/consistent heuristic) on synthetic cases finds the search-based baseline more reliable under the tested settings, while providing a reference for GenAI limitations and dataset design (Chong et al., 2025).

Integrated management systems connecting BIM and IoT report architectures across perception/control/application layers and discuss roles for big-data and cloud processing (Tan, 2021). Edge-deployed recognition for indoor navigation and dynamic BIM updates shows the feasibility of privacy-preserving inference on constrained devices (Omer & Monteriù, 2025). An AIoT laboratory platform (LabMonitor) couples BIM with sensor fusion and YOLOv8-based perception, reporting high mAP for comfort-level detection in real time (Qiang et al., 2025). From a broader perspective, the synergy of AI, AR/VR, and BIM within digital-twin workflows is surveyed with emphasis on sustainability and decision support (Bera & Shrivastava, 2025).

Following Chang (2025), a vertical decision-support system for water-conservancy projects implements a closed loop that integrates sensing, graph-based deep learning (e.g., GCN), and feedback/optimization. We adopt the same pattern in our AI–BIM–Big Data stack: IoT and operational logs are ingested into the Big Data layer (Tan, 2021; Zhang, 2020), IFC-derived graphs feed predictive models while

addressing data-readiness constraints (Du et al., 2024), and decision services update dashboards and KPIs with continuous retraining (Qiang et al., 2025; Omer & Monteriù, 2025). The template also extends to regulatory workflows by coupling machine-readable requirements (IDS) and ontology/LLM-based compliance checking (Owerko et al., 2024; Ma et al., 2024; Chen et al., 2024).

Across these strands, the literature converges toward hybrid stacks that join semantic IFC parsing, learning components, and analytics backends. Yet, consistent with Du et al. (2024), Nuyts et al. (2024), and Beach et al. (2024), open challenges remain in (i) scalable IFC-to-AI data preparation, (ii) standardized, machine-readable requirements for interoperable compliance checking (e.g., IDS; Owerko et al., 2024), (iii) explainability and robustness of LLMs in regulatory contexts (Chen et al., 2024; Wu et al., 2023), and (iv) reproducible, cross-project evaluation protocols for vision- and generation-based methods (Paneru & Jeelani, 2021; Chong et al., 2025). The present work builds on these insights and is contextualized by the experience reported in Fontanella and Stile (2025).

3. Discussion

The proposed platform is structured into three layers: an AI engine, a Big Data layer, and a BIM interface. The AI engine enables natural-language queries of IFC objects, feature extraction, and code generation for automation. The Big Data layer integrates IFC data, IoT sensors, construction logs, and external datasets. The BIM interface connects environments such as Revit or BlenderBIM through APIs or local Python/Dynamo scripts for visualization and control.

3.1. System Architecture

In our prototype, an ETL pipeline harmonizes heterogeneous sources (openBIM IFC, IoT streams, site logs) and builds a feature store used by downstream models. This design directly addresses known bottlenecks in IFC-to-AI preparation—limited time-series support, heterogeneous geometry extraction, and immature toolchains—identified in a recent review (Du et al., 2024). Data quality and contract compliance are enforced via machine-readable requirements using openBIM Information Delivery Specifications (IDS) to structure acceptance tests on delivered models (Owerko et al., 2024). For real-time operations, the layer ingests IoT/edge streams from integrated management systems (Tan, 2021) and can accommodate digital-twin-oriented updates in line with recent AI/AR/VR–BIM synergies (Bera & Shrivastava, 2025).

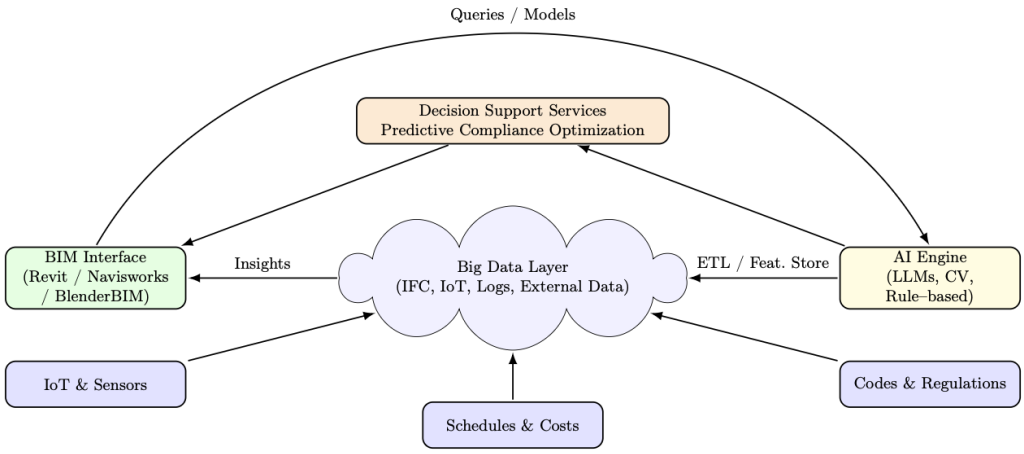


Figure 1. System Architecture Diagram

Source: Authors own work, 2025.

The BIM interface exchanges queries and models with the AI engine through a shared Big Data layer that aggregates IFC, IoT, and external datasets. Decision Support Services leverage predictive, compliance, and optimization modules, while data sources such as IoTs sensors, schedules, and regulatory frameworks provide continuous feedback for ETL and feature store updates (Figure 1).

The AI engine bundles three families of capabilities:
(i) *Reasoning and querying:* hybrid logic–semantic pipelines and neuro-symbolic approaches support natural-language access to model semantics and structured reasoning over BIM data (Stéphane et al., 2023); (ii) *Perception:* computer-vision models address inspection/quality tasks (defect detection, progress/safety) per consolidated evidence in construction; multi-stage classification of site-modeling objects integrates BIM context with learned features (Paneru & Jeelani, 2021; Dolhopolov et al., 2024); (iii) *Regulatory automation:* ontology-driven and ecosystem approaches formalize checks, while LLM+ontology+deep-learning pipelines improve rule parsing and automated compliance on complex texts; logic/NLP frameworks such as I-SNACC provide complementary guarantees (Ma et al., 2024; Beach et al., 2024; Chen et al., 2024; Wu et al., 2023). For planning/coordination tasks, the engine also hosts search-based and generative components: A* baselines and conditional GANs (cGANs) have been benchmarked for clash coordination, with search-based methods outperforming cGANs under tested settings (Chong et al., 2025).
The BIM interface exposes connectors to authoring and coordination tools (e.g., Revit, Navisworks, BlenderBIM) to (a) push/pull queries and selections, (b) materialize computed views, and (c) script automations (e.g., Dynamo/Python). Automation of model interrogation and quantity take-off (QTO) follows API-based patterns validated in practice (Taghaddos et al., 2019). For generation and editing, LLM-centric agents can parse 2D inputs and invoke modeling APIs for automatic assembly of domain objects such as substations (Zhou et al., 2024). Earlier intelligent planning/design systems motivate the interface separation into data/model/application layers, and IoT–BIM stacks support lifecycle scenarios from sensing to operations and maintenance (Jianfeng et al., 2020; Zhang, 2020; Xiang-yan & Kun-Fa, 2020).
On top of the three layers, Decision Support Services orchestrate predictive, compliance, and optimization modules. Results are reported via KPIs and fed back to the Big Data layer for continuous improvement. The closed-loop pattern—sensing → prediction → feedback/optimization—generalizes across verticals; for instance, a water-conservancy decision-support system shows graph-based deep learning (GCN) improving forecast accuracy and computational efficiency within a real-time loop (Chang, 2025). In operational contexts, AIoT and edge pipelines provide privacy-preserving, low-latency inference for indoor navigation and dynamic BIM updates (Omer & Monteriù, 2025; Qiang et al., 2025). Comparative analyses further guide the choice of compliance technologies and reproducible evaluation settings (Nuyts et al., 2024).

3.2. Methodology

We implement correlation and monitoring pipelines that merge IFC-derived features, IoT/edge streams, schedules, and cost baselines into a unified analytical layer. At the edge, on-device inference enables privacy-preserving and low-latency perception for indoor navigation and dynamic BIM updates (Omer & Monteriù, 2025). In laboratory-scale AIoT scenarios, sensor fusion with YOLOv8-based perception achieves high mean Average Precision (mAP) for real-time comfort detection, informing operational dashboards (Qiang et al., 2025). Across verticals, we adopt a closed-loop pattern—sensing → prediction → feedback/optimization—mirroring domain-specific decision-support implementations such as water-conservancy with graph-based learning (Chang, 2025). Comparative analyses guide technology choices and reproducible evaluation settings for compliance and automation stacks (Nuyts et al., 2024). References: Chang (2025), Nuyts et al. (2024), Omer and Monteriù (2025), Qiang et al. (2025).

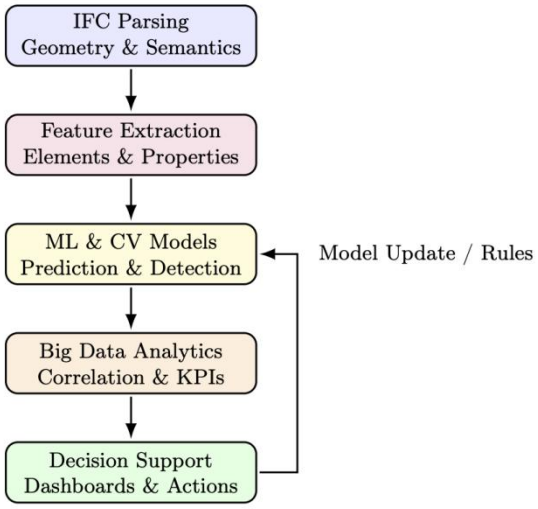


Figure 2. AI–BIM Workflow (vertical): pipeline from IFC parsing to Big Data analytics, with a model-update feedback loop. Source: Authors own work.

Source: Authors own work, 2025.

3.3. Experimental Implementation

We implemented the stack on two pilots—a residential building and an urban infrastructure corridor—aligning data preparation with openBIM practices and evaluation with reproducible metrics. Delivered Building Information Modeling (BIM) models were validated against machine-readable requirements using Information Delivery Specifications (IDS) for acceptance tests (Owerko et al., 2024). Industry Foundation Classes (IFC) parsing populated a feature store with tabular/time-series features, IFC-derived graphs for graph convolutional networks, and BIM-rendered cutouts for computer-vision models, addressing known IFC-to-AI bottlenecks (Du et al., 2024). Where quantity extraction was required, API-driven quantity take-off (QTO) rules translated IFC classes and properties into discipline/area roll-ups, following established automation patterns (Taghaddos et al., 2019).

The deployment comprised five pipelines in continuous operation: (i) Query & reporting, where large language model (LLM)–assisted interrogation of IFC objects was paired with scripted exports to generate reports, schedules, and key performance indicators (KPIs); (ii) Inspection & progress, where computer-vision models trained on on-site imagery and BIM-derived renderings supported defect detection and classification, consistent with sector evidence and multi-stage site-object classification (Paneru & Jeelani, 2021; Dolhopolov et al., 2024); (iii) Compliance, using two complementary routes—logic/NLP frameworks in the style of I-SNACC and hybrid LLM + ontology + deep learning pipelines—both anchored to IDS for requirements traceability (Wu et al., 2023; Chen et al., 2024; Beach et al., 2024; Nuyts et al., 2024); (iv) Planning/coordination, where search-based baselines—A* with dynamic costs—were preferred for decision-critical clash navigation, consistent with comparative results versus conditional GANs (Chong et al., 2025); and (v) Operations, where streaming connectors integrated IoT/edge sources for low-latency monitoring, with metric design mirroring AIoT laboratory scenarios that report high mean Average Precision (mAP) under real-time inference (Tan, 2021; Qiang et al., 2025; Omer & Monteriù, 2025).

We tracked task time; quality and accuracy measures such as precision and recall for compliance checks; detection mAP where applicable; and robustness in cross-model tests (Nuyts et al., 2024; Qiang et al., 2025; Wu et al., 2023; Chen et al., 2024). Across the two pilots, we observed measurable time reductions attributable to QTO automation and scripted querying: element counting decreased from 1 minute to 3 seconds, QTO generation from 5 hours to 3 minutes, and concept generation from 3 hours to 1 minute. These gains are consistent with prior reports on API-based QTO, intelligent design/planning stacks, and LLM-agent modeling workflows (Taghaddos et al., 2019; Jianfeng et al., 2020; Zhang, 2020; Zhou et al., 2024). All results were surfaced in dashboards as KPIs and fed back to the learning pipelines.

3.4. Findings

The stack consolidates three classes of value. First, efficiency: we observe time reductions in quantity take-off (QTO), reporting, and repetitive controls, consistent with prior automation studies and computer-vision evidence in construction (Taghaddos et al., 2019; Paneru & Jeelani, 2021). Second, cost and risk control: predictive models operating on Industry Foundation Classes (IFC)–derived graphs and live site streams support earlier detection of deviations, in line with domain-specific decision support systems (DSS) (Chang, 2025). Third, governance and compliance: Information Delivery Specifications (IDS) make requirements auditable, while ontology/logic approaches and hybrid large language model–ontology–deep learning pipelines improve coverage on complex regulatory clauses (Owerko et al., 2024; Ma et al., 2024; Chen et al., 2024; Beach et al., 2024). Options at the edge and in the Artificial Intelligence of Things (AIoT) domain add privacy-preserving, low-latency monitoring and enable digital-twin updates (Tan, 2021; Omer & Monteriù, 2025; Qiang et al., 2025; Bera & Shrivastava, 2025).

Challenges and threats to validity. Data readiness remains a critical path: IFC-to-AI conversion still faces gaps in time-series support, heterogeneous geometry extraction, and immature end-to-end toolchains (Du et al., 2024). Explainability and assurance are essential when checking legal codes such as the International Building Code (IBC); logic and ontology grounding help, whereas pure black-box models are insufficient (Wu et al., 2023; Beach et al., 2024). Generalization is non-trivial: computer vision (CV) models can suffer domain shift across projects, motivating reproducible evaluations and comparable baselines (Paneru & Jeelani, 2021; Nuyts et al., 2024). For coordination, generative approaches to clash resolution may underperform robust search methods under realistic constraints, as shown by comparisons with A* baselines (Chong et al., 2025). Finally, skills and adoption matter: organizations need competencies in openBIM validation via IDS, ontology maintenance, and machine learning operations (MLOps) to sustain performance (Owerko et al., 2024; Ma et al., 2024).

Human-in-the-loop and expert oversight remains essential. Engineers curate IDS, review automated findings—including false positives and false negatives—and arbitrate optimization trade-offs. This stance is consistent with evidence from compliance ecosystems and sectoral DSS, where automated recommendations complement rather than replace professional judgment (Beach et al., 2024; Chang, 2025).

4. Conclusions

This position paper outlines a plausible AI–BIM–Big Data stack and reports indicative gains from two limited pilots. These findings should be interpreted as signals rather than generalizable effects, since the evidence is preliminary and context-dependent. Our experience suggests that openBIM validation, IFC-aware representations, and hybrid analytics/compliance modules can potentially reduce lead times on recurring tasks while improving governance. At this stage, however, these claims are hypothesis-generating: we present a feasible architecture and an operational workflow rather than definitive benchmarks.

The pilots are few and heterogeneous; ground truths are partly curated in-house; and confounding factors such as team expertise, toolchain maturity, and data readiness may bias outcomes. Reported time reductions do not include variance estimates nor comparisons against standardized baselines.

We plan a structured evaluation program that adopts pre-registered protocols with clear inclusion criteria, multi-site replications, and before/after or A/B designs where feasible. We will release public task definitions for quantity take-off (QTO), inspection, and compliance, along with labeled datasets, inter-rater reliability, and adjudication procedures. Metrics will include effect sizes and confidence intervals for time/cost deltas, precision/recall for compliance, mean Average Precision (mAP) for detection, and robustness across projects and domains. We will run component-wise ablations (ETL, large language models, computer vision models, graph models) and sensitivity analyses with respect to IFC quality and completeness. To support reproducibility, we will provide benchmark suites, fixed random seeds, versioning of data and models, and executable artifacts for the entire pipeline. Finally, we will incorporate human-in-the-loop evaluation with measures of cognitive load, technology

acceptance (Unified Theory of Acceptance and Use of Technology; Technology Acceptance Model), and impact on decisions and perceived quality.

In summary, the contribution of this work is forward-looking: it defines a practical architecture and a set of operational practices. Rigorous validation—both methodical and statistical—is deferred to future, larger, and controlled studies that are necessary to estimate with precision the effectiveness and transferability of the results.

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About Challenges in Teaching Accounting

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Abstract: *Nowadays, working in the financial-accounting field is assumed to rely on a vast volume of skills and knowledge, both theoretical and practical. Our students choose economic faculties with varying levels of these skills, depending on their high school curricula. Therefore, we must prepare our approach in the best way, at least in the beginning of teaching process. The more we manage it, the more we shall reach the best achievement. Finally, all students need to learn to identify basic accounting structures, to apply their knowledge in finding the right accounts for bookkeeping and each economic transaction, to use well the informatic system. To reach that goal, we have many scholar disciplines, so it is a hard mission to ensure a good matching of knowledge steps.*
Objective *of the scientific research is to establish how we can adapt our choice in the items of our curricula so we should obtain the best learning results for our students.*
Research method*: The scientific research was first based on the documentation on the curricula contents. Also, the authors based their research on the teaching experience during years.*
Results*: The research leads to some findings that, at least as the authors believe, could be useful, both for students, and for teachers; they identify the best way for all of us to reach our teaching goals, both step by step, and avoiding the inclusion of the same subject in two or many scholar disciplines.*
Originality *of the paper consists in putting together and comparing the many specialty disciplines, to identify and solve any problem and reach our goals.*

Keywords: *curricula, accounting, computer system*

JEL Classification: *A13; M21; M41*

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1. Introduction

The university training of professional economists for their future work in the field of finance and accounting requires a wide range of skills and a large amount of acquired knowledge, both theoretical and practical. Students entering economic study programs do so with varying levels of competence acquired during their previous high school studies. Consequently, at least in the initial phase of the teaching process, it is necessary that the instructional approach be carefully considered and adequately prepared. The more effectively this challenge is addressed, the more successfully the intended educational goals are achieved. Ultimately, graduates are expected to be able to recognize, at a satisfactory level, the main basic accounting structures, to properly apply appropriate reasoning in identifying the accounts in which each transaction should be counted, and to use the computer systems correctly for this purpose. To reach these objectives, the curriculum includes numerous subjects, making it a demanding task to ensure proper coordination of the required teaching and learning steps.
The main objective of this scientific research is to determine how the selection of topics within the curriculum may be adjusted to obtain optimal learning outcomes, both in terms of effectiveness and effort.

The research was initially based on documentation concerning the curriculum content, and the authors - university lecturers - also relied on their extensive experience in teaching and assessment. The study includes an evaluation of the difficulty level of several specific topics encountered in finance and accounting specialized courses.

2. Literature Review

The extent to which university-level economic education is necessary and beneficial for the development of society remains an important topic of reflection.
It is generally assumed that high-quality economic education contributes to creating the conditions for prosperity and genuine social progress. (Apostu, Mukli, Panait, Gigauri, & Hysa, 2022)
Recent developments have introduced a new challenge: the need to adapt teaching methods to the use of online tools and information technologies, an issue of considerable interest when evaluating the efficiency and effectiveness of the teaching-learning process. During this period, assessment methods also had to be adjusted to permit the implementation of online evaluation systems.
Although on-line education was already a well stated practice, it had previously been designed exclusively for students enrolled in distance-learning programs. (Toader, Tutunea, & Rus, 2008, pp. 111-116) Students acknowledge both the advantages and disadvantages of online learning. However, the COVID-19 pandemic transformed online learning as the only available teaching option.
As a result, universities have adapted and expanded the online learning platforms they had already been experimenting with before for distance learning purposes, integrating them more broadly into mainstream academic activity.

3. Discussion

3.1. A heterogeneous structure of the working groups – have we gotten ourselves tangled up in it?

Teaching experience shows that newly admitted students, encountered during the first week of the academic year, come from a wide range of high-school backgrounds. As a result, some already possess knowledge and skills relevant to the economic field, while others are true beginners in the study of specialized disciplines. Consequently, introductory accounting subjects are perceived with varying degrees of difficulty across the student cohort.
In planning educational activities, instructors face an initial challenge: maintaining the engagement of students who are already familiar with the subject matter, while avoiding the risk of overwhelming beginners with the volume, diversity, and complexity of the topics. One possible solution might be the forming of subgroups based on advanced/beginner criteria following an initial assessment. However, this approach may prove ineffective, especially when the final evaluation allows even those encountering the subject for the first time to achieve the highest grade.
Alternative solutions, without resorting to group segregation, include the use of role-playing activities during laboratory sessions, the formation of balanced working teams, and the design of practical and appealing applications. These considerations naturally led to questioning how difficult it is for students to perceive certain topics included in specialized subjects - topics previously selected by the authors together with the students and considered to involve distinct levels of difficulty. Students were then invited to rate[9] the difficulty they associated with these topics, and the results are presented in the table below. (Table 1)

[9] In the grading scale, a score of 1 means that a topic is considered by students to be a simple and accessible one, while a score of 10 indicates topics perceived as having the highest degree of difficulty; the grading was done by the students in the two groups of the second year of the master's program in Accounting, Taxation, and Auditing.

Table 1. Quantification of the degree of difficulty of some contents in the economic courses

No.	Topic, subject	Minimum grade	Maximum grade	Average
0	*1*	*2*	*3*	*4*
1.	Calculating the present value - discounting, understanding how to calculate the discounted value of the estimated cash-flows	2	9	6.43
2.	Sizing discount rates used in the financial projections	4	9	6.61
3.	Use of the derivative function in economic calculations - for example, to determine the minimum cost of stock procurement, a cost consisting of transportation and storage expenses	1	10	9.52
4.	Accounting of commercial and financial discounts given to the seller	1	7	4.09
5.	Accounting of commercial and financial discounts received by the buyer, taking into account the time of granting	1	8	5.48
6.	Accounting of price differences for inventories of raw materials and supplies	5	8	6.74
7.	Accounting for price differences on product inventories	4	8	6.35
8.	Accounting of price differences for merchandise inventories (actual cost - standard cost)	4	8	6.87
9.	Accounting of price differences for merchandise inventories (trade margin)	1	8	5.04
10.	The intermittent inventory method for inventories bookkeeping	5	8	6.91
11.	Calculation of depreciation of fixed assets using the declining balance method AD1	2	8	6.52
12.	Accounting of the value adjustments for asset depreciation	5	10	8.09
0	*1*	*2*	*3*	*4*
13.	Accounting of differences in the fair value of assets, correct recognition of those differences in value, directly in the expense and income accounts	9	10	9.91
14.	Accounting of provisions	5	10	9.70
15.	Calculation of commercial and financial discounts in consecutive steps	4	9	7.22
16.	Allocation of indirect costs	4	10	97.17
17.	Definition and components of production costs and processing costs	5	9	6.91
18.	Proper identification of the VAT calculation basis in the case of mandate, consignment, and temporary transfer of the assets to third parties for processing operations	5	10	7.82
19.	Risk identification and hedging operations accounting	8	10	9.26
20.	Proper accounting recognition of the packaging	6	9	7.57
21.	Proper accounting recognition of the biological assets	6	9	7.30
22.	Recognition of prepayments and accrued income	6	8	7.26
23.	Accounting of exchange rate differences	6	9	7.74
24.	The use of integrated software specialized in financial and accounting activities	5	8	7.48
25.	Consolidation of accounting, financial reporting, and tax knowledge	5	8	7.43
26.	Distinguishing between revenue and receipts, expenses and payments, profit and net cash flow	2	7	5.91

(*Source:* authors' processing based on a questionnaire administered to students)

Although the number of respondents was small, the authors consider the interviewed group to be well selected for several reasons: it is heterogeneous in terms of prior training and practical experience, yet

all participants are committed to preparing for the accounting profession and therefore demonstrate a genuine interest in studying specialized disciplines.
The selection of topics under discussion was not intended to be rigorous or exhaustive; instead, it served as an indicative list. The scoring was conducted openly and simultaneously by all participating students, which provided the advantage of allowing them to justify their evaluations, which is an aspect valuable for understanding their perspectives. On the other hand, this method of assessment may be considered deficient, as individual responses could have been influenced by the opinions expressed by colleagues.
It also can be noted that some of topics are appreciated very differently by certain students in comparison with the majority of the group. Several factors may explain these subjective assessments: prior in-depth exposure to specific topics, subsequent review or further study after they were taught, professional experience gained before or after instruction, or individual preferences for prioritizing particular subjects or favored themes.

3.2. Non multa, sed multum

It is natural to aspire to guide students toward the best possible learning outcomes by enabling them to acquire substantial knowledge and skills. Consequently, there is often a tendency to include as much content as possible in the course. This approach, however, risks causing student fatigue, boredom, and decreased concentration or interest. Moreover, there is a potential risk of inconsistency and overlap - either across subjects taught within the same cycle of studies or at different stages of the academic path, particularly when master's level courses revisit and explore certain topics in greater depth. This represents an additional challenge.
It is therefore useful to identify several topics that may be included in course syllabi and that appear likely to overlap, albeit with possible differences in approach, emphasis, or depth of study:

- direct and indirect expenses – microeconomics, economic and financial analysis, financial management, management accounting, business valuation;
- fixed and variable costs – microeconomics, economic and financial analysis, economic statistics;
- break-even point – microeconomics, economic and financial analysis, management, financial management, business diagnosis and valuation;
- calculation of depreciation of fixed assets, depreciation schedules – financial accounting, financial management, microeconomics, management;
- opportunity cost – microeconomics, management;
- marginal utility – microeconomics, economic and financial analysis;
- cost of equity – financial management, economic and financial analysis, management;
- interest calculation – currency and credit, bank accounting, financial mathematics;
- VAT – microeconomics, financial accounting, finance, taxation, economic and financial analysis;
- commercial margin, margin on direct expenses – financial management, accounting, economic and financial analysis;
- leverage effect of debt – economic and financial analysis, business valuation, financial management;
- working capital – economic and financial analysis, business valuation, financial management;
- rates of return – economic and financial analysis, business valuation, financial management;
- debt ratio – economic and financial analysis, taxation, business valuation, financial management.

These observations highlight the importance of addressing several key aspects in the teaching process:

- harmonizing and correlating the contents of the subject files, so that the points of intersection do not appear as repetitions of some concepts and themes;
- ensuring the right balance in the amount of content and its level of difficulty;
- gradually introducing topics across consecutive specialized courses, gradually increasing the complexity;
- avoiding the risk of omission of essential topics from course syllabi;
- integrating financial accounting knowledge with the use of specialized software;
- allocating an adequate number of credits and an optimal balance between teaching hours and individual study time for each discipline;
- placing enhanced emphasis on the practical training of students.

4. Conclusions

A first conclusion that emerges from the analysis above is that learning can be facilitated for beginners - while simultaneously maintaining the interest of more advanced students - only by identifying ways to engage all participants in laboratory activities through practical simulations and interactive games. The diversity of skill levels requires an adaptation of teaching methods, and the heterogeneity of student groups calls for instructional flexibility. An uniform approach is ineffective; therefore, traditional teaching methods must be complemented with interactive strategies such as case studies, simulations, and project-based learning to ensure that content remains accessible to all students. This objective, however, is notably more difficult to achieve in exclusively online settings.

Blended learning can help reduce training gaps. Online platforms, video tutorials, and supplementary materials enable less-prepared students to catch up, while offering opportunities to advanced students to deepen their understanding.

Another conclusion is that even after the consolidation of knowledge, students' perceptions of the degree of difficulty associated with specific topics continue to differ. It also follows that excessive content coverage, or the introduction of overly difficult material may lead to negative outcomes, such as a decline in student interest across multiple subjects or even a reduction in their learning aspirations. Maintaining an appropriate balance in the workload required by students therefore becomes essential.

To achieve better results, topics must be presented in a logical sequence, with appropriate correlation between successive or related subjects. This approach helps avoid both the repetition of previously covered content and the omission of essential material relevant to the education of future accounting professionals.

Continuous assessment contributes to the ongoing adjustment of teaching strategies. Formative assessments - such as short tests, questionnaires, or applied assignments - enable instructors to identify knowledge gaps and intervene promptly. Immediate feedback supports learning and encourages active engagement.

Connecting theoretical content with professional practice also enhances student motivation. Explaining accounting concepts through concrete examples or introducing specialized software used in professional settings fosters deeper understanding. In a heterogeneous learning environment, the instructor's role extends beyond the transmission of knowledge to that of educational mentor, guiding students in overcoming cognitive barriers, identifying their own learning strategies, and building a strong foundation for their professional development.

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Multi-Generational Interaction in the Agro-Food Workplace

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Abstract: *This study examines generational diversity and interaction in the workplace, which is becoming an increasingly challenging issue for contemporary organizations as multiple age groups—Baby Boomers, Generation X, Generation Y, and Generation Z—now coexist within them. Each generation develops specific values, behaviors, and work expectations based on its distinct historical, economic, and cultural context. While these differences can enrich organizational life, they can also generate tensions that affect communication, collaboration, and collective performance. This study was conducted in Antananarivo within the agro-food sector and aimed at analyzing the influence of generational diversity on organizational climate. The study focused on three generations (X, Y, and Z) and examined several dimensions, including management style, relationships among colleagues, the frequency and causes of conflicts, and job satisfaction. The results indicate that, although management style and job satisfaction do not differ significantly across generations, perceptions of workplace relationships, conflict frequency, and intergenerational interactions are strongly influenced by generational identity. The findings suggest that there are intergenerational factors and logic, they are transversal factors and organizational climate factors related to the generation of belonging. These factors impact the organizational climate. Two complementary approaches were proposed to address these dynamics: the intergenerational approach, which strengthens shared needs such as recognition, fairness, and meaning at work, and the differential approach, which adapts management and communication strategies to the specific characteristics of each generation. Together, these approaches foster cohesion and diversity within organizations. Though this study is limited to the agro-food sector and the Antananarivo region, it underscores the strategic importance of generational inclusive and adaptive management in enhancing performance, social cohesion, and sustainability in an increasingly multigenerational workplace.*

Keywords: *Organizational climate; Madagascar; intergenerational conflict; management style*

JEL Classification: A14; J52; M14

1. Introduction

Generational conflict refers to the tensions, differences or misunderstandings that arise between groups of people belonging to different age cohorts. These cohorts are shaped by different historical, economic, cultural, and technological contexts (Eyerman & Turner, 1998; Pilcher, 1994). These differences can become sources of conflict when the values, expectations, and norms of one group contradict those of another (Pilcher, 1994). Generational conflict reflects the tension between continuity and change, and between heritage and innovation, which runs through every society (Twenge & Campbell, 2008). The contemporary world of work is characterized by an unparalleled level of generational diversity (Islas-Moreno et al., 2024; Lu, 2024). For the first time in professional history, four generations are present within organizations: baby boomers, Generation X, Generation Y, and Generation Z (Lu, 2024; Ollivier, 2008). In the workplace, this diversity can lead to tension when the norms and values of these groups clash (Benson & Brown, 2011). Organizations must therefore manage several generational cohorts with different trajectories, experiences, and expectations (Costanza & Finkelstein, 2015). The emergence of Generation Y and Generation Z presents new challenges for companies in terms of human resources management, intergenerational transmission, and team cohesion (Dejoux & Wechtler, 2011). Research must therefore move beyond a purely conflictual interpretation of these differences. When managed effectively, generational diversity can promote complementarity and innovation, thereby strengthening an organization's capacity for adaptation and collective intelligence (Bencsik et al., 2016).

2. Literature Review

A generation can be defined as a group of people who share a similar way of life, outlook, and culture. It is a group of people who have a collective memory that brings them together over a given period (Eyerman & Turner, 1998). Several major approaches to understanding the formation, identity, and role of generations in social change have been identified in literature. The first of these is formulated by Karl Mannheim (1928), which provides the classic theoretical foundation. He defined generation as a group of individuals who share a collective consciousness born of common historical experiences. According to this approach, individuals exposed to similar events, such as wars, crises, or cultural transformations, at key moments in their socialization, develop shared frameworks of perception, values, and behaviors. He distinguishes three levels: age cohort, generational unity, and generational consciousness. This socio-historical approach emphasizes the relationship between age, history, and social transformation. It enables us to understand intergenerational differences and their role in the evolution of modern societies (Pilcher, 1994; Thorpe & Inglis, 2019). Eyerman and Turner (1998) provide a modern interpretation; they situated Mannheim's theory within the cultural and communication issues of contemporary societies. According to them, generations are not merely biological cohorts, but rather symbolic communities formed through collective memory, the media, and institutions. Generational consciousness is formed through cultural mediation: historical experiences are selected, interpreted, and transmitted within a symbolic framework that produces a shared identity. Their model articulates three complementary levels: structural (economic, political, and institutional conditions); cultural (shared values, lifestyles, and collective narratives), and interactional (relationships between individuals, intergenerational tensions, and knowledge transmission). Three central dimensions are also key: age cohort, generational habitus, and collective memory. These connect individuals through shared narratives and experiences, ensuring continuity and cohesion. This approach enables generations to be considered as symbolic agents of continuity and social transformation, transcending the concept of simple demographic succession (Eyerman & Turner, 1998; Pilcher, 1994). Strauss and Howe's cyclical theory (Holly, 2012) reinforces this viewpoint by providing an ongoing interpretation of social and cultural history. According to this theory, society evolves through cycles of approximately 80 to 100 years, known as 'saecula', which are composed of four successive phases: High (unity), Awakening (spiritual challenges), Unravelling (individualism), and Crisis (emergence of new structures). Each phase is associated with a generational archetype: Prophets (idealists), Nomads (pragmatists), Heroes (cooperators), and Artists (adaptors). Therefore, each generation is defined by the historical context of its socialization, contributing to the periodic renewal of values and institutions. This theory is widely used to analyse contemporary intergenerational dynamics in areas such as work, marketing, and social governance (Strauss & Howe, 1991; Twist & Newcombe, 2021). Jean Twenge's theory takes a psychological and empirical approach; it is based on the analysis of longitudinal data (Twenge & Campbell, 2008). Unlike cyclical or socio-historical approaches, it focuses on behavioral and individual differences between generations. Millennials and Generation Z (iGen) are characterized by increased individualism, more pronounced narcissism, and heightened psychological sensitivity. These characteristics are a consequence of contemporary cultural, technological, and educational transformations. Intensive use of digital technologies, social media, and smartphones influences development, mental health, and social interactions. It leads to anxiety, loneliness, and decreased autonomy. This theory highlights the contemporary generational shift towards digital technology and emotional individualism, offering insight into the behavior of younger generations in postmodern societies (Rodrigues, 2018; Twenge & Campbell, 2008). Together, these four approaches provide essential frameworks for studying intergenerational dynamics in professional, organizational, and social contexts by shedding light on the challenges of cooperation, cohesion, and the renewal of knowledge and practices in modern societies.

3. Conceptual framework of the study

This study was conducted in Antananarivo, the capital of Madagascar. The city is characterized by a high concentration of agro-food companies, as well as notable diversity in terms of size and organizational structure. The city is therefore an ideal setting in which to explore intergenerational interactions in the agri-food sector, given the simultaneous presence of large companies, small and

medium enterprises and start-ups, as well as a diverse workforce in terms of age and hierarchical level. Data collection was based on a mixed approach combining a structured individual questionnaire covering the study's main variables and semi-structured interviews with a sub-sample. This allowed to collect qualitative observations on intergenerational relations.

The study sample comprises seven agro-food companies, which were selected in a stratified manner to represent the organizational diversity of the sector in Antananarivo. The sample consists of 150 employees. Respondents were selected based on availability and voluntary consent to ensure representation of several generations in each company. Two hypotheses guide the study: H_1, that different generations share common factors in the organizational climate; and H_2, that different generations differ in their perception of the work relationship. The study's variables are derived from these hypotheses. The independent variable is the respondent's generation, it is defined according to standard categories (i.e. Generation X, Generation Y, and Generation Z). The dependent variables include the respondent's preferred management style and their assessment of working relationships with colleagues, as well as the positive and negative aspects of these relationships. Other dependent variables include the frequency of conflicts with colleagues, the causes of these conflicts, the duration of conflicts, the ease with which the respondent interacts with other generations, and the difficulty they experience in interacting with other generations, as well as job satisfaction. The main method of data analysis is the chi-squared test of independence (χ^2). This test is suitable for qualitative variables that do not necessarily follow a normal distribution. This test determines whether the observed differences between generations are statistically significant or simply due to chance. The significance threshold (α) was set at 0.05; a p-value of less than 0.05 indicates a significant association between the variables. However, the chi-square test does not provide information on the strength of this association. The study, therefore, uses Cramer's V index to assess the strength of the link between the independent and dependent variables.

4. Findings and discussion

The following two tables summarize the results of the Chi² independence test. The dependent variables are listed in the first row of the tables. The statistical indicators and their interpretation are listed in the first column.

Table 2. Independence test results (part 1)

	Style	**Relationship**	**Positive**	**Negative**	**Frequency**
p-value	0.188	0.524	< 0.0001	< 0.0001	0.010
alpha	0.050	0.050	0.050	0.050	0.050
Interpretation p-value	p-value greater than alpha	p-value greater than alpha	p-value smaller than alpha	p-value smaller than alpha	p-value smaller than alpha
Conclusion on the null hypo	H_0 retained	H_0 retained	H_0 rejected	H_0 rejected	H_0 rejected
Conclusion on the relations	No significant relationship between variables	No significant relationship between variables	Significant relationship between variables	Significant relationship between variables	Significant relationship between variables
V of Cramer			0.672	0.404	0.279
Interpretation of results	Style not related to Generation	Relationship not related to generation	Positive aspect of the relationship related to generation	Negative aspect of the relationship related to generation	Frequency of generational conflict

Table 3. Independence test results (part 2)

	Cause	**Duration**	**Ease**	**Dificult**	**Satisfaction**
p-value	0.012	0.238	< 0.0001	< 0.0001	0.355
alpha	0.050	0.050	0.050	0.050	0.050
Interpretation p-value	p-value smaller than alpha	p-value greater than alpha	p-value smaller than alpha	p-value smaller than alpha	p-value greater than alpha
Conclusion on the null hypo	H_0 rejected	H_0 retained	H_0 rejected	H_0 rejected	H_0 retained
Conclusion on the relations	Significant relationship between variables	No significant relationship between variables	Significant relationship between variables	Significant relationship between variables	No significant relationship between variables
V of Cramer	0.275		1.000	0.592	
Interpretation of results	Cause of generational conflict	Duration of the conflict unrelated to generation	Intergenerational ease linked to generation	Intergenerational difficulty related to generation	Job satisfaction unrelated to generation

These results highlight the absence of correlation between Generation and the dependent variables of management style, working relationships with colleagues, duration of conflict with colleagues, and job satisfaction, which are unrelated to generation. However, Generation does correlate with the positive and negative aspects of relationships with colleagues, the frequency of generation-related conflict, the causes of generation-related conflict, and intergenerational ease and difficulty. The intensity of these correlations varies from moderate to very strong.

Intergenerational factors and logic

The results show that management style, the quality of relationships between colleagues, the duration of conflicts, and job satisfaction do not depend on generational affiliation. These factors are universal and transversal dimensions of the professional environment. According to exchange theory, working relationships are based on reciprocal material and symbolic exchanges (support, respect, recognition, trust), which directly influence the organizational climate (Blau, 2017; Cropanzano & Mitchell, 2005). When employees feel valued and listened to, they develop harmonious relationships and experience fewer prolonged conflicts, which increases job satisfaction (Eisenberger et al., 1986; Rhoades & Eisenberger, 2002). Transformational leadership theory confirms this interdependence (Day et al., 2004). Furthermore, all generations share common values such as empowerment, flexibility, and altruism (Sobrino-De Toro et al., 2019; Schullery, 2013), as well as a commitment to collaboration and recognition of ideas (Brčić & Mihelič, 2015; Zahra et al., 2025).

Organizational climate factors related to the generation of belonging

The perception of relationships between colleagues, the frequency and causes of conflicts, and the quality of interactions depend on generational affiliation. This influences the organizational climate according to the composition of the present generations in the workplace. As Mannheim explains through the concepts of age cohort, generational unity, and generational consciousness (Pilcher, 1994; Thorpe & Inglis, 2019), each generation is shaped by historical, social, and cultural factors. Furthermore, Generations are not limited to biological cohorts, but constitute symbolic communities that are constructed socially through collective memory, the media, and institutions (Eyerman & Turner, 1998; Pilcher, 1994). The historical context experienced by each generation brings about changes in values, attitudes, and personality, resulting in differences in how relationships are perceived and conflicts are managed (Holly, 2012; Rodrigues, 2018; Twenge & Campbell, 2008; Twist & Newcombe, 2021). Studies have highlighted significant differences in professional values and priorities between generations (Malik et al., 2023; Schullery, 2013). The importance attached to various aspects of organizational climate differs between generational groups. It reveals distinct sensitivities to working conditions (Sobrino-De Toro et al., 2019). Even when certain attitudes are shared, differences in intensity persist, reflecting nuances in commitment to, and perception of, the professional environment across generations (Brčić & Mihelič, 2015).

Generalization of the discussion

The multigenerational nature of the workforce is now a defining feature of contemporary organizations (Costanza & Finkelstein, 2015; Joshi et al., 2011; Parry & Urwin, 2021). This coexistence is the result of biological, organizational, succession, and social factors (Eyerman & Turner, 1998; Holly, 2012; Pilcher, 1994). It includes longer careers, the intergenerational transfer of skills and complementary knowledge, and the imperative of sustainability (Andrianaivoarimanga & Rasoanaivo, 2024; Bansal & DesJardine, 2014; Lub et al., 2016; Rezaee, 2016). In this context, management must reconcile performance and social cohesion. If not managed well, generational diversity can lead to either organizational radicalism based on the marginalization of certain cohorts (Boss, 2025) or passive

pluralism, which is simply the sterile coexistence of generations (Cennamo & Gardner, 2008; Henry, 1987; (Joshi et al., 2011).

To overcome these shortcomings, a dual-component, multigenerational approach is recommended: intergenerational and differential approaches. The intergenerational component emphasizes needs common to all generations, such as recognition, fairness, autonomy, and a sense of purpose at work (Schullery, 2013; (Sobrino-De Toro et al., 2019). Meanwhile, the differential component takes into account the specific values, expectations, and communication styles of each cohort (Brčić & Mihelič, 2015; Cennamo & Gardner, 2008; Twenge & Campbell, 2008). This double-integrated approach transforms and scales up generational diversity into a strategic resource by stimulating cooperation, knowledge transfer, and the creation of an inclusive organizational climate (Cennamo & Gardner, 2008; Lyons & Kuron, 2014). Its implementation can be drawn from the CSR approach, which prioritizes relationships and working conditions for sustainability (Andrianaivoarimanga & Rasoanaivo, 2024; MIDSP, 2013). Steps include management commitment, diagnosis, definition of strategic priorities, participatory implementation, and continuous evaluation (Andrianaivoarimanga et al., 2020; MIDSP, 2013). However, this management must form part of a gradual acculturation process that respects the pace of change (Berry, 1992; Andrianaivoarimanga, 2023; Andrianaivoarimanga & Ranosy, 2023). This collective learning process fosters an organizational culture centered on collaboration, inclusion, and sustainability.

5. Conclusion

The findings of this research show that, in terms of fundamental values related to work, there are both similarities and differences between generations. Management style, the quality of relationships with colleagues, the duration of conflicts, and job satisfaction are transversal factors that are not related to an individual's generation. However, perceptions of aspects of relationships with colleagues, the frequency of conflict, the causes of conflict, and the way in which people interact are linked to generational affiliation. This highlights the need for realistic management of generational diversity to leverage performance and cohesion. Effective management must therefore strike a balance between unity and differentiation. Such a balanced approach would unite generations around shared values such as recognition, quality relationships, and purpose. Furthermore, it would appreciate the unique attributes of each generation. This study has two managerial implications. Firstly, organizations must establish mechanisms that promote intergenerational cooperation based on shared values. Secondly, they must recognize and utilize generational differences as a strategic resource in order to prevent tensions and strengthen the sense of belonging. When managed intelligently, generational diversity can contribute to innovation, organizational sustainability, and social cohesion. The sustainability of human capital depends on intergenerational knowledge transfer through mentoring, co-learning, and knowledge management. This approach would ensure continuity of skills and organizational resilience in the face of technological change. At the same time, implementing inclusive human resources policies that address the specific expectations of each generation is an ethical and strategic imperative that promotes equity, well-being, and corporate social responsibility. Future research could extend the analysis to other sectors and regions to better understand the influence of socio-economic and cultural contexts. Adopting mixed methodologies that integrate variables such as gender, hierarchical level, and career trajectory would allow for a deeper understanding of intergenerational dynamics.

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Bridging the Gap Between Abstract Mathematics and Applied Economics: Making Math Stop Being the Villain

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Abstract: *Mathematics in economics is often cast as the villain of the story—more like an unexpected oil spill in a Ploiești refinery than a reliable analytical tool. Many students see equations as monsters lurking under the bed of the syllabus, ready to ambush them with derivatives and optimization problems. This paper argues that mathematics is, in fact, the unsung sidekick of economic reasoning: less Voldemort, more Watson. Drawing on recent literature on mathematics anxiety, self-efficacy, contextual learning, active methods, and humor in higher education, we outline a framework for transforming abstract mathematical concepts into approachable, memorable tools for applied economics. The approach emphasizes visualization, collaborative problem-solving, and local analogies: supply-and-demand graphs become treasure maps to equilibrium, profit curves feel like rollercoasters whose peaks and drops can be predicted, linear programming resembles fair pizza allocation under strict constraints, and the Ploiești hot-water crisis becomes a living lesson in resource optimization. Evidence from prior studies and classroom experience suggests that when math is presented with context, interaction, and playful micro-analogies, student engagement rises, anxiety falls, and understanding deepens. In short, mathematics stops being the villain and becomes a co-pilot guiding students through the wild terrain of economic analysis—with logic, structure, and more than a few smiles.*

Keywords: *Applied Mathematics, Student Engagement, Math Appreciation, Humour in Learning, Fun Math*

JEL Classification: *A22; I23; C87; D81*

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1. Introduction

It is common knowledge that students often fail to understand why Mathematics is so present in the Economics field of study curriculum… hated and feared, it is the villain that we don't bother to understand. Maybe it can be referenced as Voldemort[10], however it is keenly fond of using Greek letters and less inclined to go for horcruxes. Were students to vote a discipline out of the Economics curriculum, this bad guy would be chalked off in a split nano second. Spreading awe and sending chills down their spine, by the dark powers of calculus, algebra and matrix twitches, this recurrent ghastly figure must mingle with every model market, graph bent and derivative, by means of shady symbols and scary enchantments. Or is it not an evil bent spell-book user, but rather a loyal detective assisting us, much like Watson[11]? It seems to us that Economics without Math is like cereal without milk, Holmes without Watson, that is a bunch of well-shaped words forming cool theories, but without a reasonable binder or proof. What Watson does for Holmes is bringing to the Economics table structure, clarity and predictive

[10] *Voldemort – The main antagonist in the Harry Potter series, known for being intimidating, feared, and seemingly impossible to defeat just like mathematics is often perceived by students.*
[11] *Watson – Sherlock Holmes' loyal and highly competent companion, known for assisting Holmes in solving complex problems, just like mathematics can be a helpful and reliable ally.*

power, turning idea and concept into evidence, telling us beforehand when profits will peak or plunge into the abyss.
Our paper is advocating that Mathematics should be greeted by students as a peculiar astute assistant rather than their executioner when the exam time comes. This change of focus is fundamental to their perception. By means of humor, relatable scenarios and interactive teaching strategies, mathematics can be enjoyed and praised by students as their best companion when dealing with economic reasoning.

2. Literature Review

2.1 Anxiety and Avoidance: The Math Anxiety Monster

The anxiety math can induce is very real and frequent. It feeds on working memory (Ashcraft & Moore, 2009). Some freeze as if confronted with dark magic and feel like target practice when they see something like $\int$. This very fear generates a natural feeling of ducking which in turn is incompatible with performance and fear. It all turns very quickly into something coming straight from a B horror movie. Research has unveiled that there are comfortable solutions at hand and humor is one of them. Humor helps us shield against panic and fight fear, as it contributes to lessening the cognitive load and improves recollection (Banas et al., 2011; Garner, 2006). Laughter also expands cognitive space and improves resilience (Banas et al., 2011; Garner, 2006).
When it comes down to specifics of Romanian higher education, we can confirm those conclusions: students enjoy and thrive in interactive contexts, especially in technical areas, while widely preferring playful learning strategies (Toader et al., 2023). Games boost skills and performance and motivation improve in class, while students get a smile or two.

2.2 Contextualization: When Math Talks About Real Life and Students Say "Wait, I Know This!"

Comprehension is easier when mathematical concepts are presented as familiar things from the students' life (Ainsworth & Loizou, 2003). Let's try to think of a constrained optimization problem but not as such, rather as a challenge to identify the optimal number of seats for fans so that cheering (or booing) is maximal at Ilie Oana stadium. And we find that, out of the blue, the Lagrange multiplier seems to become the FIFA Manager stadium decision maker and not the scary executioner. If we talk about elasticity, lightning-fast understanding ensues if we focus on the perceived price of pastry before or after payday, while equilibrium viewed as a snap shot taken from the Ploiesti Horse Racecourse chart means students will immediately see that too many racing horses and too few bettors signify disequilibrium while a perfect balance will be rewarded by applause. More specifically, Romanian students seem particularly keen to come across scenarios they can relate to and examples that are culturally significant to them (Mâţă et al., 2024). Basically, if they know it from their turf, the math behind it becomes easy. As such, thinking about the engineers that manage operations in the Ploiesti refineries, they will understand the paramount importance of optimization in Economics, they will stop being concerned only about predicting market trends. A derivative that finds its right place in their calculations will therefore prevent a dangerous spill. Supply-and-demand graphs can be understood better as treasure maps to uncover equilibrium and profit curves can be about the joy of skilled navigation, avoiding going too fast or too slow and preventing wrecking your boat.

2.3 Self-Efficacy: The Watson Confidence Factor

At the core of self-efficacy lies belief, the belief that problems can be solved (Bandura, 1997). When students trust themselves and their abilities, they dare more, they choose and see differences easier (Haciomeroglu, 2017), and every small victorious step nurtures more wins. It is just as Watson brings calm and trust to Sherlock when they face the apparent lack of logic of a chaotic murder scene: self-efficacy ensures students' inner voice whispers in their ear *"You can actually solve this integral."* Math ensures light shreds apart the darkness of the murder scene.

2.4 Visualization: Transforming Invisible Logic into Action

So, how does this all work? As demonstrated by research, technology brings concepts closer and understanding is improved when the relationship between cause and effect becomes immediate (Chew & Cerbin, 2020). Visual aid, simulations and real-time graphs are way more dynamic than simple static symbols. We may lecture all we want, but when students see the immediate change in revenue when we simply pick another point on a graph, understanding follows. Seeing is believing. This leads to them understanding that derivatives have the economic superpower of prediction. Boring things become interactive, while confusing concepts become visible and crystal-clear (*"I get it now!"*).

2.5 Active and Social Learning: Math Stops Being Lonely. Team Sherlock vs. Solo Despair

Learning together means better academic performance and improved satisfaction (Freeman et al., 2014). There is little debate on the advantages of teamwork in everyday life, let alone in the wild. It is the same in class. Solving math problems in class no longer feels like being trapped in a room and waiting for punishment if we do it with peers. It becomes team strategy: "*we'll show you, supply curve*!" or "*we got this, we will all go through or we will all fail trying*". When students investigate together, it is like Sherlock working with Watson or, sometimes, an entire policemen squad: it works better and faster. A lonely interrogation works less often than a mission based on cooperation where clues (that may be equations) are filtered by multiple minds and from different angles. It is no different for Romanian students, patterns stay the same, games and teamwork boost motivation (Toader et al., 2023).

2.6 The Grand Conclusion of Literature

All research, be it international or local, has come to the same conclusion, that students learn quantitative skills better when they are acknowledged as useful, tangible, visible and provided with a humorous context.

3. Conceptual Framework. Or How We Turn Math into a Sidekick

Our approach is composite, while taking into account appropriate literature, we are experimenting with class strategies and keep an eye on real-time student reactions. Things are even simpler: the design of our classes is based on what we witnessed triggers panic, curiosity and fun within the students and, as a consequence, we tried to encourage the last two reactions.

The applications we conceived integrate math inside recognizable economic scenarios. We see supply chains behave similarly to the harmonized gears and cogs at the Nicolae Simache Clock Museum, optimization like controlled refinery valves that prevent cost disasters, so let's allow our students to be the engineers of derivatives. And, as we all remember, the famed Ploiesti summer without hot water was a stark signal to relearn scarcity and planning so we used it for a case study as part of the syllabus. While performing these experiments, we helped steer decisions, by observing jokes and eye rolls, well received analogies, "*Aha*!" moments for certain graphs, instead of shudders. This perspective ensured our strategies were not simple funky teacher fantasies, but facts grounded in what real students understand and enjoy.

Our suggested cheerful model could be called Watson's Framework for Mathematical Engagement. Mathematics is the Watson of the Sherlock of Economics, always investigating, calculating, predicting and, occasionally, even saving the day. Our conceptual model is built on five pillars that transform fear into engagement (Figure.1).

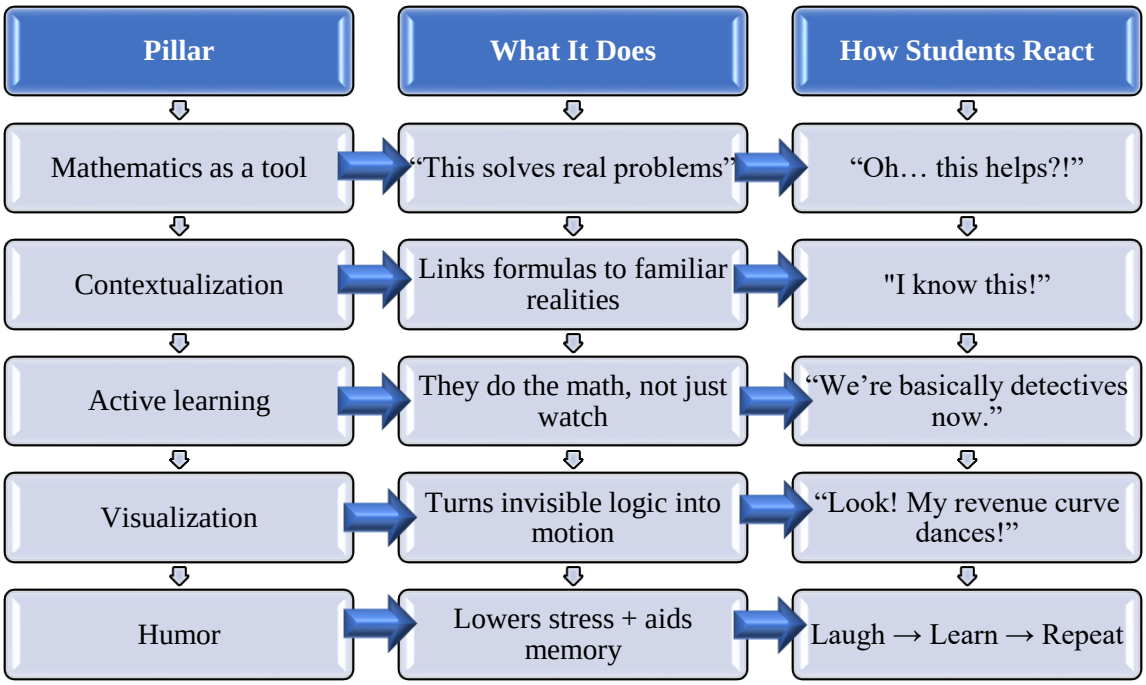


Figure 1. Conceptual framework of humorous math engagement (or Watson's Framework for Mathematical Engagement).

Source: Georgiana Popescu, Ileana Dumitru, Erik Popescu, 2025

Students' engagement (E) is influenced by 5 instructional traits: self-efficacy (SE), context (C), active learning (AL), visualization (V), and humor (H). The relationship can be formalized as:

$$E = f(SE, C, AL, V, H) \quad (1)$$

Each component increases engagement and breaks the myth of math as the villain. In the end, no villain remains. To put it simply, if math bears a friendly face, students will welcome it, rather than pushing it in the pit.

4. Discussions

So, what does it look like, in practice, when implementing this type of approach? Imagine blending elements from an escape room, a sports match and a survival game, but with derivatives as alarms for protection. Our research on the effects of Watson's Framework for Mathematical Engagement is not extensive, but we can quote several instances of the exchanges between students and teachers, as well as the reactions.

- Supply-and-demand graphs transformed into treasure maps: Student 1: *"Where is the equilibrium?"*, Student 2: *"Well, it is under the second curve: past the bakery, take a left."*
- Profit curves like rollercoasters: thrilling on the way up, regrettable on the way down. Students cheer when predicting peaks and boo when profit plummets – learning Economics turned emotional.
- Mistakes transformed into humorous moments rather than traumatic: Student: "*Why is my profit negative?*" Professor: "*Because you paid more to sell the product than customers paid to buy it. Your price is so low even the competitors feel bad. It seems like you accidentally invented a charity*."

What we observed was that self-efficacy soared and fear melted. Math finally felt good. In these cases, we observed that, while fighting with derivatives, students laughed. A few of them even forgot they were doing math. But, most importantly, students learned. We can say our mission was accomplished.

5. Results: When Math Finally Stops Being the Villain

As stated above, in the few cases we implemented this method, we noticed some important effects:

- Anxiety dropped
- Participation increased
- Degree of conceptual mastery improved
- Humor boosted willingness to try

Students began voluntarily asking questions such as: "*Can we run another optimization problem? That was fun*." Students felt the content truly spoke their language, which improved trust and risk-taking. Mathematics turned into a spirited assistant that can help crack cases. Not feared, not avoided—*respected*.

6. Limitations

Our detective – style experiments were definitely exciting for all parties involved, but it is not to say that is how Mathematics in Economics should be taught everywhere; it is, however, a more than promising case file. The implementation was bound by limiting factors: a limited number of lessons from a single university, the same teachers and a familiar group of students. These factors contributed, undeniably, to the smiles, reduced levels of anxiety and increased enthusiasm for derivatives in this specific learning environment, taking also into account the personal dynamics of the actors involved. Just because it worked for us in Ploiesti and optimization was successful as a rollercoaster simulation, it doesn't mean it will work in Timisoara, Bangkok or Oslo. The validation and tuning of these strategies are subject to broader studies, within various institutions, cultures and with different actors. Research should focus more on subjects and Watsons in order to definitely establish how well humor, contextualization and visualization work in different educational circumstances. For now, we can confidently say: the clues look good, but the investigation continues.

7. Conclusions

Mathematics is not born the villain. It became that after it was stripped of humor, relevance and background story. Once these are restored, it shines as the brilliant Watson who can solve any puzzle and pours light into chaos. Once we turn formulas into clues, graphs into maps and students into detectives, something interesting happens:

- Economic logic becomes intuitive
- Equations become allies
- Energy in the classroom becomes tangible
- Confidence replaces fear

In Economics, every number tells a story. When students become part of that story, mathematics becomes a friend. Math is not Voldemort. Math is Watson. And we think it is time every student got properly introduced.

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The role of the European Framework and ESG Factors in the Transition to Climate Neutrality: Developments, Regulation and Implications for the Banking Sector

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Abstract *The paper explores how global and European climate policies have evolved from the early recognition of environmental challenges to the implementation of concrete, measurable actions for sustainable development. The study focuses on the European Union's (EU) leadership in shaping climate governance frameworks – most notably through the European Climate Law, the Fit for 55 Package, and the European Green Deal – which aims to achieve decarbonization by 2030 and climate neutrality by 2050.*
Methodologically, the research relies on a documentary and comparative approach, integrating official sources from the European Commission, OECD, EBA, and World Bank, combined with Eurostat indicators on the Sustainable Development Goals (SDGs). The analysis also draws on the theoretical ESG model (Environmental, Social, Governance), newly adapted to signal novelty and relevance for the financial and banking sectors.
This study contributes originally by developing an integrated analytical framework that links EU climate policies (Green Deal, Fit for 55) with central banks' integration of climate risks into monetary policy and supervision, using a comparative documentary method with recent Eurostat SDG data and ESG adaptation for banking—addressing gaps in prior research focused mainly on general disclosures rather than operational risk frameworks (e.g., ECB 2025 stress tests). Results reveal a significant interconnection between financial stability and sustainability. Central banks and supervisory authorities play a growing role in the green transition, integrating climate-related and social risks into monetary policy, financial supervision, and risk assessment frameworks. The findings emphasize that the success of the green transition depends on coherent coordination between economic, financial, and educational policies, alongside strong governance and transparent ESG reporting mechanisms

Keywords: *Climate change, European Green Deal, ESG, Sustainable finance, Central banks*

JEL Classification: *Q54, Q56, G18, E58, F64*

1. Introduction

Climate change has become one of the defining challenges of the 21st century, influencing economic, political, and social agendas worldwide (IPCC, 2023). The Paris Agreement (UNFCCC, 2015) established a global commitment to limit global temperature rise to below 2°C, representing a milestone in international climate governance. Following this, the European Union (EU) emerged as a global leader in environmental and sustainable policy innovation, promoting legally binding targets for decarbonization by 2030 and climate neutrality by 2050 (European Commission, 2019). The European Climate Law (European Union, 2021) formally enshrines these goals, while the Fit for 55 Package translates them into sector-specific measures that cover energy, transport, and industry (European Commission, 2021a). These initiatives are part of a broader strategic framework — the European Green Deal, which aims to transform the EU into a modern, resource-efficient, and competitive economy (European Commission, 2019).
The main objective of this study is to analyze how global and European efforts have evolved from the stage of recognizing climate risks to that of implementing actionable policies that integrate environmental, social, and governance principles (ESG) (NGFS, 2022). The paper particularly highlights the role of the financial and banking sector in accelerating the green transition through sustainable investment mechanisms and risk management tools (ECB, 2023; EBA, 2021).

2. Methodological Approach

The research employs a qualitative documentary and comparative analysis of carefully selected international and European policy documents from primary sources (UNFCCC, European Commission, OECD, EBA, World Bank) (UNFCCC, 2015; European Commission, 2019; European Union, 2021), selected based on the following criteria: (1) official regulatory status (binding legislation or authoritative guidance); (2) direct relevance to climate-finance interfaces (Green Deal, Fit for 55, European Climate Law, central bank climate risk frameworks); (3) publication/post-implementation date within the 2015-2025 period to capture Paris Agreement-to-EGD implementation dynamics; and (4) representation of multi-level governance (global→EU→national central banks), complemented by the interpretation of select Eurostat and OECD indicators aligned with SDG targets 7, 8, 9, 13 (climate action, decent work, industry/innovation, energy) (Eurostat, 2024; OECD, 2023).The study also incorporates the ESG analytical framework as a theoretical model to examine how environmental, social, and governance factors interact to influence economic sustainability and financial stability (World Bank, 2022). Comparative method: Cross-sectional (EU vs. global benchmarks) and longitudinal (policy evolution 2015-2025) comparisons structured as follows: (1) thematic matrices mapping climate policy milestones against central bank integration timelines; (2) indicator benchmarking (Eurostat SDG progress vs. OECD green finance metrics); (3) qualitative pattern analysis identifying convergence/divergence in ESG-risk operationalization across supervisory frameworks. Triangulation via multiple sources ensured analytical robustness, with findings validated against 2025 ECB 'Fit-for-55' stress test parameters.

3. Literature Review

The concept of sustainable development has been shaped by multiple global milestones, starting with the Brundtland Report (1987), which defined sustainability as meeting present needs without compromising the ability of future generations to meet theirs. This principle underpins the UN 2030 Agenda for Sustainable Development, encompassing 17 interlinked goals.
In Europe, the European Green Deal (2019) redefined policy priorities by positioning sustainability at the core of economic and financial decision-making. This approach promotes a just and inclusive transition, ensuring that no region or community is left behind.
From a financial perspective, sustainability is no longer seen as an ethical choice but as a systemic requirement for long-term economic resilience. Studies by the World Bank (2024) and OECD (2023) confirm that financial systems integrating ESG principles are more resistant to crises and display stronger recovery capacity in the face of shocks.

3.1. Theoretical Review

The theoretical foundation of this research builds upon ESG-based models used by institutions such as the World Bank, European Central Bank (ECB), and OECD, which emphasize the relationship between sustainable development and macro-financial stability.
The relationship between sustainability performance and the main ESG factors can be expressed as:

$$Y = \alpha + \beta_1 E + \beta_2 S + \beta_3 G + \varepsilon$$

where:

- Y– overall sustainability outcome (for example, GDP adjusted for environmental impact, SDG index, or climate neutrality progress);
- E– environmental dimension (reduction in CO_2 emissions, renewable energy use, and energy efficiency);
- S– social dimension (employment, education, health, equity);
- G– governance dimension (institutional quality, transparency, corruption control);
- ε– residual term reflecting other influences not captured by the model.

In this functional form, each coefficient $\beta_i$measures the marginal effect of the corresponding ESG dimension on sustainable performance. A positive and statistically significant β_3, for example, would indicate that improvements in governance quality enhance overall sustainability outcomes. Moreover, stronger governance frameworks may reinforce the effectiveness of environmental and social policies by improving institutional credibility and policy implementation capacity.

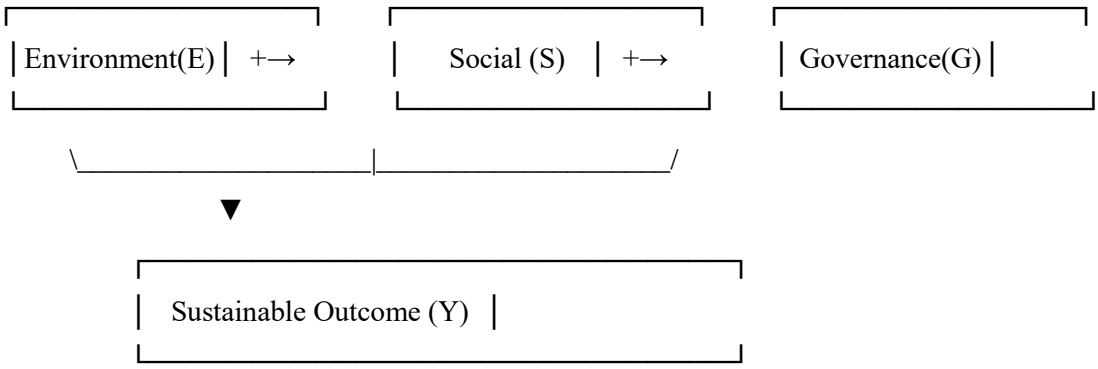


Figure 1. Simplified ESG–Sustainability Relationship

Source: Source: author's processing

The model illustrates that the three ESG pillars function synergistically: environmental protection reduces physical risks, social inclusion enhances adaptability, and governance ensures accountability. Empirical studies (OECD, 2023; World Bank, 2024; EBA, 2025) highlight that governance quality exerts the strongest long-term impact, acting as a stabilizing force that magnifies the effects of environmental and social improvements.

4. Discussion

4.1. European Climate Governance and Green Finance

The European Union's policy framework combines environmental legislation with financial instruments designed to support a Just Transition. The Just Transition Mechanism (JTM) provides financial aid for regions dependent on high-carbon industries, encouraging green innovation and workforce reskilling.
Financial supervision has also adapted to the realities of climate risk. The European Central Bank (ECB) integrates environmental considerations into monetary policy and macroprudential supervision. The European Banking Authority (EBA) introduced ESG guidelines under CRD VI, requiring banks to assess climate and social risks within their capital planning processes.
Over 70% of EU/EEA banks have substantial exposures to corporations operating in sectors with major contributions to climate change (carbon-intensive sectors such as energy, manufacturing, and transport), according to the EBA 2025 ESG Dashboard. This implies significant transition risks if sustainability policies affect these sectors. Recent progress in integrating climate-related risks into stress tests (EBA/ECB 2025) indicates moderate reductions in CET1 capital (by approximately 74–77 basis points), but also identifies "pockets of undetected risk" within misaligned portfolios.



Figure 2. Final Guidelines on the management of ESG risks

Source: European Banking Authority (2025), Final Guidelines on the management of ESG risks

Recent data (EBA, 2025) show that over 80% of EU banks now incorporate ESG criteria into their internal governance frameworks, while the share of sustainable investments within total financial portfolios has increased by an average of 25% per year since 2022.

Table: Key EU Climate Indicators for Banks (2025)

Indicator	**Value**	**Definition / Source**	**Implications**
Exposure to Carbon-Intensive Sectors	Over 70% Corporate Portfolios (majority of EU/EEA countries)	% Exposure to Energy / Manufacturing / Transport Sectors; EBA ESG Dashboard 2025	High Transition Vulnerability (policy / technology shifts)
Incremental Credit Losses (Transition Risks)	74 bps CET1 Capital Decline	Additional under EBA Adverse Scenario 2025; High Energy-Intensive Sectors	Moderate Impact, but Amplified under Macro-Adverse Conditions
Growth in Renewable vs. Fossil Fuel Financing	~11% Average Annual Growth (2021–2025)	Evolution Ratio; Based on 8–9 Decarbonised Sectors	Below Paris-Aligned Trajectory; Acceleration Needed for Net-Zero 2050
Banks with Published Transition Plans	~All Major EU Banks (2025)	Decarbonisation Targets (e.g. –30% Oil/Gas); EBA Guidelines	Progress in Transparency, but Gaps in Sectors (Agriculture, Shipping)

Source: author's processing

4.2. Global Coordination and Policy Challenges

At the global level, institutions such as the Network for Greening the Financial System (NGFS) and the Task Force on Climate-related Financial Disclosures (TCFD) play a central role in promoting uniform

climate reporting standards. These mechanisms enhance transparency, allowing policymakers and investors to assess exposure to climate risks.

Nevertheless, the transition remains uneven. Developed economies have advanced faster in integrating ESG frameworks, while developing countries face challenges related to financing capacity and institutional readiness. The OECD (2023) estimates that keeping global warming below 2°C requires approximately 630 billion USD in additional annual investments over the next decade.

To address these gaps, the EU introduced flexible compliance measures under the Omnibus legislative package (2024) and the "stop the clock" mechanism, ensuring gradual adoption of reporting standards like CSRD (Corporate Sustainability Reporting Directive).

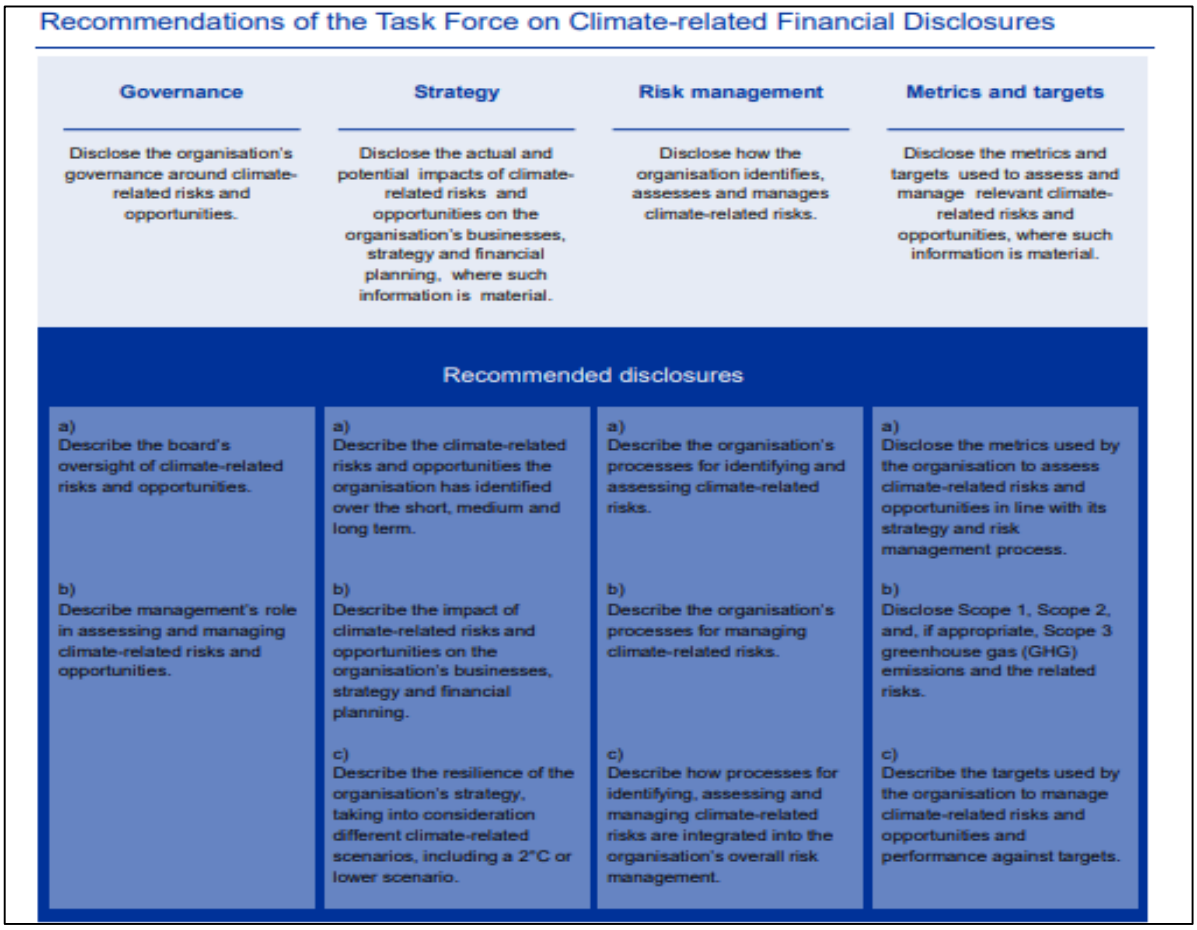


Figure 3. Recommendations of the Task Force on Climate-related Financial Disclosures

Source: Task Force on Climate-related Financial Disclosures, *2025;*

4.3. The Role of Central Banks in the Green Transition

Central banks increasingly acknowledge climate and nature-related risks as systemic threats to financial stability. They now integrate these risks into their analytical models, scenario testing, and supervisory policies.

While the ECB has actively embraced climate considerations, other institutions, such as the U.S. Federal Reserve, maintain a more limited approach due to legal constraints on their mandates.

This divergence illustrates the ongoing debate between institutional neutrality and sustainability activism in central banking. Despite differing approaches, a growing consensus supports the inclusion of ESG factors in assessing macroeconomic resilience.

5. Conclusions and personal recommendations

The European Union has established itself as a global leader in the transition toward a sustainable, low-carbon economy. This research innovates by empirically demonstrating, through comparative analysis of EU policies and central bank practices, the mutual reinforcement of financial stability and sustainability via ESG-embedded frameworks—offering a novel banking-specific adaptation and policy coordination model absent in existing literature on climate-monetary policy interfaces. The analysis confirms sustainability and financial stability are mutually reinforcing objectives. By embedding ESG principles in monetary, fiscal, and investment policies, the EU promotes a resilient model of economic growth capable of withstanding global shocks. For countries such as Romania, aligning domestic strategies with EU standards is essential for accessing green financing instruments and attracting international investment. Strengthening governance, improving transparency, and developing green education programs are key steps in achieving this goal.

Ultimately, climate neutrality by 2050 will depend on continued cooperation between governments, financial institutions, and civil society. The ESG framework provides the foundation for this collaboration, ensuring that economic development remains compatible with environmental protection and social equity.

However, the study also has several limitations. The analysis relies mainly on publicly available documents and broad indicators, which may not fully capture sector-level differences or country-specific institutional constraints. In addition, the absence of detailed financial data and long-term ESG performance metrics limits the ability to accurately assess the real impact of policies and regulatory measures.

6. AI Disclosure

The author used OpenAI's ChatGPT tool solely for language refinement and formatting adjustments. The author retains full responsibility for the accuracy and integrity of the manuscript.

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The Artificial Legal Intelligence Society (ALIS) as an Open, Multi-Sided Platform for Law-as-Computation

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Abstract: *The deployment of artificial intelligence in legal domains has produced a distinctive power configuration: the emergence of a techno-legal aristocracy that concentrates influence at the intersection of technical capability and legal authority. This paper examines how platform dynamics in legal AI simultaneously promise democratization while enabling new forms of knowledge enclosure. We argue that existing approaches to legal technology development replicate and reinforce aristocratic structures through what we term selective permeability, the strategic control of access points that determines who can participate in law-as-computation and on what terms. Drawing on platform economics, techno-feudalism scholarship, and legal epistemology, we introduce the Artificial Legal Intelligence (ALI) Society (ALIS) as a design framework for community-governed infrastructure that reconceptualizes legal work as computable argumentation. The ALIS Framework addresses fundamental challenges through a four-layer architecture: a Commons Layer providing open ontologies and argument schemas as foundational infrastructure; a Service Layer delivering explainable inference through standardized APIs; a Governance Layer implementing transparency mechanisms and safety protocols; and an Application Layer enabling differentiated private offerings built on shared foundations. Rather than applying technology to law or regulating technology through law, the ALI Society proposes developing a new integrated language that transcends both the legal and technical vernaculars while remaining accountable to both domains. This paper presents the ALIS Framework as a theoretically grounded design proposal, specifying architectural principles, governance mechanisms, and evaluation criteria for future implementation. We contribute to emerging scholarship on AI governance by demonstrating how platform architecture can be designed to balance openness with sustainability, expertise with accessibility, and computational efficiency with epistemic integrity.*

Keywords: *Legal Technology; Platform Economics; Techno-Feudalism; Knowledge Governance; Artificial Legal Intelligence; Design-Science Research*

JEL Classification: *K00; L86; O33; D71; M15*

Note: *A prior version of this abstract is available in the references (Allega, 2025).*

1. Introduction

The deployment of artificial intelligence in legal contexts has exposed a fundamental tension. Powerful language models promise to democratize access to legal knowledge, reducing barriers that have historically concentrated expertise within professional guilds (Susskind, 2017; Remus & Levy, 2017). Yet the infrastructure required to deliver these capabilities — computational resources, training data, domain expertise, and regulatory approval — creates new dependencies that may relocate rather than eliminate concentrations of power (Pasquale, 2015).

The current landscape of legal AI is characterized by fragmentation and opacity. Isolated point solutions optimize single tasks without establishing shared, auditable foundations (Surden, 2014). Each vendor constructs proprietary knowledge representations, creating interoperability barriers and vendor lock-in

that limit AI's transformative potential in legal practice (Hildebrandt, 2018). The technical complexity of these systems renders them inaccessible to the legal professionals who must ultimately take responsibility for their outputs, widening the gap between those who build legal AI systems and those who use them (Flood, 2019).

We identify this configuration as the emergence of a techno-legal aristocracy — a power structure formed through the convergence of traditional legal authority and contemporary technical capability. This aristocracy operates through what we term selective permeability: the strategic management of access points that determines who can participate in law-as-computation and under what conditions. Understanding this dynamic requires situating legal AI within broader scholarly conversations about platform economics (Parker et al., 2016; Constantinides et al., 2018) and what Varoufakis (2023) has termed techno-feudalism.

Against this background, we introduce the Artificial Legal Intelligence (ALI) Society (ALIS) as a design framework for community-governed platform infrastructure (Allega, 2025). The ALIS Framework does not claim to resolve the tensions inherent in knowledge commoditization; indeed, as we have argued elsewhere (Allega & Puzio, 2025a), such resolution may be structurally impossible. Rather, it proposes architectural and governance mechanisms designed to make these tensions visible, contestable, and subject to collective deliberation. The framework operationalizes principles derived from our prior work on multi-expert legal reasoning (Allega & Puzio, 2025b) and community-based AI alignment (Allega & Puzio, 2025c), extending them into the domain of platform design.

Our methodology follows design-science research principles (Hevner et al., 2004) combined with platform-ecosystem analysis (Kretschmer et al., 2022). We construct specific artifacts — schemas, protocols, and governance templates — then evaluate them against explicit utility criteria encompassing interoperability, auditability, safety, and maintainability.

2. Theoretical Background

2.1 The Techno-Legal Aristocracy

The concept of aristocracy invokes hereditary privilege and power concentration through self-reproducing mechanisms. In legal technology, we observe an analogous dynamic: the emergence of a new elite defined not by bloodline but by the capacity to operate simultaneously in legal and technical registers.

The asymmetry is structural. The technical aristocracy — comprising major technology platforms, AI laboratories, and the specialized talent they command — has demonstrated remarkable capacity to absorb other professional aristocracies. Medicine has witnessed technological incursions into diagnostics and drug discovery; finance has been transformed by algorithmic trading and platform-mediated lending (Sundararajan, 2016); academics find knowledge production increasingly dependent on proprietary computational infrastructure.

The legal profession presents a distinctive case. Unlike medicine or finance, law possesses peculiar institutional embeddedness: legal authority is a constitutive feature of the state apparatus itself (Abbott, 1988). This provides the legal aristocracy with defensive resources unavailable to other professions — the capacity to regulate, license, and define legitimate practice boundaries. Yet legal systems require information infrastructure; legal practice depends on document management, research databases, and increasingly on predictive analytics. The legal aristocracy cannot refuse engagement with the technical aristocracy without sacrificing efficiency gains that competitors will capture.

What emerges is a marriage of convenience conducted in the only language both parties reliably share: money. Commercial transactions mediate the relationship but do not produce mutual understanding. Legal professionals may use AI tools without comprehending their technical foundations; engineers may build legal applications without grasping the epistemic requirements of legal reasoning. The resulting systems may function commercially while failing epistemically.

2.2 Platform Dynamics and Techno-Feudalism

The techno-feudalism thesis holds that contemporary digital platforms create new forms of economic extraction paralleling feudal rent-seeking more closely than market competition (Varoufakis, 2023; Durand, 2020). Platform owners extract value through control of essential infrastructure — the digital equivalent of controlling land or trade routes. Zuboff's (2019) analysis of surveillance capitalism emphasizes how platforms extract behavioral data and transform it into prediction products, with concerning implications for legal AI systems trained on attorney work products and client communications.

Platform economics scholarship identifies several power-concentrating mechanisms (Srnicek, 2017; Parker et al., 2016). Network effects create winner-take-all dynamics; data feedback loops reinforce early-mover advantages; switching costs lock users into chosen platforms (Tilson et al., 2013; Eaton et al., 2015). Legal AI platforms exhibit all these dynamics while adding domain-specific complications: legal knowledge varies by jurisdiction, practice area, and interpretive tradition, creating opportunities for specialization strategies while professional and regulatory constraints reinforce the techno-legal aristocracy configuration.

2.3 The Knowledge Commoditization Paradox

Underlying the techno-legal aristocracy is the knowledge commoditization paradox (Allega & Puzio, 2025a): the simultaneous necessity and impossibility of reducing complex organizational knowledge to tradable computational representations. Law operates through what Hart (1961) identified as a constitutive duality: abstract principles providing interpretive scaffolding and concrete rules governing specific situations. Competent legal reasoning requires navigating between these levels through multiple methodologies embodying distinct epistemological commitments (Allega & Puzio, 2025b). Generic large language models, trained on undifferentiated corpora, collapse this epistemic structure into statistical patterns producing linguistically fluent but legally unfounded outputs.

The process of semantic vectorization introduces what we term semantic entropy: progressive degradation of contextual information through successive abstraction layers. Arrow's (1962) foundational analysis identified the information paradox — buyers cannot assess value without consuming information — while digital reproduction exhibits near-zero marginal costs. Yet creating high-quality legal knowledge representations requires substantial domain expertise, computational resources, and iterative refinement. Organizations face a dilemma: oversimplified representations failing to capture domain complexity, or elaborate encoding schemes reintroducing the transaction costs digitalization was meant to eliminate.

2.4 Legal Epistemology and Computational Representation

Legal reasoning possesses characteristics complicating computational representation beyond general knowledge management challenges. Dworkin (1986) argued that law operates as an interpretive enterprise where legal propositions derive truth conditions from constructive interpretation of legal practice as a whole. Alexy's (2002) theory formalizes this process, identifying rational discourse rules distinguishing valid from invalid legal arguments. A legal AI generating conclusions without exposing supporting reasoning violates basic legal epistemology requirements, regardless of correctness.

Moreover, legal systems exhibit what Luhmann (1993) characterized as operational closure combined with cognitive openness. Law determines validity through internal operations while remaining cognitively open to other social systems. Legal AI systems cannot simply import external accuracy or efficiency standards; they must operate according to criteria law itself recognizes as legitimate. Recent developments demonstrate that AI systems can achieve remarkable performance on legal examinations (Katz et al., 2024), yet such metrics capture only a fraction of what constitutes competent legal reasoning.

3. The ALI Society Framework

3.1 Design Philosophy: Integration, Not Translation

The ALI Society represents a design framework for community-governed platform infrastructure addressing the challenges identified above. The framework emerges from a specific diagnosis: the techno-legal aristocracy operates through the absence of a shared language adequate to law-as-computation demands.

One response would be translation: training specialists to render legal concepts in technical terms and vice versa. But translation preserves language separateness; the translator remains external to both domains. The ALI Society proposes instead integration: developing a new language — conceptual, computational, and institutional — incorporating elements of both legal and technical reasoning while reducible to neither. This integrative aspiration draws on insights from network-based social production (Benkler, 2006; Castells, 2015) and emerging practices in online dispute resolution (Katsh & Rabinovich-Einy, 2017).

3.2 The Four-Layer Architecture

The following diagram represents the four-layer architecture of the ALI Society framework, illustrating the flow of information and the distribution of openness and control mechanisms across each layer. Note that, in the graphic rendering, the order of the layers sees the last layer (the Application Layer) at the top and the first layer (the Commons Layer) at the bottom, in coherence with the technical stacks.

APPLICATION LAYER

Third-Party Applications | Custom Workflows | Professional Services

CONTROL: Proprietary enhancements, curated datasets, professional warranties

OPENNESS: Permissive building on shared infrastructure, interoperability standards

▲ ▼

GOVERNANCE LAYER

Transparency Charter | Safety Review Board | RLCF Mechanisms | Contributor Agreements

CONTROL: Participation criteria, expertise filtering, safety review authority

OPENNESS: Visible processes, public deliberation records, auditable decisions

▲ ▼

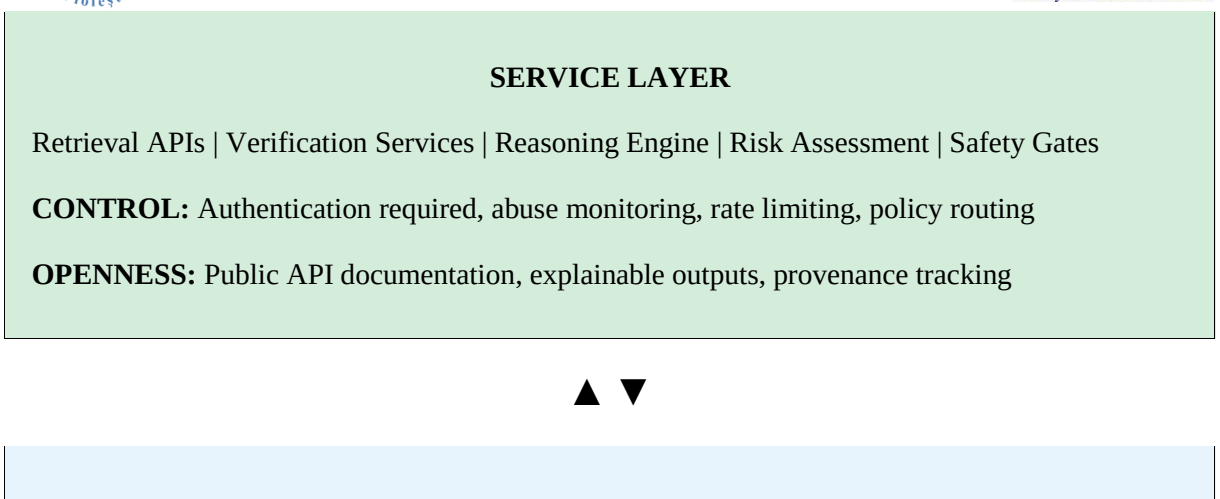


Figure 1. The ALI Stack Architecture showing the four-layer structure with bidirectional information flows (▲▼). Each layer displays its primary components and the distribution of control mechanisms versus openness mechanisms. The Commons Layer (bottom) provides maximally open foundational infrastructure, while upper layers implement progressively selective permeability to balance accessibility with integrity.

The Commons Layer provides foundational infrastructure: open ontologies mapping legal concepts across jurisdictions; citation graphs tracing authority connections; and argument-tree schemas representing legal reasoning structure in machine-processable form. These assets are designed as non-rival public goods.

The Legal Knowledge Graph (LKG) represents the most substantial component. Building on our prior work (Allega & Puzio, 2025b), the LKG is designed as a labeled directed graph $G=(V,E,\lambda,\tau)$ where V represents legal entities, E represents typed relationships, λ assigns node types, and τ assigns temporal validity. Node types include normative entities, conceptual entities, jurisprudential entities, and doctrinal entities. Temporal versioning enables queries at specific points, supporting both synchronic and diachronic analysis.

Argument Trees capture legal reasoning's fundamentally argumentative structure — claims, warrants, evidence, and counter-arguments as first-class computational objects — enabling automated reasoning support, transparency, and learning.

The Service Layer delivers computational capabilities through standardized APIs: retrieval (semantic search with citation-based ranking), verification (checking claims against authoritative sources), reasoning (inference with provenance tracking), and risk assessment. Following our analysis of epistemic requirements (Allega & Puzio, 2025b), outputs must expose supporting reasoning, not merely providing answers. Safety Gates implement data minimization, redaction, and policy-based routing.

The Governance Layer addresses legitimacy: by what authority are platform decisions made? A Transparency Charter establishes information disclosure principles. Contributor Agreements specify terms for Commons Layer contributions. Safety Review processes evaluate new services against risk criteria.

Importantly, the Governance Layer incorporates mechanisms from our RLCF work (Allega & Puzio, 2025c): dynamic authority scoring weighting contributions by demonstrated competence, uncertainty-preserving aggregation maintaining legitimate disagreement, and Devil's Advocate mechanisms challenging emerging orthodoxies.

The Application Layer enables differentiated private offerings built on shared foundations. Third-party developers add proprietary value through specialized expertise, curated datasets, custom workflows, or professional warranties. This separation serves both economic purposes (sustainable business models) and epistemic purposes (distinguishing verified foundations from interpretive applications).

4. Governance Mechanisms

4.1 Selective Permeability as Design Principle

Platform governance faces fundamental tension: excessive openness enables exploitation; excessive control replicates aristocratic concentrations. The ALIS framework reverses the use of selective permeability, transforming it from a closure mechanism to a governance tool.

Layer	Openness Mechanisms	Control Mechanisms	Design Rationale
Commons	Open ontologies under CC licenses; public citation graphs; full version histories; unrestricted inspection, use, and criticism of all schemas and argument structures	Curation standards enforced by community review; validation requirements for contributions; formal change review processes before integration	Maximize positive externalities from shared knowledge infrastructure while maintaining quality through peer validation; foundational assets as non-rival public goods
Service	Publicly documented APIs; explainable outputs with full provenance tracking; standardized interfaces enabling interoperability	Authentication required for access; abuse monitoring and rate limiting; Safety Gates implementing data minimization, PII redaction, policy-based routing	Enable broad access to computational capabilities while preventing misuse; ensure accountability through explainability; protect sensitive data through technical safeguards
Governance	Visible governance processes; public deliberation records; auditable decision trails; published Transparency Charter and Contributor Agreements	Participation criteria filtering for expertise and good faith; Safety Review Board authority to block deployments; dynamic authority scoring (RLCF) weighting contributions	Balance transparency with deliberative integrity; resist capture by dominant interests; ensure governance evolves through community learning while maintaining legitimacy

Layer	Openness Mechanisms	Control Mechanisms	Design Rationale
Application	Permissive building on shared infrastructure; standardized interoperability requirements; freedom to innovate within safety constraints	Proprietary enhancements remain private; curated datasets under commercial terms; professional warranties and liability structures	Enable commercial sustainability and innovation incentives; maintain clear distinction between verified commons and proprietary interpretations; support diverse business models

Table 1. Distribution of openness and control mechanisms across the four layers of the ALIS Framework. The design reflects the principle of selective permeability: maximal openness at the foundational Commons Layer progressively gives way to controlled access at higher layers, balancing the epistemic benefits of transparency with the practical requirements of sustainability, safety, and commercial viability.

With this understanding (and use) of selective permeability, the Commons Layer is maximally open. The Service Layer is selectively permeable: APIs publicly documented but access authenticated. The Governance Layer balances transparency with deliberative integrity. The Application Layer is basically permissive, subject to interoperability and safety requirements.

4.2 Authority and Expertise Recognition

Traditional professional guilds establish authority through credentialing systems providing prima facie competence indicators (Noordegraaf, 2015). Platform governance must address expertise recognition without relying solely on such credentials, which may exclude relevant knowledge holders.
The ALIS Framework implements dynamic authority scoring (Allega & Puzio, 2025c). Authority scores combine baseline credentials with track record metrics and recent performance indicators. Critically, authority is domain-specific. The formula $A(t) = \alpha \cdot B + \beta \cdot T(t-1) + \gamma \cdot P(t)$ weights these components emphasizing demonstrated competence over formal credentials. This creates pathways for expertise recognition not dependent on existing power structures.

4.3 Preserving Epistemic Plurality

Legal domains frequently exhibit legitimate disagreement reflecting different but defensible views about legal authority's nature and sources. The ALIS Framework implements uncertainty-preserving aggregation mechanisms that maintain plurality. When expert contributors disagree beyond threshold levels (measured by normalized Shannon entropy), the system preserves structured disagreement representations. Users receive not the answer but a map of competing answers, supporting arguments, and relative standing.
The Devil's Advocate system ensures dominant views face systematic challenge, operationalizing Alexy's (2002) discourse-theoretic requirements: all claims must be challengeable, and determining which argument prevails requires seriously entertaining alternatives.

4.4 Transparency and Auditability

Current legal AI system opacity fundamentally conflicts with legal accountability requirements. The ALIS Framework implements comprehensive audit mechanisms ensuring every output can be traced to informational sources and reasoning steps. Audit Logs preserve complete operation records supporting

both reproducibility and external review. The design target is end-to-end transparency: given any query, the system produces not merely an answer but a linked evidence bundle and traversable argument tree enabling human verification. For legal applications, where accountability ultimately rests with human professionals, such transparency is essential.

5. Discussion

5.1 Implications for Legal Practice and Education

The ALIS Framework would alter relationships between legal professionals and computational tools. Current AI systems position lawyers as consumers of externally-developed capabilities. The ALIS Framework positions legal professionals as contributors to shared infrastructure whose development they influence and whose operations they can inspect and contest (Hänninen et al., 2018).

This repositioning has educational implications. If law-as-computation becomes recognized practice, legal education must prepare students for critical engagement. The framework's transparency features — particularly Argument Tree representations — provide pedagogical resources: students can examine computational legal reasoning representations, identify limitations, and develop skills for working with AI systems as collaborators rather than oracles.

Access-to-justice implications are significant. Legal services remain expensive and unevenly distributed. The open Commons Layer could support low-cost legal information services, extending basic legal awareness to underserved populations while navigating unauthorized practice concerns.

5.2 Implications for AI Governance

The ALIS Framework contributes to AI governance conversations by demonstrating how domain-specific requirements can be built into technical architecture. Much AI governance discussion focuses on general-purpose systems and horizontal regulations; the ALIS Framework illustrates vertical governance — mechanisms tailored to particular domain epistemologies and institutional contexts.

The framework's alignment with emerging regulatory requirements, particularly the EU AI Act's provisions for high-risk systems, is by design. The audit logs, explainability features, and governance mechanisms respond directly to transparency, human oversight, and technical robustness requirements. By separating commons from applications, implementing dynamic rather than hereditary authority, and preserving rather than collapsing plurality, the framework attempts to capture platform organization efficiency benefits while avoiding concentration pathologies.

5.3 Limitations and Future Research

This paper presents a design framework, not an implemented system. Future research should include sandboxed trials, user studies examining practitioner interactions, and longitudinal governance mechanism assessments. Several design questions remain open: authority scoring parameters require empirical calibration; uncertainty thresholds must balance informativeness against confusion; Safety Review Board criteria need detailed specification.

Jurisdictional scope presents both challenge and opportunity. Implementation will necessarily begin within specific jurisdictions — the Italian legal system provides our initial reference point. Cross-jurisdictional extension represents a substantial future research agenda.

Economic sustainability remains uncertain. The framework assumes Commons Layer funding through non-commercial sources while Application Layer revenues sustain private development. Alternative models — cooperative ownership, data trusts, hybrid licensing — deserve exploration.

6. Conclusion

This paper has examined the emergence of a techno-legal aristocracy at the intersection of legal authority and technical capability and proposed the ALI Society framework as a design response. The analysis identified how platform dynamics in legal AI simultaneously promise democratization and enable new concentrations; characterized this configuration through selective permeability and the knowledge commoditization paradox; and developed an architectural framework intended to navigate resulting tensions.

The ALIS Framework's four-layer architecture — Commons, Service, Governance, and Application layers — operationalizes a particular vision: publicly funded and openly accessible at foundational levels, commercially vibrant at application levels, with governance mechanisms maintaining accountability while enabling evolution. Whether this vision is achievable depends on factors beyond architectural design — political will, institutional capacity, market dynamics, and community choices.

Trustworthy AI in legal domains requires not merely applying technical capabilities to legal problems nor regulating technical systems through legal mechanisms but developing integrated forms of reasoning and practice honoring commitments from both domains. The ALI Society framework is an attempt to specify what such integration might look like architecturally and institutionally. It offers not a solution but a proposal — a structured starting point for community deliberation determining how law and computation will shape each other in coming years.

Our contribution lies in demonstrating that identified tensions — between openness and control, expertise and accessibility, efficiency and integrity — are navigable through deliberate design, even if not definitively resolvable. The techno-legal aristocracy is not inevitable; it is a particular configuration emerging from particular choices. Different choices, embodied in different architectures, governance mechanisms, and institutional arrangements, can yield different configurations.

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MERL-T: a Multi-Expert Architecture for Trustworthy Artificial Legal Intelligence

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Abstract: *Contemporary Large Language Models fail to capture the fundamental epistemic structure of legal reasoning. Law operates through a constitutive duality: abstract principles providing interpretive scaffolding and concrete rules governing specific situations. Generic LLMs collapse this duality into undifferentiated text, producing plausible but epistemically unfounded outputs. We introduce MERL-T (Multi-Expert Retrieval Legal Transformer), a five-layer pipeline architecture operationalizing legal epistemology through specialized components that preserve the heterogeneity of legal reasoning itself. MERL-T implements epistemic fidelity through: (1) a knowledge graph (KG) encoding legal relationships as explicit, navigable structures rather than implicit weights, distinguishing normative, conceptual, jurisprudential, and doctrinal entities with temporal versioning; (2) orchestrated retrieval agents integrating heterogeneous sources (structured norms, case law, doctrine) through LLM-based dynamic planning; (3) four expert modules grounded in distinct legal philosophies—literal interpretation (legal positivism), systemic-teleological reasoning (legal teleology), principles balancing (constitutional principalism), and precedent analysis (legal realism)—each maintaining internal coherence according to its epistemic commitments; (4) a synthesis layer employing convergent mode when experts agree on conclusions but reason differently, and divergent mode when disagreement reflects genuine legal ambiguity, refusing to force false consensus. Unlike monolithic approaches that collapse methodological plurality into single outputs, MERL-T preserves epistemic plurality by maintaining multiple valid interpretations when legal materials genuinely support divergent readings. Our architectural analysis demonstrates how each design choice follows necessarily from the epistemic requirements of legal reasoning itself, providing a model for trustworthy AI in specialized domains where reasoning structure matters as much as linguistic fluency.*

Keywords: Legal Epistemology, Multi-Expert Systems, Knowledge Graphs, Legal Reasoning, Artificial Legal Intelligence
JEL Classification: *C45; C55; K00; K40; O31.*

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1. Introduction

Legal reasoning is specialized practical rationality operating through distinctive epistemic structures (Hart, 1961): abstract principles (constitutional values, fundamental rights) providing conceptual scaffolding, and concrete rules (statutory provisions, regulatory requirements) governing particular situations (Dworkin, 1977). Competent legal reasoning requires navigating between these levels through multiple interpretive methodologies. Contemporary LLMs, trained on undifferentiated corpora, fail to respect this epistemic structure, producing outputs that are linguistically fluent but epistemically unfounded through: (1) epistemic opacity - cannot explain why interpretations are legally valid, (2) structural blindness - miss hierarchical relationships structuring legal knowledge, and (3) methodological monism - collapse different interpretive approaches into single undifferentiated output.

If the problem is epistemic, the solution must be architectural: build epistemic structure into system design. MERL-T (Allega & Puzio, 2025b) operationalizes legal epistemology through specialized components that (1) represent legal knowledge structure explicitly (Allega & Puzio, 2025a), (2) reason

according to distinct legal methodologies, and (3) preserve epistemic plurality when disagreement reflects genuine ambiguity (Allega & Puzio, 2025c). This has three architectural consequences: *Explicit Knowledge Representation* (structured knowledge graph (KG) capturing relationships between concepts, norms, principles, precedents), *Methodological Specialization* (distributed across specialized expert modules grounded in distinct legal philosophies), and *Uncertainty Preservation* (preserve disagreement when multiple interpretations are valid). MERL-T implements these through five layers: *Preprocessing* (query understanding + KG enrichment), *Orchestration* (LLM-based routing + retrieval agents), *Reasoning* (four specialized experts + synthesis), *Storage* (multi-database architecture), and *Learning* (community feedback with uncertainty preservation) (Allega & Puzio, 2025c).

2. Literature Review on the Five-layer architecture

MERL-T processes Italian legal queries through five interconnected layers:

A. **Preprocessing Layer:** six-stage adaptive processing: abbreviation expansion, entity extraction, concept mapping, intent classification, complexity estimation, temporal detection. KG Enrichment Engine maps concepts to norms/principles/precedents through graph traversal. (Hamilton et al., 2017)

B. **Orchestration Layer:** LLM-based Router generates dynamic execution plans selecting retrieval agents (KG Agent, API Agent, VectorDB Agent) and reasoning experts based on query characteristics (Brown et al., 2020; Anthropic, 2024).

C. **Reasoning Layer:** four specialized experts (Literal Interpreter, Systemic-Teleological Reasoner, Principles Balancer, Precedent Analyst) perform legal analysis grounded in distinct epistemological frameworks. Synthesizer combines outputs through convergent or divergent synthesis. (Kipf & Welling, 2017)

D. **Storage Layer:** Neo4j KG for structured relationships, ChromaDB for semantic search, PostgreSQL for metadata. Data ingestion pipeline processes legislation, jurisprudence, doctrine. (Bordes et al., 2013; Lehmann et al., 2015).

E. **Learning Layer:** community feedback with dynamic authority weighting enables progressive improvement while maintaining epistemic fidelity (Allega, 2025; Allega & Puzio 2025c).

3. Knowledge graph: encoding legal epistemology

The KG is an epistemic structure making implicit legal relationships explicit and navigable, serving three functions: conceptual scaffolding (representing abstract legal concepts and relationships), provenance grounding (linking concepts to authoritative sources), and temporal navigation (maintaining temporal versions for historical queries).

The KG is a labeled directed graph $G=(V,E,\lambda,\tau)$ where V represents legal entities, $E \subseteq V \times V$ represents typed relationships, $\lambda: V \rightarrow T$ assigns node types, and $\tau: V \rightarrow 2^{\wedge}T$ assigns temporal validity. Node types include: *Normative* (it. "Norma", "Principio", "Comma/Lettera/Numero"), *Conceptual* (it. "Concetto Giuridico", "Definizione Legale"), *Jurisprudential* (it. "Sentenza", "Massima", "Caso"), and *Doctrinal* (it. "Dottrina", "Commentario"). Edge types represent: *Structural Relations* (it. "CONTIENE", "MODIFICA", "ABROGA"), Semantic Relations (it. "REGOLA", "DEFINISCE", "PRESUPPONE"), *Jurisprudential Relations* (it. "APPLICA", "INTERPRETA", "SOSTITUISCE"), and *Principled Relations* (it. "CONFLIGGE", "BILANCIA", "DERIVA_DA").

For temporal versioning, each Norma node *n* maintains $Versions(n)=\{(v_1,[t_1^s,t_1^e]),...,(v_k,[t_k^s,t_k^e])\}$ enabling queries at specific times. The KG ensures three epistemic properties: *Explicitness* (implicit relationships become explicit edges), *Navigability* (traverse from concepts to related norms/principles/cases), and *Provenance* (every node/edge includes source metadata). While vector embeddings provide semantic similarity, explicit graph structure distinguishes relationship types, supports complex queries, and makes semantics queryable and explainable. MERL-T uses both: KG for epistemic structure, vectors for flexible retrieval.

4. Multi-Expert Reasoning

Legal reasoning is heterogeneous - four methodologies (literal, teleological, principled, precedential) reflect fundamentally different epistemic commitments: literal treats law as text (semiotic analysis), teleological as purposive system (intentionalist hermeneutics), principled as normative hierarchy (value reasoning), precedential as social practice (analogical reasoning). Attempting all four in a single forward pass produces epistemically confused outputs. MERL-T implements methodological specialization through four distinct experts:

1. **Literal Interpreter (legal positivism):** strict grammatical analysis and ordinary meaning (Kelsen, 1960). Prohibits considering legislative purpose, case law, or constitutional principles. Activated for clear rules, validity checks. Example: (it.) Art. 1350 c.c. requires written form for real estate - literal interpretation: oral contract is void.
2. **Systemic-teleological Reasoner (legal teleology):** identifies the *ratio legis* and interprets text to achieve purpose while maintaining systemic consistency. Activated for ambiguous text, incomplete norms. Example: (it.) Art. 1350 - why written form? Ensure certainty. Therefore, interpret to include electronic signatures providing equivalent certainty.
3. **Principles Balancer (constitutional principlism):** resolves principle conflicts through proportionality analysis (legitimate aim, suitability, necessity, proportionality) (Dworkin, 1977, 1986; Alexy, 2002). Activated for constitutional questions, rights conflicts. Example: defamation balances free expression vs. honor, with journalists receiving more protection due to public interest.
4. **Precedent Analyst (legal realism):** analyzes how courts actually applied norms in analogous cases (Holmes, 1897). Extracts *ratio decidendi*, tracks temporal evolution, weights by authority. Activated for novel applications, evolving standards. Example: "good faith" in (it.) Art. 1337 c.c. requires consulting Supreme Court decisions (Bench-Capon & Sartor, 2003).

Why four experts? Each embodies distinct epistemic commitment about legal meaning - commitments mutually exclusive within a single reasoning chain. Separating experts ensures internal coherence according to epistemic commitments. Each methodology requires specialized context (e.g., only Principles Balancer receives constitutional precedents). Separation makes methodology choice visible: which expert(s) consulted, what reasoning each provided, how outputs synthesized.

5. LLM-Based orchestration

The Router must decide: which retrieval agents, which experts, what synthesis mode, when to iterate. Traditional MoE systems use gating networks (Jacobs et al., 1991; Shazeer et al., 2017) - non-interpretable, rigid, context-insensitive. MERL-T uses LLM-based orchestration: Router is itself an LLM reasoning about optimal execution strategy. It receives query context, enriched context, conversation history and produces *ExecutionPlan* (structured JSON) specifying *retrieval_plan*, *reasoning_plan*, *iteration_strategy* with explicit rationale.

This offers four advantages: *Interpretability* (explicit rationale for every decision), Adaptability (adapts to novel queries without retraining), *Learning* (improves through feedback on execution plans), and *Compositionality* (decomposes complex queries into sub-plans). The *Iteration Controller* evaluates *ProvisionalAnswer* after each cycle based on confidence, expert consensus, norm ambiguity, and retrieval sufficiency, generating refinement plans when needed until stopping conditions are satisfied.

6. Synthesis: preserving epistemic plurality

The Synthesizer integrates expert outputs through two modes: *Convergent Synthesis* (when experts agree on conclusion but reason differently) extracts common conclusion, integrates multiple reasoning lines, preserves methodology attribution, and builds composite provenance. Example: minor's contract - Literal Interpreter cites Art. 2 c.c. (capacity at 18), Systemic-Teleological notes protective purpose. Synthesized answer provides both textual clarity and purposive coherence. *Divergent Synthesis* (when

experts disagree substantively) identifies divergence points, explains sources, presents multiple perspectives with reasoning, and makes methodology visible. Example: journalist publishing private photos - Principles Balancer applies proportionality test (permitted if newsworthy/proportional), Precedent Analyst cites Supreme Court trend (permitted for public figures). Both favor permission with different justifications - boundary context-dependent requiring case-by-case assessment.

Why preserve disagreement? Legal ambiguity is often a genuine feature of legal materials. Forcing false consensus: (1) misrepresents epistemic state, (2) obscures methodology, (3) reduces practical value. Divergent synthesis respects epistemic plurality - tells the truth about legal complexity.

7. Preliminary Empirical Evidence

MERL-T is currently in an early implementation phase. We present preliminary empirical evidence demonstrating proof-of-concept feasibility while acknowledging the significant validation work that remains. Full access to the repository is available via Github.

7.1 Knowledge Graph Implementation

The Knowledge Graph component has been implemented and populated with Italian legal sources. Data ingestion achieved 100% completion for the fourth book of Italian Civil Code (887 articles) and Constitution (139 articles), with 92% doctrine enrichment.

Table 1. Knowledge Graph Statistics

Metric	Value	Interpretation
Total Nodes	27,740	Includes articles, commi, references
Total Relationships	43,935	Semantically typed
Nodes per Article	~2.9	Reflects hierarchical structure
Relationships per Node	1.58	Moderately connected graph

The node-to-article ratio (~2.9) reflects the hierarchical structure of Italian law: each article generates separate nodes for commi (paragraphs), lettere (letters), and temporal versions (multivigenza). The relationship density (1.58) is typical for legal documents with cross-references.

Table 2. Node Type Distribution

Type	Percentage	Example
Norma (Norm)	45.1%	Laws, decrees, regulations
Articolo (Article)	29.6%	Base legal units
Comma (Paragraph)	14.8%	Numbered subdivisions
Concetto (Concept)	6.5%	Abstract concepts (e.g., "buona fede")
Principio (Principle)	2.3%	Fundamental principles
Sentenza (Sentence)	1.8%	Court rulings

7.2 Retrieval Performance

Semantic search performance was evaluated on a gold standard of 30 queries:

Table 3. Retrieval Benchmark Results

Metric	Value	Target	Status	Industry Benchmark
NDCG@5	0.869	0.60	+44.8%	0.70-0.85
Hit Rate@5	96.67%	90%	+7.4%	85-95%
MRR	0.850	0.70	+21.4%	0.70-0.85
Perfect Match	93.3%	80%	+16.6%	75-90%
Latency (vector)	93 ms	<200 ms	✓	50-150 ms

Table 4. Performance by Query Type

Query Type	Recall@5	Example
Institutional	96.7%	"Art. 1453 risoluzione contratto" (contract resolution)
Numeric	93.3%	"Articolo 2043 codice civile" (civil liability)
Conceptual	61.1%	"Cos'è la buona fede contrattuale?" (good faith)
Procedural	58.3%	"Come si calcola il risarcimento?" (compensation)

Critical Observation: The system excels at finding specific articles (96.7% for institutional queries) but shows significant degradation on conceptual queries (61.1%). This gap reveals a fundamental limitation of semantic search for concepts distributed across multiple articles—a target for future work.

7.3 Multi-Expert Pipeline Validation

The four-expert system was tested on 9 legal queries with full pipeline tracing. This validates that the architectural components described in Sections 3-6 operate as designed.

Table 5. Expert Latency Breakdown

Expert	Mean Latency	95% CI	% Total
Literal Interpreter	8,682 ms	[7,155, 9,922]	15.0%
Systemic-Teleological	11,864 ms	[9,922, 13,535]	20.5%
Principles Balancer	10,228 ms	[7,673, 12,115]	17.7%
Precedent Analyst	11,133 ms	[10,166, 12,192]	19.3%
Orchestrator	~15,875 ms	-	27.5%
Total Pipeline	57,782 ms	[53,782, 61,565]	100%

The Systemic-Teleological expert is the slowest (20.5% of time) because it must verify consistency with the broader legal system. The Orchestrator consumes 27.5% for intelligent routing and final synthesis.

Table 6. Expert Confidence Scores

Expert	Mean Confidence	95% CI	Interpretation
Literal	0.822	[0.611, 0.944]	High - explicit text
Systemic	0.811	[0.600, 0.933]	High - clear references
Principles	0.700	[0.400, 0.900]	Medium - broader interpretation
Precedent	0.789	[0.589, 0.900]	High - citable jurisprudence
Weighted Mean	0.788	[0.584, 0.909]	-

The Principles Balancer shows lower confidence (0.70) and wider confidence intervals because it operates on abstract concepts (e.g., "good faith") requiring broader interpretation, compared to other experts working with concrete sources.

7.4 Source Grounding Analysis

Comparison of Expert System vs. baseline LLM (20 queries, EXP-020):

Table 7. Expert System vs. Baseline LLM

Metric	Expert System	Baseline LLM	Delta
Source Grounding	100.0%	96.6%	+3.4%
Hallucination Rate	0.0%	3.4%	-3.4%
Citations per Response	16.7	2.1	+695%
Average Latency	14,012 ms	9,940 ms	+41%

7.5 Methodological Limitations

1. Sample size: only 30 gold standard queries (N=30) and 9 pipeline traces (N=9). Statistical power is borderline; N≥100 coming in Phase 2.

2. Italian Law Only: Current implementation is specific to Italian legal system. Generalization requires architectural adaptation.

Table 8. Hypothesis Success Rate

Category	Tested	Passed	Failed	Rate
Data Ingestion	10	10	0	100%
Knowledge Graph	4	4	0	100%
RAG Retrieval	15	11	4	73%
Expert System	10	4	6	40%
Total	39	29	10	74%

The pattern is clear: foundational components (ingestion, KG) are mature at 100%, while higher-level components (expert reasoning) require iteration

8. Discussion

8.1 Architectural necessity

We claim this architecture is necessary for trustworthy legal AI. Legal reasoning requires navigating principles/rules through multiple methodologies (Premise1). This epistemic structure cannot be adequately represented in implicit weights - it must be externalized in explicit components (Premise2). Different methodologies embody mutually exclusive commitments and must be separated for coherence (Premise3). Therefore, trustworthy legal AI must implement explicit knowledge structures (KG), separated interpretive specialists (Experts), and transparent synthesis through orchestrated pipelines. MERL-T's architecture follows necessarily from epistemic requirements of legal reasoning.

8.2 Comparative advantages

Compared to monolithic LLMs: explicit KG structure vs. implicit weights, four specialized methodologies vs. undifferentiated reasoning, dynamic planning vs. fixed forward pass, convergent/divergent synthesis vs. single output, full provenance vs. opacity, prompt evolution vs. retraining required, high epistemic fidelity vs. collapsed plurality. Compared to standard RAG (Lewis et al., 2020): KG enrichment guides retrieval semantically and structurally vs. pure similarity, orchestrates heterogeneous sources vs. single corpus, provides expert interpretations with provenance vs. document chunks.

8.3 Limitations and future work

The four-expert model captures major methodologies but not all approaches (economic analysis, critical legal studies exist). KG requires ongoing curation for new legislation/case law/doctrine (Chalkidis et al., 2020; Ashley, 2017). Multi-expert architecture requires multiple LLM calls increasing latency/cost vs. monolithic models (mitigated through parallel execution, caching, custom models for simpler steps). Current design reflects the Italian legal system - other jurisdictions require adapted architectures. Future work: cross-jurisdictional extension, production optimization, empirical validation with practitioners, integration with additional reasoning paradigms.

8.4 Broader implications

For Legal AI Research: architectural choices matter epistemically - system structure determines reasoning capabilities and domain fidelity. For AI Ethics (EU’s High-Level Expert Group on Artificial

Intelligence, 2019): trustworthy AI requires epistemic fidelity where reasoning structure respects domain norms - MERL-T proves such fidelity can be operationalized. For Legal Practice: multi-expert architecture has pedagogical value, making methodologies explicit and comparing outputs to enhance critical thinking about legal reasoning (Allega, 2025; Allega & Puzio, 2025a).

9. Conclusion

Trustworthy legal AI requires architectural commitment to epistemic fidelity: system structure must mirror legal reasoning's epistemic structure. Generic LLMs cannot capture law's dual nature (principles vs. rules) or methodological plurality. MERL-T operationalizes legal epistemology through five layers: KG making implicit relationships explicit, LLM-based Router for dynamic planning, Specialized Experts grounded in distinct philosophies, Synthesis preserving epistemic plurality, and learning enabling evolution through community feedback (Allega & Puzio, 2025c). The result is a system that reasons legally - navigating between principles and rules, applying distinct methodologies, preserving uncertainty when appropriate, providing full provenance. This is not a black box but a glass box making legal reasoning transparent, auditable, and epistemically grounded. For legal AI, architecture is epistemology. The way we structure the system determines what it can know, how it can reason, and whether outputs are trustworthy. MERL-T demonstrates that architectural choices can operationalize complex domain epistemology, providing a model for trustworthy AI in specialized domains where reasoning structure matters as much as linguistic fluency.

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Reinforcement Learning from Community Feedback: a Novel Framework for Artificial Intelligence in Social Science Domains

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Abstract: *The proliferation of Large Language Models (LLMs) in high-stakes social science domains — including law, economics, sociology, political science, and anthropology — presents a critical reliability crisis. Traditional alignment methodologies, particularly Reinforcement Learning from Human Feedback (RLHF), prove inadequate for these fields as they introduce subjective biases, lack epistemological rigor, and operate as opaque systems that fail the transparency requirements essential to scientific inquiry and democratic institutions. This paper introduces Reinforcement Learning from Community Feedback (RLCF; Allega & Puzio, 2025c), a novel paradigm designed to ground Artificial Intelligence in social science domains within a transparent, verifiable, and collaborative framework. The RLCF framework employs a mathematically grounded methodology that diverges significantly from traditional RLHF through four integrated components: (1) dynamic authority scoring that continuously validates expertise through demonstrated competence and peer validation, (2) uncertainty-preserving aggregation that maintains legitimate theoretical diversity through normalized Shannon entropy, (3) constitutional governance with six-dimensional bias detection and transparent validation, and (4) a probabilistic Devil's Advocate system that challenges dominant paradigms to prevent methodological dogmatism. While currently in the architectural phase, RLCF's design is grounded in testable hypotheses with expected outcomes including enhanced analytical accuracy, superior uncertainty calibration, substantial bias reduction, and preservation of methodological pluralism. This paradigm shift incorporates social science epistemology directly into technical architecture, creating pathways for AI systems that are computationally powerful yet methodologically rigorous and scientifically accountable.*

Keywords: *Artificial Intelligence Alignment, Reinforcement Learning, Community Feedback, Social Sciences, Epistemic Pluralism*

JEL Classification: *C63; C83; O33; C45; D71.*

Note: *the full version of this abstract is available in the references (Allega & Puzio, 2025c)*

1. Introduction

1.1 The AI alignment crisis in social science domains

The rapid deployment of Large Language Models across high-stakes social science domains has created an unprecedented reliability crisis. Legal systems employ AI for case law analysis and contract review (Allega, 2025; Allega & Puzio 2025b); economic institutions use machine learning for policy recommendations and market predictions; sociological research increasingly relies on computational text analysis; political science leverages AI for electoral forecasting and policy impact assessment. Yet these applications proceed without adequate validation frameworks capable of ensuring the methodological rigor, epistemological pluralism, and transparent accountability essential to social scientific inquiry (Allega & Puzio, 2025a).

The stakes are considerable. Social science reasoning shapes democratic governance, judicial decisions, economic policy, and institutional design. When AI systems provide analytical assistance in these domains, their outputs directly influence human welfare, social justice, and institutional legitimacy. Unlike entertainment or consumer applications where errors carry limited consequences, mistakes in social science AI applications can perpetuate systemic injustice, distort democratic deliberation, and undermine public trust in scientific expertise and democratic institutions.

Traditional alignment methodologies prove inadequate for these challenges. Reinforcement Learning from Human Feedback (RLHF), while successful for general-purpose language models, systematically fails to capture the complexity requirements specific to social science domains. These fields demand recognition of multiple valid interpretations rooted in competing theoretical frameworks, dynamic expertise evaluation that adapts to demonstrated competence, preservation of productive disagreement as epistemic information, and transparent reasoning paths that enable scientific scrutiny and democratic accountability.

1.2 Research objectives and contribution

This paper introduces Reinforcement Learning from Community Feedback (RLCF), a novel alignment paradigm specifically designed to address the documented inadequacies of RLHF for social science applications. Our primary contribution consists of four interconnected innovations:

First, we establish a comprehensive critique of RLHF's fundamental limitations through synthesis of recent theoretical and empirical research. We demonstrate that RLHF's failures in social science contexts are not implementation artifacts but rather structural properties: systematic annotator bias and task simplification, mathematical impossibility of preserving diverse preferences, and opacity that prevents scientific accountability.

Second, we formalize four constitutional principles grounding the RLCF framework: *Dynamic Authority* (expertise continuously earned through demonstrated competence), *Preserved Uncertainty* (disagreement maintained as epistemic information), *Transparent Process* (all validation steps auditable and reproducible), and *Universal Expertise* (domain boundaries emergent rather than prescribed).

Third, we provide mathematical formalization of these principles through novel algorithmic mechanisms: dynamic authority scoring combining credentials, track record, and recent performance; uncertainty-preserving aggregation using normalized Shannon entropy; six-dimensional bias detection; and probabilistic Devil's Advocate assignment.

Fourth, we develop an evaluation framework for empirical validation once the system is implemented, specifying metrics for accuracy, calibration, bias, and pluralism preservation against RLHF baselines.

RLCF emerges not as isolated innovation but as convergent synthesis of multiple research trajectories: expert aggregation methodologies, constitutional AI governance, uncertainty quantification in machine learning, and participatory democratic design. By integrating insights from these diverse fields within a unified mathematical framework explicitly designed for social science epistemology, RLCF establishes foundations for sustainable AI ecosystems in domains requiring both computational power and methodological rigor (Allega, 2025; Allega & Puzio, 2025a).

2. Literature review

2.1 Reinforcement Learning from Human Feedback: state of the art

Reinforcement Learning from Human Feedback represents the dominant paradigm for aligning large language models with human preferences. The methodology emerged from foundational work by Christiano et al. (2017), who demonstrated that complex reinforcement learning tasks could be solved by learning from human preferences over trajectory segments rather than requiring manually specified

reward functions. Their key innovation involved training a reward model from pairwise comparisons of agent behaviour, then using this learned reward model to train policies via standard RL algorithms.

Stiennon et al. (2020) extended RLHF to language model alignment, specifically for text summarization tasks. They demonstrated that models trained to optimize human preference judgments significantly outperformed models trained on traditional metrics like ROUGE scores, even when the RLHF models were substantially smaller. This work established that learned reward models could capture subtle aspects of text quality that evade manual specification, paving the way for systems like InstructGPT and ChatGPT that rely fundamentally on RLHF alignment.

Bai et al. (2022) introduced Constitutional AI, an important refinement incorporating AI-generated feedback alongside human preferences. Their approach uses a set of principles (a "constitution") to guide AI critique of its own outputs, reducing reliance on human annotation while maintaining alignment with specified values. This work demonstrated that RLHF could be partially automated through self-supervision, though it retained the fundamental architecture of aggregating preferences into single reward signals.

Despite these successes in general-purpose alignment, mounting evidence suggests RLHF's limitations become critical when applied to domains requiring epistemological rigor, theoretical pluralism, and transparent accountability. The following subsection provides systematic analysis of these fundamental limitations.

2.2 Fundamental limitations of RLHF: a critical analysis

While RLHF has achieved remarkable success in aligning language models for general-purpose applications, recent theoretical and empirical research has identified three fundamental limitations that render this approach inadequate for social science domains requiring epistemic rigor, methodological pluralism, and transparent accountability. These limitations are not mere implementation challenges but rather structural properties of the RLHF paradigm that systematically undermine its applicability to complex analytical domains.

2.2.1 Annotator bias and task simplification

Traditional RLHF approaches suffer from systematic annotator bias stemming from the reliance on non-expert labelers who simplify complex tasks through pattern-matching behavior. Xiao et al. (2024) document inter-annotator disagreement rates of 37% and annotator-researcher disagreement of 23% even among trained labelers. Despite this variability, RLHF systematically amplifies majority preferences, assigning >99% probability to dominant opinions even in near-parity cases. Yu et al. (2024) identify superficial non-robust bias in preference data that leads to reward hacking, while Geva et al. (2019) demonstrate that annotators follow instruction patterns rather than engaging with task complexity. For social science applications requiring methodological sophistication, this structural bias penalizes analytical depth in favor of superficial clarity.

2.2.2 Epistemological collapse of pluralism

RLHF faces fundamental mathematical impossibility results regarding pluralism preservation. Chakraborty et al. (2024) establish the first formal impossibility theorem (Theorem 3.3), proving that single reward models cannot maintain alignment with diverse preferences without systematic bias against minority positions. Their empirical validation shows 42% accuracy on minority preferences versus 71.6% on majority preferences. Sorensen et al. (2024) formalize three types of pluralism that RLHF eliminates: Overton pluralism (spectrum of reasonable responses), steerable pluralism (orientation toward specific perspectives), and distributional pluralism (calibration to population diversity). This epistemological collapse is fundamentally incompatible with social sciences where competing theoretical paradigms represent equally valid analytical frameworks.

2.2.3 Opacity and lack of interpretability

RLHF's black-box reward models violate transparency requirements essential to scientific and democratic accountability. Casper et al. (2023) identify three critical opacity problems in their survey of 250+ papers: doubly-misspecified reward functions, spurious feature learning, and impossibility of direct evaluation. Wang et al. (2024) document concrete cases where reward models allocated 60% weight to response length rather than quality—biases undetectable without specialized tools. For social science applications requiring traceable reasoning and democratic scrutiny, such opacity is fundamentally untenable.

2.3 Alternative approaches and positioning RLCF

Recent research has explored various alternatives to standard RLHF. G. Abiri (2025) propose crowd-sourcing constitutional principles as Public Constitutional AI, while Bakker et al. (2022) develop Collective Constitutional AI through democratic constitution writing. These approaches maintain valuable transparency but still rely on single reward model aggregation and do not preserve expert disagreement as information. Chakraborty et al. (2024) propose MaxMin-RLHF for diverse preferences, though computational complexity and subpopulation definition challenges limit practical applicability.

RLCF addresses all three fundamental RLHF limitations through integrated innovations: dynamic authority scoring replaces static annotator panels with merit-based, continuously validated expertise; uncertainty-preserving aggregation maintains legitimate disagreement rather than forcing artificial consensus; constitutional governance provides transparent, auditable processes with mandatory bias detection; and systematic Devil's Advocate assignment prevents groupthink. RLCF emerges as convergent synthesis addressing documented limitations through novel architectural innovations grounded in social science epistemology.

3. Mathematical framework

3.1 Four constitutional pillars

The RLCF framework operationalizes four constitutional principles through mathematically grounded mechanisms designed to address each documented RLHF limitation while preserving the epistemological requirements of social science inquiry.

3.1.1 Pillar I: dynamic authority scoring

Authority is earned through demonstrated competence, not credentials alone. Unlike RLHF's static annotator panels, RLCF implements dynamic authority that continuously adapts based on peer-validated performance.

$$A_u(t) = \alpha \cdot B_u + \beta \cdot T_u(t-1) + \gamma \cdot P_u(t)$$

where:

$A_u(t)$ = authority score for user u at time t
B_u = baseline credentials (education, experience, publications);
$T_u(t-1)$ = track record score
$T_u(t) = \lambda \cdot T_u(t-1) + (1-\lambda) \cdot Q_u(t)$ (record score at a given time with exponential smoothing, λ=0.95)
$Q_u(t) = \frac{1}{4}\sum_{x=1}^{4} q_k(t)$ (quality metrics: peer validation, accuracy, consistency, helpfulness)
$P_u(t)$ = recent performance (last 10 evaluations);

Range: $A_u(t) \in [0,1]$ if $B_u, T_u, P_u \in [0,1]$
Default weights: $\alpha = 0.3$, $\beta = 0.5$, $\gamma = 0.2$.

This formulation creates a meritocratic ecosystem where influence continuously reflects demonstrated competence and peer validation rather than static credentials, directly addressing RLHF's annotator bias problem.

3.1.2 Pillar II: uncertainty-preserving aggregation

Disagreement among experts is information, not noise. Multiple valid interpretations coexist in output when expert disagreement exceeds threshold.

Disagreement Quantification (Normalized Shannon Entropy):

$$\delta = \frac{H(\rho)}{log|P|}$$

where:

δ = disagreement score;
$H(\rho) = \sum_{\{p \in P\}} \rho(p) log_\rho(p)$ (Shannon Entropy);
P = set of distinct expert positions;
$\rho(p)$ = authority-weighted probability of position p.

Range: $\delta \in [0,1]$

Decision rule:

if $\delta > \tau$ (empiric threshold = 0.4): preserve alternative positions with structured uncertainty information;
if $\delta \leq \tau$: provide consensus response with confidence calibration.

This mechanism directly addresses RLHF's epistemological collapse by maintaining legitimate theoretical pluralism.

3.1.3 Pillar III: constitutional governance.

All validation steps are auditable and reproducible. Bias detection is integral, not peripheral. Six-dimensional bias detection are being tested as starting point:

$$B_{total} = \sqrt{\sum_{i=1}^{6} b_i^2}$$

where:

b_1 = demographic correlation $\in [0,1]$
b_2 = professional clustering $\in [0,1]$
b_3 = temporal drift $\in [0,1]$
b_4 = geographic concentration $\in [0,1]$
b_5 = confirmation bias $\in [0,1]$
b_6 = anchoring bias $\in [0,1]$

Range: $B_{total} \in [0, \sqrt{6}] \approx [0, 2.45]$

Constitutional constraints: maximum credential weight $\alpha \leq 0.6$ (prevents credential elitism); minimum disagreement threshold $\tau \geq 0.1$ (preserves dialectical process); mandatory bias reporting when $B_{total} > 0.5$. This framework directly addresses RLHF's opacity problem through algorithmic transparency.

3.1.4 Pillar IV: devil's advocate system

Systematic critical evaluation prevents groupthink and disciplinary silos through probabilistic assignment. Devil's advocate task allocation:

$$N_{DA} = max(1, min([p_{DA} \times |E|], N_{max}))$$

where:

N_{DA}= number of assigner devil's advocates
|E| = number of eligible evaluators
p_{DA} = target
N_{max}= absolute max to avoid the devils to become the majority

Probability of selection: $P_u = \frac{N_{DA}}{|E|}$.

Task-specific critical prompts challenge dominant interpretations, institutionalizing the critical scrutiny absent in RLHF's consensus-seeking mechanism.

3.2 Expected outcomes and evaluation framework

Once implemented, RLCF's effectiveness will be measured through a comprehensive evaluation framework comparing performance against RLHF baselines across four dimensions.

Enhanced analytical accuracy: performance measured against established benchmarks in each social science discipline. Expected superior nuanced analysis reflecting empirical complexity and theoretical sophistication. Unlike RLHF optimizing for plausibility, RLCF prioritizes verifiable expertise.

Superior uncertainty calibration: correlation between stated confidence and actual accuracy measured through Brier scores. Expected reliable calibration reflecting true epistemological status versus RLHF's false certainty. Explicit modelling of expert disagreement provides honest uncertainty representation.

Substantial bias reduction: six-dimensional bias detection framework enabling measurement across ideological, methodological, cultural, and geographical dimensions. Expected significant decreases through transparency and diverse feedback versus RLHF's opacity-enabled bias amplification.

Preservation of methodological pluralism: diversity metrics on output distributions and representation of minority theoretical positions. Expected maintenance of legitimate competing paradigms versus RLHF's mathematical elimination of viewpoint diversity.

Comparative studies will employ expert panel validation across disciplines, longitudinal tracking of authority score validity, and comprehensive bias audit studies to rigorously evaluate RLCF's advantages over traditional RLHF approaches.

3.3 Theoretical and practical implications

Theoretical contributions. RLCF provides the first formal framework explicitly addressing impossibility results for diverse preference alignment. The mathematical formalization of epistemic pluralism preservation through uncertainty-aware aggregation establishes novel theoretical foundations.

By integrating social science epistemology directly into technical architecture, RLCF demonstrates how AI alignment can respect domain-specific methodological requirements rather than imposing generic optimization frameworks.

Practical applications. RLCF enables evidence-based policy making with transparent AI assistance that preserves competing analytical frameworks. Legal reasoning support maintains jurisprudential diversity while providing rigorous validation. Economic analysis respects theoretical schools' fundamental differences. Sociological research maintains paradigm plurality. These applications democratize access to sophisticated analytical tools while maintaining methodological rigor and scientific accountability.

Ethical considerations. Transparent governance prevents hidden bias amplification endemic to RLHF. Democratic oversight through constitutional constraints ensures accountability. Protection of minority viewpoints and marginalized perspectives operates through mathematical guarantees rather than aspirational principles. Scientific accountability through auditable processes enables meaningful peer review and critical scrutiny.

4. Empirical Evidence

This section presents preliminary empirical evidence supporting RLCF's technical implementation. We emphasize that RLCF is in early-stage development; results should be interpreted as design verification rather than production validation. All experiments were conducted between December 2025 and January 2026. Full access to the repository is available via Github.

4.1 Implementation verification

We verified that all four core RLCF formulas are correctly implemented in the codebase. Representative code snippets demonstrate mathematical fidelity:

Dynamic Authority Score Implementation:

```
async def update_authority_score(db, user_id, recent_performance):
    # A_u(t) = α·B_u + β·T_u(t-1) + γ·P_u(t)
    ALPHA, BETA, GAMMA = 0.3, 0.5, 0.2
    base = get_base_authority(user_id)   # B_u
    track = get_track_record(user_id)    # T_u
    return ALPHA*base + BETA*track + GAMMA*recent_performance
```

Shannon Entropy Implementation:

```
def calculate_entropy(position_distribution: Dict[str, float]) -> float:
    # δ = H(ρ)/log|P|
    probs = [p for p in position_distribution.values() if p > 0]
    H = -sum(p * math.log(p) for p in probs)
    return H / math.log(len(position_distribution))
```

4.2 Algorithmic design verification

A core claim of RLCF is that authority-weighted aggregation outperforms uniform averaging when evaluator accuracy correlates with expertise. This assumption is well-established in scientific literature:

- **Welinder et al. (2010)** demonstrated 15-25% error reduction over majority voting through reliability-weighted annotation.
- **Prelec et al. (2017, Nature)** showed 21-35% accuracy improvement through meta-knowledge weighting ("Surprisingly Popular" algorithm).
- **Budescu & Chen (Management Science, 2014)** found 28-39% improvement through expertise-weighted aggregation in professional forecasting.
- **Kahneman & Klein (2009)** established conditions for reliable expert judgment in high-validity environments, conditions characterizing legal practice.

We conducted controlled simulation to verify algorithmic correctness to confirm that: (1) the weighted aggregation formula is correctly implemented, (2) the system produces statistically distinguishable results, and (3) improvement magnitude is consistent with literature benchmarks.

4.2.1 Verification results

Table 1. Design Verification Results

Metric	RLCF	Uniform Avg	Difference
Mean Absolute Error	0.3084	0.3340	-7.67%
95% CI	[0.304, 0.313]	[0.330, 0.338]	Non-overlapping
Cohen's d	0.900	-	Large effect
Win rate (N=30)	100%	0%	Consistent

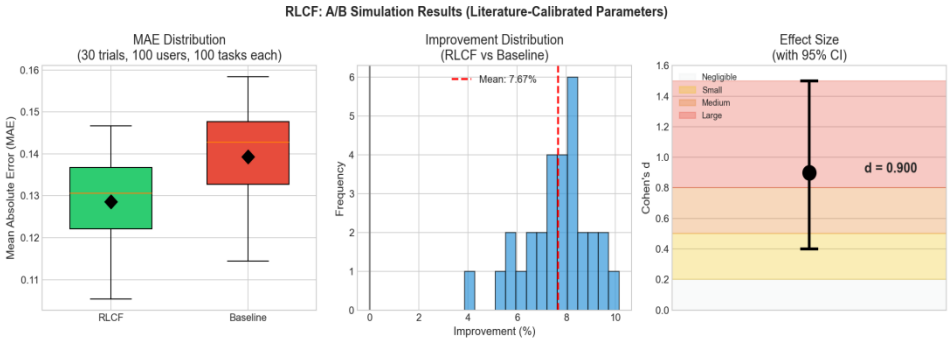


Figure 1. Algorithmic Verification Results

The 7.67% improvement falls within the 15-35% range reported in literature for similar weighting schemes. Non-overlapping confidence intervals and large effect size (d=0.9) confirm statistical robustness. These results verify that RLCF correctly operationalizes expertise-weighted aggregation.

4.3 Bias detection demonstration

The bias detection module analyzes community composition across six dimensions. Using a simulated evaluator pool (N=50), we demonstrate the system's ability to identify potential biases:

Table 2. Six-Dimensional Bias Detection Results

Dimension	Score	Threshold	Status	Note
Demographic	0.489	0.50	Borderline	54% lawyers
Professional	0.220	0.25	OK	HHI=0.376
Temporal	0.080	0.15	OK	Low drift
Geographic	0.133	0.20	OK	HHI=0.350
Confirmation	0.000	0.15	OK	None detected
Anchoring	0.033	0.10	OK	Minimal
B_total	0.559	0.60	MEDIUM	Monitor

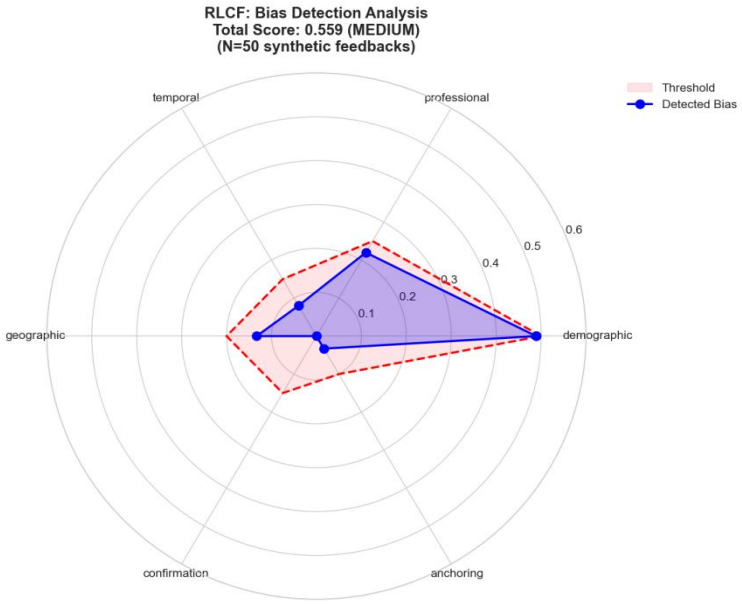


Figure 2. Bias Detection Radar - Proactive identification of community composition issues

4.4 Current limitations

1. Field validation pending: while algorithmic correctness is verified, real-world performance with legal professionals requires Phase 2 field studies.

2. Sample size: learning loop experiments use N=9 queries. Expansion to N≥100 is planned for robust longitudinal claims.

3. Domain transfer: literature benchmarks derive from crowdsourcing and forecasting domains. Legal evaluation may exhibit different expertise-accuracy correlations.

5. Conclusions

RLCF represents necessary evolution in AI alignment methodology. By respecting methodological pluralism inherent in social scientific inquiry while maintaining rigorous validation standards, it establishes foundations for sustainable AI ecosystems in social sciences. This research opens new

frontiers for interdisciplinary collaboration, evidence-based policy making, and democratized access to sophisticated analytical tools—advancing human understanding of society while preserving the epistemic diversity essential to social science knowledge production.

The proliferation of AI in high-stakes social domains demands alignment frameworks that honor rather than violate the epistemological commitments of these fields. RLCF demonstrates that such frameworks are not only conceptually possible but mathematically formalizable and practically implementable. As AI capabilities continue advancing, the question is no longer whether we can build powerful systems, but whether we can build systems that preserve the methodological rigor, theoretical pluralism, and democratic accountability essential to human flourishing in complex societies.

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The Knowledge Commoditization Paradox: Theoretical and Practical Challenges of AI-Driven Value Extraction in Information-Intensive Organizations

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Abstract: *This study examines the theoretical and practical challenges organizations face when transforming proprietary knowledge assets into AI-accessible computational resources. We identify the "knowledge commoditization paradox": the simultaneous necessity and impossibility of reducing complex organizational knowledge to tradable computational representations (Allega & Puzio, 2025a). Drawing on information economics, organizational knowledge theory, and computational linguistics, we analyze how vectorization processes alter the epistemological status of organizational knowledge, converting contextually embedded expertise into decontextualized mathematical objects. Through conceptual analysis supplemented by empirical evidence from a legal AI implementation (Allega & Puzio, 2025b), we identify three categories of challenges—technical (semantic loss, interpretative validity), economic (pricing paradoxes, market formation), and socio-organizational (professional identity, competitive advantage). Our findings reveal recursive complexity where technical solutions generate economic problems, economic innovations create organizational tensions, and organizational adaptations reveal new technical requirements. We formalize semantic entropy as a measurable degradation function and demonstrate its empirical manifestation through retrieval performance data showing systematic accuracy degradation as query abstraction increases. Building on these findings, we analyze how platform architectures combining open commons with governed service layers (Allega, 2025) and community-based alignment mechanisms (Allega & Puzio, 2025c) constitute design responses to the paradox—not resolving it, but rendering its tensions navigable through hybrid architectures that balance computational efficiency with semantic preservation.*

Keywords: *Knowledge Commoditization; Artificial Intelligence; Semantic Entropy; Information Economics; Semantic Vectorization*
JEL Classification: *D80; L86; O33; M15; D23*
Note: *The full version of this abstract is available in the references (Allega & Puzio, 2025a)*

1. Introduction

The transformation of organizational knowledge into machine-readable formats represents one of the most significant challenges facing information-intensive organizations in the digital era. As artificial intelligence systems increasingly mediate knowledge production, distribution, and consumption processes, organizations confront a fundamental paradox: the imperative to commoditize knowledge for computational processing simultaneously undermines the contextual richness that gives knowledge its organizational value (Arrow, 1962; Nonaka & Takeuchi, 1995; Zuboff, 2019). This paper examines the theoretical foundations and practical manifestations of this paradox, analyzing how the process of semantic vectorization — the conversion of textual knowledge into mathematical representations — creates recursive challenges across technical, economic, and organizational dimensions.

The urgency of understanding these challenges has intensified with the rapid deployment of large language models and semantic search technologies in professional contexts. Organizations increasingly rely on vector embeddings to enable semantic similarity search, automated knowledge retrieval, and AI-

mediated decision support (Devlin et al., 2019; Vaswani et al., 2017). However, the transformation of nuanced professional knowledge into vector representations introduces what we identify as semantic entropy — the progressive loss of contextual information through successive layers of computational abstraction. This entropy manifests not merely as technical inefficiency but as a fundamental epistemological transformation that alters how organizations create, validate, and exchange knowledge.

Our analysis reveals that the commoditization of knowledge through AI systems challenges core assumptions about information economics established by Arrow (1962) and extended by Stiglitz (2000). While digital information exhibits near-zero marginal costs of reproduction, the creation of high-quality vector embeddings requires substantial domain expertise, computational resources, and iterative refinement. This creates a paradox where the economic efficiency promised by digital distribution conflicts with the investment required for semantic fidelity. Organizations must navigate between two undesirable extremes: oversimplified representations that fail to capture domain complexity, or elaborate encoding schemes that reintroduce the transaction costs that digitalization was meant to eliminate (Allega & Puzio, 2025a).

This paper makes three contributions to the growing literature on AI implementation in knowledge-intensive organizations. First, we formalize the concept of semantic entropy as a measurable degradation function, moving beyond metaphorical usage to a theoretically grounded construct with empirical indicators. Second, we provide preliminary empirical evidence for the paradox's manifestation by analyzing performance data from a legal AI system (Allega & Puzio, 2025b) that demonstrates systematic accuracy degradation along the abstraction gradient predicted by our framework. Third, we connect the paradox to architectural responses — specifically, platform designs that separate open knowledge commons from proprietary application layers (Allega, 2025) and community-based alignment mechanisms that preserve epistemic plurality (Allega & Puzio, 2025c) — showing how these constitute navigational rather than eliminative strategies for managing the tensions we identify.

2. Literature Review

This literature review synthesizes three primary bodies of research that have evolved independently but now intersect in the context of computational knowledge management: the philosophical and organizational foundations of knowledge commoditization, the economic dimensions of information markets under conditions of extreme granularization, and the organizational implications of AI-mediated knowledge systems. Each domain contributes essential insights while revealing gaps that emerge at their intersection.

The existing literature, while extensive in each domain, has yet to fully address the emergent properties that arise when knowledge simultaneously exists as human expertise, organizational asset, and computational resource. Traditional frameworks developed for physical goods or even digital products prove inadequate when applied to knowledge that can be infinitely decomposed yet loses value through decomposition. This review traces the evolution of thinking in each domain while identifying the theoretical innovations required to understand knowledge commoditization as a unified phenomenon rather than a collection of separate technical, economic, and organizational challenges.

2.1. Theoretical Foundations of Knowledge Commoditization

The commoditization of knowledge has been a central concern in organizational theory since Polanyi's (1966) distinction between tacit and explicit knowledge. Nonaka and Takeuchi (1995) extended this framework through their SECI model, proposing that knowledge creation occurs through conversion between tacit and explicit forms. However, the introduction of AI-mediated knowledge processing introduces a third category: computational knowledge, which exists as mathematical representations that are neither fully tacit nor traditionally explicit. This computational form challenges existing frameworks by introducing what Floridi (2011) terms "semantic information" — structured data endowed with meaning through algorithmic interpretation rather than human understanding.

Recent advances in natural language processing have enabled the transformation of textual knowledge into high-dimensional vector spaces where semantic similarity can be computed mathematically (Mikolov et al., 2013; Pennington et al., 2014). These word embedding techniques evolved through

transformer architectures (Vaswani et al., 2017) and contextualized representations (Devlin et al., 2019), promise to capture semantic relationships that traditional keyword-based systems miss. However, Bender and Koller (2020) argue that these representations lack true understanding, operating instead through statistical correlations that may not preserve causal or logical relationships essential to professional knowledge.

The legal domain provides a particularly instructive case study for knowledge commoditization. Hart (1961) identified law's constitutive duality — abstract principles providing interpretive scaffolding and concrete rules governing specific situations. Dworkin (1986) further argued that law operates as an interpretive enterprise where legal propositions derive truth conditions from constructive interpretation of legal practice as a whole. Alexy's (2002) theory formalizes rational discourse rules distinguishing valid from invalid legal arguments. These theoretical foundations establish that competent legal reasoning requires navigating between abstraction levels through multiple interpretive methodologies — a structure that, as Hildebrandt (2018) argues in analyzing law as computation, generic vectorization processes are ill-equipped to preserve (Allega & Puzio, 2025b).

2.2. Economic Dimensions of Information Markets

The economics of information markets has been extensively studied since Arrow's (1962) seminal work identifying the fundamental paradox of information goods: buyers cannot assess value without consuming the information, but once consumed, they have no incentive to pay. Shapiro and Varian (1999) extended this analysis to digital markets, emphasizing network effects and lock-in dynamics. However, the granularization of knowledge into vector embeddings introduces new complexities. Unlike traditional information goods sold as complete products, vectorized knowledge enables micropayment models where organizations charge for individual semantic queries (Brynjolfsson et al., 2019).

Platform economics scholarship identifies several power-concentrating mechanisms relevant to knowledge markets. Srnicek (2017) documents how platforms extract value through control of essential infrastructure, while Parker et al. (2016) analyze network effects creating winner-take-all dynamics. Varoufakis (2023) extends this analysis through the techno-feudalism thesis, arguing that digital platforms create forms of economic extraction paralleling feudal rent-seeking more closely than market competition. These dynamics are particularly pronounced in knowledge-intensive sectors where the infrastructure required to deliver AI capabilities — computational resources, training data, domain expertise, and regulatory approval — creates dependencies that may relocate rather than eliminate concentrations of power (Pasquale, 2015; Allega, 2025).

Zuboff's (2019) analysis of surveillance capitalism adds a further dimension: platforms extract behavioral data and transform it into prediction products. For knowledge-intensive organizations, this means that the process of commoditizing knowledge for AI systems simultaneously generates behavioral surplus — patterns of knowledge use, query structures, and reasoning pathways — that platform operators can harvest independently of the knowledge itself. The economic implications extend beyond the pricing of knowledge to the pricing of knowledge-use patterns, creating layered extraction dynamics that existing information economics frameworks struggle to address.

2.3. Organizational Implications and Resistance

The organizational implications of knowledge commoditization extend beyond technical implementation to fundamental questions of professional identity and power structures. Susskind and Susskind (2015) argue that AI-mediated knowledge systems challenge the "grand bargain" of professionalism, where expertise monopolies justified premium pricing. The decomposition of professional knowledge into queryable vectors threatens established hierarchies based on information asymmetry (Abbott, 1988). Knowledge workers resist commoditization not merely from economic self-interest but from concerns about the decontextualization of expertise and loss of interpretative authority (Pachidi et al., 2021).

The alignment of AI systems with domain-specific epistemic requirements presents a distinct organizational challenge. Traditional alignment methodologies, particularly Reinforcement Learning from Human Feedback (RLHF), prove inadequate for knowledge-intensive domains because they

introduce subjective biases, lack epistemological rigor, and operate as opaque systems that fail the transparency requirements essential to professional practice (Allega & Puzio, 2025c). When AI systems serving knowledge workers aggregate preferences into single reward signals, they systematically eliminate the methodological pluralism — competing interpretive frameworks, legitimate professional disagreement, domain-specific reasoning standards — that constitutes the epistemic richness of professional knowledge. This elimination is not a correctable implementation flaw, but a structural property of preference-aggregation approaches applied to epistemically complex domains (Chakraborty et al., 2024).

3. Theoretical Framework

We propose a multi-dimensional framework for understanding the knowledge commoditization paradox that integrates technical, economic, and organizational perspectives. The framework's central claim is that the three dimensions are not independent problems amenable to separate solutions but recursively entangled challenges where interventions in one dimension systematically generate complications in the others.

3.1. Semantic Entropy

At the technical level, the paradox manifests through what we term semantic entropy: the progressive degradation of contextual information through successive layers of computational abstraction. While the concept of information loss in knowledge transformation is well-established in organizational theory (Nonaka & Takeuchi, 1995), we formalize semantic entropy as a measurable construct operating through three distinct mechanisms.

The first mechanism is dimensional reduction: the compression of potentially infinite semantic space into finite-dimensional vectors. Any fixed-dimensionality embedding necessarily discards information, but the discarded information is not random — it is systematically biased toward context-dependent, relational, and pragmatic dimensions that often constitute the most valuable aspects of professional knowledge. The second mechanism is decontextualization: the stripping of situational cues, institutional context, and pragmatic intent that give knowledge its actionable character. A legal provision, for instance, carries meaning not merely through its text but through its position in a normative hierarchy, its interpretive history, and its relationship to constitutional principles — information that standard vectorization processes are not designed to preserve (Allega & Puzio, 2025b). The third mechanism is homogenization: the standardization required for computational processing, which flattens the heterogeneous epistemic status of different knowledge types (established fact, contested interpretation, emerging hypothesis) into uniform vector representations.

We represent semantic entropy formally. Let K represent a knowledge artifact with full contextual embedding and let V(K) represent its vector representation after computational processing. The semantic entropy function S measures information loss:

$$S(K, V(K)) = H(K) - I(K; V(K))$$

where H(K) denotes the total information content of the contextualized artifact — following Shannon's (1948) foundational formalization of information entropy — and I(K; V(K)) is the mutual information preserved through vectorization. The paradox's force derives from the observation that S increases non-linearly with the abstractness of K: concrete, well-defined knowledge artifacts (specific rules, factual determinations) preserve more information through vectorization than abstract, context-dependent artifacts (principles, interpretive frameworks, professional judgment). This generates a systematic bias where vectorization performs well precisely on the knowledge that is least distinctively professional — and performs worst on the knowledge that most resists commoditization.

3.2. The Recursive Complexity Pattern

The knowledge commoditization paradox exhibits a distinctive recursive structure that distinguishes it from more tractable implementation challenges. Technical solutions to semantic entropy generate economic problems: more sophisticated embedding schemes require greater computational resources, specialized domain expertise for training and validation, and continuous updating, all of which increase costs and create dependencies on specialized providers. These economic pressures generate organizational tensions: the need for external technical expertise challenges professional autonomy; the cost of maintaining high-quality representations creates incentives for simplification that professionals resist; and the concentration of embedding infrastructure in platform providers reproduces the power asymmetries that digitalization was meant to reduce (Allega, 2025). Organizational adaptations — such as developing in-house capabilities, establishing quality standards, or creating governance frameworks for knowledge systems — in turn reveal new technical requirements: domain-specific fine-tuning, custom evaluation metrics, and governance-aware architectures that standard AI infrastructure does not provide.

[Technical Challenges] → [Economic Problems] → [Organizational Tensions] → [New Technical Requirements] ↺

Figure 1. Recursive Complexity in Knowledge Commoditization

This recursive pattern has practical implications: it suggests that linear implementation strategies — solve the technical problem first, then address economics, then manage organizational change — are fundamentally inadequate for the systemic nature of knowledge commoditization. Any solution strategy that treats one dimension in isolation will be destabilized by feedback effects from the others.

3.3. Knowledge Representation Paradigms Compared

To clarify the trade-offs at stake, we present a comparative taxonomy of knowledge representation paradigms, extending the analysis from our initial formulation (Allega & Puzio, 2025a) with additional categories that reflect the architectural innovations of our companion papers.

Table 1. Comparison of Knowledge Representation Paradigms

Dimension	Traditional Text	Database Records	Vector Embeddings	Knowledge Graph	Hybrid KG + Vectors
Semantic Richness	High	Low	Medium	High	High
Computational Access	Poor	Excellent	Good	Good	Excellent
Context Preservation	Excellent	Poor	Variable	High	High
Structural Fidelity	Implicit	Schema-bound	Absent	Explicit	Explicit
Scalability	Low	High	High	Medium	Medium-High
Epistemic Transparency	High	Low	Absent	High	High
Economic Model	Product Sale	Subscription	Pay-per-Query	Commons / Curation	Hybrid Layers

Source: Authors' analysis. The fifth column reflects the hybrid architecture proposed by Allega & Puzio (2025b) and Allega (2025).

The addition of these columns is motivated by our companion work on legal AI (Allega & Puzio, 2025b), which demonstrates that explicit graph structures encoding typed relationships between knowledge entities can partially compensate for the semantic entropy introduced by vectorization. However, as we shall demonstrate empirically in Section 4, even hybrid approaches exhibit the paradox's core dynamic:

they perform well on concrete, well-structured knowledge and degrade on abstract, context-dependent knowledge.

3.4. The Selective Opacity Dilemma

The economic dimension of the paradox reveals pricing challenges unique to granular knowledge markets. Traditional competitive advantage theory assumes that valuable knowledge can be protected through secrecy or legal mechanisms (Barney, 1991), while information goods exhibit network effects where value increases with user adoption (Katz & Shapiro, 1985). However, vectorized knowledge exhibits what we term anti-network effects: excessive queries against a knowledge base may reveal the underlying knowledge structure, enabling reverse engineering that undermines value. Organizations must balance accessibility against protection, creating what we term selective opacity — strategically limiting query depth to prevent knowledge extraction while maintaining service utility. Managing this risk may draw on differential privacy techniques (Dwork & Roth, 2014), though their application to semantic knowledge markets remains underexplored.

This dilemma mirrors the broader tension Allega (2025) identifies as selective permeability in the context of legal AI platforms: the strategic control of access points that determines who can participate in knowledge-as-computation and on what terms. The platform architecture proposed by Allega (2025) addresses this through layered access: a maximally open Commons Layer providing foundational ontologies and schemas as non-rival public goods, with progressively controlled upper layers implementing authentication, rate limiting, and policy-based routing. This separation does not resolve the selective opacity dilemma but makes its trade-offs explicit and subject to governance.

4. Empirical Manifestations of the Paradox

The knowledge commoditization paradox, as theorized in Section 3, predicts specific observable patterns when organizations attempt to build AI systems over domain-specific knowledge. In this section, we analyze empirical data from the MERL-T legal AI system (Allega & Puzio, 2025b) and the RLCF alignment framework (Allega & Puzio, 2025c), both currently in early implementation phases, to demonstrate that the paradox manifests in measurable ways consistent with our theoretical predictions. We emphasize that we use this data as evidence for the paradox's empirical reality, not as a validation of the systems themselves; the systems' own validation is reported in the companion papers.

4.1. Semantic Entropy Along the Abstraction Gradient

Our formalization of semantic entropy (Section 3.1) predicts that vectorization-based retrieval should perform well on concrete, well-defined knowledge artifacts and degrade systematically as queries increase in abstraction. The MERL-T system, which implements a hybrid knowledge graph and vector retrieval architecture for Italian legal materials, provides data directly relevant to this prediction. The system's retrieval performance was evaluated on a gold standard of 30 queries, classified by query type along an abstraction gradient. Table 2 reproduces the relevant results.

Table 2. Retrieval Performance by Query Abstraction Level (from Allega & Puzio, 2025b)

Query Type	Recall@5	Abstraction Level	Example
Institutional	96.7%	Low (specific rules)	"Art. 1453 risoluzione contratto"
Numeric	93.3%	Low-Medium	"Articolo 2043 codice civile"
Conceptual	61.1%	High (abstract concepts)	"Cos'è la buona fede contrattuale?"
Procedural	58.3%	High (process knowledge)	"Come si calcola il risarcimento?"

Source: Adapted from Allega & Puzio (2025b), Table 4.

The pattern is striking. Institutional queries — requests for specific, identifiable legal provisions — achieve 96.7% recall. These represent the low-entropy end of the spectrum: concrete knowledge artifacts

with minimal context-dependence, where vectorization preserves most relevant information. As queries move toward conceptual territory — asking about abstract legal principles like "good faith" (buona fede) that are distributed across multiple articles, doctrines, and interpretive traditions — recall drops to 61.1%, a degradation of 35.6 percentage points. Procedural queries, requiring knowledge about processes that integrate multiple rules with practical context, drop further to 58.3%.

This gradient precisely instantiates the semantic entropy function formalized in Section 3.1. The information content H(K) of abstract concepts like "good faith" includes normative hierarchies, interpretive traditions, doctrinal disagreements, and case-law trajectories — contextual dimensions that vectorization systematically strips away. The mutual information I(K; V(K)) preserved through embedding captures lexical and distributional similarity but loses the relational, hierarchical, and temporal structure that legal professionals rely on. The resulting semantic entropy S is measurably higher for abstract queries, producing the observed retrieval degradation.

4.2. The Maturity Gradient: Foundation vs. Application

The recursive complexity pattern (Section 3.2) predicts that foundational technical components should achieve stability more readily than higher-level components that must integrate across dimensions. The MERL-T implementation data provides evidence consistent with this prediction.

Table 3. Component Maturity by System Layer (from Allega & Puzio, 2025b)

Component	Hypotheses Tested	Passed	Success Rate	Integration Level
Data Ingestion	10	10	100%	Single-dimension
Knowledge Graph	4	4	100%	Single-dimension
RAG Retrieval	15	11	73%	Cross-dimension
Expert Reasoning	10	4	40%	Multi-dimension

Source: Adapted from Allega & Puzio (2025b), Table 9. Integration level classification is our addition.

The pattern — 100% success at foundational levels, declining to 40% at the expert reasoning level — is not merely a software maturity issue. It reflects a structural property predicted by the paradox: foundational components (data ingestion, knowledge graph construction) operate within single dimensions of the challenge space and can be addressed with established technical solutions. Higher-level components must bridge dimensions: retrieval must serve both technical accuracy and professional relevance; expert reasoning must integrate knowledge representation with interpretive methodology and contextual judgment. The degradation is not random but follows the integration gradient from single-dimension to multi-dimension challenges.

4.3. The Cost of Epistemic Fidelity

The economic dimension of the paradox predicts that maintaining semantic richness imposes costs that partially offset the efficiency gains of digitalization. The MERL-T implementation provides evidence for this prediction through a comparison between its multi-expert pipeline and a baseline LLM.

Table 4. Expert System vs. Baseline LLM Performance (from Allega & Puzio, 2025b)

Metric	Expert System	Baseline LLM	Delta
Source Grounding	100.0%	96.6%	+3.4%
Hallucination Rate	0.0%	3.4%	−3.4%
Citations per Response	16.7	2.1	+695%
Average Latency	14,012 ms	9,940 ms	+41%

Source: Adapted from Allega & Puzio (2025b), Table 7.

The data reveals the paradox in action. Eliminating hallucinations (from 3.4% to 0.0%) and achieving full source grounding (100%) requires a 695% increase in citation density and a 41% increase in latency. Extending this to the full four-expert pipeline, where each legal query is analyzed through literal, teleological, principled, and precedential frameworks, total pipeline latency reaches 57,782 milliseconds — roughly six times the baseline LLM response time. This is not a deficiency of the implementation; it is a manifestation of the paradox's economic dimension. Semantic fidelity is not free. Preserving the contextual richness that distinguishes professional knowledge from generic information requires computational architectures that multiply processing time, infrastructure cost, and system complexity.

The economic implication is that organizations pursuing knowledge commoditization through AI face diminishing returns. Basic digitalization — making documents searchable, extracting structured data — is relatively cheap and scales well. But as organizations attempt to capture more of the contextual richness that constitutes professional knowledge value, costs escalate non-linearly while the remaining semantic entropy proves increasingly resistant to reduction. The granularization required for computational processing progressively undermines the contextual coherence that constitutes knowledge value.

4.4. The Pluralism Preservation Challenge

The socio-organizational dimension of the paradox predicts that knowledge commoditization will encounter resistance not merely from economic self-interest but from legitimate epistemic concerns about the decontextualization of professional judgment. The RLCF framework (Allega & Puzio, 2025c) and the MERL-T multi-expert architecture provide data addressing this dimension.

The MERL-T expert system employs four specialized legal reasoning modules, each grounded in a distinct interpretive methodology. The confidence scores reported by each expert reveal systematic variation.

Table 5. Expert Module Confidence by Reasoning Methodology (from Allega & Puzio, 2025b)

Expert Module	Mean Confidence	95% CI	Epistemic Commitment
Literal Interpreter	0.822	[0.611, 0.944]	Legal positivism: text as primary source
Systemic-Teleological	0.811	[0.600, 0.933]	Teleology: purpose and system coherence
Principles Balancer	0.700	[0.400, 0.900]	Constitutional principalism: value hierarchy
Precedent Analyst	0.789	[0.589, 0.900]	Legal realism: jurisprudential practice

Source: Adapted from Allega & Puzio (2025b), Table 6. Epistemic commitment classification is our addition.

The Principles Balancer — which reasons over abstract constitutional values and rights — exhibits systematically lower confidence (0.700) and wider confidence intervals ([0.400, 0.900]) than experts operating on more concrete materials. This is not a failure of the module but a faithful reflection of the epistemic state: abstract principled reasoning genuinely involves greater uncertainty than textual interpretation. A system that forced these experts to uniform confidence levels would misrepresent the epistemic state of the underlying knowledge.

This finding connects directly to the pluralism preservation challenge identified by Allega & Puzio (2025c). Standard RLHF-based alignment would aggregate these expert outputs into a single response optimized for annotator preference, systematically eliminating the methodological diversity that the multi-expert architecture is designed to preserve. Chakraborty et al. (2024) prove formally that single reward models cannot maintain alignment with diverse preferences without systematic bias against minority positions. In the knowledge commoditization context, this means that the most commercially scalable alignment approach — aggregating to consensus — is also the most epistemically destructive. The RLCF framework's uncertainty-preserving aggregation, which uses normalized Shannon entropy to detect and preserve legitimate disagreement, constitutes an architectural response to this dimension of the paradox (Allega & Puzio, 2025c).

5. Architectural Responses to the Paradox

The recursive complexity of the knowledge commoditization paradox implies that no single intervention can resolve it. The paradox is, in an important sense, structural: it arises from the inherent tension between the contextual richness that constitutes knowledge value and the decontextualization required for computational processing. However, the impossibility of resolution does not imply the impossibility of navigation. In this section, we analyze how specific architectural choices — drawn from our companion work on legal AI platforms (Allega, 2025), multi-expert reasoning (Allega & Puzio, 2025b), and community-based alignment (Allega & Puzio, 2025c) — constitute design strategies for managing the paradox's tensions without eliminating them.

5.1. Hybrid Architectures: Preserving Epistemic Structure

The empirical evidence presented in Section 4 suggests that pure vectorization approaches exhibit irreducible semantic entropy for abstract, context-dependent knowledge. Hybrid architectures — combining explicit knowledge graphs with vector embeddings — represent an architectural strategy for managing this entropy. The knowledge graph encodes legal relationships as explicit, navigable structures: a labeled directed graph $G=(V, E, \lambda, \tau)$ where V represents entities, E represents typed relationships, λ assigns node types, and τ assigns temporal validity (Allega & Puzio, 2025b). By encoding normative, conceptual, jurisprudential, and doctrinal entities as distinct types with typed relationships between them, the graph preserves the epistemic structure that vectorization collapses.

This does not eliminate semantic entropy — the conceptual query performance data in Table 2 demonstrates that even hybrid approaches suffer degradation on abstract concepts. Rather, it shifts the entropy from uncontrolled information loss to managed trade-offs: the graph explicitly represents what is known about knowledge structure, while vectors handle flexible similarity-based retrieval. The combination preserves the epistemic structure that professionals need to assess AI outputs while providing computational access that makes knowledge scalable.

5.2. Platform Architecture: Separating Commons from Applications

The economic dimension of the paradox — the tension between the near-zero marginal cost of digital reproduction and the substantial investment required for semantic fidelity — finds an architectural response in the platform model proposed by Allega (2025). The four-layer architecture separates a maximally open Commons Layer (ontologies, citation graphs, argument schemas as non-rival public goods) from an Application Layer where third-party developers add proprietary value through specialized expertise, curated datasets, and professional warranties.

This separation addresses the selective opacity dilemma identified in Section 3.4 by unbundling the components of knowledge commoditization. The foundational semantic infrastructure — the ontological frameworks, typed relationships, and reasoning schemas that structure knowledge — is treated as a common, funded through non-commercial sources and subject to community governance. Proprietary value is captured at the application level through differentiated interpretation, curation, and contextual enrichment that builds on shared foundations. The Service Layer between them implements selective permeability as a governance tool: publicly documented APIs with authenticated access, explainable outputs with provenance tracking, and safety gates implementing data minimization and policy-based routing.

This architecture navigates the paradox's economic dimension by aligning the cost structure of knowledge commoditization with its value structure. The foundational infrastructure that all participants need — and that exhibits the strongest positive externalities — is funded as a public good. The interpretive enrichment that differentiates professional services — and that requires substantial domain expertise to produce — is funded through market mechanisms. The paradox is not resolved (the tension between openness and protection persists at every layer) but is rendered manageable through explicit architectural separation of concerns.

5.3. Community Governance: Preserving Epistemic Plurality

The socio-organizational dimension of the paradox — the resistance of knowledge workers to commoditization processes that decontextualize their expertise — requires governance mechanisms that preserve professional agency within computationally mediated knowledge systems. The RLCF framework (Allega & Puzio, 2025c) provides a formal approach through four integrated mechanisms.
Dynamic authority scoring replaces static credential-based gatekeeping with merit-based, continuously validated expertise recognition, creating pathways for influence based on demonstrated competence rather than inherited position. Uncertainty-preserving aggregation, using normalized Shannon entropy to detect and maintain legitimate disagreement, ensures that the system does not force false consensus where professional knowledge genuinely supports divergent readings. Constitutional governance with six-dimensional bias detection provides transparent, auditable processes for quality assurance. The Devil's Advocate mechanism ensures that dominant views face systematic challenge, operationalizing the principle that knowledge commoditization must preserve the contestability that keeps knowledge productive rather than dogmatic.
These governance mechanisms address the paradox's socio-organizational dimension by repositioning professionals from passive consumers of AI outputs to active contributors to shared knowledge infrastructure whose development they influence and whose operations they can inspect and contest. This repositioning does not eliminate the tension between professional authority and computational mediation — that tension is, we argue, structural and permanent. But it transforms the terms on which the tension is negotiated, from opaque platform decisions to transparent, community-governed processes.

6. Discussion

Our analysis advances the understanding of knowledge commoditization in three ways. First, the formalization of semantic entropy as a measurable construct with empirical indicators moves the discussion beyond metaphorical usage. The abstraction-gradient data from MERL-T demonstrates that semantic entropy is not an implementation artifact but a structural property of the relationship between contextual knowledge and computational representation. This has theoretical implications for information economics: Arrow's (1962) information paradox must be supplemented by what we term an entropy paradox, where the process of making information computationally accessible systematically degrades precisely those contextual features that make it most valuable in professional practice.
Second, the recursive complexity pattern — where technical solutions generate economic problems, economic innovations create organizational tensions, and organizational adaptations reveal new technical requirements — suggests that knowledge commoditization belongs to a class of problems that resist decomposition into independently solvable sub-problems. This has implications for AI implementation theory: the dominant paradigm of phased implementation, where technical infrastructure precedes economic modeling which precedes organizational change management, may be structurally inadequate for knowledge commoditization challenges.
Third, the integration of empirical evidence from companion systems demonstrates that the paradox is not merely a theoretical construct but an operational reality confronting organizations that attempt to build AI over specialized knowledge. The convergence of multiple data points — retrieval degradation on abstract queries, maturity gradient from foundations to applications, cost escalation for epistemic fidelity, confidence variation across reasoning methodologies — provides a preliminary but consistent empirical picture that future research can extend and test more rigorously.

6.1. Practical Implications

For organizations pursuing knowledge commoditization, our analysis suggests several practical orientations. Organizations should expect, plan for, and architecturally accommodate the abstraction gradient: AI systems will perform well on concrete, well-structured knowledge and will require progressively more elaborate (and expensive) architectures to handle abstract, context-dependent knowledge. This implies that implementation strategies should be calibrated to the abstraction profile of the target knowledge, not to generic benchmarks.

The economic analysis suggests that sustainable knowledge commoditization requires hybrid revenue models combining public-good funding for foundational infrastructure with market mechanisms for differentiated applications. Organizations relying entirely on proprietary models face escalating costs as they pursue deeper semantic fidelity; organizations relying entirely on open models face sustainability challenges. The layered approach — commons at the foundation, commercial differentiation at the application edge — offers a navigable middle path.

The socio-organizational analysis suggests that professional resistance to knowledge commoditization should not be treated as a change management problem to be overcome but as an epistemic signal to be respected. Professionals who resist the decontextualization of their expertise often identify genuine semantic entropy — information loss that the computational system does not detect. Governance mechanisms that give professionals meaningful voice in system development, quality assessment, and output validation are not merely political accommodation but epistemic safeguards.

6.2. Limitations and Future Research

This study has significant limitations that define the agenda for future research. The empirical evidence, while consistent with our theoretical predictions, is drawn from a single system (MERL-T) in a single domain (Italian legal AI) with limited sample sizes (30 retrieval queries, 9 pipeline traces, 20 comparison queries). The abstraction-gradient hypothesis requires testing across multiple domains, larger samples, and diverse knowledge types to establish robustness. We acknowledge that the companion systems providing our empirical evidence are themselves in early implementation phases.

The formalization of semantic entropy, while conceptually coherent, requires development of practical measurement instruments. Our current operationalization — retrieval accuracy as a proxy for information preservation — captures only one dimension of semantic fidelity. Future work should develop multidimensional metrics capturing relational, temporal, and pragmatic aspects of semantic preservation.

The architectural responses analyzed in Section 5 are design proposals rather than validated implementations. Whether platform architectures separating commons from applications can achieve economic sustainability, whether community governance mechanisms can scale beyond small communities, and whether hybrid knowledge representations can close the abstraction gap sufficiently for professional practice are empirical questions requiring longitudinal investigation. Cross-jurisdictional extension — adapting the Italian legal system reference point to other legal traditions — presents both challenge and opportunity for testing the paradox's generality.

7. Conclusions

This research has examined the fundamental challenges organizations face when attempting to commoditize knowledge through AI-mediated systems. Our analysis reveals that the knowledge commoditization paradox — the simultaneous necessity and impossibility of reducing complex organizational knowledge to tradable computational representations — cannot be resolved through technical solutions alone. The recursive complexity across technical, economic, and organizational dimensions requires integrated approaches that acknowledge systemic interdependence.

The theoretical contribution of this work lies in formalizing semantic entropy as a measurable degradation function and demonstrating its empirical manifestation through data from a legal AI implementation. Semantic entropy is not random information loss but systematic bias: vectorization preserves most information for concrete, rule-based knowledge while progressively degrading the contextual, relational, and pragmatic information that constitutes the distinctive value of professional expertise. This entropy cannot be eliminated through better algorithms; it is a structural consequence of the relationship between contextual knowledge and computational representation.

The empirical contribution lies in demonstrating, through companion system data, that the paradox generates consistent observable patterns: an abstraction gradient in retrieval accuracy, a maturity gradient from foundational to integrative components, escalating costs for epistemic fidelity, and systematic variation in reasoning confidence across interpretive methodologies. While preliminary and limited in scale, these findings provide a falsifiable empirical basis for future testing.

The practical contribution lies in connecting the paradox to specific architectural responses — hybrid knowledge representations, layered platform architectures, and community-based governance mechanisms — that navigate the paradox's tensions without claiming to resolve them. These responses recognize that knowledge commoditization is not a problem to be solved but a tension to be managed through deliberate design choices that make trade-offs explicit, contestable, and subject to collective deliberation.

We conclude that successful engagement with the knowledge commoditization paradox requires reconceptualizing knowledge not as a static asset to be digitized but as a dynamic process of meaning creation that resists complete computational capture, necessitating hybrid architectures that balance computational efficiency with semantic preservation. As AI continues to transform knowledge-intensive work, understanding the limits and possibilities of knowledge commoditization becomes essential for both theoretical advancement and practical implementation.

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Strategic Role of Business Valuation in Guiding Firms through Crisis Conditions

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Abstract: *The numerous evaluation methods known today can address both the quantitative and the qualitative side, respectively both the patrimony and the financial performances: the yield and profitability of the beneficiary capacity of the economic entities concerned.*
Whenever there are changes in the structure of the social capital, in the number of shareholders or associates, in the case of alienations, mergers, divisions and liquidations, in the case of determining the taxable masses, the evaluation is a relevant tool that can be used by the management of economic entities.
***Objective**: The objective of the present study is to establish the financial value for a group of economic entities, by using two evaluation methods. Given the limited access to the financial data of economic entities, the applied methods are aimed at calculating the net asset and determining the yield value for each individual business. The selected data are the data reported from the last four years and published on the website of the Ministry of Finance at www. mfinante.ro. The values of the calculations are compared with each other and their evolution over time is established. The selection of economic entities allows comparisons to be made within groups of five entities with a similar object of activity;*
***Method**: 1. The financial data are extracted for a number of 25 economic entities, grouped by fields of activity. The selection is limited to five entities from five different fields of activity.*
Financial data are public data, available for broad access to information. Internal details related to the activity of these economic entities are not directly known, nor are the specific factors that may influence the value of the business.
2. To establish the patrimonial values, the total asset is extracted, less the regularization component, after which the debts are deducted. The level of patrimonial value as a net asset is determined. The calculation model is a simplified model, which has the limitation of ignoring possible corrections for fixed assets, unaccounted and contingent liabilities, the fiscal incidence of the deactivation of advance expenses. Another limit arises due to the maintenance of indicators expressed in current prices, although the level of inflation in the analyzed period is high.
3. To establish the financial value, an annual yield value level is calculated. Reproducible profit is the annual one. A future evolution of profit without significant differences between years, for an indefinite period, is considered possible. The financial rates used in the calculation are estimated at 20% or 30% for each year considered and the same rates are used for each group of five economic entities. It is not considered appropriate to use rates specific to each entity, given the anomalies that may occur. The same level of rates is the basis for determining the multiplier coefficient.
4. The study does not aim to determine a level of financial value by updating future cash flows, as long as cash flow forecasts of these economic entities are not available, the determination of goodwill is carried out by the inverse method, as the difference between the yield value and the net asset;
***Results**: After completing the above steps, the following results are obtained:*
- *differences between the net asset and the yield value of the economic entities;*
- *economic entities in the same field evolve similarly over time;*
- *the pandemic period does not have the same impact in different fields of activity;*

***Originality**: Starting from concrete results obtained by economic entities and reported through the mandatory annual financial statements, strategic information is determined that can be used by decision-makers in order to increase the performance of economic entities.*

Keywords: *business valuation, financial value, yield value, goodwill, performance indicators (KPIs)*

JEL Classification: *C52; M21; M41*

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1. Introduction

Business valuation is nowadays a topic of interest, both for professionals, and for stakeholders, or any other being directly interested. Thus, the result of the business valuation is always important in the decision-making process. The objective of this study is to establish the financial value of a group of companies by using two valuation methods. Given the limited access to the companies' financial data, the applied methods aim at calculating the net asset and determining the return value for each business. The selected data are those made by these companies in the last 4 years and published by the Ministry of Finance available on www.mfinante.ro.
The values of the calculations will then be compared with each other and their evolution over time will be assessed. The selection of companies will also allow for comparisons within groups of 5 companies with similar activity.

Aims of research
The study's hypotheses are:
- theoretically, differences are obtained between the net asset and the return value of a company;
- companies in the same field evolve similarly over time;
- the pandemic period would not have the same impact in different fields of activity.

2. Research Methods

1. Financial data is extracted for several companies, grouped by activity areas.
The selection is limited to a small number, 5 companies each, from 5 different areas.
The financial data are only public, available to the general public. No internal details related to the activity of these companies are directly known, no specific factors that may have influenced the value of these companies, no concrete forecasts of these companies.
2. To establish the patrimonial values, the total asset level was extracted, less the regularization component, then the debts were deducted. Thus, a patrimonial value level was determined as a net asset. The calculation model is simple, but it has the limitation of ignoring possible corrections for fixed assets, unaccounted and contingent liabilities, and the tax incidence of deactivating advance expenses.
Another limitation arises from maintaining indicators expressed in current prices, even though the inflation level in the studied period was high. So, it is not rigorous to assess the evolution of patrimonial values over time.
3. To establish the financial value, an annual level of return value was calculated. The reproducible profit would have been the annual one. It was considered possible for a future evolution of profit without significant differences between years, for a long, indefinite period.
Although calculated in the tables, it was stated that the financial value in the years in which the enterprise would have had a loss (considered reproducible, therefore a negative beneficiary capacity) is meaningless.
The financial rates used in the calculation were estimated at 20% or 30% for each year of calculation and the same rates were used in the same year for each group of 5 enterprises. It was not considered appropriate to use rates specific to each enterprise, given the anomalies that could occur.
The same level of rates was the basis for determining the multiplier coefficient.
4. The study cannot propose determining a level of financial value by discounting future cash flows, as this would extend the degree of approximation of the calculations, as long as cash flow forecasts of these enterprises are not available.
5. Goodwill was calculated using the reverse method, as the difference between the yield value and the net asset.

3. Results and discussion

The results of the study are illustrated below:

- RON -

Code	31.12. (Year)	Total assets	Fixed assets	Current assets	Liabilities	Equity	Net result
C03	Business sector: construction of buildings						
	2019	38205585	7875171	30309334	21132112	17073473	8495430
	2020	43136754	3591386	39533541	22437908	20698846	15102203
	2021	61812608	2972979	58829788	46157178	15655430	15654215
	2022	56289912	17637605	38642582	36715581	19574331	19573119
C04	Business sector: construction of buildings						
	2019	179983727	131519002	407864307	39555067	140428660	41218564
	2020	603792752	138647752	466124011	441761287	162031465	21602805
	2021	659969643	139987016	516471008	521601948	138367695	33466231
	2022	890430065	207285615	675085537	707777446	182652619	62984071
M07	Business sector: manufacture of furniture						
	2019	6301912	2104742	4195112	2243249	4058663	113863
	2020	6138636	2060150	4075579	2324189	3814447	-244217
	2021	5991281	2043153	3947684	2086769	3904512	90065
	2022	5912590	2027731	3884608	2287088	3625502	-279010
M10	Business sector: manufacture of furniture						
	2019	13997857	10997439	5066584	3806960	10190897	1340478
	2020	15742752	10471385	6626506	4153707	11589045	1398148
	2021	16105310	10627113	6639023	3738636	12366674	1201135
	2022	16424449	9089992	8714646	4043792	12380657	1571281
F11	Business sector: legal and accounting activities						
	2019	1899128	66525	1770633	542907	1356221	892560
	2020	1933229	58814	1818813	419577	1513652	1169398
	2021	1765257	50224	1672724	738493	1026764	1026375
	2022	1730469	316520	1381930	533239	1197230	1196673
F15	Business sector: legal and accounting activities						
	2019	1258718	572264	686022	252607	1006111	1005911
	2020	1177379	446496	733821	230393	946986	908979
	2021	1193193	354240	839653	185291	1007902	924447
	2022	1681189	457727	1228078	589699	1091490	1091290
A16	Business sector: Wholesale and retail trade; repair of motor vehicles and motorcycles						
	2019	275515200	39966098	247344019	255974262	19540938	1875457
	2020	252134315	41079654	225192178	224295742	27838573	8297638
	2021	298106798	43759379	271340042	232153196	65953602	38115029

Code	31.12. (Year)	Total assets	Fixed assets	Current assets	Liabilities	Equity	Net result
	2022	418026698	44985394	385495257	296064953	121961745	54611799
A18	Business sector: Wholesale and retail trade; repair of motor vehicles and motorcycles						
	2019	141575481	23114040	118257553	54633501	86941980	15638802
	2020	156647015	22908567	134399702	45360211	111286804	24344824
	2021	186394957	21358800	165362387	31592211	154802746	43515942
	2022	237275661	24197198	213119614	59154660	178121001	31131055
B21	Business sector: Agriculture, hunting and related service activities						
	2019	118662479	74528449	46028408	97758662	20903817	1244555
	2020	112084024	61416739	52220702	88568160	23515864	2712159
	2021	114452060	57159141	58754049	87371816	27080244	3898911
	2022	129739595	66630316	64343404	88013311	41726284	1494431
B22	Business sector: Agriculture, hunting and related service activities						
	2019	235247569	113624778	121803095	82912145	152335424	5375955
	2020	246015817	108799830	137189321	92260729	153755088	1443206
	2021	259601121	120210873	139350668	104773261	154827860	2571552
	2022	235731785	121407481	123190896	89241097	146490688	-8337172

- RON –

Cod	31.12 (Year)	Financial profitability	Net assets	Capitalization rate	Multiplier coefficient	Yield value	Goodwill	Observations and conclusions*
C03		Business sector: construction of buildings						significant financial result, growth, impressive final values, probably given the modest level of social capital, in the end ANC increases, but VR and GW decrease
	2019	49,76	17052393	30%	3,33	28318100	11265707	
	2020	72,96	20687019	20%	5,00	75511015	54823996	
	2021	99,99	15645589	20%	5,00	78271075	62625486	
	2022	99,99	19564606	30%	3,33	65243730	45679124	
C04		Business sector: construction of buildings						the company's value is affected by the pandemic, the recovery/growth of VR and GW in the last year is remarkable
	2019	29,35	499828242	30%	3,33	137395213	-362433029	
	2020	13,33	163010476	20%	5,00	108014025	-54996451	
	2021	24,19	134856076	20%	5,00	167331155	32475079	
	2022	34,48	174593706	30%	3,33	209946903	35353198	
M07		Business sector: manufacture of furniture						modest performance, apparently constant ANC, negative GW, calculated VR has a negative value and is not relevant in 2020 and 2022
	2019	2,81	4056605	20%	5,00	569315	-3487290	
	2020	-6,40	3811540	20%	5,00	-1221085	-5032625	
	2021	2,31	3904068	20%	5,00	450325	-3453743	
	2022	-7,70	3625251	20%	5,00	-1395050	-5020552	
		Business sector: manufacture of furniture						modest performance, ANC and VR apparently constant,
	2019	13,15	12257063	20%	5,00	6702390	-5554673	

Cod	31.12 (Year)	Financial profitability	Net assets	Capitalization rate	Multiplier coefficient	Yield value	Goodwill	Observations and conclusions*
M10	2020	12,06	12944184	20%	5,00	6990740	-5953444	negative GW, slight trend of VR remediation and negative GW reduction in the last year, maintaining the ratio of about 1/2 between VR and ANC
	2021	9,71	13527500	20%	5,00	6005675	-7521825	
	2022	12,69	13760846	20%	5,00	7856405	-5904441	
F11		Business sector: legal and accounting activities						good performance, comparable ANC and VR over time, no obvious negative effects of the pandemic, modest social capital, high GW, ANC and VR regression in 2021, amid exaggerated debts, ANC and VR growth in 2022
	2019	65,81	1294251	30%	3,33	2975200	1680949	
	2020	77,26	1458050	30%	3,33	3897993	2439943	
	2021	99,96	984455	30%	3,33	3421250	2436795	
	2022	99,95	1165211	30%	3,33	3988910	2823699	
F15		Business sector: legal and accounting activities						ANC and VR compatible over time, impressive financial performance, against the background of minimal share capital, alarming increase in debt in 2022, massive positive GW in all targeted years
	2019	99,98	1005679	30%	3,33	3353037	2347358	
	2020	95,99	949924	30%	3,33	3029930	2080006	
	2021	91,72	1008602	30%	3,33	3081490	2072888	
	2022	99,98	1096106	30%	3,33	3637633	2541527	
A16		Business sector: Wholesale and retail trade; repair of motor vehicles and motorcycles						continuous increase in ANC and VR, negative GW in the first years
	2019	9,60	31335855	30%	3,33	6251523	-25084332	
	2020	29,81	41976090	30%	3,33	27658793	-14317297	
	2021	57,79	82946225	30%	3,33	127050097	44103872	
	2022	44,78	134415698	30%	3,33	182039330	47623632	
A18		Business sector: Wholesale and retail trade; repair of motor vehicles and motorcycles						ANC and VR growth in the first years, negative GW throughout the period, comparable financial profitability, with a decrease in the last year, modest share capital
	2019	17,99	86738092	30%	3,33	52129340	-34608752	
	2020	21,88	111948058	30%	3,33	81149413	-30798645	
	2021	28,11	155128976	30%	3,33	145053140	-10075836	
	2022	17,48	178162152	30%	3,33	103770183	-74391969	
B21		Business sector: Agriculture, hunting and related service activities						modest positive profitability, negative GW
	2019	5,95	22798195	20%	5,00	6222775	-16575420	
	2020	11,53	25069281	20%	5,00	13560795	-11508486	
	2021	14,40	28541374	20%	5,00	19494555	-9046819	
	2022	3,58	42960409	20%	5,00	7472155	-35488254	
B22		Business sector: Agriculture, hunting and related service activities						modest profitability, loss in the last year, constant net assets, negative GW
	2019	3,53	152515728	20%	5,00	26879775	-125635953	
	2020	0,94	153728422	20%	5,00	7216030	-146512392	
	2021	1,66	154788280	20%	5,00	12857760	-141930520	

Cod	31.12 (Year)	Financial profitability	Net assets	Capitalization rate	Multiplier coefficient	Yield value	Goodwill	Observations and conclusions*
	2022	-5,69	155357280	20%	5,00	-41685860	-197043140	

*ANC - accounting net asset, VR - yield value, GW - goodwill

4. Discussions and conclusions

The comparative analysis of the eight companies across five economic sectors for the period 2019–2022 allows the formulation of several general conclusions:
1. Sectoral differences are substantial. Legal and accounting activities demonstrate the highest profitability and strongest value creation capacity, while agriculture and furniture manufacturing record modest or negative performance.
2. The pandemic impact was uneven. Construction and trade companies experienced temporary declines in 2020, followed by strong recovery phases. In contrast, legal and accounting activities were minimally affected.
3. Goodwill reflects real value creation disparities. Persistent positive goodwill (F11, F15, partially C03 and C04 in later years) indicates strong income-generating capacity above accounting capital. Negative goodwill (M07, M10, A18, B21, B22) signals limited economic performance relative to invested resources.
4. Financial leverage amplifies profitability. Entities with lower capitalization rates and higher multiplier coefficients show amplified financial returns, but this also increases exposure to risk in adverse periods.
5. Resilience correlates with capital intensity and business model. Service-based activities with low fixed assets demonstrate greater stability and adaptability compared to asset-intensive sectors such as agriculture and manufacturing.

In conclusion, the study confirms that profitability alone is insufficient to assess company performance. A combined analysis of accounting net assets, yield value and goodwill provides a more comprehensive perspective on financial sustainability and value creation. The results emphasize the importance of sector-specific dynamics and capital structure in determining long-term economic performance.

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Fintech Challenges – Compliance with Existing Regulations

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Abstract: *The expansion of financial technology (fintech) has reshaped the financial sector, introducing innovative solutions in payments, lending, and investment. However, as fintech firms redefine financial intermediation, they face increasing regulatory complexity. This study analyses the main compliance challenges emerging from the European Union's evolving payment services framework, focusing on the Payment Services Directive (PSD2/PSD3) and the forthcoming Payment Services Regulation (PSR).*

Adopting a conceptual and regulatory analysis, the paper examines the alignment between fintech business models and EU legal framework on payments, with particular attention to European Banking Authority (EBA) guidelines and supervisory practices. It further considers the role of regulatory innovation tools, such as sandboxes and innovation hubs as a monitoring mechanism in mediating the relationship between technological dynamism and regulatory oversight.

The findings indicate persistent fragmentation across jurisdictions, from the innovation monitoring perspective, escalating compliance costs, and tensions between the pace of innovation and the need for legal certainty. Although PSD2 and PSR provide a clearer structure for payment service providers, emerging technologies such as embedded finance, decentralized architectures, and artificial intelligence might introduce new regulatory ambiguities. Greater clarity on eligibility from the authorization perspective as a payment service provider, cross-border operations, and security measures remain necessary to ensure consistency and trust in the payment ecosystem.

By integrating payment-specific requirements within a broader supervisory perspective, this study offers a comprehensive understanding of fintech compliance in the EU. It highlights the importance of coherent, innovation-friendly legal framework to balance market dynamism with secure payments services and payment service users' confidence, contributing to a more integrated and resilient European digital financial landscape.

Keywords: *Fintech compliance; Regulatory frameworks; Payment services; EU digital finance; Innovation governance*

JEL Classification: *G21; G28; O33; E58; K23*

1. Introduction

The digital transformation of financial services has reached unprecedented levels, with payment services emerging as one of the most dynamic and heavily regulated sectors in the European Union. The intersection of financial technology innovation and regulatory frameworks presents unique challenges for both emerging fintech companies and established financial institutions (Brener, 2024). This study examines the critical compliance challenges faced by fintech firms operating within the European payment services regulatory framework, particularly under PSD2, the proposed PSD3, and the emerging Payment Services Regulation (PSR).

The regulatory landscape for payment services has evolved significantly since the introduction of the first Payment Services Directive (PSD1) in 2007, followed by PSD2 in 2015, and the ongoing discussions around PSD3 and PSR (Polasik et al., 2024), with an envisaged horizon for adoption and entry into force within two years. This evolution reflects the European Union's effort to harmonize payment services across member states while addressing technological innovations and protecting payment service user interests. However, the rapid pace of technological development has created

implementation gaps that fintech companies must navigate while maintaining compliance with complex regulatory requirements (Jan Skrabka, 2023).

Payment services represent one of the most regulated systems globally, and this is particularly characteristic of the EU legal framework (Zetzsche *et al.*, 2017).

The fintech sector has experienced remarkable growth across the European Union, though this growth is not distributed homogeneously. Fintech entities tend to concentrate in developed financial centres where supporting infrastructure exists, including private initiatives such as fintech incubators and accelerators, as well as regulatory support mechanisms like Innovation Hubs and Regulatory Sandboxes (Helgadóttir, 2019; Romanova *et al.*, 2018). This geographical concentration reflects both market opportunities and the varying approaches to fintech regulation and support across member states.

This study addresses a critical gap in understanding how payment services regulation impacts fintech innovation and market entry. While existing literature has examined specific aspects of PSD2 implementation or fintech business models, there remains a need for comprehensive analysis that bridges regulatory requirements with operational challenges faced by fintech firms. This research aims to provide a perspective from this point of view that might offer valuable insights to policymakers, regulators, fintech entrepreneurs, and academic researchers.

The structure of this paper proceeds as follows: Section 2 reviews relevant literature on fintech regulation and payment services compliance; Section 3 discusses the primary challenges faced by fintech companies in navigating payment services regulation and examines regulatory perspectives and supervisory challenges; and Section 4 concludes with policy recommendations and implications for the future of fintech regulation in Europe.

2. Literature Review

2.1. Evolution of Payment Services Regulation in the EU

The regulatory framework for payment services in the European Union has undergone substantial transformation to accommodate technological innovation while maintaining payment service user protection and secure payment services. The first Payment Services Directive (PSD1), implemented in 2007, established the initial framework for harmonizing payment services across EU member states (Loo, R.V., 2016). However, the emergence of new payment methods, mobile technologies, and digital platforms necessitated more comprehensive regulation, leading to the adoption of PSD2 in 2015 (Vives, X.,2019).

PSD2 introduced several groundbreaking provisions, most notably the requirement for banks to provide third-party providers (TPPs) with access to customer account information and payment initiation capabilities through Application Programming Interfaces (APIs) (Zachariadis & Ozcan, 2017). This "open banking" mandate aimed to increase competition, foster innovation, and enhance payment service user choice in payment services (Polasik et al., 2024). However, empirical studies reveal that PSD2 implementation has been uneven across member states, with significant variations in supervisory practices and technical implementation (European Banking Authority, 2022).

Recent proposals for PSD3 and the Payment Services Regulation (PSR) represent the next phase of regulatory evolution, addressing gaps identified during PSD2 implementation and responding to emerging technologies and business models (Jan Skrabka, 2023). These proposals aim to further harmonize the regulatory framework, enhance payment services users' protection, and address specific challenges from the security perspective related to strong customer authentication, liability frameworks, and cross-border operations (European Commission, 2023).

2.2 Authorization and Licensing Requirements

Authorization and licensing represent fundamental compliance challenges for fintech payment service providers. The literature consistently identifies the complexity and cost of obtaining payment services authorization as significant barriers to market entry (Brener, A., 2024; Douglas et al., 2017). EU-level authorization requirements encompass detailed capital adequacy standards, safeguarding obligations,

governance structures, and strong customer authentication mechanisms, all of which impose substantial operational and compliance burdens on new entrants (Polasik et al., 2024; Magnuson, 2018).

Research demonstrates that authorization processes vary considerably across member states despite harmonization efforts under PSD2 (Brener, 2024). Supervisory divergence in interpreting and applying authorization criteria creates inconsistent licensing outcomes and undermines the single market objective (Ferrarini & Paolo, 2015). Different national competent authorities apply varying standards for capital requirements, organizational structures, and technical capabilities, leading to regulatory arbitrage opportunities and competitive distortions (Avgouleas & Kiayias, 2019).

The costs associated with achieving and maintaining compliance with authorization requirements are particularly challenging for smaller fintech startups. Studies document high financial and technical costs required to implement PSD2 Regulatory Technical Standards (RTS) and related obligations, which can limit fintechs' ability to capitalize on open banking opportunities (Jan Skrabka, 2023). These costs include not only initial authorization expenses but also ongoing compliance monitoring, reporting obligations, and periodic supervisory assessments (Anagnostopoulos, 2018).

2.3 Regulatory Fragmentation and Legal Uncertainty

Regulatory fragmentation emerges as a persistent theme in the literature on fintech payment services compliance. Despite EU-level harmonization efforts, significant variations exist in how member states transpose and implement payment services directives (Jan Skrabka, 2023). This fragmentation creates legal uncertainty for fintech firms operating across multiple jurisdictions and increases compliance costs (Fenwick et al., 2017).

Studies identify several sources of regulatory fragmentation. First, inconsistent rules and requirements applied to non-bank payment service providers across jurisdictions create legal asymmetries and compliance uncertainty (Jan Skrabka, 2023). Second, tensions between PSD2's data access mandate and other legal frameworks, particularly the General Data Protection Regulation (GDPR), produce complex compliance questions around lawful processing, consent mechanisms, and data minimization (Helgadóttir, 2019; Loo, 2016).

Research also highlights that where traditional institutions or supervisors resist the full harmonization of PSD2 requirements, regulatory change has sometimes failed to change deep market practices, reducing intended effects on competition and access to payment services (Vives, 2019). This implementation gap between regulatory intent and market reality represents a significant challenge for fintech firms seeking to benefit from the PSD2 opportunities.

2.4 Regulatory Sandboxes and Innovation Support

Regulatory sandboxes and innovation hubs have emerged as important tools for supporting fintech innovation while managing regulatory compliance challenges. The literature presents mixed evidence of their effectiveness. Empirical studies show that regulatory sandboxes and open innovation environments are associated with stronger fintech development and higher incidence of license applications in jurisdictions that offer them (Zetzsche et al., 2017; Zetzsche et al., 2017).

However, research also indicates that sandboxes facilitate testing and regulator-firm dialogue but do not remove fundamental obligations such as capital requirements, safeguarding rules, or cross-border supervisory divergence (Zetzsche et al., 2017; Jan Skrabka, 2023). Sandboxes provide some temporary regulatory relief and learning opportunities but do not fully solve technical challenges related to API access or bank account access (Ringe & Ruof, 2020). Some scholars argue that while sandboxes lower entry frictions and foster experimentation, they represent partial remedies rather than comprehensive solutions to structural regulatory challenges (Bromberg *et al.*, 2017). This is also because there is not a uniform EU legal framework applicable for regulatory sandbox access, especially on the payment side, that tends to be one of the most EU regulated activities.

Industry and regulator-backed infrastructure, such as dedicated open banking platforms, are proposed as complementary measures to ease operational integration with incumbent banks and reduce technical barriers to compliance (Zachariadis & Ozcan, 2017). These collaborative platforms can standardize

technical implementations, provide shared resources for smaller players, and facilitate more consistent application of regulatory requirements across jurisdictions (Klein & Verhagen, 2020).

2.5 Compliance Costs and Innovation Trade-offs

A critical theme in the literature concerns the trade-off between regulatory compliance costs and innovation capacity. Research documents that high compliance costs can constrain fintech firms' ability to innovate, particularly for smaller startups with limited resources (Cumming & Schwienbacher, 2018). The financial burden of meeting authorization requirements, implementing strong customer authentication, ensuring data protection compliance, and maintaining ongoing supervisory relationships can divert resources from product development and market expansion (Braggion et al., 2018).

Studies examining the impact of PSD2 on fintech innovation present nuanced findings. While the directive has created opportunities through open banking mandates, the associated compliance costs and implementation challenges have also created barriers (Polasik et al., 2024; Jan Skrabka, 2023). Some research suggests that larger, better resourced fintech firms and incumbent financial institutions have been better positioned to capitalize on PSD2 opportunities compared to smaller startups (Haddad & Hornuf, 2019).

The literature also explores how compliance requirements shape fintech business models and strategic choices. Regulatory constraints can influence decisions about target markets, product offerings, partnership strategies, and growth trajectories (Mention, 2019). Understanding these dynamics is essential for policymakers seeking to calibrate regulatory frameworks that protect payment service users and maintain financial stability while enabling beneficial innovation.

3. Discussion

3.1 The Most Important Challenges Faced by Fintech

Competent authorities, whether national or international, have significant responsibility to analyse, support, and oversee innovative fintech developments, particularly those comprising the most dynamic financial activity as payment services. Thorough analyses have been launched to assess the challenges faced by fintech entities in launching their services, especially within the extended context of digitalization processes (European Banking Authority, 2021).

Whether these are services pursuant to the existing legal framework or technological support services for carrying out regulated activities, the digitalization process involves associated risks, particularly on the information and communication technology (ICT) and security side. The European Supervisory Authorities and the European Commission share the concern, urging member state authorities to strengthen innovation monitoring through effective tools that promote technological advancement in financial markets. (European Commission, 2020; European Banking Authority, 2021). This approach calls for jurisdiction-level analysis of the fintech sector and coordinated measures to foster technological innovation and effective monitoring, supporting the development of a consolidated European single market. (European Securities and Markets Authority, 2019).

3.2 Authorization and Compliance Challenges

As financial technology evolves, fintech firms face complex regulatory environments where authorization, registration, and ongoing compliance remain challenging due to their stronger technological than regulatory orientation. (Magnuson, 2019).

Insufficient preliminary preparations for fintech companies may result in compliance breaches and ultimately large penalties, or especially where authorization is needed, refusal from competent authorities regarding granting authorization or registration. Insufficient preparation on the fintech side might be a critical factor preventing small startups from entering the market or remaining compliant due to changing legislation and establishing effective compliance practices, especially within highly regulated domains like payment services (Arner et al., 2017).

The authorization process demands fintech firms to prove technical competence alongside solid governance, capital adequacy, and risk management, often forcing startups to divert resources from innovation to regulatory compliance. (Brummer & Yadav, 2019).

3.3 Regulatory Complexity and Jurisdictional Challenges

These issues are complicated and vary by different jurisdictions. The regulatory landscape around fintech, such as digital payments, is constantly developing, posing important issues for regulators as well as fintech companies. Fintech startups must first navigate the highly regulated sector and obtain regulatory approval before commencing envisaged activities, either within a pre-consultation process with competent authorities or through efficient legal advice (Fenwick & Vermeulen, 2019).
To address regulatory challenges, fintech startups should leverage their agility by integrating compliance and innovation, fostering a strong compliance culture that builds trust with investors, customers, and regulators. (Schueffel, 2016).
A strong compliance culture enables fintech firms to differentiate from traditional competitors, add business value, and drive the financial sector's digital transformation alongside rapid innovation and market growth. (Gomber et al., 2018).
Recent fintech advances have pushed traditional financial institutions to innovate and adapt to customer needs, yet the sector still faces financial, legal, and regulatory barriers, particularly within the EU's highly regulated payment services framework. (Stulz, 2019).

3.4 The Regulatory Landscape Fragmentation

A key legislative challenge for fintechs in payment services is the lack of a unified global regulatory framework, as compliance standards vary across jurisdictions. (Iman, 2018).
An exception to this fragmentation is presented by the EU's uniform regulatory framework applicable for providing different financial services. However, in terms of regulation or support policies for the fintech sector, significant differences remain regarding rules and tools used by competent authorities. Thus, at first glance, it may appear as a complex bureaucratic legal framework (Claessens et al., 2018). Regulatory fragmentation poses a major challenge for fintechs whose multifunctional business models span overlapping regimes, requiring advanced legal expertise and significant compliance resources to manage conflicting requirements. (Hornuf et al., 2021).

3.5 Challenges Faced by Regulators due to the Fast-Moving Fintech Phenomenon

The fast-paced evolution of financial technologies offers fintech firms agility to innovate and enables traditional providers to integrate new tools for enhanced services (Boot et al., 2021). In this respect, it seems that regulators, however, face challenges in keeping pace with this innovation, as complex legal frameworks and limited resources hinder effective oversight (Ringe, 2020; Buckley et al., 2020). Existing regulatory models, designed for traditional institutions, often misalign with fintech's multifunctional business structures, creating uncertainty and potential arbitrage risks (Zetzsche et al., 2017). To respond effectively, it seems that supervisory authorities must strengthen their technical capacity in areas like AI, blockchain, and cloud computing through innovation hubs and specialized expertise (European Banking Authority, 2017).

3.6 Balancing Innovation and Payment service user Protection

Fintech regulation must balance fostering innovation with protecting payment service users and ensuring financial stability, as security and fraud prevention requirements can conflict with rapid market experimentation. (Broeders & Khanna, 2015).

The regulatory response to this tension has included proportionality principles, whereby regulatory requirements are calibrated to the risks posed by different types of payment services and providers. However, determining appropriate proportionality remains challenging, particularly for novel business models where risk profiles may not be fully understood (Packin & Lev-Aretz, 2018).

Regulatory sandboxes represent one approach to managing this balance, allowing limited-scale testing of innovative products under supervisory oversight with some regulatory flexibility. However, as the literature review indicated, sandboxes provide only partial solutions and do not eliminate fundamental compliance requirements or supervisory divergence across jurisdictions (Zetzsche et al., 2017; Ringe & Ruof, 2020).

3.7 The Path Forward: Regulatory Adaptation and Industry Collaboration

Effectively addressing fintech compliance challenges in the EU requires coordinated action: harmonizing regulatory and supervisory practices under PSD3 and PSR (Polasik et al., 2024; European Commission, 2023), strengthening dialogue through innovation hubs and consultations (Financial Stability Board, 2019), adopting RegTech tools for efficient oversight (Arner et al., 2017), and ensuring clear, accessible regulatory guidance to support fintech growth and compliance (Macchiavello & Siri, 2020).

4. Conclusion

The intersection of fintech innovation and payment services regulation presents both opportunities and challenges for the European financial ecosystem. This study has examined the key compliance challenges faced by fintech firms operating within the EU payment services regulatory framework, with particular focus on PSD2, emerging PSD3 proposals, and the Payment Services Regulation.

The analysis reveals several critical findings. First, despite harmonization efforts under PSD2, significant regulatory fragmentation persists across member states, creating compliance complexity and costs for fintech firms seeking to operate cross-border. Authorization processes remain burdensome, with supervisory divergence producing inconsistent outcomes and undermining single market objectives.

Second, while PSD2's passporting mechanism theoretically enables pan-European operations, practical barriers related to bank account access, API implementation, and incumbent resistance continue to constrain cross-border scaling. The concentration of fintech activity in certain jurisdictions reflects not only market factors but also variations in regulatory environments and supervisory approaches.

Third, regulatory sandboxes and innovation hubs provide valuable support for fintech development but represent partial rather than comprehensive solutions. These tools facilitate experimentation and dialogue but do not eliminate fundamental compliance requirements or address structural challenges related to regulatory fragmentation and supervisory coordination.

Fourth, the rapid pace of fintech innovation creates challenges not only for firms navigating compliance but also for regulators developing appropriate frameworks. The misalignment between traditional regulatory categories and novel fintech business models creates classification difficulties and potential regulatory gaps.

4.1 Policy Recommendations

Based on these findings, several recommendations emerge for policymakers and regulatory authorities:

Streamline authorization processes: Establishing standardized, proportionate authorization requirements across EU member states can reduce compliance costs and uncertainty, while making proportional rules mandatory for small payment institutions to prevent regulatory arbitrage and inconsistencies.

Enhance cross-border regulatory harmonization: Strengthening supervisory coordination and providing clear guidance on regulatory requirements can reduce implementation gaps, ensure consistent application across jurisdictions, and clarify how payment services rules interact with emerging technologies and other legal frameworks.

Support fintech compliance through regulatory infrastructure: Invest in shared compliance infrastructure, standardized technical interfaces, and collaborative platforms that can reduce individual firms' compliance costs while enhancing overall regulatory effectiveness.

Adopt risk-based, proportionate regulation: Calibrate regulatory requirements to the actual risks posed by different payment services and payment service providers, avoiding one-size-fits-all approaches that may impose excessive burdens on lower-risk activities.
Foster continued dialogue and collaboration: Maintain and expand channels for regulator-industry engagement, including innovation hubs, industry consultations, and collaborative working groups that can bridge knowledge gaps and inform regulatory development.

4.2 Implications for Fintech Companies

For fintech companies seeking success in the European payment services market, several strategic implications emerge:
Early regulatory engagement: Fintech firms should engage regulators early and invest in robust compliance infrastructure, leveraging innovation hubs and pre-consultation mechanisms to align product development with regulatory requirements.
Development of regulatory expertise: Fintech firms should integrate regulatory and technological capabilities, strategically select jurisdictions, and foster transparent operations to ensure compliance, maintain innovation, and build trust with stakeholders.
Collaborative approaches: Engage with industry associations, collaborative platforms, and shared infrastructure initiatives that can reduce individual compliance burdens and strengthen the overall fintech ecosystem.

4.3 Future Research Directions

Future research intended to focus on several key directions. It seems that empirical studies need to track how PSD3 and the PSR perform once implemented, assessing whether they close the gaps left by PSD2 and improve regulatory consistency across the EU. This seems an important aspect to be assessed especially if the balance between compliance and innovation is achieved. Comparative analyses between the EU, the UK, the US, and Asia-Pacific regions can reveal how different jurisdictions manage payment regulation and what lessons can be shared. Another direction of research should also quantify the real compliance costs faced by fintech firms of various sizes and models to support proportionate and innovation-friendly regulations. Further work should evaluate how regulatory tools, such as sandboxes, innovation hubs, and accelerators might enhance collaboration between supervisors and industry. Finally, examining how emerging technologies like AI, blockchain, and decentralized finance interact with payment regulations will be essential to understand and shape the next stage of digital finance governance.

4.4 Concluding Remarks

The European Union’s payment services framework strives to balance innovation, competition, consumer protection, and security of the payment services. Persistent challenges, such as regulatory fragmentation, complex authorization process and cross-border inconsistencies, it seems that are relevant factors to hinder this balance but also open opportunities for reform. The transition from PSD2 to PSD3 and the introduction of the PSR will offer a crucial moment to close existing gaps and enhance coherence. Achieving this might require joint efforts: regulators must adapt to technological realities, fintech firms must commit to transparent compliance, and policymakers must ensure proportional and harmonized rules. The future of EU payments depends on maintaining this balance, by fostering innovation while safeguarding consumer trust and reinforcing the single digital market.

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Reorganizing the Scientific Publishing Ecosystem: Open Access, Platforms, and the Future of Academic Publishing

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Abstract: *This study aims to investigate the scientific publishing environment, that is undergoing a structural transformation driven by the interaction of digitalization, the global Open Science (OS) movement, and increased demands for transparency and accessibility of scientific results. Traditional subscription models are being replaced by Open Access (OA) principles, which are significantly changing the economic and organizational architecture of scientific communication. This study analyzes new OA business models (in particular, APC, Diamond OA, Subscribe-to-Open) and innovative platforms, assessing their sustainability and potential to overcome the shortcomings of traditional publishing – high barriers to publication and concentration of market power. Against the background of international initiatives (Plan S, UNESCO Recommendation, FAIR principles) that aim for inclusivity and fairness, OA growth is stable (about 10% for journals and 20% for articles annually). The distribution of OA publications shows regional differences: Europe and North America use institutional repositories, while Latin America and Africa rely heavily on local subsidies. OA policies supported by government programs (e.g. Horizon 2020) enhance the visibility of national research and international collaboration. The proposed hypothesis states that the percentage of OA articles depends on a set of factors, including OA efficiency, regulatory framework, global science funding, scientific development, researcher engagement, and the level of digital infrastructure development. The analysis puts the foundation for assessing Ukraine's position, where the use of OA can become a significant element of sustainability and international integration despite existing financial and infrastructural constraints.*

Keywords: *Open Access; Business Models; Open Science; Publishing Platforms; University Presses*

JEL Classification: *L15; O30; M00*

1. Introduction

The scientific publishing ecosystem is going through a fundamental reconfiguration, influenced by the interplay of three key forces: quick digitalization, the global open science movement, and intensified societal demands for greater transparency, accessibility, and efficiency in the dissemination of academic knowledge.

Established licensing and subscription paradigms are increasingly viewed with scepticism and are being displaced by the philosophy of Open Access (OA) and broader Open Science frameworks. This paradigm shift is substantially transforming the financial and structural foundations of scholarly communication.

This study analyzes new OA-business models and innovative technological platforms in the publishing sector, assessing their long-term viability, scalability potential, and the strengthening effect they have on global research ecosystems.

The initial phase of the analysis identifies structural shortcomings of the traditional publishing landscape, including elevated access barriers, disproportionate diffusion of scholarly outputs, and the concentration of dominant market power within a small group of international publishing conglomerates.

These critical imbalances have catalyzed a series of international regulatory and policy initiatives, such as Plan S (Petrak et al., 2021), UNESCO's Recommendation on Open Science (Research4Life, 2022), and the FAIR principles (International Data Spaces, 2020), with the central aims of inclusivity, interoperability, and equitable participation in knowledge creation.

In response, alternative financial architectures are being developed to ensure the open dissemination of research results while safeguarding the economic sustainability of publishing operations and institutions. Key strategies include:

- article processing charges (APCs): a widespread yet contested mechanism, as author-side fees can deepen inequalities in access to publishing opportunities;
- diamond OA: a model that eliminates fees for both authors and readers; operational costs are covered through institutional grants, university consortia, or public subsidies;
- subscribe-to-open (S2O): a cooperative funding mechanism whereby annual subscription revenue, once it reaches a defined threshold, automatically unlocks journal content for OA;
- community-owned publishing platforms: including institutional repositories, preprint servers, and university presses, these provide decentralized, participatory channels that broaden involvement and democratize the distribution of scholarly work.

2. Literature Review

OA policy has become an important element of the scientific landscape, contributing to the accessibility of research results, strengthening citations and global cooperation between scientists. Table 1 illustrates how OA policy changes scientific communication. The number of OA journals and OA articles is stable in its increasing. On average annual growth of OA journals is 10%, and articles - about 20%.

Table 1. Growth of quantities of journals and articles with OA

Year	Number OA journals	General number articles (million)	General number citations (million)	Source
2015	10,500	2.5	100	DOAJ
2018	12,800	3.2	120	DOAJ, PLOS ONE
2021	16,000	5.0	140	DOAJ, MDPI
2024	18,000	6.5	155	OPUS Project

Source: Open and Universal Science [OPUS] Project, 2023

In regions such as Latin America and Africa (Table 2), the higher number of OA publications can be attributed to the development of local initiatives and subsidies aimed at enhancing software accessibility. In contrast, developed countries in North America and Europe (Basson et al., 2022) actively utilize institutional repositories to facilitate OA, whereas in developing countries, growth in OA is supported by initiatives that provide funding for local journals.

Table 2. Distribution by regions and disciplines of OA publications

Region	Percentage of OA publications	Main OA platforms	Features	Source
North America	45%	PubMed, arXiv	Institutional repositories	OECD, PLOS ONE
Europe	55%	Horizon 2020, Zenodo	Politicians on EU levels	European commission, OECD
Latin America	65%	SciELO, AmeliCA	Assistance regional magazines	OPUS Project
Africa	70%	AJOL, local initiatives	High dependence from subsidies	PLOS ONE, OPUS Project

Source: Bernal, 2013

State-initiated OA policies promote transparency and accelerate knowledge dissemination. For instance, Horizon 2020 mandates OA for all EU-funded research, while Plan S requires immediate OA availability for all scientific publications upon release (Table 3).

Table 3. Political initiatives for OA support

Initiative	Country / region	Description	Source
Horizon 2020	European Union	Mandatory OA	European commission
Plan S	Europe	OA for all scientific works	Science Europe
The White House OA Mandate	USA	OA for state research	National US institutions
SciELO	Latin America	Local support for OA journals	SciELO, OPUS Project

Source: OECD, 2016

Financial aspects of OA policy: interrelations and possible factors

Funding scientific research and publishing is a critical driver of a country's economic and social development. Investment in supporting scientific journals (OA, particularly) yields significant benefits, as it:

- enhances the visibility and citation impact of Ukrainian research, fostering global recognition;
- elevates the prestige and international standing of Ukrainian universities;
- promotes equitable access for Ukrainian scientists to the global academic community, facilitating collaboration and knowledge exchange.

This study seeks to establish a comprehensive linkage between OA, scientific funding, and OS, with a particular emphasis on their interplay within the paradigm of OS and Ukraine's evolving role within it. The analysis is grounded in structured data encompassing the number of OA publications across EU countries from 2000 to 2022, sourced from international online databases (National Center for Science and Engineering Statistics [NCSES], 2024; Macrotrends LLC, n.d.; OECD, n.d.; Scopus, 2023). This temporal scope allows for an examination of long-term trends and the impact of policy shifts on OA adoption. To explore these dynamics, a hypothesis is proposed: the percentage of articles published in OA (%) is influenced by a set of interrelated factors, each contributing to the broader framework of OS. The first factor, the efficiency of OA, is measured by the percentage of research outputs available in OA (Piwowar et al., 2018), reflecting the extent to which scholarly works are freely accessible and reusable (Balsyte et al., 2023). This metric serves as a foundational indicator of OA penetration within academic communities. Secondly, the OA declaration framework, represented by regulatory guidelines such as those outlined in the EU's OA policies, provides directional mandates that encourage the dissemination of research in open formats, shaping institutional and national strategies (Huang et al., 2020). Thirdly, global scientific funding is considered, offering insights into the allocation of GDP by states towards research. Evidence suggests that state-funded research predominantly results in OA publications, highlighting the financial underpinnings of OS (Shevchenko et al, 2020).

Additionally, the overall development of science is hypothesized to propel OA growth by fostering collaboration and innovation, a trend observed in international research networks (Cockerill & Knols, 2008). The percentage of OA articles among top universities is included as a potential driver, suggesting that leading institutions may set precedents that cascade down to broader OA adoption (Piwowar et al., 2020). Furthermore, the engagement of researchers (Zhu, 2017), particularly the number of young scientists and staff, is posited to influence OA rates, as increased research activity and publication output often in OA formats – may amplify the proportion of accessible works (Olejniczak & Wilson, 2020).

Finally, the number of internet users is integrated as a critical indicator of digital infrastructure development, alongside the volume of data generated. Although comprehensive data on published content over the study period (2000–2022) is inconsistent, internet usage is prioritized as a secondary yet significant metric. The rapid exchange of scientific information facilitated by internet growth is believed to catalyze OA expansion, aligning with the OS paradigm (Zhang et al., 2022). This model, initially proposed using aggregated EU data, provides a framework that can be adapted to assess Ukraine's position, where geopolitical challenges and limited funding intersect with the global push

toward OS. Ukraine's inclusion in this analysis highlights its potential to leverage OA for resilience and international collaboration, despite infrastructural and financial constraints.

3. Discussion

This study argues that innovative OA models are not only changing the way knowledge is disseminated, but also reimagining the value of scholarly publications. Joining these models with principles of openness, inclusion, and equity provides the foundation for creating research ecosystems that are more financially viable and globally interdependent. Future directions should prioritize hybrid funding models, strengthen institutional support, and integrate open platforms into academic assessment systems to ensure their long-term sustainability. Future OA policy must move beyond simply achieving OA and focus on how it is achieved. This requires intervention to stimulate price transparency. Funders and institutions should demand detailed cost breakdowns from publishers behind the APCs. Without such pressure, the market will remain opaque, and prices will continue to rise, driven by prestige rather than value.

4. Conclusions

Evidence from different regions and initiatives suggests that the adoption of OA is driven by the interaction of policy initiatives, funding structures, institutional capacity, and digital infrastructure. APC-oriented models scale quickly but can create gaps where author contributions are mandatory; diamond OA and S2O shift costs to sponsors and consortia, aligning incentives with the public good of scholarly communication and lowering barriers for authors. Community-owned platforms (institutional repositories, preprint servers, university presses) complement both approaches by decentralizing governance and reducing fixed costs, especially in systems with limited budgets. The cross-regional patterns in Tables 1–2 show that Latin America and Africa have higher shares of open access where cooperative platforms and subsidies exist, while North America and Europe expand open access through repository ecosystems and policy frameworks (e.g. Horizon 2020, Plan S) that enable direct openness. The proposed set of factors: OA effectiveness, policy framework strength, government R&D efforts, leading university leadership, researcher demographics, and Internet penetration – provide an empirical framework for assessing the dynamics of OA article numbers.

For Ukraine, the combination of military rule, limited systemic funding, and widespread use of open science underscores the value of models focused on diamond-like open access, consortial governance, and alignment with European open science infrastructures to strengthen the operations of scholarly publishing, increase transparency, and mitigate inequalities. Most Ukrainian academic journals use Open Journal Systems (OJS) with limited institutional support, and most operate in a diamond open access mode supported by universities without charging authors or readers. However, a lack of stable funding, fragmented editorial practices, and pressure to adhere to international indexing standards create additional obstacles.

Ukraine's gradual integration into the European Research Area and harmonization with the European Union's open science policy is becoming the basis for the implementation of innovative business models. It also includes the creation of consortia of university presses to strengthen editorial autonomy and increase the international visibility of national research.

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Play, Solve, Repeat: Gamifying Quantitative Disciplines for Engaged Learning in Higher Education

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Abstract: *Students in economics programs — spanning accounting, management, finance, human resources, and economic informatics — often perceive quantitative disciplines like mathematics, statistics, optimization, and programming as intimidating puzzles. Formulas appear as hieroglyphs, data tables as riddles, and algorithms as unsolvable mysteries. Yet these disciplines are vital for modelling, analyzing, and solving real-world economic problems. We argue that gamification — applying game design elements in learning — can transform these barriers into engaging, motivating experiences. Grounded in Self-Determination Theory (Deci & Ryan, 2000), Flow Theory (Csikszentmihalyi, 1990), and gamification frameworks (Deterding, Dixon, Khaled, & Nacke, 2011), we present four concrete strategies: a Matrix Dungeon Escape Room for linear algebra, a Time-Series Treasure Hunt in statistics, a Resource Allocation Simulation for optimization, and a Coding Quest for informatics. Each module includes narrative-driven stages, hints, optional collaboration, instant feedback, and meaningful rewards — for instance, a "Mathemagician's Amulet" or "CEO's Seal of Efficiency." Our qualitative framework demonstrates how gamification can satisfy psychological needs, promote flow, and connect abstract concepts to practical applications. This paper illustrates that even complex formulas can become adventures, not chores, for economics students.*

Keywords: *Gamification, Interactive Learning, Quantitative Disciplines, Higher Education, Student Engagement*

JEL Classification: *A22; I23; I29*

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1. Introduction

For teachers with even a moderate degree of experience in practical work with students, especially those from the areas of study of quantitative disciplines such as mathematics, statistics, optimization and informatics, it comes as no surprise that interactions with them during classes are severely influenced by intimidation, lack of enthusiasm and interest, coldness or boredom. These are often rooted in their reactions to spreadsheets, formulas or probability distributions that may appear like hieroglyphs, puzzles or riddles of sorts.

However, the importance of the above-mentioned disciplines cannot be overlooked, since they are needed in analyzing or solving complex problems, yet lectures and traditional approaches in teaching don't seem to be very successful in chasing away the negative feelings we keep on detecting when we are in front of our more or less young audience.

We firmly believe in the powers of gamification and those of other various forms of interactive learning and teaching that can significantly help turn abstract numbers into spicy challenges. Gamification has the advantage of blending story, challenge, feedback and reward, thus serving our students a cocktail that helps give abstract concepts a smooth, palatable and engaging taste.
The aim of this paper is to explore, from a qualitative point of view, the way teaching strategies centered on gamification turn quantitative disciplines into memorable, enjoyable, motivating experiences; these areas of study and interest become interactive adventures rather than tedious tasks, via playful scenarios, progressive challenges and enticing rewards.

2. Literature Review

2.1 Motivation and Gamification Foundations

According to the Self-Determination Theory, intrinsic motivation is boosted when satisfaction of the principles of autonomy, competence and relatedness is achieved (Deci & Ryan, 2000). We find that autonomy comes from choice when given tasks, competence is connected to meaningful feedback and carefully scaled difficulty and relatedness can't be separated from competition and collaboration (Félix da Silva et al., 2024). Extrinsic rewards should just be the icing on the cake, not undermine its foundation, which is intrinsic motivation. In flow theory, deep engagement comes from challenges tailored to match skill level, clear goals and immediate feedback (Csikszentmihalyi, 1990). One of the benefits of gamified modules is that it offers flow by scaling tasks with a view to complexity and instant guidance (Issabek, Oliveira, Hamari, & Bogdanchikov, 2025). A game design style like MDA (Mechanics-Dynamics-Aesthetics) turns structural elements into emotional moments which stem from the paramount sensitivity of context for motivational results (Hunicke, LeBlanc, & Zubek, 2004). Deterding et al. (2011) showed leaderboards and badges lead to motivation, while taking into account factors like story, challenge and social context. Gamification has a strong influence on intrinsic motivation, if autonomy and relatedness are taken into account; it can be argued that the effects on competence are less perceivable (Xu, Hamari, & Others, 2024). Novelty and equity are taken into account when conceiving challenges, while shielding learners from losing motivation or getting overwhelmed.

2.2 Domain-Specific Applications

According to Montenegro-Rueda et al. (2023), higher education gamification type of teaching boosts engagement and satisfaction in learning. More specifically, in Economics, playful, interactive tasks arouse interest in participation. It is interesting that for undergraduate courses RPG based simulations sharpen emotional engagement, while the cognitive side tends to vacillate, which calls for responsible, careful design (Frontiers in Education, 2024). This means guaranteeing equitable participation, ethical care and long-term motivation (Denoni-Buján et al., 2025; Klock, Santana, & Hamari, 2023). As a conclusion, relevant literature backs gamification up as a critical means in teaching quantitative disciplines, if used responsibly.

3. Gamified Strategies for Quantitative Learning

The approach of this study is qualitative, while based on relevant literature and structures used in higher education pedagogy; we focused on the identifying gamification strategies that can help with teaching quantitative disciplines. Gamification aims at turning the study of such disciplines into playful, vivid sequences, by means of challenges, narratives that make the students' interaction with concepts alive. Their ability to solve problems is enhanced and they enjoy the benefit of friendly competition. For Mathematics, Escape-Room like challenges offer students a variety of stages, mathematical riddles, sequences of problems (e.g. linear equations, matrix operations) that are conceived like a fun and immersive scenario. For Statistics, we consider that using Kahoot or Socrative platforms can spark friendly competition, while for Optimization problems, simulation games are particularly relevant; for

example, students will need to manage imaginary limited budgets assigned to them, allocating resources between production, logistics, marketing and other areas, in order to maximize profit and avoid bankruptcy. For Informatics, we recognize leaderboard - like challenges as one of the best motivating ways for students to refine algorithms and models or to design simulations, while earning points and the recognition of their peers. The above methods are interchangeable, not dedicated as such to a certain field or domain.

3.1 Mathematics: The Matrix Dungeon (Escape Room)

Mathematics is often called the "universal language"; while beautiful to mathematicians, interesting, concise, direct, it is intimidating to others. Students frequently approach it with anxiety, especially when facing hieroglyphic formulas. Gamified approaches reduce stress by reshaping challenges as adventures, encouraging sequential reasoning and working together. For example, for linear algebra, let's consider an escape room game where students accept a scenario called "The Matrix Dungeon". Each of the doors stands for a system of linear equations.

- *Entrance Hall:* Students are supposed to solve a 2x2 linear system that stands for a "door lock". Upon solving it, they get the first numeric key. There are also colourful posters in the room (the digital version will prompt pop-up clues) as hints, if needed.
- *Gallery of Mirrors*: Next stage, students need to solve a 3x3 system, making use of the Gauss elimination method. They need to find the coefficients, identify patterns and mirror the matrix to get to the target system. Students are encouraged to work as a team, feedback is immediate.
- *Puzzle Library*: At this stage, students will be tasked with converting real-world contexts into algebraic formulas and therefore they will face a problem shaped as a treasure map and transformed into a 3x3 matrix. After each attempt, they will be given instant feedback.
- *Final Chamber*: As a final step, students will need to use all previous clues in order to solve the final, most difficult, system. A door will be unlocked and they will get to a treasure chest.

It is not the adventure per se, as this game pushes for sequential reasoning, working together and critical thinking. When working as a team, the students improve their connections; immediate feedback generates competence, well-designed hints help keep frustration under control. The reward of this task is the "Mathemagician's Amulet" that students can exhibit or …flaunt about. As (Csikszentmihalyi, 1990; Deci & Ryan, 2000) put it, the reward satisfies psychological needs: competence (mastery), autonomy (navigating rooms) and relatedness (sharing the adventure).

3.2 Statistics: Time-Series Treasure Hunt

Statistics can feel like being stranded in a jungle of leafy numbers. Gamification transforms data analysis into treasure hunt: students investigate trends and correlations to uncover hidden clues.
Students become "Statistical Explorers," investigating a fictional economy through a series of time-series charts. Each stage of the treasure hunt challenges them to apply statistical techniques in a fun, narrative-driven way. Clues can vary in difficulty, from easy to more challenging ones.

- *Market Square:* First, students will find themselves exploring a market square of sorts, where time-series charts are displayed, showing inflation, unemployment or GDP. These graphs contain hidden clues, more or less elaborate (for example, an easy clue would be something like "the key to door no.2 is the year when unemployment soared").
- *Stock Tower*: Students will need to calculate moving averages, but also detect anomalies in charts, while deciphering hidden clues; their interpretations will be prompted with immediate feedback meant to guide them.
- *Prophet's Way*: Students will need to run simple regression models, based on quarterly data, in order to have a chance to forecast future values evolution. In so doing, they will get a hint. Regression analysis is used for reasonable predictions, so that they can take actions and decisions once the abstract trendlines become transparent.
- *Xmas Fair*: A playful scenario for students to analyze correlations and make connections between data sets.
- *Treasure Vault*: Students complete the quest by using the hints they previously received and complete a report that will grant access to the final clue in a hidden area.

Upon completion, students earn a "Statistical Explorer Badge" - a personalized token. They can also unlock a bonus data set for a mini-challenge, plunging into autonomy and curiosity (Montenegro-Rueda et al., 2023; Félix da Silva et al., 2024). This approach illustrates practical data interpretation in a narrative context, making temporal patterns and correlations tangible. By embedding friendly competition or collaboration, students experience engagement, curiosity, and autonomy, while the "Statistical Explorer Badge" incentivizes effort without overwhelming (Montenegro-Rueda et al., 2023; Félix da Silva et al., 2024). Gamification in Statistics helps students see data as stories, stimulating meaningful learning and critical thinking.

3.3 Optimization: Economic Quest Simulation

Real world decision-making is inherent to Optimization, for example how to allocate limited resources while observing constraints; however, students sometimes feel like abstract models have little to do with reality. Simulation games help fill this gap, allowing students to experience consequences in a safe, playful environment. Students will be asked to walk a mile in a CEO's shoes, managing an imaginary company. They will have to observe realistic constraints: budgets, limited resources, logistics and production capacity. Students will have to learn to manage and allocate limited budgets, in order to maximize profit, while avoiding imaginary bankruptcy.

- *The Production Plant*: This challenge is supposed to help students tackle the resource allocation problem; they will choose how to allocate raw materials while observing capacity constraints and will receive immediate simulated results output and profit wise.
- *Logistics Maze*: Students will have to plan transports routes on a map, tuning fleet size, delivery grouping and viability of costs; these are supposed to raise their awareness about the impact inventory strategies and selected transport routes have on costs (that should be kept at a minimum), but still meeting the delivery deadlines. As usual, feedback is immediate and they can watch the impact of their assumed decisions.
- *Marketing Hub*: Students have limited marketing budgets and must be wary of overspending while trying to maximize sales. Teamwork is not compulsory, but helps with negotiation.
- *Executive Suite*: As a final round, students will run a full simulation, based on all the previous decisions they made, in order to estimate the net profit, the sustainability and the efficiency of the costs involved. Their goal is to avoid bankruptcy and to get the best outcome possible profit wise, as a consequence of their production, logistics, and marketing decisions.

This simulation merges theory and applied practice. It encourages iterative thinking, experimentation and reflection on trade-offs, one of the benefits being intrinsic motivation. Upon successful completion, participants unlock the "CEO's Seal of Efficiency" – a personalized digital certificate or physical token – and may gain access to a bonus, enhanced scenario. This reward system acknowledges students' strategic thinking and deep understanding. (Tonhão et al., 2024).

3.4 Informatics: Coding Quest

For Informatics, we believe leaderboard type challenges provide some of the best ways to motivate students to refine algorithms and models, design simulations, while earning points and recognition. Informatics and programming are inherently interactive, therefore particularly suitable for gamification. Students often struggle with algorithmic thinking, debugging, and simulation design. Gamified coding exercises provide immediate feedback, progression, and visible achievements, all while reducing the anxiety associated with programming errors.

Students engage in a series of algorithmic challenges, from basic problem solving to mini-programming projects, while following a quest embedded in a story.

- *Algorithm Arena:* Students solve small C++ puzzles (e.g., loops, arrays) or write small C++ functions (e.g., sorting, search) in order to be allowed through the first gate. Immediate feedback is provided based on how correct their code is.
- *Data Pit*: Students will be tasked with debugging and optimizing a given code; by means of a testing engine, they will be provided with information about runtime and memory efficiency, aimed at improving their performance.

- *Simulation Core*: Students are asked to generate an economic simulation in Excel or C++ (be it an inventory model or a supply chain or production scenario) with checkpoint validation.
- *Leaderboard Lobby*: Students will compare their solutions and optimize the algorithms, cross referencing and learning from their peers; their scores and performance will be submitted on a leaderboard and ranked by correctness and efficiency criteria. Leaderboards are a recognized tool for encouraging friendly competition and mastery.

Completion of all stages awards the "Code Conqueror Medal", a token of proficiency and the possibility to attempt bonus coding challenges for additional points, encouraging autonomy and peer recognition. This design helps improve autonomy, mastery and social recognition (Fei Gao, 2025; Félix da Silva et al., 2024).

Gamification in Informatics strengthens computational thinking, highlights algorithmic elegance, and transforms coding into a playful exploration (Fei Gao, 2025; Félix da Silva et al., 2024).

3.5 Integrative Reflection

For gamification, the following conclusions apply to all 4 disciplines taken into account:

- It connects abstract concepts to a story or a tangible scenario.
- It gives the scene to engagement, autonomy and collaboration.
- It offers immediate feedback and boons of note.
- It leads to repeated practice, perfecting command, desire to explore, in a risk-free setup.

Blending playful examples and conceptual debate in a well-conceived frame turns quantitative disciplines into adventure and learning into an experience founded on inner motivation.

4. Discussion

Put under a responsible lens, gamified modules are key to turning quantitative disciplines learning into immersive experience, by ensuring the flow via appropriate finely tuned challenges, taking into account level of mastery, feedback, interactive story that all ensure the tasks stay memorable. Motivation and inclusivity are rooted in balanced rewards, competition and collaboration.

5. Limitations & Future Directions

Our conceptual approach needs the seal of continuous practice in order to assess its effects on learning, motivation and anxiety. Further experience and study should take into account tinkering with variety of rewards, scope and intensity of chosen narratives, ratio of collaboration vs competition modules or long-term engagement (Denoni-Buján et al., 2025; Issabek et al., 2025).

6. Conclusions

Our paper aims at providing a qualitative framework that improves the setup of interactive and motivated learning, while staying relevant, by means of blending concept focused probing and vivid examples (like Escape Room style mathematics challenges, resource allocation simulations, and leaderboard - driven programming contests). We found out that gamification is much more than a mere motivational tool, it is a bridge between abstract quantitative reasoning and practical applications, proving that, rather than a painful chore, complex formulas are an adventure. Gamification is more than just fun, it is a way to close the gap between abstract concepts and reasoning and practical, motivated education.

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The Role of AI in Optimizing Resource Management and Advancing Circular Economy Practices

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Abstract: *Growing global pressure on natural resources, driven by population growth, urbanization, and high consumption, is making the linear economic model increasingly unsustainable. The circular economy (CE) has emerged as a regenerative alternative aimed at keeping materials and products in use for longer, but large-scale adoption is still difficult because organizations struggle with fragmented data, weak monitoring systems, and limited predictive capability.*
This paper examines how Artificial Intelligence (AI) can help overcome these barriers by improving resource management and supporting more efficient circular practices. The study uses a structured literature synthesis and comparative case-study approach, drawing on peer-reviewed sources published between 2020 and 2025. These studies cover AI applications in manufacturing, energy systems, smart cities, start-ups, and social enterprises.
The findings show that AI is becoming a strategic enabler of circular transitions. Evidence across the reviewed cases demonstrates that AI improves recycling accuracy, enables predictive maintenance, and optimizes supply-chain and energy management. These capabilities reduce waste, support higher recovery of materials, and encourage new circular business models such as repair-and-reuse or product-as-a-service systems. Although improvements in European circular indicators, such as the Circular Material Use Rate (CMU%) and Resource Productivity (GDP/DMC), are still modest, they appear to align with the gradual adoption of AI technologies.
Overall, the paper argues that AI strengthens both the operational and institutional foundations of the circular economy, helping organizations move towards more sustainable and efficient resource use.

Keywords: *Artificial Intelligence; Circular Economy; Resource Optimization; Sustainable Business Models; Waste Reduction; Energy Efficiency; Digital Platforms*

JEL Classification: *Q01; Q53; Q55; O33; L23*
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1. Introduction

Global pressure on natural resources has increased quickly in recent decades, driven by industrialization, population growth, and rising consumption. This has resulted in higher emissions, resource depletion, and growing doubts about the long-term viability of the linear "take-make-dispose" model. Eurostat (2025) reports a slight drop in the EU's Domestic Material Consumption since 2020 and a rise in resource productivity to about 3 €/kg in 2024. Even so, material use per person remains high, and countries such as Romania still show low productivity levels, close to 1 €/kg, which means the shift toward sustainable resource management is still incomplete. Because of climate change and resource scarcity, sustainability has moved to the center of economic policy. OECD (2023) now includes environmental inputs, energy, land, and materials, in productivity assessments, reinforcing the need to decouple growth from resource use. This context explains the growing interest in the circular economy, which aims to keep materials in use for as long as possible. Yet real circularity remains limited: the EU's Circular Material Use Rate was only 11.8% in 2023 (Eurostat, 2025). Researchers like Bashynska and Prokopenko (2024) argue that scaling CE depends on strong technological support, especially for

managing large and complex data flows. Artificial Intelligence is becoming central to this shift. Studies show that AI can optimize material flows, improve recycling accuracy, reduce waste, and support predictive maintenance in industry (Jose et al., 2020; Oladapo et al., 2024; Snoun et al., 2025; Zavrazhnyi, 2024). Combined with digital platforms and IoT devices, AI also increases transparency across supply chains (Bashynska & Prokopenko, 2024). In this sense, AI acts as a key enabler of circular practices rather than just an additional tool.

This paper investigates AI as a strategic enabler for the CE, arguing it is essential for overcoming data barriers in resource management. Using a mixed-method approach covering 2020-2025, the study correlates rising AI adoption with improvements in CE indicators like the Circular Material Use Rate. It addresses three main questions:

1. How does AI influence resource productivity and circular material use?
2. Which AI applications most effectively reduce waste and improve efficiency?
3. How do EU data reflect the broader move toward AI-enabled circularity?

Key findings highlight that AI applications such as predictive maintenance and computer vision can boost recycling accuracy by over 80% and reduce industrial waste by 20-25%. The authors conclude that while regional progress varies, AI significantly strengthens the operational foundations required for sustainable resource decoupling.

2. Literature Review

2.1. Circular Economy and Resource Management

The circular economy has become a key idea in sustainability discussions because it challenges the old "take-make-dispose" model. Instead, it tries to keep materials and products in circulation for as long as possible through reuse, repair, remanufacturing, and recycling (Eurostat, 2025). At a broader level, CE aims to reduce material inputs while keeping economic output stable, basically trying to "decouple" growth from resource use. OECD (2023) supports this by including environmental inputs, like energy, land, and water, in productivity measures, showing that long-term growth depends on how efficiently resources are managed. Several authors add a business perspective. Bashynska and Prokopenko (2024) and Bossuwë (2023) argue that circularity requires new ways of thinking, where waste becomes a resource and products are treated more like services. Lodar-Miculeac et al. (2025) also stress the role of digital tools in making circular practices operational across supply chains. But, as their work and Oladapo et al. (2024) suggest, companies can't really achieve circularity without technologies that help them process complex data and make decisions faster, this is where Artificial Intelligence becomes essential.

2.2. AI in Material Efficiency, Recycling, and Waste Reduction

AI is now seen as one of the strongest enablers of circular practices. It offers predictive and analytical abilities that help reduce waste, optimize resource flows, and extend product lifetimes. Jose et al. (2020) showed that AI improves energy management by predicting consumption patterns. Oladapo et al. (2024) found that AI-supported industrial systems increased recycling efficiency by more than 80% and cut waste by around 20-25%. AI is also transforming waste management. Snoun et al. (2025) describe how computer vision can sort recyclable materials with much higher accuracy, while machine-learning models predict waste generation. These tools increase recovery rates and lower costs. Zavrazhnyi (2024) adds that AI-based predictive maintenance extends equipment life and reduces material consumption. When integrated with digital platforms and IoT technologies, AI creates what Bashynska and Prokopenko (2024) call "intelligent circular ecosystems," enabling companies and cities to monitor material flows in real time. Similar trends appear in urban systems as well, where AI supports smart waste collection and resource tracking (Jogarao & Naidu, 2024). Even at the entrepreneurial level, AI helps young businesses and students model resource cycles and test circular ideas (Keivanpour, 2024), making it a bridge between data and practical decision-making.

2.3. Indicators for Circular Performance

Circular performance is usually assessed through two indicators: the Circular Material Use Rate and Resource Productivity. CMU% measures how much secondary material re-enters the economy. In 2023 it reached 11.8% in the EU, while Romania stayed below 2% (Eurostat, 2025). This gap shows that different countries progress at very different speeds. Resource Productivity looks at how much economic value is produced per kilogram of material used. Eurostat (2025) reports that EU productivity rose to about 3 €/kg in 2024, whereas Romania remains near 1 €/kg. OECD's (2023) environmentally adjusted productivity indicators also show the importance of considering resources and ecosystem services in economic performance. These indicators matter for this study because they help identify whether AI-enabled systems contribute to improved efficiency, as suggested by Lodar-Miculeac et al. (2025) and Oladapo et al. (2024).

2.4. Knowledge Gaps and Research Rationale

Although research on AI and CE has expanded quickly, several gaps remain. Hernandez et al. (2025) note that many studies focus on specific technologies, like waste sorting, without looking at their broader impact on national indicators such as CMU% or GDP/DMC. Much research is also sector-based, covering manufacturing, energy, or waste separately (Jose et al., 2020; Snoun et al., 2025; Oladapo et al., 2024), but fewer studies look at cross-sector systems where AI connects different stages of resource use. Another issue is that small and medium-sized firms often lack the skills or resources to adopt AI effectively (Bossuwë, 2023; Redko, 2024). Finally, current indicators measure outcomes but don't directly show how AI contributes to those results. Bridging this gap requires combining statistical trends with real-world evidence from digital and AI-enabled practices (Lodar-Miculeac et al., 2025; Zavrazhnyi, 2024). For these reasons, this paper aims to better understand how AI supports resource optimization and how these improvements appear in both quantitative data and day-to-day operations.

3. Methodology

This study uses a mixed-method design, combining quantitative indicators with a qualitative review of recent research. The aim was to assess not only measurable progress in circular economy performance, but also the ways in which Artificial Intelligence supports this progress in practice. The analysis focuses on 2020-2025, a period marked by stronger CE commitments in Europe and a noticeable rise in AI adoption. The quantitative component relies on official datasets from Eurostat (2025) and OECD (2023), which provide comparable data on material efficiency, resource productivity, and circular material use for EU member states, including Romania. The qualitative component reviews peer-reviewed studies, such as Bashynska and Prokopenko (2024), Jose et al. (2020), Oladapo et al. (2024), and Lodar-Miculeac et al. (2025), that document practical applications of AI in manufacturing, energy systems, waste management, and supply chains. The goal was to identify whether the improvements described in the literature align with shifts seen in the indicators.

The analysis is not intended to establish strict causality but to explore whether AI adoption tends to move alongside improvements in CE outcomes. Three indicators guide the framework:

4. Circular Material Use Rate (CMU%), which reached 11.8% in the EU in 2023 and remained below 2% in Romania (Eurostat, 2025).
5. Resource Productivity (GDP/DMC), which rose to about 3 €/kg in the EU and remained near 1 €/kg in Romania (Eurostat, 2025).
6. AI Maturity in Circular Applications, a qualitative measure informed by WEF and Accenture (2023) and studies reporting 20-25% efficiency gains linked to AI adoption.

All data were taken from institutional or peer-reviewed sources and standardized into simple time-series trends for 2020-2024. The analytical process involved comparing EU and Romanian patterns, integrating insights from OECD, UNEP, and WEF reports, and linking these trends with evidence from recent AI-CE case studies. Several limitations should be noted. Eurostat values for 2025 are provisional, and causation cannot be confirmed because CE outcomes depend on broader policy and market conditions. AI maturity is also assessed qualitatively, as no harmonized EU-wide metric exists. Even

with these limits, the approach provides a balanced picture of how AI contributes to CE progress by connecting quantitative indicators with real-world technological evidence.

4. Results

Eurostat data show modest but steady gains in Europe's circular performance, with CMU% rising from 11.5% to 11.8% and resource productivity reaching about 3 €/kg in 2024 (Eurostat, 2025), while countries like Romania remain far lower, near 1 €/kg. These trends appear to align with early digitalization and AI adoption. The literature consistently shows that AI stabilizes energy demand (Jose et al., 2020), cuts industrial waste by 20-25% and raises recycling efficiency above 80% (Oladapo et al., 2024), improves waste-sorting accuracy through computer vision (Snoun et al., 2025), and supports predictive maintenance and supply-chain optimization (Zavrazhnyi, 2024; Lodar-Miculeac et al., 2025). Case studies highlight similar benefits across manufacturing, logistics, and urban systems, including smarter waste collection and municipal sorting accuracy above 90% (Jogarao & Naidu, 2024; Snoun et al., 2025). Social enterprises also use AI to create value from waste (Redko, 2024; Bossuwë, 2023). Countries and firms with higher AI maturity perform better on circular metrics, as shown by Bashynska and Prokopenko (2024) and the World Economic Forum (2023), with advanced adopters reporting up to 15-20% reductions in material use (Lodar-Miculeac et al., 2025). Overall, the evidence suggests that AI has quietly become an important driver of Europe's gradual circular progress.

5. Discussion

AI is starting to support Europe's circular economy, although progress is still modest: CMU% rose to 11.8% and resource productivity reached about 3 €/kg in 2024 (Eurostat, 2025). Studies show that AI improves material tracking, cuts waste, and raises recycling efficiency, with sorting accuracy often above 90% (Oladapo et al., 2024; Snoun et al., 2025). Countries with stronger digital capacity, such as the Netherlands and Belgium, perform far better than Romania, suggesting that digital readiness and CE outcomes move together. AI-enabled tools, including predictive analytics, machine learning, and digital twins, help extend product lifecycles, reduce material use, and support cleaner energy systems (Zavrazhnyi, 2024; Jose et al., 2020; Lodar-Miculeac et al., 2025). Challenges such as fragmented data, energy demands, and limited SME capacity remain, but overall evidence points to AI as a key enabler of circularity.

6. Conclusions

The study shows that Artificial Intelligence is becoming an effective enabler of the circular economy. Research such as Raut et al. (2025), Oladapo et al. (2024), and Lodar-Miculeac et al. (2025) demonstrates that AI tools, including machine learning, predictive analytics, and digital twins, improve material efficiency, recycling accuracy, and supply-chain transparency. Eurostat (2025) and OECD (2023) data also indicate gradual progress: EU CMU% rose from 11.5% to 11.8%, and resource productivity reached about 3 €/kg in 2024, suggesting early signs of decoupling. Policymakers should integrate AI into CE strategies by improving data standards, shared digital systems, and AI-based monitoring tools (Bashynska & Prokopenko, 2024). Managers can use predictive maintenance, advanced sorting, and digital-twin systems to reduce waste and cut costs (Zavrazhnyi, 2024; Snoun et al., 2025). The study links AI maturity with stronger circular outcomes, showing that CE increasingly depends on data-driven processes rather than only physical resource flows. Practical applications, from waste recognition to predictive maintenance, already demonstrate this shift.

Future research should develop clearer metrics that capture AI's direct contribution to CE performance, strengthen interoperable data systems (Raut et al., 2025), and examine both the socio-economic impacts and the energy footprint of AI (Jose et al., 2020; Oladapo et al., 2024).

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Artificial Intelligence Challenges in Business: Tax Profiles and Regulatory Perspectives

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Abstract: *This paper investigates the challenges that artificial intelligence (AI) introduces to modern tax systems and regulatory frameworks. The study analyses how the rise of algorithmic processes, data-driven value creation and autonomous systems transforms the traditional legal categories on which taxation relies, such as physical presence, human labour, and identifiable assets. It identifies three main areas of disruption: the definition of the taxable event, the attribution of income from AI-driven processes, and the valuation and allocation of intangibles linked to AI systems. Drawing on international tax principles and current supranational initiatives—particularly the OECD/G20 BEPS 2.0 project—the paper highlights the increasing mismatch between territorial tax concepts and the borderless nature of digital and AI-based business models. The discussion emphasises the need for structural reform of tax systems to ensure fairness, efficiency, and legal certainty in the algorithmic economy. The findings suggest that a new global approach is necessary, one that combines adaptive governance, transparency, and international cooperation to prevent base erosion, protect taxpayer rights, and support technological innovation.*

Keywords: Artificial Intelligence; Tax Law; Algorithmic Economy; BEPS; Digitalisation
JEL Classification:H26; K34; O33; F23; M48

1. Introduction

Artificial intelligence (AI) is profoundly transforming how economic activities are organized and conducted. What was once the domain of human labour is increasingly taken over or assisted by algorithmic processes, automated decision-making, and networked infrastructures. In business models rooted in data, algorithms, cloud platforms and digital services, production, distribution and consumption take on dematerialised, global and fluid characters. In this evolving landscape, tax law—traditionally anchored on clear legal categories such as physical presence, human labour, territorial nexus, and identifiable assets—faces a structural shift in the underlying economic paradigm.
In particular, the emergence of AI in business gives rise to a set of theoretical and practical challenges that demand a rethinking of the legal categories upon which taxation is based, especially in the international domain. This article explores three main dimensions: (i) the taxable event (objective and subjective), (ii) attribution of income from algorithmic/AI systems, and (iii) valuation and allocation of intangibles tied to AI. It then analyses the use of AI by tax administrations themselves, the implications for taxpayer rights, and the supranational regulatory initiatives (notably the OECD/G20 "BEPS 2.0" process). Finally, it reflects on the need for structural reform of the tax system in view of the algorithmic economy, balancing equity, efficiency and legal certainty.
Recent international tax reforms already acknowledge that highly digitalised business models can create value in a jurisdiction without physical presence. In particular, the OECD/G20 Inclusive Framework on BEPS, through Pillar One, introduces a new concept of "Amount A" aimed at reallocating taxing rights over residual profits of large digitalised and consumer-facing enterprises, thereby partially detaching nexus from physical presence. Although not designed specifically for AI, this reform implicitly targets business models driven by algorithms, platforms and data-intensive processes, which are increasingly powered by artificial intelligence.

1.1 Methodology and analytical framework

This study adopts a doctrinal and analytical mapping methodology. It does not rely on econometric modelling or empirical tax-return data, but instead systematically analyses the interaction between artificial intelligence and international tax law through three steps.

First, a selection of primary legal and policy sources was conducted, focusing on (i) OECD instruments (Model Tax Convention, Transfer Pricing Guidelines, BEPS 1.0 and BEPS 2.0 reports), (ii) European Union legal and policy documents on digitalisation and artificial intelligence in tax administration, and (iii) leading academic contributions on AI and taxation. The temporal scope of the analysis covers the period 2017–2024, corresponding to the emergence of both large-scale AI deployment in business and the development of the BEPS 2.0 framework.

Second, these materials were examined to identify recurring legal frictions between AI-driven business models and existing tax concepts. Through this comparative reading, three main clusters of disruption were derived: (a) the definition of the taxable event and nexus, (b) the attribution of income and taxpayer identity, and (c) the valuation and allocation of AI-related intangibles. These three clusters form the paper's "three-part disruption taxonomy".

Third, the paper applies this taxonomy to both private-sector business models and public-sector tax administration, in order to evaluate not only how AI reshapes taxable capacity but also how it transforms enforcement, compliance and taxpayer rights. This combined approach allows the study to connect normative tax rules, administrative practice and technological change within a single analytical framework.

2. Taxable Event in the AI Economy

In traditional tax systems, the taxable event (for instance, the generation of business profits) is often concretely connected to human activity, physical presence, factors of production located in a jurisdiction, or identifiable assets in use. With AI, several structural changes intervene:

- Production factors become dematerialised: data, algorithms, cloud infrastructures, digital services replacing or complementing machines and labour.
- Infrastructures and digital platforms may be located in different jurisdictions or even "virtual", with servers distributed, or operations executed via networked autonomous systems.
- Decision-making autonomy of AI (algorithms) means economic activities can be carried out with fewer or no humans continuously intervening.

  These features challenge the traditional territorial and human-centred criteria of tax jurisdiction. For example, a business may generate value in a country through AI-driven services, without a physical presence or personnel in that country. The cornerstone of international taxation — the concept of a "permanent establishment" under Article 5 of the OECD Model Tax Convention — may no longer capture such scenarios.

The criterion of permanent establishment (PE) presupposes a fixed place of business, human presence, or agent acting on behalf of the enterprise. AI-driven business models raise questions such as: can a cluster of servers, a distributed algorithm or a network of autonomous agents constitute a "place of business"? Can the mere provision of digital services, or algorithmically-managed platforms, trigger a taxable nexus? Some commentators talk of "virtual permanent establishments" or "decentralised servers" as emerging models that challenge the source State's ability to tax. The difficulty lies in mapping taxable events onto existing nexus thresholds. From a subjective perspective (who is the taxpayer?), the challenge becomes even more acute: when the economic activity is executed by an intelligent system, is the business (legal person) liable, or should the algorithm itself in some sense be attributed? At present, legal systems do not recognise autonomous systems as taxpayers. Therefore the conventional scaffolding of taxpayer identity becomes strained.

For businesses operating in a global, AI-enabled environment, this raises multiple tax risks and uncertainties:

- unclear whether and how profits generated by AI services in a given country will be taxed there;
- risk of double non-taxation (neither home State nor source State taxes) due to mismatches or gaps in nexus rules;
- planning opportunities: enterprises may design operations so that algorithmic value-creation occurs in low-tax jurisdictions or jurisdictions with weak nexus rules;

- compliance burdens: businesses must monitor evolving tax rules, ensure proper documentation of where value is created, and assess whether they are liable for tax in jurisdictions where they may lack physical presence.

The OECD has acknowledged this misalignment by recognising that highly digitalised business models may have a "significant economic presence" in a jurisdiction without any physical footprint, a premise that underlies the new nexus rules introduced under BEPS 2.0, Pillar One.

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Illustrative scenario 1 – AI as a service with distributed servers

A company incorporated in State A provides AI-powered credit-scoring services to banks in State B. The algorithm is hosted on cloud servers located across States C and D, while no employees are present in State B. Under traditional PE rules, the company may have no taxable presence in State B, despite generating significant revenue from local clients. Under the BEPS 2.0 Pillar One approach, however, a portion of residual profits could be reallocated to State B based on sales, partially overcoming this nexus gap. From a subjective perspective (who is the taxpayer?), the challenge becomes even more acute: when the economic activity is executed by an intelligent system, is the business (legal person) liable, or should the algorithm itself in some sense be attributed? At present, legal systems do not recognise autonomous systems as taxpayers. Therefore the conventional scaffolding of taxpayer identity becomes strained.

Illustrative scenario 2 – Training and deployment in different jurisdictions.

A multinational enterprise trains a large machine-learning model using data and engineers located in State X. The trained model is then deployed on a platform operated in State Y, which sells AI-driven services to customers worldwide. Profits are booked in a low-tax subsidiary in State Z that formally owns the intellectual property. This structure raises difficult questions of where the taxable event actually occurs: where the model was trained, where it is operated, where users are located, or where the IP is legally held.

- for businesses operating in a global, AI-enabled environment, this raises multiple tax risks and uncertainties:
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- risk of double non-taxation (neither home State nor source State taxes) due to mismatches or gaps in nexus rules;
- planning opportunities: enterprises may design operations so that algorithmic value-creation occurs in low-tax jurisdictions or jurisdictions with weak nexus rules;
- compliance burdens: businesses must monitor evolving tax rules, ensure proper documentation of where value is created, and assess whether they are liable for tax in jurisdictions where they may lack physical presence.

These risks are precisely those that BEPS 2.0 seeks to mitigate by reallocating taxing rights and by introducing a global minimum tax under Pillar Two, although neither pillar fully resolves the specificities of AI-driven value creation.

3. Attribution of Income and the Autonomy of Intelligent Systems

A further challenge is the attribution of income generated through AI-based processes. The question "who should be considered the taxpayer when income is derived from an economic process entirely managed by AI?" is largely unanswered in current tax jurisprudence and administrative practice.

When business models rely on machine learning models, autonomous agents, algorithmic decision-making (such as dynamic pricing, predictive supply-chain management or autonomous platforms), the

human oversight may be minimal and intermittent. The value-creation process may be embedded in the algorithm rather than in direct human inputs. This raises questions:

- if the algorithm makes decisions, executes trades or manages assets without human intervention, who receives the income? The legal entity owning the algorithm? The entity designing/training the model?
- should the algorithm itself arguably be considered as performing economic activity? (Legal systems currently do not treat AI agents as autonomous legal persons or taxpayers, but the notion poses theoretical reflection).
- How to trace the chain of value creation when multiple entities (data suppliers, model-trainers, platform operators) contribute to the algorithmic ecosystem?

From the perspective of international tax law, these questions must be resolved within the existing framework of legal personhood and ownership of assets, as reaffirmed by the OECD Transfer Pricing Guidelines. Even where decision-making is automated, profits must still be attributed to the legal entity that controls the economically significant risks and owns or has the right to exploit the relevant intangible assets, including algorithms and trained models.

3.1. Implications for Multinational Enterprises

Multinational enterprises (MNEs) face significant issues of transfer pricing and profit allocation when AI systems cross borders and contribute to value creation globally. Traditional transfer pricing relies on correctly identifying functions, assets and risks—and attributing returns accordingly under the arm's length principle. When the intangible asset is an algorithm or a trained model, some challenges arise:

- Identifying comparable transactions is difficult because AI-driven models are unique, rapidly evolving and often kept confidential.
- How to allocate returns between jurisdictions when the algorithm is trained in one location, hosted in another, and deployed on a platform in a third?
- How to identify and price the contribution of data, model training, iteration and operational autonomy in value creation?

The OECD Transfer Pricing Guidelines (2022) already recognise that hard-to-value intangibles and unique intangibles require a careful analysis of where DEMPE functions (Development, Enhancement, Maintenance, Protection and Exploitation) are performed. In the AI context, DEMPE functions may be split across jurisdictions: data collection in one State, model training in another, and commercial exploitation on a global digital platform.

3.2 Challenges in Transfer Pricing and Arm's Length Principle

Under many jurisdictions (for example, Article 110(7) of the Italian Income Tax Code, which addresses intra-group services and risk allocation), the arm's length principle remains foundational for allocating profits in multinational contexts. But AI-related intangibles offer several complications:

- scarcity of reliable comparables: AI models are frequently bespoke, making benchmarking harder;
- Volatility and rapid obsolescence: The value of an algorithm can change quickly due to technological advances or competitive disruption;
- Data contribution difficulties: Data may be sourced globally, cleaned, labelled and used in model-training; attributing value to data vs. model vs. deployment is complex;
- Licensing and royalty flows: Multinationals may allocate intellectual-property rights to subsidiaries in low-tax jurisdictions and charge royalties for use of AI assets. Tax authorities face difficulty in challenging these arrangements when the substance is dispersed.

These structures are directly addressed by the OECD's guidance on profit allocation for intangibles, which requires tax authorities to look beyond contractual ownership and identify where control over risks and strategic decision-making related to the AI system are actually exercised. In AI-driven business

models, this control may lie with the entity that determines how the model is trained, updated and commercially deployed, rather than with the entity that merely holds the legal IP.

3.3 Tax Planning, Base Erosion and Profit Shifting (BEPS)

The combination of intangible-heavy business models, digital platforms and algorithmic distribution of value increases the risk of base erosion and profit shifting. Businesses can locate intangible development in favourable jurisdictions, host digital platforms in minimal-tax countries, and serve customers globally without physical presence. From an enforcement perspective, tax authorities contend with reduced transparency, complex value chains and evolving business models. This heightens the need for effective control techniques by tax administrations.

These dynamics explain why the OECD/G20 BEPS project identifies digitalisation and intangibles as key drivers of profit shifting. In AI-intensive groups, the gap between where value is economically created and where profits are booked can be particularly wide, making AI a new vector for BEPS strategies unless countered by coordinated international rules.

4. Tax Administration, AI and Taxpayer Rights

Tax administrations themselves are increasingly adopting AI, machine learning and data-analytics tools. The OECD report *Governing with Artificial Intelligence: The State of Play and Way Forward in Core Government Functions* highlights that tax administrations use AI for risk-selection, audit targeting, service-delivery automation and fraud detection.

However, this use raises critical issues:

- Data protection and privacy: tax administrations access large volumes of sensitive personal and business data; governance frameworks must ensure confidentiality and compliance with standards such as the General Data Protection Regulation (GDPR).
- Transparency, explainability and trust: Taxpayers must have the right to challenge decisions, understand the basis of assessments, and rely on accountable procedures. The “black box” nature of many AI/ML systems challenges this requirement.
- Skills, cost and infrastructure: Deploying AI effectively demands high-quality data, investment, governance, and professional skills—barriers for many administrations.
- Risk of bias and unfair outcomes: Poorly trained models, skewed data or opaque criteria may lead to improper auditing, unfair targeting of taxpayers or erosion of trust.

These risks have been explicitly acknowledged by the OECD, which stresses that the use of AI in tax administration must respect due process, proportionality and accountability, especially when algorithmic tools influence audit selection or tax assessments.

In this evolving environment, protecting taxpayer rights remains critical. Some key principles:

- legal certainty: taxpayers must be sure of the tax obligations and the basis on which tax authorities act. The absence of specific rules for AI-driven economic activity undermines this.
- right to reasoned decisions: if AI systems influence tax assessments, taxpayers must have access to “human in the loop” decisions, explanations and the possibility of appeal.
- data protection and fairness: personal data must be handled under appropriate safeguards; algorithmic decision-making should avoid bias, discrimination or unfair treatment.
- transparency of audits and risk-profiling frameworks: tax authorities should disclose the criteria for selecting cases, providing fairness and avoiding arbitrary targeting.

These principles are reinforced at EU level by the GDPR and by the emerging framework of the EU Artificial Intelligence Act, which classifies certain uses of AI in public administration, including tax enforcement, as “high-risk” and subjects them to strict requirements of transparency, human oversight and accountability.

5. Supranational Initiatives and the Digital/AI Economy

The international tax architecture is adjusting to the digital economy through the BEPS 2.0 process led by the OECD and G20. The two-pillar approach aims to adapt taxation to digitalised and globalised business models:

- Pillar One seeks to introduce new nexus and profit allocation rules for highly digitalised businesses, moving beyond the requirement of physical presence.
- Pillar Two proposes a global minimum tax to counter harmful tax competition and profit-shifting.

While neither pillar is explicitly tailored to AI alone, they address business models that heavily rely on AI, platforms and data-driven value creation.

Although neither pillar is explicitly designed for AI alone, both directly affect AI-driven business models, where algorithms, platforms, and data-intensive processes generate value across multiple jurisdictions without human presence. Pillar One's "Amount A" reallocates a portion of residual profits to jurisdictions where consumers are located, which implicitly captures AI-generated value.

For example, an AI-driven recommendation engine deployed globally may generate revenue from users in multiple States. While the legal ownership of the algorithm may reside in State X, Pillar One allows part of the profits to be reallocated to States Y and Z where the customers are located, partially addressing the mismatch between traditional nexus rules and algorithmic value creation. These initiatives signal recognition that the taxable capacity of source States and attribution of profits must evolve in line with digital-economy realities. Despite these advances, a coherent normative framework specifically addressing algorithmic/AI-driven value creation is still missing.

Some key gaps:

- clear definition of what constitutes algorithmic value-creation and where it is "generated" for tax purposes;
- specific rules on attribution of income from autonomous systems, including risk and reward allocation when human oversight is minimal;
- valuation rules and comparables for AI-intangible assets, given their novelty and rapid evolution;
- harmonised standards for transparency, data governance and cross-border algorithmic value flows.

Therefore, although BEPS 2.0 contributes to the digital economy revision, a dedicated AI-tax framework is yet to emerge.

6. Toward Structural Reform: Vision for the Future

Given the scale of the transformations currently underway, tax systems can no longer rely on small, incremental adjustments to rules that were designed for a very different era. What is required instead is a structural reform grounded in a long-term vision capable of balancing tax equity, system efficiency, and legal sustainability within an increasingly algorithm-driven economy. Such a reform should focus on three key areas. First, it should redefine the concept of taxable presence, moving beyond physical location to capture the value created through data, algorithms, and autonomous systems. Second, it should establish clear rules for the attribution of profits, integrating AI-related intangibles, DEMPE functions, and the allocation of risks in accordance with the OECD Transfer Pricing Guidelines. Third, it should provide robust methodologies for valuing AI-related intangibles, including hard-to-value assets, real-time model iteration, and the effects of network externalities.

Several reform options could be considered. One approach would be to introduce AI-specific nexus rules, explicitly defining taxable presence based on value creation through AI and implementing reallocation rules similar to those proposed under Pillar One. Another option would be to develop a unified framework for AI intangibles, aligned with OECD guidance, to standardize the treatment of DEMPE functions and valuation of AI models and data across borders. A further complementary measure would be to enhance taxpayer protection and transparency by establishing binding EU and OECD standards for human oversight, audit explainability, and data governance in AI-driven taxation.

Implementing such reforms inevitably involves trade-offs. Policymakers must balance legal certainty and flexibility, recognizing that overly rigid rules may stifle innovation, while excessive discretion could lead to inconsistent taxation. At the same time, the administrative burden of monitoring AI-generated value across multiple jurisdictions must be weighed against fairness and compliance costs for both businesses and governments. Moreover, reforms should seek to reconcile incentives for innovation with the need to prevent base erosion and profit shifting, ensuring a fair allocation of profits without discouraging investment in AI technologies.

Empirical validation of AI value creation remains limited, legal frameworks may lag behind technological advances, and cross-border coordination is still incomplete. Future research should therefore focus on case studies, developing AI valuation models, and examining the real-world implementation of Pillars One and Two in sectors that rely heavily on artificial intelligence.

7. Conclusion

The integration of artificial intelligence into business models presents profound challenges for contemporary tax law. The transformation is not merely technological, but structural: it transcends traditional categories of production, human labour, location and assets.

To respond effectively, policymakers and tax authorities must adopt a multi-layered, actionable approach**:**

1. apply revised nexus rules and profit reallocation frameworks reflecting AI-generated value.
2. implement OECD-compliant transfer pricing and DEMPE guidance for AI intangibles.
3. ensure robust taxpayer rights and audit transparency, using EU and OECD AI governance principles

Only through such an integrated approach can a tax system regulate the algorithmic economy effectively, safeguarding public interests, competitiveness, and taxpayer rights.

In summary, the paper provides both a diagnosis of AI-related tax challenges and a roadmap for actionable reforms, combining international coordination, structural rule adaptation, and strengthened governance. By implementing these measures, tax systems can remain fair, efficient, and legally certain, even as AI continues to reshape economic activity globally.

Tax law must now engage with changes that reflect value-creation in a dematerialised, algorithmic, networked economy. The responses cannot be mere technical tweaks or piecemeal reforms; what is required is a coherent, forward-looking framework—international in scope and multidisciplinary in approach—that reconciles tax equity, system efficiency and legal certainty.

Only through such an integrated approach can a tax system be built that is capable of regulating the algorithmic economy effectively, while simultaneously safeguarding public interests, competitiveness and taxpayer rights. As AI continues to evolve and embed itself into economic life, tax law must not lag behind. In the words of the OECD, as AI becomes a “core government function” and business model input, the challenge for both tax administrations and taxpayers is to ensure that the rules of the game remain fair, intelligible and sustainable.

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Taxation in the Digital Era: Challenges and Prospects for Greece

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Abstract: *The transition to the digital economy and the emergence of new business models pose significant challenges for traditional tax systems. In the case of Greece, where a com plex and unstable tax framework prevails, the need for adaptation to the new techno logical and economic conditions shaped by the platform economy and dynamic innovation ecosystems is becoming increasingly evident. This article examines the extent to which the existing Greek tax system either facilitates or hinders economic growth in the context of digital transformation. Through data analysis and a comparative review of international practices, the effectiveness of current tax policies, the competitiveness of the tax base and the potential use of digital tools to enhance transparency and tax compliance are assessed. Based on these findings, an adaptive framework for tax reform is proposed, specifically tailored to the needs of the Greek economy, with the aim of enhancing innovation, broadening the tax base and ensuring sustainable growth. The study seeks to contribute scientifically to the ongoing dialogue on the formation of a modern, functional and supportive tax environment in the digital era.*

Keywords: *Digital Economy, Economic Growth, Greece, Tax Policy, Reforms.*

JEL Classification: *F6; H2; K1; M4*

1. Introduction

A key feature of today's era is the rapid digital transformation, which contributes to the radical change of the economy, creating new forms of entrepreneurship and overturning traditional institutional and regulatory frameworks.
Taxation is a key pillar of economic policy and is called upon to adapt to this new environment, with a view to ensuring the balance between innovation, competitiveness and tax justice. In particular, in the case of Greece, whose current tax system is characterized by complexity and instability, the challenge is twofold: on the one hand, the integration of new technological data and on the other hand, the creation of a more effective, transparent and development-friendly framework.
The purpose of this article is to present the basic conceptual framework and dimensions of the digital economy, as well as the problems arising from its operation, such as tax deregulation and the unequal distribution of benefits. At the same time, the policies adopted by the European Union to address these challenges are analyzed, with particular emphasis on the case of Greece. The country's position is assessed in comparison with other European countries, in terms of digital readiness and the implementation of relevant policies.
Finally, a series of policy interventions are proposed, aiming to strengthen the country's digital convergence with the rest of Europe.

2. Literature Review

Since the early 1990s, the global economy has been in a constant transition towards a new model, which is widely recognized as the digital economy. The earliest definitions focused on the Internet, which, since the early 1990s, has emerged as a key driver of technological progress, especially in the developed countries of the global North. Thus, initially, the term digital economy primarily referred to the recent and largely unrealized changes taking place in various sectors through the digitization of data, with the computer serving as an essential tool (Luyanda Dube Williams, 2022).

In this article, the aim is to present definitions of the digital economy that are as specific and clearly delineated as possible. The first to define the concept of the digital economy was Don Tapscott, in 1995, in his book entitled <<The Digital Economy: Promise and Peril in the Age of Networked Intelligence>>. According to Tapscott, the Internet and the World Wide Web contribute to the development of a new economy grounded in human intelligence. Subsequently, other definitions of the concept emerged. In early literature, the digital economy was described as an electronic commerce infrastructure representing the entire segment of the economic system used to support both electronic business processes and e-business more broadly (F. Daoud, 2000).

In 2007, the digital economy was defined as the extensive use of technology and information technology (e.g. hardware, software, applications) and telecommunications and their impact on all aspects of the economy (Atkinson, R.D., McKay, A.S., 2007). The literature also describes the digital economy as an economy whose functioning is supported primarily through electronic transactions conducted via the Internet (L. Belova, 2021). More recently, the digital economy has been defined as an economy that uses information technology to create, adapt, market, and consume goods and services based on digital technologies, with the ultimate goal of generating profit (Nguyen O., 2023).

Finally, the literature highlights that measuring the digital economy presents significant challenges, such as the ambiguity of its boundaries, the difficulties in valuing and pricing digital goods and services, the low quality of available data, and the limited visibility of many digitized activities in official statistical records (Luyanda Dube Williams, 2022).

3 Taxation of the Digital Economy in the EU over the years

The rapid development of the digital economy in the European Union has raised critical issues regarding the current tax systems of its countries. Thus, the Presidency of the Council, in cooperation with the President of the European Council and the European Commission, organised the first-ever Tallinn Digital Summit on 29 September 2017.

The purpose of this Summit was to formally launch discussions on plans for digital innovation, so that the European Union can be a pioneer in technological developments and manage to become the global leader in the digital space in the coming years. The main conclusion of the European Council, following the requests of the EU leaders, on the taxation of the digital economy was the creation of an effective and fair tax regime, adapted to the needs of the digital age. The Council stressed the urgent need to reach an agreement at international level on a common policy response to ensure that companies pay their fair share of tax. It also underlined the importance of ensuring a level playing field at global level, in the context of the ongoing work of the OECD.

A landmark year could be 2018, when the European Commission proposed new rules on the taxation of the digital economy, aimed at achieving fair taxation and promoting growth. However, these proposals are now on hold, due to the progress made in international negotiations within the OECD/G20. If a comprehensive solution and agreement is reached in these negotiations and effective implementation is achieved, then these proposals will be obsolete.

As regards the content of the 2018 digital tax package, it included two legislative proposals with a dual purpose. The first was to reform corporate taxation rules so that profits are taxed in the place where companies have a significant digital presence. The second was to introduce a temporary tax on revenues arising from the provision of digital services (digital services tax).

Given that the taxation of the digital economy in the EU is part of the EU's tax policy, cooperation between Member States is essential, mainly through the exchange of tax information.

Furthermore, the digitalisation of the economy creates new difficulties, as national tax authorities do not always have access to information on income or revenue from digital activities. To address this problem, and following international standards, the EU is expanding the rules on cooperation between Member States through specific changes to the Directive on Administrative Cooperation in Taxation (DAC).

More specifically, in March 2021 the Council adopted new rules (DAC7) under which, from 2023 onwards, EU national tax authorities will automatically exchange information on income from professional activity on digital platforms.

In this way, on the one hand, tax evasion and tax avoidance in the operation of digital platforms will be prevented and, on the other hand, tax justice will be strengthened and a level playing field will be ensured, both for the platforms themselves and for the users/sellers operating on them.

2023 is the year in which the Council will proceed with the amendment of the current DAC8 in order to strengthen the framework for cooperation between tax administrations and to broaden the scope of registration and reporting obligations. More specifically, points were amended regarding the way of informing and automatically exchanging information related to income from transactions in cryptocurrencies and the exchange of information on tax rulings for the wealthiest (high net worth) individuals. The necessity of these amendments was great, as until then the tax administrations of the Member States could not ensure tax compliance in this area.
The last amendment to the ITC rules was made on 14 April 2025 by the Council. The new rules DAC9 were adopted with the aim of promoting cooperation and improving the exchange of information related to the minimum effective taxation of companies. In essence, these new rules together contribute to the creation of a single standard form with which both multinational groups of companies and large domestic groups will have to fulfil their reporting obligations under the second pillar directive, which implements the G20/OECD global agreement. This will facilitate the exchange of data between tax authorities while minimising the administrative burden on businesses. Finally, Member States are required to transpose the DAC9 into their national law by 31 December 2025.

4. Taxation of the Digital Economy in the EU today

A. Minimum corporate taxation

The establishment of laws and rules in the European Union on corporate taxation is inextricably linked to the ongoing efforts to tax the digital economy, led by the G20 and the OECD. This work is mainly carried out by the OECD/G20 Inclusive Framework on Base Erosion and Profit Shifting (BEPS). The milestone date is 8 October 2021, when this Framework reached an agreement on the key aspects of a major reform of the international rules on the taxation of the profits of multinational enterprises. This agreement is included in the so-called "OECD/G20 BEPS Framework Declaration" of October 2021 and proposes a solution to two key points for managing tax challenges arising from the digitalization of the economy. In essence, the ultimate goal of this cooperation is to identify a long-term global solution to today's tax challenges, and the EU is also helping in this. This international tax reform focuses on two pillars, the first concerning the redistribution of taxing rights and the second relating to minimum effective taxation. More specifically, the first pillar includes a set of rules and regulations that will contribute to the redistribution of taxing rights between jurisdictions where the largest and most profitable multinational groups have their market share and make profits. The main product that will emerge under the first pillar is a multilateral agreement, which will serve as a basis for the contracting parties to exercise or even "redistribute" a new taxing right ("Amount A"). This agreement will contain a wide range of rules that will cover issues such as scope, connecting factor, tax base, as well as mechanisms for the elimination of double taxation, the prevention and resolution of disputes, the abolition or suspension of unilateral measures (such as national digital taxes), and the entry into force of the agreement. In addition, "B" of the first pillar aims to enhance tax certainty by establishing standardised transfer pricing benchmarks for common forms of transactions. As for the second pillar, it contains a set of rules that ensure the minimum effective taxation of the largest multinational groups, with the main aim of limiting opportunities for base erosion and profit shifting. It is primarily intended to ensure the payment of the agreed global minimum corporate tax rate (15%). It is important to mention that the work on the second pillar has progressed significantly faster than that on the first. A key element of this pillar is the minimum effective taxation, which is based on the two global standard rules against base erosion (GloBE rules). More specifically, the first of these is the income inclusion rule (IIR rule) and the second is the one on payments subject to reduced taxation (UTPR rule). In conclusion, the reason for the existence of these rules is to ensure that the profits of multinational groups with a turnover of at least 750 million euros will be taxed at an effective rate of at least 15%.
The EU VAT Regulation acts as a guiding framework, providing Member States with the necessary tools for cooperation and exchange of information on VAT, thus strengthening the effective management of VAT at cross-border level.

Based on the new data and the rapid development of the digital economy, the EU is called upon to proceed with radical changes concerning the VAT regulation. Thus, the Council of the EU approved a

series of legislative measures for both the modernisation and the digitalisation of the VAT system. The ultimate aim of these changes is to simplify tax procedures, improve the efficiency of the VAT system in general and finally strengthen the mechanisms against tax evasion and tax avoidance.
By 2035, the EU plans to introduce a fully digital system for submitting VAT data in real time and at the same time expand the "points of single contact" to simplify VAT registrations for businesses in various Member States.
It is worth noting that on 11 March 2025, the final package of measures "VAT in the digital age" was approved. The one-stop shop for VAT registration is therefore proposed. This service now gives businesses the right to declare and pay VAT for cross-border sales within the EU from a single Member State and in a single language. In the event that a company wishes to conclude sales to consumers outside its country of establishment, then the company must register for VAT in these additional Member States. Traders who only wish to transport and/or store stocks in another Member State have the same obligation.
In the same context, on 13 May 2025 the Council is proceeding with the adoption of a new directive on VAT rules for distance sales of imported goods and VAT on imports. Based on this, foreign traders or platforms will now be liable for VAT on imports and distance sales of imported goods in the Member State of final destination of the goods.
Finally, as part of the EU's efforts to eliminate tax evasion in EU countries, strict rules are being re-established for digital platforms active in short-term rental of real estate and transport services. Data has shown that many providers of accommodation rental and passenger transport services via online platforms do not pay VAT, either due to ignorance or due to exemptions. This essentially leads to the creation of unfair competition with traditional businesses that are liable for VAT. Thus, this is being remedied by the introduction of new rules, under which these platforms now become responsible for collecting and remitting VAT when their service providers do not.

5. Digital readiness and policy implementation Greece in comparison with EU countries

Digital readiness is a key factor for the effective implementation of policies related to the taxation of the digital economy. According to the Digital Decade 2024 report, official data for Greece showed that the coverage of basic digital skills was achieved at a rate of 52.4%, while the corresponding rate for the EU average was 55.5%. Furthermore, it should be emphasized that, taking into account the official data for 2021, there is no progress in this area. At the same time, the percentage of Information and Communication Technology (ICT) professionals in total employment is only 2.4%, significantly below the European average (4.8%), despite the ever-increasing demand for digital skills in the labor market (https://digital-strategy.ec.europa.eu/en/factpages/greece-2024-digital-decade-country-report).
Microsoft's Digital Futures Index for 2022 also measured the level of digitalization in a sample of 16 European countries, one of which was Greece. This index results from the collection of data on the level of digitalization of each country and identifies the most successful sectors, as well as those that are lagging behind and that need to accelerate the digital transformation process. It is worth noting that digitalization is associated with 5 categories of digital development: Digital Enterprise, Digital Government and Public Sector, Digital Infrastructure, Digital Sector and Human Capital. The country's overall score for digital development is 81, which is 17% below the average for Central and Eastern Europe. More specifically, compared to Central and Eastern European countries, Greece ranks below average in Digital Enterprise, Digital Governance and Public Sector, Digital Infrastructure and Digital Sector, but above average in Human Capital, with 96.94 compared to 100 (https://digital-skills-jobs.europa.eu/en/latest/briefs/greece-snapshot-digital-skills).
Furthermore, recent Eurostat data and the Digital Intensity Index show that Greece is lagging behind the European average. This index measures the use of digital technologies by businesses, such as Artificial Intelligence, social media, cloud computing and e-commerce. It should be noted that achieving at least a basic level of digital readiness requires the use of at least four of these technologies. More specifically, 2023 data showed that only 43.8% of Greek businesses recorded at least a basic level of digital readiness, while the EU average exceeds 59%. In fact, the leaders in digital readiness in the EU were those operating in Finland, Malta and the Netherlands, as they recorded the highest percentages of enterprises

that achieved a very high level of digital intensity. On the other hand, Greece, together with Romania and Bulgaria, had the highest percentage of enterprises with a very low digital intensity, with 56.2% of Greek enterprises falling into this category. (https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240829-1). In addition, Greece is ranked last in the EU for 2024 in terms of the percentage of specialists in the field of Information and Communication Technologies (ICT), with only 2.5% of all employees, compared to the EU average of 5%. ICT specialists include those with advanced skills related to the operation and maintenance of ICT systems. The EU overview for 2024 showed that over 10 million people held jobs as ICT specialists across the EU. Of this number, 2.3 million worked in Germany, which appears to have had more than a fifth (22.1%) of all employed ICT specialists in its workforce in the EU. This was followed by France, Spain and Italy with concentrations of 13.6%, 10% and 9.2% respectively. In terms of the percentage of the population working in ICT, Sweden held the first place (8.6%), followed by Luxembourg (8.0%) and Finland (7.8%). More than 5% of total employment in countries such as Estonia, the Netherlands, Ireland, Denmark, Belgium, Austria, Lithuania, Malta, Portugal, Cyprus and Croatia concerned ICT specialists. Conversely, Greece and Romania, according to official data, were the countries with the lowest percentages, with 2.5% and 2.8% respectively (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment). Finally, although Greece seems to lag behind in key digital development indicators, such as the employment of ICT specialists, it is recording positive steps in the field of digital public services. Specifically, regarding services to citizens, the country approaches the European average with a rate of 75.9% compared to 79.4%, while in the field of digital public services for businesses, Greece exceeds the EU average, reaching 86.2% compared to 85.4%, which indicates progress and prospects for further improvement (https://www.mindigital.gr/archives/6303).

6. Conclusions

Greece, like all other European countries, is now faced with a new reality, the era of the digital economy and its taxation. International experience has shown that countries which invested in digital infrastructure and focused on actions strengthening it achieved digital readiness and progress.

Using other European countries as examples that have made progress in the digital economy and its taxation, Greece must move decisively, adopting a holistic and adaptive reform model capable of responding to the needs of the digital era. In particular, there is an urgent need for reform, as the EU has already set ambitious goals for the EU Digital Decade. The EU's main goal is that by 2030, over 90% of EU small and medium-sized enterprises will have already achieved a basic level of digital intensity. However, the latest available data show that Greek SMEs are unable to achieve this goal, which highlights the need to accelerate digital reforms in the country's business and tax environment.

To address the above challenges, Greece needs a modern, flexible and socially fair tax framework. Initially, it is necessary to achieve the full digitalization and automation of tax procedures. The expansion of electronic books (myDATA) to all professionals, the use of self-audit tools for businesses, as well as the integration of artificial intelligence (AI) and big data analytics technologies in tax administration can contribute decisively to reducing tax evasion and enhancing the effectiveness of audits. With the digitalization of tax procedures, such as the implementation of electronic books (myDATA), the Independent Public Revenue Authority will be able to monitor in real time the flow of financial transactions and identify cases of tax evasion in a timely manner. On this basis, continuous training of AADE executives in digital tools, artificial intelligence and data analysis, combined with cooperation with universities and research institutions, is essential in forming an administration capable of responding to the increased challenges of the new era.

It is important that Greece, in the context of digital transformation, does not remain inactive but has proceeded to design a series of strategies and initiatives aimed at the modern digital development of society and the economy. In particular, the Digital Transformation Programme (PPsiMet) 2021-2027 co-financed by the European Regional Development Fund (ERDF) and the European Social Fund + (ESF+) aims to develop digital platforms and services to support businesses and local governments, ensure high-speed connectivity and train citizens and businesses in digital skills. Thus, through this, the

country will be able to catch up with other European countries (https://digital-skills-jobs.europa.eu/en/latest/briefs/greece-snapshot-digital-skills).

Also, the Greek Recovery and Resilience Plan plays a supporting role, through which the digital transformation is strengthened by investing in the digitalization of the public sector and businesses, in improving connectivity (such as the development of 5G networks) and in strengthening digital skills. This Plan concerns various sectors such as education, health and the digitalization of small and medium-sized enterprises (SMEs), promoting the integration of digital technologies in these sectors.

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Human-Centered AI Adoption in Business: Bridging Organizational Psychology and Social Sustainability

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Abstract: *Artificial Intelligence (AI) is increasingly embedded in business operations, transforming decision-making, customer engagement, and internal processes. While its economic and operational benefits are well-documented, the psychological and social implications of AI adoption remain underexplored in management research. This paper investigates how AI-driven innovation intersects with organizational psychology and social sustainability, emphasizing human-centered challenges such as employee techno-anxiety, stakeholder trust, and ethical governance. A mixed-methods approach was employed: a systematic literature review identified key psychological and social factors in AI adoption, and empirical data were collected from three multinational companies (energy, finance, retail) that implemented AI solutions. Semi-structured interviews with executives, employees, and external stakeholders explored perceptions of AI's impact on autonomy, fairness, and organizational culture. Quantitative environmental, social, and governance (ESG) metrics (e.g. employee well-being, diversity, community engagement) were analyzed to assess social sustainability outcomes. Findings reveal that AI can enhance social sustainability when integrated with psychologically informed design and stakeholder engagement. For example, AI-driven analytics improved workplace safety and reduced stress incidents, while AI-enabled learning platforms expanded inclusive access to training. However, success depends on human factors such as perceived transparency, emotional safety, and trust in algorithmic decisions. Organizations prioritizing participatory design and ethical AI governance reported higher stakeholder satisfaction and improved ESG indicators, whereas neglecting psychological dimensions led to employee resistance, reduced engagement, and reputational risks. These insights underscore the need for interdisciplinary approaches that align AI innovation with psychological well-being and ethical responsibility. The study contributes a human-centered framework for responsible AI adoption that enhances both business performance and social impact.*

Keywords: *Artificial Intelligence; Organizational Psychology; Social Sustainability; Stakeholder Engagement; Human-Centered Innovation*

JEL Classification: *M14; O33; Q01*

1. Introduction

AI technologies are being rapidly adopted across industries, reshaping how businesses operate and compete. From automating routine tasks to augmenting strategic decision-making, AI promises significant gains in efficiency and innovation (www.mckinsey.com). However, alongside these benefits, there is growing recognition of psychological and social challenges associated with AI integration in the workplace. Organizations increasingly face questions about how employees perceive AI-driven changes, how stakeholders trust algorithmic decisions, and how to balance technological advancement with ethical and sustainable business practices (sajip.co.za). Recent scholarship in organizational behavior has shifted focus toward these human-centered questions, highlighting issues of worker well-being, human–AI collaboration, fair outcomes, and multi-level impacts of AI (sajip.co.za). This reflects a broader imperative: to ensure that AI adoption not only boosts productivity but also aligns with human values and social sustainability.

1.1 Background and Problem Statement

While the economic advantages of AI are well-documented, the "softer" dimensions—such as employee emotions, organizational culture, and stakeholder trust—remain underexplored. Early evidence suggests that ignoring these dimensions can undermine AI initiatives. Employees often view AI systems as opaque "black boxes," which can trigger confusion, anxiety, or distrust, especially if the algorithms are perceived as unfair or error-prone. For instance, a systematic review by Afshani (2022) found that AI-enabled processes can improve efficiency and insight, but they may also heighten risks of stress, alienation, and job insecurity among workers. Such technostress and techno-anxiety can manifest when employees fear job displacement or struggle to adapt to AI-driven workflows. At the same time, external stakeholders (customers, regulators, communities) are increasingly concerned with how AI affects privacy, equity, and transparency. High-profile cases of algorithmic bias and unethical AI outcomes have raised public awareness and skepticism, putting pressure on companies to demonstrate responsible AI use (Cath et al., 2018; Floridi et al., 2018). These challenges highlight a crucial research gap: How can businesses adopt AI in ways that respect human psychological needs and promote social sustainability?

Stakeholder theory (Freeman, 1984) provides a useful lens for this inquiry. Unlike the traditional shareholder-focused view, stakeholder theory argues that managers must account for the interests and well-being of all parties affected by corporate actions. In the context of AI adoption, this means considering how employees, customers, and communities interpret and are impacted by new AI systems. A stakeholder-oriented approach would urge firms to engage these groups in the design and deployment of AI, thereby ensuring the technology serves broader societal goals in addition to financial objectives. Indeed, research on corporate sustainability suggests that companies embracing inclusive, long-term strategies tend to perform better over time (Eccles, Ioannou, & Serafeim, 2014). Eccles et al. (2014) found that *"high sustainability"* companies (those adopting substantial sustainability policies) had more robust stakeholder engagement processes and more long-term orientations, leading to stronger non-financial performance. These findings imply that aligning AI initiatives with social responsibility could similarly yield benefits in trust and reputation, ultimately supporting organizational performance.

1.2. Objectives and Significance

Given this backdrop, the objective of the present study is to develop a human-centered framework for AI adoption in business – one that integrates insights from organizational psychology with principles of social sustainability. We specifically examine how psychological factors (such as perceived autonomy, fairness, and trust) and organizational practices (such as participatory design and ethical governance) influence stakeholder satisfaction and ESG outcomes during AI implementation. By addressing this interdisciplinary problem, the study contributes to both theory and practice. Theoretically, it bridges the gap between AI/technology adoption research and organizational behavior literature on employee well-being and change management. Practically, it offers guidance for managers and policymakers on how to deploy AI in ways that enhance employee engagement, foster positive stakeholder perceptions, and support corporate sustainability goals.

This research is timely as businesses navigate the delicate balance between innovation and responsibility in the era of AI. International policy developments reflect this tension: for example, the European Union's AI Act proposes strict regulations to prevent harmful uses of AI, emphasizing human rights and safety, whereas other regions focus on deregulation to spur innovation. Such contrasts underscore the need for frameworks that can *"balance economic opportunity with social protection"*, ensuring AI-driven growth does not come at the expense of human-centered values. By examining real-world cases of AI adoption through a human-centered lens, our study aims to provide empirically grounded insights into creating AI-enabled workplaces that are both high-performing and socially sustainable.

2. Literature Review

This section reviews relevant literature in two key domains. Section 2.1 discusses organizational psychology perspectives on technology adoption, focusing on how AI systems interface with human

behavior, emotions, and cognition in the workplace. Section 2.2 then explores the concept of social sustainability and stakeholder engagement in the context of AI, including ethical frameworks and corporate responsibility considerations. Together, these strands form the theoretical foundation for our study and inform the research framework.

2.1. AI Adoption and Organizational Psychology

Technostress, Anxiety, and Employee Well-Being: Rapid technological change can induce stress and anxiety among employees, a phenomenon often termed *technostress*. When new AI tools are introduced, employees may worry about their ability to learn the system or fear that the technology will render their roles obsolete. Brougham and Haar (2018) describe how workers' awareness of AI and related smart technologies can spark a "STARA" (Smart Technology, Artificial Intelligence, Robotics, Algorithms) anxiety, leading to job insecurity and resistance to change. Such anxiety can negatively affect job satisfaction and mental health, which in turn hampers productivity and innovation. On the other hand, if managed well, AI can also alleviate certain stressors—automating tedious tasks may reduce burnout and free employees for more meaningful work (Seligman, 2011). According to positive psychology, meaningful engagement and the opportunity to use one's strengths are key components of human well-being and *flourishing* (Seligman, 2011). Thus, AI implementation strategies that support employees in upskilling and finding purpose in new tasks can contribute to higher satisfaction rather than stress. This aligns with Self-Determination Theory, which posits that individuals have innate needs for autonomy, competence, and relatedness (Ryan & Deci, 2000). When AI tools are deployed in a way that respects employees' autonomy (e.g., allowing them control over how to use AI assistance), builds their sense of competence (through training and mastery of new skills), and fosters social relatedness (by enhancing collaboration rather than isolation), employees are more likely to embrace the technology positively.*Trust in AI and Perceived Fairness:* Trust is another critical factor in AI adoption. Human trust in AI systems is influenced by perceptions of the system's transparency, reliability, and fairness (Glikson & Woolley, 2020). If an AI algorithm's decision-making process is opaque or produces outcomes seen as biased or unjust, users will be reluctant to rely on it. Research has shown that *perceived fairness* in algorithmic decisions (such as in AI-driven HR or customer service systems) strongly affects acceptance: users are more likely to accept AI recommendations if they believe the system's criteria are fair and accountable (Lee, 2018). Glikson and Woolley's (2020) review of empirical studies on trust in AI highlights that frequent, clear communication about how AI tools work and the provision of explanations for AI decisions can significantly enhance trust. This is closely tied to the concept of *psychological safety* in organizations (Edmondson, 1999)—the shared belief that it is safe to engage and express concerns. An environment of high psychological safety will encourage employees to voice questions or doubts about AI systems, allowing organizations to address issues early and improve the human-AI interface. Conversely, in low-safety climates, silent skepticism can fester, eroding trust in AI and dampening its usage. Scholars also emphasize the role of *ethical AI design* in building trust: incorporating privacy protections, bias mitigation, and accountability mechanisms from the outset (Floridi et al., 2018). Ethical design not only reduces the likelihood of harm but also signals to stakeholders that the organization is committed to responsible AI practice, thereby increasing confidence in the technology. *Cognitive Bias and AI Interpretation:* There is a bidirectional relationship between human cognitive biases and AI systems. On one hand, AI algorithms can inherit or even amplify biases present in training data or human design choices (Cath et al., 2018). This has social implications—for example, biased AI in credit lending or recruitment can lead to unfair discrimination, undermining stakeholder trust and triggering psychological reactance among those treated unjustly. On the other hand, individuals have cognitive biases in how they interpret and interact with AI. For instance, *automation bias* leads people to over-rely on AI recommendations even when flawed, whereas *algorithm aversion* causes people to undervalue algorithmic advice after seeing it err once. Both phenomena can disrupt optimal human-AI collaboration. Research in organizational psychology suggests training and change management efforts are needed to calibrate trust: employees should neither blindly trust nor irrationally distrust AI, but rather develop a calibrated trust based on understanding the AI's capabilities and limits (Madhavan & Wiegmann, 2007). Some organizations have responded by creating *"AI literacy"* programs—educating staff about basic AI principles and fostering skills to critically evaluate AI outputs. Early evidence indicates that such initiatives can reduce anxiety and improve effective use

of AI tools (Shin, 2021). Taken together, the literature underscores that successful AI adoption is as much a psychological and organizational challenge as a technical one: it requires addressing fears, managing perceptions of fairness, and actively cultivating trust through transparency and education.

2.2. AI, Social Sustainability and Stakeholder Engagement

Social Sustainability in Business Innovation: Social sustainability refers to the aspect of sustainable development that concerns human well-being, equity, and community resilience in the context of economic activity. In corporate practice, this often translates to policies and outcomes related to employee welfare, diversity and inclusion, consumer privacy, community impact, and ethical governance. The rise of AI in business has opened a new frontier for social sustainability: organizations now must consider how AI systems affect the social fabric both within the firm (employee relations and culture) and externally (customer trust, societal welfare). According to a recent McKinsey report, advances in AI have "expanded its potential to address social issues defined by the UN Sustainable Development Goals", indicating that AI can be a powerful tool to improve lives and protect the planet if applied conscientiously. Indeed, researchers have begun mapping AI's contributions to the Sustainable Development Goals (SDGs); for example, Vinuesa et al. (2020) found that AI can positively enable many SDG targets (such as enhancing quality of education and healthcare delivery) but can also hinder certain goals if misused or left unchecked. This dual potential places a responsibility on businesses to steer AI adoption toward social good. Companies leading in "AI for social good" initiatives demonstrate that aligning AI projects with societal needs (like using AI to optimize energy use, or to improve workplace safety) can create shared value for both the business and its stakeholders (McKinsey & Company, 2024). However, capturing these benefits usually requires deliberate strategies that integrate ethical considerations and stakeholder input throughout the AI development lifecycle. *Stakeholder Engagement and AI Ethics Governance*: Effective stakeholder engagement is central to socially sustainable AI adoption. Given the multifaceted impact of AI, a wide range of stakeholders—employees, customers, investors, regulators, and community members—have legitimate interests in how AI is used by organizations. Engaging these stakeholders means involving them in dialogue and decision-making about AI systems' design, deployment, and oversight. For instance, involving employees and end-users in the participatory design of AI (through user testing, feedback sessions, co-creation workshops) can surface concerns about usability, fairness, or unintended consequences early on. Such inclusive approaches not only lead to more human-centered AI solutions but also increase stakeholder buy-in and satisfaction, as people feel their voices are heard. This aligns with Freeman's (1984) argument that considering stakeholder needs leads to better organizational outcomes and extends it to the AI era. When stakeholders perceive that an AI system is developed with them rather than done to them, they are more likely to trust and support it. In parallel, the establishment of robust AI ethics governance frameworks inside organizations has emerged as a best practice. This includes creating ethics committees or advisory boards, crafting principles for AI use (such as fairness, accountability, transparency), and setting up processes for algorithmic audits and impact assessments (Floridi et al., 2018). For example, some companies have adopted guidelines to ensure AI decisions are explainable and appealable, especially in sensitive applications like hiring or lending. Others tie managerial incentives to ethical AI outcomes, akin to how "high sustainability" firms linked executive compensation to sustainability metrics (ideas.repec.org). Research by Eccles et al. (2014) suggests that such governance measures can embed social values into core business processes, fostering a culture that prioritizes long-term stakeholder value over short-term gains. In the AI context, an ethical governance approach can mitigate risks of scandals or harms, thereby protecting the company's reputation and stakeholder trust. *Linking Psychological Well-Being and ESG Performance*: A growing body of literature connects the internal dynamics of organizations (culture, employee well-being, leadership) with external measures of corporate social performance. For instance, studies have shown that companies with higher employee satisfaction often have better scores on social and governance criteria, and may even financially outperform peers (Edmans, 2011; Eccles et al., 2014). The logic is that treating employees well and fostering a positive, ethical culture translates into more responsible products and practices, as well as higher productivity. In the case of AI adoption, this implies that an organization attentive to the human side of AI—investing in training, maintaining open communication, upholding fairness—will not only ease employee concerns but also likely yield more innovative, customer-

friendly, and ethically sound AI applications. These, in turn, can improve metrics like customer satisfaction, brand loyalty, and community trust, which are components of the "Social" and "Governance" aspects of ESG performance. Early empirical evidence supports this integrative view. For example, companies that have adopted AI for monitoring worker safety (a social benefit) report not only lower accident rates but also higher morale and trust in leadership (as employees see that their well-being is prioritized). Moreover, firms that are transparent about their AI use and outcomes tend to experience less regulatory friction and enjoy a better public image, indicating that socially sustainable AI practices can be a source of competitive advantage. On the contrary, organizations that deploy AI without considering these factors have faced backlash—ranging from employee protests over unethical AI contracts to public relations crises when algorithms are found to be biased. Thus, the literature converges on a clear message: aligning AI adoption with organizational psychology insights and stakeholder expectations is not just a "nice to have," but a strategic imperative for sustainable business innovation.

2.3. Research Framework and Methodology

Building on the literature insights above, we developed a research framework positing that *human-centered implementation of AI* (through attention to psychological factors and stakeholder engagement) leads to higher stakeholder satisfaction and improved social sustainability outcomes, compared to tech-centric implementation alone. To investigate this framework, we adopted a mixed-methods research design comprising both qualitative and quantitative components. *Data Collection:* We conducted case studies in three multinational companies that have recently implemented AI-based solutions in their operations: (1) an energy company using AI for predictive maintenance and safety management, (2) a financial services firm deploying AI in customer service and risk analysis, and (3) a retail company implementing AI-driven analytics for supply chain and personalization. These firms were selected to cover diverse sectors and to allow cross-case comparison. Within each organization, we identified key stakeholder groups: top management and AI project leaders, employees directly affected by the AI systems (e.g., analysts working with AI tools, front-line staff whose workflows changed), and external stakeholders (such as customers or community representatives, where relevant).

Primary data were collected through semi-structured interviews and surveys. We interviewed 5–8 individuals per company, including C-level executives, project managers, and a sample of employees, for a total of 20 interviews. The interviews explored perceptions of the AI initiative's impact on work processes, autonomy, job satisfaction, fairness in decisions, and overall trust in the technology. We also included questions about stakeholder engagement in the AI adoption process (e.g., whether employees had input, how customer feedback was considered) and about any ethical guidelines or governance measures in place. Interviews were recorded, transcribed, and coded for thematic analysis. In addition, we administered a short survey to a broader group of employees in each firm (N = 50–80 per company) to gauge general sentiments on AI (using Likert-scale items for constructs like *techno-anxiety*, *trust in AI*, *perceived fairness*, and *perceived impact on well-being*). For the quantitative aspect related to social sustainability outcomes, we collected relevant ESG performance data from company reports and internal metrics both before and after the AI implementation (where available). We focused on indicators that could plausibly be affected by the AI projects in the short-to-medium term—such as employee turnover rates, employee engagement survey scores, diversity in training participation, number of safety incidents, customer satisfaction ratings, and community project investments. While these metrics cannot be solely attributed to AI adoption, we looked for patterns or changes concurrent with the introduction of AI, triangulating with interview insights to infer plausible connections. *Data Analysis:* Qualitative data from interviews were analyzed using a *thematic analysis* approach. Two researchers independently coded the transcripts to identify recurring themes related to our constructs of interest (e.g., feelings of anxiety or empowerment, trust or skepticism, perceptions of transparency, changes in collaboration dynamics). Codes were then discussed and refined into a set of key themes and illustrative quotes. For the survey data, we computed basic descriptive statistics and correlations. In particular, we examined correlations between employees' attitudes towards AI (e.g., trust levels, anxiety levels) and their reported job satisfaction or well-being, to see if the hypothesized relationships held. Due to sample size limitations per company, we treat these quantitative results as exploratory and complementary to the

qualitative findings. We also performed a comparative analysis across the three case companies to see how differences in implementation approach might relate to different outcomes. Notably, Company A (energy) and Company B (finance) had formal *ethical AI guidelines* and conducted extensive employee training before and during AI rollout, whereas Company C (retail) adopted AI more rapidly with less structured change management. This allowed us to observe variations: whether more human-centered approaches correspond with better stakeholder reception and ESG indicators, as our framework suggests. By combining multiple data sources and methods, our aim was to build a rich, triangulated understanding of the interplay between AI technology, human factors, and social impact in business settings. The next section presents the integrated results of this investigation, followed by a discussion of their implications.

3. Discussion

The findings from our multi-case study provide important insights into how AI adoption can be aligned with human-centered principles to yield positive psychological and social outcomes. Overall, the results support our proposition that organizations which proactively address human factors and ethics in AI implementation tend to experience higher satisfaction among stakeholders and better social sustainability performance.

3.1. Key Findings and Thematic Synthesis

Across all three companies studied, we observed that AI tools indeed brought operational improvements but also introduced significant human and social dynamics that influenced their ultimate success. In Company A (energy sector), the AI-driven predictive maintenance system successfully reduced unplanned equipment outages and improved workplace safety metrics. Employees reported fewer stressful emergency repairs and appreciated the reduction in hazardous incidents – a clear boost to well-being. One maintenance supervisor noted, *"The AI catches problems before they escalate, which means we're not scrambling at 2 AM anymore. It's a relief and feels safer."* This corresponds with a drop in annual injury rates at Company A after AI implementation, suggesting a tangible social sustainability benefit (safer working conditions). However, these gains were closely linked to the company's human-centric rollout: Company A involved technicians early in selecting and testing the AI, provided extensive training, and established a clear protocol that AI recommendations would *assist* (not replace) human decision-making. This participatory approach appears to have fostered trust and acceptance. Survey data showed high trust in AI among Company A employees; over 80% agreed that "the AI system helps me do my job better" and a similar percentage felt the implementation process was handled transparently and with respect for their input.

Company B (finance) had a different context – implementing AI in customer service (via chatbots) and in risk assessment models. Here, the benefits included faster response times for customers and more predictive ability in detecting fraud. These align with *economic* gains for the firm and potentially improved service quality (a positive social outcome for customers). Internally, frontline service employees initially feared the chatbots would reduce their value or jobs, reflecting *techno-anxiety*. In response, management repositioned roles: employees were trained to handle more complex client issues while routine queries were diverted to AI. Over time, many employees reported lower workload on trivial tasks and higher engagement in skilled problem-solving, which improved job satisfaction for a majority. One customer service agent mentioned, *"At first I thought the bot was a threat, but now I'm relieved it handles the repetitive queries. I focus on the harder cases and feel more challenged in a good way."* This illustrates how redesigning jobs to complement AI can transform an anxiety-provoking situation into a win-win for employees and the firm – supporting the idea of AI augmenting rather than automating away human work (Raisch & Krakowski, 2021). Notwithstanding, Company B learned a hard lesson on perceived fairness: their AI risk model, shortly after launch, was found to flag certain low-income customers as higher risk in a way that raised fairness concerns. This was picked up by an internal audit (prompted by the company's AI ethics board) and led to a model adjustment. The incident, while swiftly managed, underscores how *algorithmic bias* without proper oversight can erode trust. After correcting the model and openly communicating the fix, the company restored confidence among

stakeholders. Such transparency and willingness to address issues are crucial – as several interviewees noted, *"No AI is perfect, but it's how we handle the problems that matters for trust."* This aligns with broader ethical AI guidance that stresses accountability and continuous monitoring (Floridi et al., 2018). Company C (retail) presented a contrast as a cautionary tale. The company's AI analytics for supply chain optimization resulted in cost savings and reduced waste (a potential environmental sustainability win). However, the implementation was done top-down with minimal employee or supplier consultation. Many employees in procurement and logistics suddenly had to follow algorithm-driven directives (e.g. inventory levels, order timings) without understanding the rationale. This lack of explanation or involvement led to frustration and reduced sense of autonomy. In our survey, Company C had the highest proportion of employees indicating *AI-related stress* and skepticism; less than 40% felt the AI tool was beneficial to their work. Moreover, the company faced pushback from some local suppliers who felt the automated system's predictions (which sometimes cut orders for certain products) were unfair or insensitive to on-ground nuances. The absence of a stakeholder engagement strategy meant these grievances went unaddressed until they escalated—Company C experienced public criticism when a story broke in the news about how their AI-driven cuts affected small suppliers. The resulting reputational hit is an example of how neglecting social considerations can undermine the sustainability of AI innovation. This case reinforced that participation, transparency, and empathy are not just ethical niceties but practical necessities. Company C's experience echoes prior findings that failing to manage the change process can lead to resistance and implementation failure. It stands in stark contrast to Companies A and B, where deliberate efforts were made to involve and support people, yielding much smoother adoption and stakeholder approval.

3.2. Integration with Theory and Prior Research

Our findings resonate with and extend the existing literature in several ways. First, consistent with Self-Determination Theory (Ryan & Deci, 2000), we observed that AI implementations respecting employees' need for autonomy and competence garnered better acceptance. In Company A and B, giving employees agency (e.g., through training and input opportunities) helped satisfy their autonomy and competence needs, reducing anxiety and building *ownership* of the AI tools. This aligns with the notion that autonomous motivation (feeling one has a choice and capacity) enhances engagement with new technology. Meanwhile, Company C's more controlling approach thwarted these needs, resulting in lower motivation and higher resentment. These qualitative patterns mirror the broader principle that human motivation and well-being are critical for organizational change success.

Second, our study underscores the importance of trust and psychological safety identified by Edmondson (1999) and others. Where organizations created an environment of open communication about AI (as in Company B's addressing of the bias issue), stakeholders maintained trust even when issues arose. This supports Glikson and Woolley's (2020) emphasis that transparency and responsiveness are key to sustaining trust in AI. The case findings also vividly illustrate the abstract idea of *calibrated trust*: employees learned to trust the AI for some tasks but also felt free to question it when it seemed wrong – a healthy balance suggested by prior human–AI teaming research (Miller, 2018). We found evidence that companies fostering such an environment saw more effective human-AI collaboration, consistent with Bankins et al. (2024), who identified *worker well-being* and *fairness in processes* as central to future AI–organizational behavior research. Our empirical observations give concrete examples to those themes, demonstrating that addressing fairness (e.g., bias audits) and well-being (e.g., relieving drudgery, ensuring safety) through AI can indeed contribute to better outcomes for both individuals and organizations.

Third, linking to stakeholder theory and corporate sustainability literature, the results show that a *stakeholder-inclusive approach* to AI adoption is both feasible and beneficial. Companies A and B engaged employees (an internal stakeholder) and, to some extent, customers or auditors (external stakeholders) in their AI processes, and they reaped benefits like higher satisfaction, innovation acceptance, and avoided conflicts. This reinforces Freeman's (1984) argument in modern form: when introducing advanced technology, considering stakeholders' concerns and values leads to more sustainable success. Additionally, the notion from Eccles et al. (2014) that *high sustainability companies integrate stakeholder concerns into governance* is exemplified in how Company B's ethics board preemptively caught a potential social harm from AI. This prevented a possible loss of trust that could

have had long-term performance costs. In contrast, Company C's relative neglect of stakeholder input aligns with lower sustainability performance (employee disengagement, supplier conflict). Notably, these insights dovetail with emerging discussions on *Responsible AI* in literature, which call for interdisciplinary governance bridging technical and human perspectives (Floridi et al., 2018; Cath et al., 2018). By providing empirical evidence from within organizations, our study adds weight to those calls and illustrates what can go right or wrong depending on the approach taken.

3.3. Toward a Human-Centered AI Adoption Framework

Synthesizing the above, we propose a conceptual framework for human-centered AI adoption, informed by our findings. The framework highlights key components and their interrelations:

- Participatory Design & Implementation: Actively involve stakeholders (employees, end-users, etc.) in AI system design, pilot testing, and rollout. This builds a sense of ownership and surfaces issues early. Our cases showed that participation increases perceived transparency and fairness, thereby reducing resistance.
- Psychological Support & Training: Provide resources to help individuals adapt to AI. This includes training programs to build competence with new tools, forums for addressing concerns (to enhance psychological safety), and clear communication that clarifies the role of AI (mitigating fear of the unknown). When people feel supported, their techno-anxiety diminishes and openness to change increases.
- Ethical AI Governance: Establish structures and processes to ensure AI aligns with ethical and societal values. As demonstrated, mechanisms like ethics committees, bias audits, and stakeholder feedback loops help maintain fairness and accountability. Governance should be an ongoing process, not a one-time checkbox.
- Alignment with Purpose & Values: Frame AI initiatives within the organization's broader mission and ESG objectives. If employees and stakeholders see that AI is being used to further positive outcomes (e.g., safer workplaces, better customer service, environmental efficiency), they are more likely to embrace it. This framing was effective in our positive cases: AI was not just a cost-cutter, but a tool to improve jobs and service quality.

These components are interdependent and collectively contribute to stakeholder satisfaction (employee engagement, customer trust, etc.) and social sustainability performance (healthy workforce, ethical culture, and community goodwill). Notably, they also reinforce each other: ethical governance and participatory practices build trust, which makes stakeholders more receptive to training and change, which in turn makes governance easier to implement due to higher compliance and cooperation.

In summary, the discussion of our results in light of existing theory suggests that the human-centered approach is not merely idealistic, but pragmatic. It creates a virtuous cycle where AI innovation and human well-being feed into each other, leading to sustainable business gains. The next section concludes the paper by highlighting the implications and future research directions stemming from this study.

4. Conclusions

This research set out to explore the intersection of AI-driven business innovation with organizational psychology and social sustainability. Through a mixed-methods study spanning multiple companies and stakeholders, we found compelling evidence that the success of AI adoption hinges not only on technical prowess but also on human-centered factors. In answer to our overarching question, we conclude that the low satisfaction sometimes observed among public and employee stakeholders in the face of AI can be explained by the neglect of key psychological and social variables. When AI initiatives are implemented with little regard for reliability, fairness, or user autonomy, satisfaction remains low and resistance high. Conversely, by ensuring reliability of service, maintaining reasonable expectations (moderate "fare" or cost to stakeholders, in a metaphorical sense), and boosting comfort and safety in usage, organizations can significantly improve stakeholder satisfaction with AI – much as a public transport system satisfies passengers when it is reliable, affordable, and safe.

The study contributes a *human-centered AI adoption framework* that aligns technological advancement with human well-being and ESG performance. In practice, this means that companies should: **(i)** design

AI interventions in ways that give employees a sense of accomplishment and growth, rather than displacement; **(ii)** foster a work environment of openness and collaboration where people can trust and co-create with AI; and **(iii)** ensure fairness, transparency, and accountability in AI decisions to uphold stakeholder trust. These recommendations echo common management wisdom, but are frequently forgotten in the excitement of AI deployment. Our findings serve as a reminder that technological innovation must be guided by human-centric values to be truly sustainable.

From a policy perspective, the insights are valuable for those planning public guidelines or corporate policies on AI. Regulators and industry groups can use this evidence to advocate for standards that include human impact assessments of AI, worker retraining programs, and stakeholder consultation processes as part of responsible AI practice. For businesses, adopting such practices is not merely about avoiding negative outcomes; it can actively drive positive ones. Firms in our study that aligned AI projects with improving employee well-being or community outcomes enjoyed higher stakeholder loyalty and even performance benefits, suggesting that *doing good and doing well can converge in the context of AI*. This aligns with the notion of pro-social growth: just as pro-poor growth strategies in economics aim to distribute benefits broadly (Pinstrup-Anderson & Pandya-Lorch, 2021), a pro-stakeholder AI strategy aims to share the value of AI across all those affected, thereby enhancing overall satisfaction and success.

4.1. Limitations and Future Research

While our study provides valuable contributions, it also has limitations that open avenues for future research. One limitation is the sample size and scope – we examined three companies in specific sectors, which may limit generalizability. Future studies could expand to different industries or cultural contexts, as the human factors in AI adoption might vary across environments (for example, perceptions of AI might differ in high-tech vs. low-tech industries, or between Western and Eastern cultures of organizational hierarchy). Longitudinal research would also be beneficial to observe how the effects on organizational culture and mental health evolve over time as AI becomes more ingrained in work processes.

Another area for further inquiry is the sector-specific dynamics of AI adoption. For instance, in healthcare and education sectors, the stakes for psychological and social factors may be even higher, given the direct human-centric services involved. Investigating AI adoption in such fields could test our framework's applicability and perhaps introduce additional factors like patient or student trust. Also, quantitative research isolating the impact of psychological interventions on AI project success (e.g., an experiment varying levels of user involvement in AI design) could provide more causal evidence for our assertions.

Finally, as AI technology rapidly evolves – particularly with the rise of generative AI and more autonomous systems – ongoing research is needed to integrate psychological insight into AI *governance*. The concept of *"ethical AI governance"* must continually adapt, potentially incorporating new metrics for psychological safety or cognitive load as part of AI system evaluations. Collaborations between technologists, organizational psychologists, and ethicists will be essential in building resilient, inclusive, and ethically sound business ecosystems in the age of AI. By keeping humans at the center of AI innovation, we ensure that progress in artificial intelligence translates into progress in human well-being and sustainable development.

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The Role of Business Strategy in Achieving Sustainable Competitive Advantage: Insights from Contemporary Management Practices

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Abstract: *The dynamics of the global business environment, characterized by rapid technological advancements, increased globalization, and the evolving expectations of consumers, have fundamentally transformed how organizations craft and implement their strategies. In this context, understanding the interplay between business strategy and sustainable competitive advantage has become essential for the long-term success and survival of firms. This paper explores the pivotal role of strategic management practices in securing sustainable competitive advantage, focusing on contemporary approaches that integrate innovation, corporate social responsibility (CSR), and digital transformation.*

The study examines the various types of strategies adopted by businesses to address the challenges posed by an increasingly competitive and uncertain market. It highlights the importance of aligning organizational capabilities with market opportunities and discusses the strategic choices available to firms in sectors ranging from manufacturing to services. Special attention is given to the strategic frameworks developed over the past few decades, including Michael Porter's Competitive Strategies (1980) and the Resource-Based View (RBV), which emphasize differentiation, cost leadership, and resource accumulation as key drivers of competitive advantage.

In the context of the modern economy, the research identifies the growing importance of innovation as a critical component of strategy formulation. Firms that continuously invest in research and development (R&D), adopt advanced technologies, and create new business models are better positioned to achieve a sustained competitive edge. The study also delves into the concept of digital transformation and its strategic implications, emphasizing the role of information technology in reshaping organizational capabilities and creating value for customers and stakeholders.

Another key aspect of the paper is the examination of corporate social responsibility (CSR) as a strategic lever for building long-term relationships with stakeholders and enhancing brand reputation. As consumer preferences shift towards companies that demonstrate ethical behaviour, environmental stewardship, and social responsibility, organizations that integrate CSR into their core strategies are increasingly able to differentiate themselves from their competitors. Furthermore, the study discusses how CSR can contribute to organizational sustainability by fostering loyalty among customers and attracting top talent, which are vital components of competitive advantage.

Keywords: *Management strategies, innovation, CSR, globalization, organizational flexibility.*

JEL Classification: *M13; M10; O33; O32.*

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1. Introduction

The accelerating pace of technological change, globalization, and rising stakeholder expectations is reshaping how firms design their strategies. Traditional strategic theories—such as Porter's cost-leadership/differentiation frameworks and the Resource-Based View (RBV)—remain relevant, but must now be complemented with contemporary elements such as innovation, digital transformation, and corporate social responsibility (CSR). These elements increasingly drive sustainable competitive advantage, defined not only in terms of financial performance but also in stakeholder engagement, reputational capital, and long-term resilience.

Emerging scholarship suggests that CSR and innovation are not separate spheres: when combined strategically, they can reinforce each other to produce lasting value (Choi & Yoo, 2022). Moreover, digital transformation acts as a crucial enabler, mediating between CSR-driven innovation and competitive performance (e.g., the work in sustainability and digital studies). In this context, firms that effectively integrate strategic management, technological change, and ethical practices can build durable competitive edge while contributing to broader ecological and social goals.

The paper also addresses the impact of globalization on strategic management, with a focus on how firms can navigate the complexities of cross-border competition and international market entry. It highlights the importance of understanding cultural, political, and economic differences when formulating global strategies and the need for firms to adapt their offerings to diverse local markets while maintaining a cohesive global brand identity. Finally, the study concludes with practical recommendations for business leaders and managers looking to create and sustain competitive advantages in today's rapidly changing business environment. It emphasizes the need for strategic flexibility, continuous learning, and the integration of both technological and human capital as essential components of long-term success. The paper suggests that businesses must focus not only on economic performance but also on social and environmental outcomes to remain competitive and relevant in the future.

This paper contributes to the academic discussion on business strategy by offering a comprehensive framework for understanding the strategic levers organizations can use to achieve a sustainable competitive advantage in a complex and evolving marketplace. It also underscores the importance of integrating traditional strategic management theories with modern concepts of innovation, CSR, and digital transformation.

2. Objectives

The study pursues the following research objectives:

The present study is guided by a set of interrelated research objectives aimed at advancing the understanding of how contemporary business strategies contribute to sustainable competitive advantage in dynamic and globally interconnected markets. Specifically, the study seeks to:

1. Examine the relationship between business strategy and sustainable competitive advantage. This objective focuses on exploring how both traditional strategic approaches (such as cost leadership and differentiation) and contemporary strategic practices (including innovation, digital transformation, and CSR integration) influence the long-term performance and resilience of organizations. By analyzing these relationships, the study aims to identify which strategic dimensions most significantly contribute to sustained competitive positioning.
2. Evaluate the continued relevance of classic strategic management frameworks. Recognizing the enduring influence of foundational theories, including Porter's Competitive Strategies (1980) and the Resource-Based View (RBV), this objective assesses their applicability within the contemporary business environment. The study investigates whether traditional frameworks remain valid in guiding managerial decision-making or whether they require integration with emergent strategic paradigms to address the challenges of globalization, technological disruption, and evolving stakeholder expectations.
3. Investigate the impact of innovation and digital transformation on strategic capabilities. Given the accelerated pace of technological change, this objective explores how investments in innovation and digitalization enhance organizational capabilities, facilitate process optimization, and generate novel value propositions. Particular attention is given to the ways in which technological advancement serves as a strategic enabler, fostering adaptability, market responsiveness, and long-term competitive advantage.
4. Examine the role of corporate social responsibility (CSR) as a strategic lever. This objective evaluates how CSR initiatives can be embedded into the core strategic agenda to reinforce brand legitimacy, foster stakeholder trust, and contribute to sustainable performance outcomes. The study seeks to determine the mechanisms through which CSR integration interacts with innovation and digital capabilities to produce synergistic effects that enhance organizational resilience and differentiation.
5. Assess the influence of globalization on strategic decision-making. This objective investigates the extent to which firms adapt their strategic approaches to navigate cross-border competition, diverse regulatory environments, and culturally heterogeneous markets. The study emphasizes how globalization necessitates strategic agility, organizational flexibility, and context-specific adaptation, while simultaneously maintaining global coherence in corporate strategy.
6. Provide evidence-based managerial recommendations for fostering sustainable competitive advantage. Building on the empirical findings, this objective aims to generate actionable insights

for business leaders and managers. The recommendations focus on the integration of traditional and contemporary strategic dimensions, the alignment of technological and human capital investments, and the operationalization of CSR principles to support long-term organizational performance and stakeholder value creation.

Collectively, these objectives offer a comprehensive framework for understanding how firms can strategically leverage innovation, digitalization, CSR, and classic competitive strategies to achieve enduring market success in complex and evolving business environments

3. Methodology

This research employs a mixed-methods convergent parallel design, combining quantitative and qualitative data collected simultaneously, which enhances the robustness of findings.

3.1 Quantitative methodology

- Sample: 150 firms from multiple industries (manufacturing, services, retail, technology), stratified by size (small, medium, large).
- Respondents: Middle and top-level managers.
- Instrument: A structured questionnaire (25 items) using a 5-point Likert scale, measuring strategic orientation (cost leadership, differentiation, innovation), digital maturity, CSR integration, organizational capabilities, and metrics of sustainable competitive advantage (e.g., market share stability, customer loyalty, brand reputation, profitability).
- Reliability & validity: Cronbach's alpha between 0.81–0.91; content validity reviewed by academics + industry experts.
- Analysis:
    - Descriptive statistics (mean, standard deviation)
    - Pearson correlation to explore associations among variables
    - Multiple regression to identify predictors of sustainable competitive advantage
    - ANOVA (Analysis of Variance) to compare across sectors

3.2 Qualitative methodology

- Semi-structured interviews: 10 in-depth interviews with CEOs and senior managers from different sectors.
- Document analysis: Strategic plans, CSR reports, annual reports.
- Focus areas:
    1. Drivers of innovation
    2. CSR integration rationale
    3. Digital transformation barriers and enablers
    4. Global strategy and local adaptation
    5. Learning culture and strategic flexibility
- Data analysis: Thematic analysis to extract key themes, supported by triangulation with quantitative data.

3.3 Ethical considerations

- Participation was voluntary, with informed consent obtained from all respondents.
- Data anonymized to protect firm identity.

Financial data for the analysed SMEs were collected from official sources and recognized databases:

- Ministry of Public Finance (MFP) – Annual financial statements of companies, available at https://mfinante.gov.ro.
- National Institute of Statistics (INS) – Data on the economic evolution of SMEs from the Romanian Statistical Yearbook, Bucharest, 2021, 2022, 2023,2024.

- Eurostat – Comparative data on SMEs at the European level, Eurostat (2023). *Small and medium-sized enterprises statistics*. Available at: https://ec.europa.eu/eurostat.
- Bucharest Stock Exchange (BVB) – For listed SMEs, publicly available financial reports at https://bvb.ro.

Statistical methods were used to identify correlations between adaptive strategies and economic performance. The linear regression model revealed that firms which implemented digitalization and flexible strategies experienced an average growth rate 18% higher than those that did not adopt such measures.

4. Results

4.1 Quantitative findings

The quantitative analysis explored the relationships between key strategic dimensions and multiple indicators of sustainable competitive advantage. Descriptive statistics (Table 1) show relatively high levels of organizational capabilities across the sampled firms. Innovation capability (M = 4.22) and brand reputation (M = 4.30) registered the highest mean values, suggesting that the organizations prioritize innovation-driven development, strategic differentiation, and long-term value creation. Digital transformation maturity (M = 3.90) and CSR integration (M = 3.75) also scored moderately high, indicating growing attention to modernization and social responsibility practices.

Table 1. Descriptive Statistics

Variable	Mean	Standard Deviation	Min	Max
Innovation capability	4.22	0.56	2.8	5.0
Digital transformation maturity	3.90	0.60	2.5	5.0
CSR integration	3.75	0.63	2.2	5.0
Cost leadership orientation	3.58	0.70	2.0	5.0
Differentiation orientation	4.07	0.52	3.0	5.0
Market share stability	3.96	0.60	2.8	5.0
Customer loyalty	4.10	0.50	3.0	5.0
Brand reputation	4.30	0.55	3.2	5.0

Correlation results (Table 2) further illuminate the strategic dynamics behind competitive advantage. Innovation capability exhibits the strongest positive correlations with all performance indicators, particularly brand reputation ($r = 0.69$, $p < .01$) and customer loyalty ($r = 0.63$, $p < .01$). Digital transformation maturity also demonstrates strong positive associations with customer-centric and market-related outcomes. CSR integration, although moderate in magnitude, remains a statistically significant predictor of loyalty and reputational gains. Classical competitive strategies—cost leadership and differentiation—significantly contribute to performance, but the magnitude of their effect is smaller compared to innovation and digital capabilities.

Table 2. Correlations between strategic dimensions and competitive advantage

Predictor	Customer loyalty	Brand reputation	Market share stability	Profitability
Innovation capability	0.63**	0.69**	0.61**	0.59**
Digital transformation	0.56**	0.61**	0.54**	0.52**
CSR integration	0.50**	0.58**	0.43**	0.45**
Cost leadership	0.40*	0.35*	0.42*	0.40*
Differentiation	0.55**	0.62**	0.57**	0.54**

* $p < 0.05$, ** $p < 0.01$

Interpretation of quantitative results:

The results indicate several key patterns:
1.Innovation capability demonstrates the strongest and most consistent positive association with all dimensions of sustainable competitive advantage, underscoring its role as a foundational driver of long-term organizational success. The robust positive correlations observed across all indicators—customer loyalty, brand reputation, market-share stability, and profitability—suggest that firms placing strategic emphasis on innovation tend to achieve superior and more durable performance outcomes. This pattern indicates that innovation functions not merely as an operational attribute but as a critical strategic resource that enhances a firm's adaptability, strengthens value creation, and sustains competitive positioning in dynamic markets.
2. Digital transformation maturity significantly enhances customer loyalty, brand reputation, and market-share stability, highlighting the pivotal role of digitalization in strengthening organizational resilience and adaptability. The positive and statistically significant correlations between digital maturity and key competitive advantage indicators suggest that firms with more advanced digital capabilities are better equipped to deliver consistent customer experiences, manage data-driven decision-making processes, and respond more effectively to technological and market disruptions. These results indicate that digital transformation functions not only as a technological upgrade but also as a strategic enabler that enhances reputation, fosters loyalty, and contributes to sustained market performance.
3. CSR integration demonstrates a positive influence on customer perceptions and contributes meaningfully to the enhancement of brand legitimacy, although its effects are comparatively more moderate than those generated by innovation capability or digital transformation maturity. The quantitative results show that CSR integration maintains a moderate but statistically significant positive relationship with both customer loyalty and brand reputation. This suggests that organizations that embed CSR principles into their strategic framework are more likely to cultivate trust, strengthen their ethical positioning in the marketplace, and reinforce consumer confidence.
Despite its less pronounced magnitude compared to innovation and digitalization, CSR remains an important complementary strategic dimension. Its contribution lies particularly in shaping stakeholder expectations, enhancing corporate credibility, and supporting a favorable public image—factors that cumulatively reinforce an organization's sustainable competitive advantage.
4. Cost-leadership and differentiation strategies continue to serve as significant predictors of organizational performance; however, their impact becomes substantially more powerful when aligned with strong innovation capabilities and advanced digital competencies. The results indicate that traditional strategic orientations remain relevant, yet their effectiveness is no longer maximized in isolation. Instead, firms achieve the greatest competitive gains when classical strategies are integrated with innovation-driven initiatives and digital transformation efforts, creating synergistic effects that enhance efficiency, value creation, and strategic distinctiveness in contemporary markets.

4.2 Qualitative findings (Thematic insights)

Qualitative evidence derived from managerial interviews and organizational documents provides deeper insights into how firms operationalize strategic capabilities. Five overarching themes emerged. From managers' interviews and document analysis, several recurrent themes emerged:

1. Innovation as a strategic pillar

Managers consistently emphasized innovation as a foundational element of competitive positioning.

- A mid-sized technology firm reported that sustained investment in AI- and IoT-based R&D accelerated its innovation pipeline and strengthened client relationships.
- Another organization restructured its innovation process through the creation of cross-functional "innovation labs," integrating CSR and product development teams to co-design environmentally responsible solutions.

2. CSR as a differentiator

CSR was frequently described as a source of competitive distinction rather than a peripheral activity.

- In a consumer-goods company, CSR initiatives—such as adopting recycled packaging—became integral to brand identity, enabling the firm to attract environmentally conscious consumers and maintain premium pricing.
- Several leaders stressed that CSR must be embedded in the core strategy to be effective, rather than treated as an isolated program

3. Digital transformation as culture change

Beyond technological upgrades, digital transformation was framed as a long-term cultural shift.

- One industrial company implemented real-time digital dashboards but achieved meaningful adoption only after extensive training and a shift toward data-driven decision-making across departments.
- Executives highlighted that successful digital transformation blends technological investments with organizational change-management capabilities.

4. Global strategy and local adaptation

Organizations expanding internationally emphasized the importance of balancing global strategic coherence with local responsiveness.

- Firms adapted CSR initiatives to regional needs—for instance, emphasizing education programs in emerging markets and renewable-energy partnerships in developed economies.
- Managers consistently emphasized strategic flexibility, maintaining a unified corporate identity while tailoring innovation and CSR tactics to local contexts.

1. Learning and strategic flexibility

A strong organizational learning culture emerged as a key enabler of resilience.

- Companies that held continuous workshops and knowledge-sharing sessions adapted more rapidly to technological disruptions and market shocks.
- Several managers described the use of scenario-planning tools that allowed their organizations to pivot efficiently when confronting emerging risks or opportunities.

The combined quantitative and qualitative data support a holistic model of strategy where traditional strategic dimensions (cost leadership, differentiation) remain relevant but must be augmented by innovation, CSR, and digital transformation to generate a truly sustainable competitive advantage.

- Innovation (both incremental and radical) consistently emerges as the strongest driver of competitive sustainability. This aligns with existing literature (Farida & Setiawan, 2022).
- Digital transformation not only boosts operational efficiency but also moderates how CSR contributes to competitive advantage. For example, in manufacturing SMEs, digital transformation amplifies the impact of CSR on green innovation.
- CSR, when strategically embedded rather than peripheral, contributes significantly to brand reputation and customer loyalty, creating long-term value (Choi & Yoo, 2022).
- Strategic flexibility, enabled by learning organizations and adaptive processes, allows firms to navigate globalization and uncertainty more effectively.

Managerially, these findings suggest that leaders should:

1. Integrate CSR into the core strategic agenda, not relegated to PR.
2. Invest in digital capabilities that support innovation and CSR.
3. Build organizational cultures that emphasize learning, adaptability, and cross-functional collaboration.
4. Tailor global strategies to local contexts without losing strategic coherence.

5. Originality and contributions

This study offers a set of original theoretical and empirical contributions to the field of strategic management, particularly regarding the mechanisms through which contemporary business strategies generate sustainable competitive advantage. The originality of the paper lies in its integrative analytical perspective, which combines classical strategic frameworks with emergent paradigms such as innovation capability, digital transformation maturity, and corporate social responsibility (CSR). While existing literature often examines these dimensions in isolation, the present research advances a

comprehensive model demonstrating how their synergistic interaction strengthens long-term organizational performance.

First, the paper contributes to theoretical development by bridging traditional perspectives—such as Porter's competitive strategies and the Resource-Based View (RBV)—with modern constructs that reflect the realities of digitalized and sustainability-oriented markets. The proposed conceptual synthesis highlights that cost leadership and differentiation remain relevant but achieve their full potential only when complemented by strong innovation capabilities and advanced digital competencies. This multidimensional articulation of strategy provides a more holistic understanding of competitive advantage in contemporary environments characterized by volatility, uncertainty, complexity, and ambiguity (VUCA).

Second, the empirical contribution of this study emerges from the integration of a mixed methods research design. The quantitative results, based on a diverse sample of 150 firms across multiple industries, provide robust statistical evidence of the differential impact of innovation, digital maturity, and CSR on various performance metrics. Notably, innovation capability is identified as the strongest predictor of sustainable competitive advantage, while digital transformation maturity significantly enhances customer-centric and market-driven outcomes. CSR integration, though moderate in effect, remains a meaningful driver of brand legitimacy and stakeholder trust. These findings enrich the empirical literature by clarifying the relative strengths and complementarities among contemporary strategic levers.

Third, the qualitative insights generated through interviews and document analysis offer an original contextual understanding of how firms operationalize strategic practices. The emergence of themes related to learning culture, strategic flexibility, and global–local hybridization provides nuanced explanations that extend beyond statistical correlations and illuminate the managerial processes through which strategic advantages are sustained. This dual contribution—linking measurable outcomes with managerial narratives—strengthens the explanatory power of the study and supports the development of practice-oriented recommendations.

Finally, the research contributes practical value by proposing a set of evidence-based strategic guidelines for managers navigating increasingly dynamic markets. These recommendations highlight the need to embed CSR within core strategy, cultivate innovation-driven cultures, and leverage digital technologies as enablers of adaptability and resilience. By articulating the interdependencies between these strategic pillars, the paper provides actionable insights that can guide decision-making in organizations seeking to secure long-term competitive sustainability.

Overall, the study advances the scholarly conversation by demonstrating that sustainable competitive advantage in the contemporary economy is not the product of isolated strategies, but rather the outcome of an integrated strategic architecture that combines innovation, digital transformation, classical positioning strategies, and socially responsible practices. This multidimensional approach constitutes the paper's principal original contribution to the strategic management literature.

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The Importance of Feedback in the Distance Learning Process

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Abstract: *Continuous improvement, optimization and updating of teaching activities and materials and the entire educational process are essential aspects that any university, faculty, must include in its strategic objectives*
The permanent evaluation and modelling of the educational process in order to obtain the best results is a goal of higher education institutions that have included distance and part-time forms of education in their offer. In this regard, a series of specific evaluation methods are used, through which the necessary information can be obtained.
Feedback in the educational process is an important part of the design and implementation of teaching activities. It can manifest itself bidirectional and has the role of improving communication between the actors involved, teachers and students, as well as the teaching and evaluation process.
The results obtained represent input data in the process of continuous improvement of educational management specific to distance and part-time forms of education.
This paper aims to present the importance of feedback as an important part of improving the distance education process, the case study being based on the author's professional experience, but also on the annual reports of the Distance and Short-Formality Education Center within the Petrol Gaze University of Ploiești. Finally, the conclusions summarize the main findings and recommendations, highlighting the importance of two-way feedback in educational management.

Keywords: *Educational process; Feedback; Distance Education*

JEL Classification: *I21, I23, A23*

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1. Introduction

Continuous improvement, optimization and updating of teaching activities and materials and the entire educational process are essential aspects that any university, faculty, must include in its strategic objectives. The precise identification of the ways in which these objectives can be achieved is based on various forms of educational management, among which an important role is played by the way of obtaining feedback from stakeholders.
Distance and part-time education represent modern ways of organizing the educational process through which students have the opportunity to pursue and graduate higher education in an optimal combination with professional and family activity. Through information and the correct choice of study programs, the accumulation of knowledge and experience in the field of work can be achieved simultaneously. Finding and maintaining a job in a world full of challenges represents a continuous stress and therefore e-learning offers the possibility of combining educational and professional activity (Ene, 2018).
The main objective of the paper is outlined starting from the specific particularities of these forms of distance learning. Forms include both face-to-face meetings and online, synchronous or asynchronous, in this way it is possible to easily identify the importance and necessity of obtaining the opinions of stakeholders, from both directions, of teachers and students, in order to improve the activity of everyone.

2. Literature Review

In the 2000s, Croos (2004) published an article that attempted to create an informal history of eLearning and its importance in distance education. This form of education organization has undergone various changes over time. Access to the Internet has favored the development of this type of education (Spector et al., 2008).
The literature in the field tries to respond to the challenges launched by alternative methods of education and learning. These methods have become part of the activity of people involved in this type of education and a challenge for universities to provide access to new educational practices (Banciu et al. 2020).

2.1. Theoretical aspects of distance education

Distance learning is a form of the educational system in which the learning process is carried out mainly through modern technologies such as e-learning platforms. This type of education proves to be very useful for people who want to combine, as opportunely as possible, educational activity with professional and family activities.
Many universities in Romania organize forms of education in which students have the opportunity to participate only occasionally in face-to-face meetings with professors. Those who have professional obligations that do not allow them to attend classes frequently, on weekdays prefer this model.
At each stage of the development of distance learning, there have been concerns about regulating these forms in order to ensure the quality of the educational act, but also a concern for training the personnel involved in education by developing specific methodological instructions (Banciu et al. 2020).
Distance higher education practiced in Romania has a series of specific characteristics, from the synergy of which the advantages of this form of organization emerge (Figure 1).

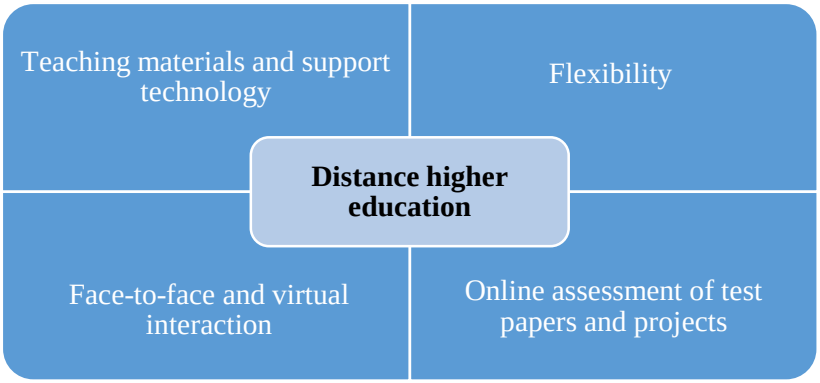


Figure 1. Characteristics to distance higher education practiced in Romania
Source: Interpretation of ARACIS standards

The documents developed by the Romanian Association for Quality Assurance in Higher Education establish that a distance learning study program can be offered entirely remotely or can be a combination of distance and face-to-face educational activities carried out on the university campus/at the headquarters of the higher education institution (ARACIS, 2020).

Detailing the characteristics:

- Teaching materials and support technology – dedicated platforms are used through which students can access teaching materials without preparation for each study subject, can upload test papers and receive feedback on them, can send questions to teachers.
- Flexibility – students can access course materials at any time, which allows them to organize their study program according to their own needs.
- Face-to-face and virtual interaction – lessons in the curricula are held in physical format but also as individual study, or accessing the course page in the forums dedicated to the subjects
- Online assessment of test papers and projects – self-assessment tests and test papers administered in the virtual environment, and feedback received electronically.

2.2. Theoretical considerations regarding two-way feedback in educational management

Hattie and Timperley (2007, p. 81) define feedback as "information provided by an agent (e.g., teacher, peer, book, parent, self, experience) about aspects of one's performance or understanding."
This definition can be considered as a starting point in justifying the need for feedback in the educational process. A learner as a desire or a necessity can view the accumulation of knowledge in a field. This

approach can be confirmed by a response from an informed person. In distance learning, even more so, the response needs to be prompt, in accordance with the specifications of the requirements and reasoned. Usually, teachers or even other colleagues provide feedback to learners on their achievements, assignments and projects, this approach having a strong and effective impact in facilitating learning (Hattie & Timperley 2007).

When it comes to distance learning in Romanian universities, the most widely used method of obtaining feedback from students is the use of standardized questionnaires in accordance with the requirements of the Association for Quality Assurance in Higher Education. However, the literature in the field states that this type of feedback provided at fixed intervals, usually semiannually, does not allow for a rapid improvement in the quality of the learning material in relation to the real needs of students (Kasakowskij et al, 2025).

Following the application of these questionnaires at the end of the course, the teacher cannot directly dialogue with the student who offered a certain opinion regarding the teaching activity or the teaching materials. All that can be done is a future improvement of the activity based on previous complaints.

In the tutorial activities carried out with physical presence, students can directly express their opinion regarding the applications and case studies presented by the teacher. In this way, the teacher can shape his speech, the content of the presentation, as well as its intensity.

Regarding the feedback that teachers give to students regarding their activity, this can manifest itself in several ways. Usually, discussions are held face to face in direct meetings, just as in the case of distance education. However, these types of meetings are of low frequency, taking place only a few times, for each discipline, during a semester.

Specific to distance education is the feedback on e-learning platforms, most often Moodle. This type of response from teachers can manifest itself by giving grades or points for the teaching tasks that students have to complete during the semester. Another way is to make recommendations in writing, on subject forums or directly next to a topic uploaded on the platform.

3. Discussions about how to get feedback in the long-distance education process. Case study

The implementation of two-way feedback is both a requirement of the authorities in the field and a necessity for continuous improvement of the educational process.

At the Distance and Part-time Education Center of the Petroleum-Gas University of Ploiești, the activity is regulated by quality procedures that aim to align with the requirements of the standards in the field. In this regard, it is aimed to obtain feedback from students in order to continuously improve the educational process.

The teaching staff is directly interested in the opinions of the students and, taking them into account, continuously shape their own activity.

On the other hand, students need feedback for their activities, assignments and projects, for a better understanding of the subjects and a timely completion of semester assignments.

Two-way feedback is of overwhelming importance in carrying out teaching activities, especially in the distance education process.

3.1. Student feedback

In order to obtain the students' opinion on concrete aspects of the educational act, a series of questionnaires are defined, specific to the directions that are being pursued. In this sense, the identification of problems and the response to them can be managed efficiently.

It is considered appropriate that the steps should aim at:

- Evaluation of teaching staff by students
- Evaluation of teaching materials made available on the e-learning platform
- Evaluation of the entire study program.

The popularization of the initiative to obtain feedback from students is done by posting these questionnaires on the e-learning platform at the deadlines specified in the quality procedures.

As an illustrative example, the questionnaire was selected through which students were questioned regarding their assessment of the study program. The questionnaire is part of the requirements that the

Romanian Agency for Quality Assurance in Higher Education specifies in the specific standard for distance education.
At the level of the Distance and Part-Time Education Center within the Petroleum-Gas University of Ploiești, this is specified in the operational procedures of the quality management system.
From the analysis of the number of responses received, it can be observed that students understood the usefulness of this approach and have a proactive attitude towards providing feedback.
To support these statements, figure 2 presents, illustratively, some of the results of the questionnaires launched on the e-learning platform in the last academic year. The example aims to identify students' opinions about the study program they are working on.

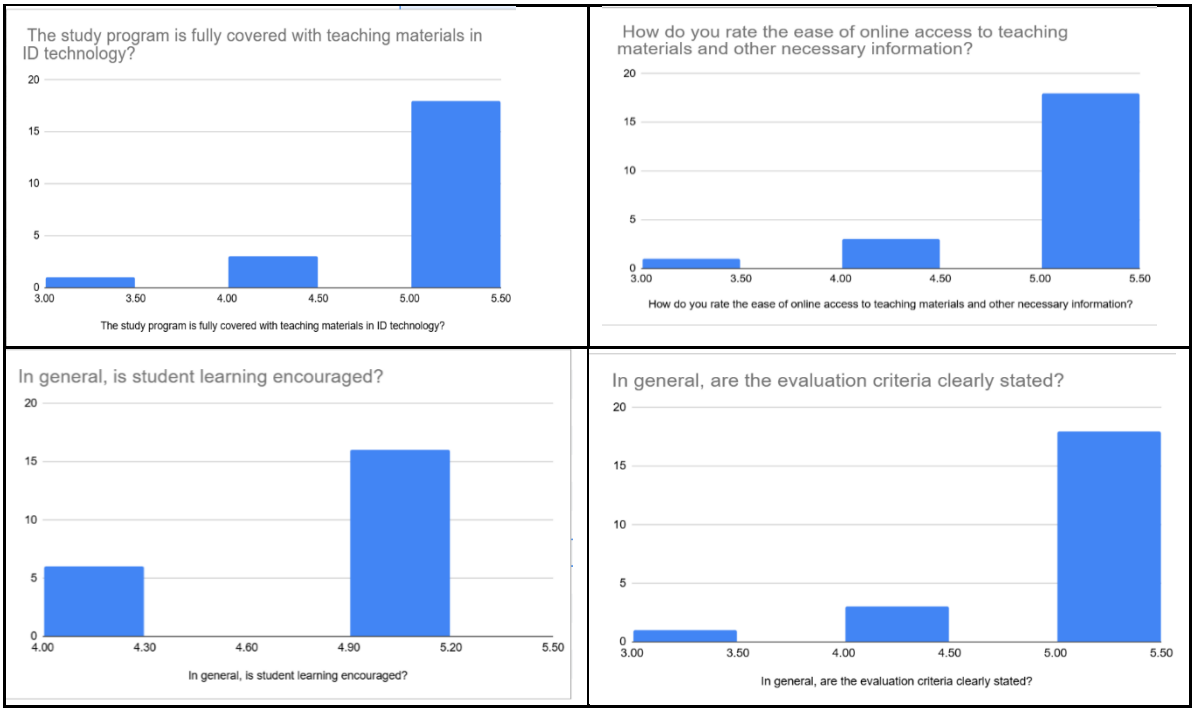


Figure 2. Interpreting the results of questionnaires launched on the e-learning platform
Source: Own processing

From the interpretation of the results, it observed that, in the vast majority, the students responses indicate a positive appreciation of the distance learning study programs. The grades were given from 1 to 5 and, from the graphic representation, it is seen that the trend is towards the maximum grade.
The importance of students' appreciation of the teaching activity in general, of the study programs and of the teaching materials made available to students, is obvious and creates a benchmark for the continuous improvement of the teaching process.

3.2 The other direction - teacher feedback

The entire activity of the students must be evaluate, appreciate and motivate by the reaction that comes from the teachers. Real-time evaluation, most often carried out online through eLearning platforms, is the most effective way for students to receive reactions from the evaluator. The purpose of feedback from teachers is to correct the trajectory of solving assignments, projects, to provide a score for self-assessment tests, so that students can quickly have a criterion for evaluating and improving their achievements.
Students complete their assignments according to the requirements received and taking into account the proposed deadlines. However, not infrequently, their achievements do not exactly meet what was requested. Feedback from teachers needs to come in a timely manner and contain information that allows students to correct their achievements.

The use of eLearning platforms in distance learning is an effective method through which student feedback is provided in a timely manner, thus creating a possibility for correcting assignments. The most commonly used feedback is provided through answers to test questions and self-assessment tests. When these answers are uploaded to the platform, students are notified via email or directly in the application, if they use this option.
Following this approach, feedback is beneficial for facilitating learning and achieving the objectives proposed through control assignments and semester projects.

4. Conclusions

Bidirectional feedback is an essential tool for the activity carried out in the learning processes. Its importance is obvious both for students who receive feedback from teachers and for teachers who can use feedback from students.
In this paper, a presentation of the state of theoretical achievements in the field was made and the necessity and importance of feedback in teaching activity was illustrated, especially in the distance learning, starting from the way in which this is carried out within the Distance and Short-Formality Education Center within the Petroleum-Gas University of Ploiești
The importance of bidirectional feedback in a digital learning environment is obvious and undeniable. Starting from self-assessment tests and real-time grading of control assignments and reaching the questionnaires accessed and completed by students, the synergy of these approaches leads to the possibility of fulfilling one of the major objectives of teaching activity, namely improving the teaching process.
The conclusions that emerge from the above analysis clearly highlight the fact that the opinions of both parties, students and teachers, are very important in the mutual shaping of the activity.
The correlation of the theoretical aspects, previously expressed by various authors, with the practical aspects highlighted by the case study, reinforces the author's opinion that supporting and developing ways to identify two-way feedback must be an important objective in the development of the distance education process.

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AI Applications in Renewable Energy Forecasting and Management

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Abstract: *The rapid global transition toward renewable energy sources has transformed the landscape of power generation across the European Union as well as in Romania, introducing both opportunities and challenges for energy systems. While wind, solar, and other renewable technologies offer significant environmental and economic benefits, their inherent variability, intermittency, and dependence on weather conditions pose substantial difficulties for accurate forecasting, grid stability, and efficient energy management, especially when paired to an aging infrastructure. Traditional statistical and physics based models have limitations in capturing the nonlinear and complex relationships present in renewable energy generation data, often resulting in operational inefficiencies. Artificial intelligence has recently emerged as a transformative solution to the complex issues energy systems face, providing advanced computational methods capable of processing vast datasets, detecting complex patterns, and generating accurate, real time predictions which help build a more resilient energy system. This paper provides a comprehensive overview of AI applications in renewable energy forecasting and management, examining a variety of techniques including machine learning algorithms, deep learning architectures, ensemble models and reinforcement learning frameworks. The study explores the use of AI in short term, medium term, and long term forecasting of renewable energy outputs, highlighting the importance of predictive accuracy for operational planning, energy trading, and grid balancing, especially in a challenging environment such as that of modern day EU. In addition, the paper investigates AI-driven strategies for optimizing energy storage systems, enhancing demand-side management, and supporting the integration of distributed energy resources into smart grids. The study underscores the critical role of AI as an enabler of sustainable, efficient, and resilient energy systems, while providing insights into future research directions aimed at fully realizing the potential of AI driven renewable energy forecasting and management.*

Keywords: *AI, Artificial Intelligence, Energy, Renewable Energy, Green Transition*

JEL Classification: *Q40, Q47, Q55*

1. Introduction

Global energy systems are witnessing a transformation, one driven by renewable energy. The imperative to limit global temperature rise has accelerated the deployment of renewable energy infrastructure at an unprecedented scale, and while these technologies support long-term sustainability goals, they also present operational challenges and introduce new complexities into power system operations. System operators and market participants are increasingly required to come up with new and innovative methods that can help them accurately forecast renewable energy production and demand in order to mitigate potential grid stability problems and market imbalances. While traditional forecasting models still provide a valuable baseline and are widely used today, their limitations are becoming increasingly apparent, especially in an era of extreme weather events, rising energy demand, and market uncertainty. Modeling the nonlinear dynamics that characterize renewable energy production (wind speeds in complex terrains, cloud formation and cover) requires the often rapid analysis and interpretation of large sets of data - something traditional methods are not able to do. However, the emergence of Artificial Intelligence and Machine Learning is quickly reshaping the way in which the energy sector approaches forecasting and management. AI is rapidly becoming an irreplaceable tool in a world where the shift from dispatchable fossil-fuel generation to non-dispatchable, weather-dependent sources is accelerating. The aim of this paper is to take an in-depth look at some of the novel ways in which AI is reshaping renewable energy forecasting and grid management.

2. Intermittency challenges and forecasting horizons

Legacy power grids operate under the assumption of controllable generation and variable demand. However, the core challenge of renewable energy production lies in its intermittency, which depends on nonlinear and highly volatile meteorological systems. Traditional forecasting models such as Numerical Weather Prediction and ARIMA lack the ability to make the short-term predictions required for renewable energy systems - predictions that often must account for local atmospheric fluctuations and ramp events, mesoscale weather dynamics, cloud motion, and a number of other variables. However, AI based solutions have the ability to make forecasts ranging from the very short term (seconds to minutes) up to weeks in advance. And while short- or very short-term forecasts are useful for quickly balancing production and demand, longer-term ones can prove crucial for planning market strategies as well as scheduling maintenance. As power grids themselves generate more and more data with the introduction of connected devices such as smart meters, recent scientific literature indicates a shift in AI methodologies - expanding from simple passive forecasting to active grid management that uses digital twins to simulate real-world scenarios and real time outcomes.

3. Advanced forecasting arhitectures and deep learning approaches

As was previously mentioned, while traditional statistical models are still in use, they are severely limited dut to their inability to process high dimensional exogenous variables such as air humidity, wind speed, air pressure and cloud cover. Modern advances in the field however, have brought along deep learning arhitectures that can model non linear realtions in order to provide a clearer, real time image of the energy system, its inflows and outflows. Recurrent Neural Networks for example have proven effective for short and medium term wind and solar forecasting that can use real time data as input in order to produce intra-hourly, hourly and daily predictions (Mishra, S. et. al. 2018). An even more powerful forecasting tool is the Temporal Convolutional Networks which, as opposed to RNNs, support paralell processing of the whole input sequence. This enables them to process every element in a data sequence simultaneously, greatly reducing the time required for training (Lara-Benítez, P. et. al. 2020). Given the fact that renewable energy production sites such as solar and wind farms are heavily influenced by geography, Spatio-Temporal and Graph-Based Models are perhaps some of the most powerful tools for predicting renewable energy output as they manage to capture both time dependent behavior and location dependent relationships (Verdone, A. et. al. 2024).

4. Digital twins – a game changer for the energy sector

When it comes to AI based solutions for the energy sector in general and for renewable energy in particular, perhaps no other technology shows as much potential as that of Digital Twins. The ideea might seem simple at first – a real time virtual simulation of a physical process, object or system. However, given the inherent complexity of energy assets such as powerplants, the grid or the entire energy system of a country coupled with a large number of exogenous variables, having the ability to run a real time simulation gives workers the ability to simulate a large number of scenarios and accurately predict their outcomes (Ismail, F. B. et. al. 2024). And while the practical applications of this technology can vary significantly, the end goal is the same – optimization. When used with live data from various types of equipment, the digital twin can help workers simulate a wide range of potential future scenarios that would otherwise be too costly or dangerous to test in the real world. This allows operators to identify how assets might respond to extreme conditions and schedule interventions well before a certain piece of equipment risks reaching the point of failure. Such interventions reduce the levelized cost of energy and ensure that a certain piece of equipment achives both maximum output and long term reliability. When it comes to solar energy for example, the technology provides the ability to pinpoint underperforming panels in large solar installations as well as calculate the most cost effective time for removing soiling (dust accumulation). But perhaps one of the most revolutionary uses for a digital twin in the energy sector is its unique ability to help manage a Virtual Power Plant.

5. Virtual Power Plants – the future of an AI managed energy sector?

The concept of Virtual Power Plants was first introduced in the late 1990s and early 2000s in an attempt to aggregate distributed energy sources such as small scale wind turbines, solar panels, and others into a single unit that could be remotely controlled from a single point and compete in wholesale energy markets. These small assets, often spread over a wide region, are controlled using software rather than traditional proximity based methods, and unified, they can be quickly dispatched to allow grid operators to balance supply and demand. Mostly made up of renewable energy sources, Virtual Power Plants quickly started replacing some fossil-fuel-based plants that had long startup times and could not be called upon for rapid grid interventions. Modern consumer-based Virtual Power Plants can aggregate millions of dispersed assets and devices owned by private individuals. While each device, taken individually, can only offer a few kilowatts of flexibility, combined together in a VPP, they can supply power or help reduce grid load at a scale comparable to that of a traditional power plant (Marinescu, B. et al., 2022).



Figure 1. Basic concept of a Virtual Power Plant. Multiple small energy producing assets can be called upon in order to feed power to the grid. The assets are not connected to each other and there can be significant physical distance between them. Made by the author using Canva.com.

Currently there are a number of such VPPs in operation in the United States, Australia and Europe. Artificial Intelligence plays an increasingly crucial role in modern VPPs. As Virtual Power Plants coordinate a large number of distributed energy sources, human operators alone would find it extremly difficult or even impossible to manage the complexity of such systems. However, AI makes real time coordination of all assets possible as it can handle forecasting (demand, supply, weather events), optimization, grid balancing, device coordination and market participation at the same time.

6. Conclusions

We are undoubtedly living in an era of accelerated AI growth and implementation across a large number of industries. The energy sector is one of the early adopters and as the shares of renewables will continue to increase in the energy mix, Artificial intelligence will most likely have to play an increasingly important role in energy operations management, forecasting and the real-time coordination of distributed energy resources. Its unique ability to quickly process large amounts of data makes it the perfect tool for managing more decentralized energy systems. While AI enabled forecasting and management tools represent one of the foundational pillars of green energy infrastructure, future work in the field will need to focus on improving physical – statistical approaches as well as integrating AI into enhanced weather models and across diverse grid environments.

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