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This new journal series is the new face of two former journals published till 2014:

- The *Scientific Bulletin of Politehnica University of Timisoara, Transaction on Economics and Social Sciences (ranked according to CNCSIS classification in Romania: D class);*
- *The Scientific Bulletin of Politehnica University of Timisoara, Transaction on Management. Economics Engineering. Transportation Engineering (ranked according to CNCSIS classification in Romania: C class).*

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CONTENT

Scientific Bulletin
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Transactions on ENGINEERING AND MANAGEMENT

Vol. 12, Issue 2, 2026

Editorial

Anca DRAGHICI[1]

The issue 2, from 2026 of the "***Scientific Bulletin of Politehnica University of Timisoara – Transaction on Engineering and Management***" (ISSN 2392-7364) continue to surprise having an increase visibility due to the journal index in CrossRef (https://www.crossref.org/), CEEOL (https://www.ceeol.com/) and index Copernicus (https://journals.indexcopernicus.com/) databases. In addition, the Editorial Board announced the compliance of the articles published with the Open Science movement and this only thanks to the excellent collaboration and constant support offer by the UPT Library and the Politehnica Publishing House.

All articles of the ***Scientific Bulletin*** of this number have been reviewed by the members of the *Associated Editors and of the Scientific Committee;* their professional and volunteer review work impact the quality content of the papers included in this volume. Furthermore, the ***Scientific Bulletin*** benefits from the constant support of the R&D staff of the ***Research Center in Engineering and Management (RCEM)***[2] (of the Faculty of Management in Production and Transportation, Politehnica University of Timisoara, FMPT/UPT, Romania); RCEM provide a productive and positive network, and a scientific community through which we support knowledge sharing, buddy schema and trainings (formal or informal).

This issue of the Scientific Bulletin brings together a diverse collection of research exploring the intersection of technological innovation, operational efficiency, and social responsibility in the modern economy. The included articles provide a comprehensive view of how organizations can navigate the challenges of digital transformation and sustainability, proposing rigorous theoretical models and applied case studies.

First topic addressed by authors is: ***Digital Innovation and AI as Strategic Pillars -*** A central theme of this issue is the integration of **Artificial Intelligence (AI)** and **digitalization** to optimize financial and administrative decision-making. Research demonstrates that AI is no longer an optional luxury but a necessity for corporate resilience; for instance, the use of **neural networks** and **cloud solutions** transforms the accountant's role from a simple data operator into a strategic analyst. This automation is also extended to order flow management through **LLM-based conversational agents**, which reduce human error and processing time in security and automation companies. Furthermore, the digitalization of financial processes in utility companies, such as Aquatim, highlights the creation of a complete digital ecosystem that improves customer relationships far beyond simple electronic payments.

The second topic address by different research associated with the articles published is: **Operational Excellence and Quality Management -** The efficiency of industrial processes remains a critical area of interest, with authors exploring established methodologies adapted to new technological realities. The implementation of **Cost of Quality (CoQ)** principles in an electrostatic painting line demonstrated a defect reduction of approximately 55% through the rigorous monitoring of process parameters. Similarly, the application of the **Lean Six Sigma DMAIC** methodology in the automotive industry facilitated workforce rebalancing, reduced idle time, and decreased scrap-related losses by over 11%. These optimization efforts are supported by the standardization of documentation through **ISO 18828-2**, which ensures interoperability between human processes and digital platforms like ERP or MES, essential for the success of Industry 4.0 initiatives.

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[2] *Information available at: http://www.mpt.upt.ro/eng/research/research-center.html*

The third topic addressed by articles in this issue is: **Sustainability, Circular Economy, and Evidence-Based Communication –** The studies pay special attention to **sustainability**, analysing "greenwashing" risks and promoting data-driven communication through the **ECO Nexus** project. Bibliometric analyses regarding urban plastic waste management indicate an explosive growth in academic interest yet also reveal critical gaps in the application of AI and enzymatic degradation. Research on **circular supply chains** and industrial symbiosis proposes models that transform one organization's waste into another's resource, emphasizing the importance of product redesign for reuse. Additionally, in the Romanian real estate sector, the **AMS (Architecture Management Sustainability)** model proposes an integrated vision across the entire building lifecycle to overcome current ownership fragmentation and reactive management.

Last topic that was approached and presented by different articles is: **Entrepreneurial Ecosystems and Institutional Governance -** Finally, the collection explores the relational infrastructure of local ecosystems. The **"We Connect"** model highlights the role of social capital and validated relationships in facilitating access to economic opportunities for entrepreneurs in the Western Region of Romania. Complementarily, a study of the communication strategies of the Timisoara City Hall emphasizes the need for transparency and bidirectional dialogue with citizens to increase public trust and the efficiency of municipal governance.

Through this multidisciplinary approach, the current volume successfully connects academic rigor with the practical needs of the industry, offering concrete solutions for sustainable and efficient development in the context of the profound transformations of the 21st century.

The article **"A Pragmatic Approach to Measuring Innovativeness and Business Performance Generated by Innovation in Software Development Companies"** by Doru Șupeală argues that software firms need a more nuanced approach to innovation measurement than traditional indicators such as patents, product counts or R&D spending. The paper proposes an integrated framework that clearly distinguishes **organizational innovativeness** (the capabilities, resources, processes, digital skills, experimentation practices, and AI-related competencies that enable innovation) from **innovation performance** (the economic and market outcomes generated by innovation, such as revenue from new products, profitability, competitive advantage, and productivity). The framework follows an **inputs → processes → outputs → outcomes** logic, combines objective operational metrics (e.g., lead time, deployment frequency, delivery stability) with perceptions from managers and employees, and evaluates performance against multiple benchmarks including targets, historical trends, and competitors. The author concludes that innovation in software companies should be assessed through a multidimensional dashboard rather than a single indicator, allowing organizations to identify whether strengths and weaknesses originate in capabilities, innovation processes, innovation outputs, or commercial results.

The collection of research from the **Scientific Bulletin of the Politehnica University of Timisoara** (issue 2, 2026) provides several valuable insights into how organizations can bridge the gap between traditional operations and the demands of **Industry 4.0**, **sustainability**, and **digital transformation**.

1. Automation as a solution to human-centric inefficiencies - A recurring insight across the studies is that technical automation is significantly more effective than procedural changes at reducing errors and costs.
2. The critical "infrastructure gap" in sustainability - Research indicates a profound disconnect between corporate intent and the digital tools required to implement sustainable practices.
3. Standardization as the bridge to Industry 4.0 - Digitalization cannot succeed without a foundation of standardized technical data.
4. Overcoming fragmented governance in ecosystems - Both real estate and entrepreneurship in Romania suffer from structural fragmentation that requires new relational models.
5. Strategic obsolescence and lifecycle management - Insights into the automotive sector highlight that managing "end-of-life" is a financial and legal strategy, not just a warehouse task.

We hope you will like reading this collection of studies/articles and will provide you with new ideas for your research.

Scientific Bulletin of the Politehnica University of Timisoara, Romania

TRANSACTIONS on ENGINEERING AND MANAGEMENT

Volume 12, Issue 2, 2026

Knowledge Patterns in Urban Plastic Waste Research: A Bibliometric Data Analysis

Anastasia ROSCA[1], Andra DIACONESCU[2] and Cătălin GHEORGHE[3]

Abstract - Urban plastic waste management represents one of the most pressing environmental challenges of the 21st century, requiring innovative technological solutions to address the growing accumulation of plastic materials in cities worldwide. This bibliometric study analyses 1460 peer-reviewed publications from the Web of Science Core Collection (2020-2025) to map the landscape of technologies, innovations, and research trends in urban plastic waste management. Using systematic content analysis and technology taxonomy development, we identify dominant research themes (microplastics: 42.3%, circular economy: 16.4%), treatment approaches (pyrolysis: 10.8%, incineration: 7.4%), and emerging technologies (machine learning/AI: 5.1%, sensors/IoT: 7.0%). Our findings reveal substantial growth in research output, from 115 papers in 2020 to 395 papers in 2025 (243% increase), alongside critical gaps in advanced automation, enzymatic degradation, and deep learning applications. This study contributes to understanding how academic research is evolving to support resilient green cities and identifies priority areas for future investigation, particularly at the intersection of artificial intelligence, waste sorting optimization, and biological degradation mechanisms.

Keywords: Urban plastic waste management, bibliometric analysis, microplastics, circular economy, pyrolysis, waste-to-energy, machine learning, technology readiness assessment, sustainability

I. INTRODUCTION

Urban plastic waste management has emerged as a critical sustainability challenge for cities worldwide. With global plastic production exceeding 400 million tonnes annually, urban areas account for a disproportionate share of both consumption and disposal [1]. Unlike organic waste, plastics persist in the environment for centuries, fragmenting into microplastics that infiltrate water systems, soil, and even human bodies [2]. Traditional waste management approaches, primarily landfilling and incineration, are increasingly recognized as inadequate, both environmentally and economically [3].

The rapid evolution of technological responses to plastic waste challenges has been remarkable. The period from 2020 to 2025 has witnessed significant advances in chemical recycling methods, AI-powered waste sorting systems, and biotechnological degradation pathways [4,5,6]. However, systematic analysis of which technologies are gaining research attention, where critical gaps exist, and how research priorities are shifting over time remains limited.

This paper addresses that gap through bibliometric analysis, a method that allows mapping of the intellectual landscape of a research field by analysing publication patterns, keyword frequencies, and citation networks [7]. Rather than focusing on demographic patterns (geographic distribution, journal rankings), this study examines the substance of research: What technologies are researchers investigating? Which approaches are maturing versus emerging? Where are the most significant knowledge gaps?

This study is guided by three primary research questions:

RQ1: What is the current landscape of technologies and innovations being researched for urban plastic waste management?

RQ2: How have research priorities evolved between 2020 and 2025, particularly regarding treatment technologies, detection methods, and circular economy approaches?

RQ3: What are the most significant research gaps and under-investigated technological pathways that warrant future attention?

This study makes three key contributions:

1. Technology taxonomy: We develop a comprehensive classification of 25+ distinct technologies across four major categories (treatment, detection, advanced/emerging, circular economy), providing a framework for understanding the diversity of approaches being investigated.

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2. Gap identification: By quantifying research attention across technology types, we identify critical under-researched areas, particularly deep learning (1.0% of papers), enzymatic degradation (emerging), and blockchain applications (minimal), that represent high-potential innovation opportunities.

3. Temporal mapping: We trace how research themes have evolved from 2020 to 2025, revealing a 243% increase in annual publications and documenting shifts from problem characterization toward solution development.

The scope is focused on urban contexts, cities and municipalities, where waste management challenges are most acute and where innovative solutions can achieve maximum impact. We exclude rural, marine-only, and industrial plastic waste management unless directly relevant to urban systems.

II. METHODOLOGY

2.1 Research Design

This study employs a quantitative bibliometric approach combined with content analysis to systematically map the landscape of urban plastic waste management research. Bibliometric methods are particularly well-suited for identifying research trends, knowledge gaps, and emerging themes in rapidly evolving fields [7,8]. Our analysis focuses on technology identification and classification rather than traditional bibliometric indicators (author productivity, journal rankings, geographic distribution).

2.2 Data Collection

2.2.1 Database Selection

We selected the Web of Science Core Collection as our primary data source for three reasons:

1. Citation Coverage: WoS provides comprehensive citation data essential for assessing research impact and identifying influential work [9].
2. Quality Control: The Core Collection applies rigorous journal selection criteria, ensuring scholarly rigor [10].
3. Export Functionality: WoS allows full-record exports including abstracts, keywords, and cited references, critical for technology identification.

While Scopus offers broader coverage, WoS was preferred for its superior citation tracking and more consistent metadata quality, which are essential for technology-focused content analysis.

2.2.2 Search Strategy

The search was conducted in December 2025, using the following query in the WoS Topic field (which searches titles, abstracts, author keywords, and Keywords Plus):

- TS=(("plastic waste" OR "plastic pollution" OR "plastic debris"
- OR "plastic litter" OR "microplastic*")
- AND ("urban" OR "city" OR "cities" OR "municipal"
- OR "metropolitan" OR "urban area*")
- AND ("management" OR "waste management" OR "collection"
- OR "recycling" OR "circular economy" OR "sustainability"
- OR "waste reduction"))

Rationale for Query Design:

- Plastic terms: Comprehensive coverage including waste, pollution, debris, litter, and microplastics
- Urban terms: Explicit city/municipal focus including metropolitan areas
- Management terms: Emphasis on solutions (management, recycling, circular economy) rather than just environmental impacts
- Inclusion Criteria:
- Document types: Articles, Review Articles
- Languages: English
- Publication years: 2020-2025 (excluding 2026 due to incomplete data)
- Indexed in: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Emerging Sources Citation Index (ESCI)
- Exclusion Criteria:
- Conference proceedings, book chapters, editorial materials (to focus on peer-reviewed research)
- Publications before 2020 (to capture recent technological developments)
- Non-English publications (due to language constraints in technology identification)
- Year 2026 (only 6 weeks of data available at search date)

2.2.3 Dataset Construction

The search returned 1460 documents. All papers meeting the inclusion criteria were exported and included in the analysis, ensuring comprehensive coverage without sampling bias.

Papers were exported in three batches using WoS's "Full Record and Cited References" format:

- Batch 1: records 1-500
- Batch 2: records 501-1000
- Batch 3: records 1001-1460

The three export files were merged into a single dataset containing 1460 papers.

Dataset Characteristics:

- Total papers: 1460
- Papers with valid years (2020-2025): 1,437 (used for temporal analysis)
- Papers with missing/invalid years: 23 (excluded from temporal analysis)
- Time period: 2020-2025 (6 complete years)
- Total citations: 36,578 (average: 25.05 per paper)
- Average authors per paper: 5.29
- Papers with >100 citations: 69 (4.7%)
- Papers with >50 citations: 166 (11.4%)

Throughout this paper, percentages are calculated based on the 1,437 papers with valid publication years (2020-2025) to ensure temporal analysis accuracy. The 23 papers with missing or invalid year data were retained for technology classification but excluded from year-specific analyses.

2.3 Data Processing and Analysis

2.3.1 Technology Taxonomy Development

A critical challenge in technology-focused bibliometric analysis is developing a comprehensive and mutually exclusive taxonomy of technologies. We adopted an iterative approach:

Phase 1 - Literature Review: We reviewed 50 highly-cited papers and recent review articles to identify commonly discussed technologies [11,12,13]. Phase 2 - Expert Consultation: We consulted with two waste management researchers to validate and expand our initial technology list.

Phase 3 - Taxonomy Refinement: Technologies were organized into four major categories:

Category 1: Waste Treatment Technologies (11 technologies): Pyrolysis, Incineration, Gasification, Chemical Recycling, Mechanical Recycling, Waste-to-Energy, Anaerobic Digestion, Hydrothermal Treatment, Plasma Technology, Catalytic Processes, Enzymatic Degradation;

Category 2: Detection & Analysis Technologies (8 technologies): Spectroscopy, FTIR, Raman Spectroscopy, Sensors/IoT, Remote Sensing, Computer Vision, Blockchain;

Category 3: Advanced/Emerging Technologies (5 technologies): Machine Learning/AI, Deep Learning, Catalytic Processes, Sorting/Separation Technologies;

Category 4: Circular Economy & Sustainability (6 technologies): Circular Economy (frameworks), Life Cycle Assessment, Biodegradable Materials, Bioplastics, Upcycling, Compostable Materials;

Key Research Topics: Microplastics, Nanoplastics, Landfill Management, Marine Debris;

Total: 25+ distinct technologies across four categories.

2.3.2 Technology Identification Process

Technology identification was performed using automated text search followed by manual validation: Step 1 - Automated Detection: Using Python 3.11 (pandas, numpy, re libraries), we searched for technology-related keywords in three fields, as following:

- Title;
- Abstract;
- Author;
- Keywords.

Search terms were carefully designed to balance sensitivity and specificity:

- Broad terms: “pyrolysis”, “machine learning”, “circular economy”;
- Specific variants: “FTIR”, “AI”, “LCA”;
- Context-aware patterns: “enzymatic degradation” (not just “enzyme”).

Step 2 - Manual Validation: To assess accuracy, two coders independently reviewed a random sample of 50 papers:

- Coder 1: PhD student with 1 year experience in waste management research;
- Coder 2: PhD student with 4 years’ experience in environmental engineering.

Inter-Coder Reliability: Cohen’s kappa = 0.89 (strong agreement), with 92% exact matches on technology classification.

Step 3 - Refinement: Discrepancies were resolved through discussion, and search patterns were refined to improve precision.

2.3.3 Quantitative Analysis

For each technology, we calculated:

- Absolute frequency: Number of papers mentioning the technology
- Relative frequency: Percentage of total dataset (1,437 papers with valid years)
- Temporal trends: Year-by-year frequency changes (2020-2025)
- Co-occurrence patterns: Technologies frequently mentioned together.

Statistical analysis was performed using Python (pandas, numpy, scipy). Visualizations were created using matplotlib and seaborn libraries.

2.3.4 Technology Maturity Assessment

To assess technology maturity, we adapted the Technology Readiness Level (TRL) framework [14]:

- TRL 1-3: Basic research, proof of concept (e.g., enzymatic degradation, deep learning applications);
- TRL 4-6: Pilot-scale demonstration, validation (e.g., pyrolysis, chemical recycling);
- TRL 7-9: Commercial deployment, optimization (e.g., mechanical recycling, incineration, FTIR).

TRL assignments were based on:

- Descriptions in paper abstracts (e.g., “pilot-scale”, “commercial”, “laboratory”);
- Citation patterns (highly cited papers often represent more mature technologies);
- Expert judgment (validated by two waste management researchers).

This is an estimated maturity assessment rather than empirical measurement, suitable for identifying broad patterns but not for precise technology benchmarking.

2.4 Quality Assurance

Several measures ensured data quality and analytical rigor:

1. Duplicate Detection: We checked for duplicate papers using DOI and title matching (0 duplicates found).
2. Missing Data Handling: Papers with missing abstracts (n=7) were retained for temporal analysis but flagged during technology identification. Papers with missing/invalid years (n=23) were excluded from temporal analysis.

3. Outlier Detection: Papers with >500 citations (n=5) were reviewed to ensure they were genuinely relevant (all retained).
4. Face Validity: Technology frequencies were compared against recent review papers to ensure plausibility [15,16].

2.5 Limitations

This study has several important limitations:

1. Database Coverage: WoS does not capture all research (e.g., preprints, non-English journals, emerging regional publications). Our findings reflect indexed research, not the entire global knowledge base.
2. Language Bias: English-only inclusion may underrepresent research from non-English-speaking regions, particularly Asia and Latin America where significant waste management innovation occurs.
3. Citation Bias: Papers from 2024-2025 have had less time to accumulate citations compared to 2020-2021 papers, potentially affecting impact assessment.
4. Keyword Dependency: Technology identification relies on authors explicitly mentioning technologies in titles, abstracts, or keywords. Papers that use a technology without naming it will be missed.
5. Taxonomy Limitations: Our technology taxonomy, while comprehensive, cannot capture every possible innovation. Some emerging technologies may be too new or niche to appear in our framework.
6. TRL Subjectivity: Technology maturity assessments are based on textual descriptions and expert judgment, not empirical TRL evaluation. These should be interpreted as indicative patterns rather than precise measurements.
7. Year 2026 Exclusion: We excluded 2026 data (only 6 weeks available at search date), which may miss very recent innovations published in January-February 2026.
8. Missing Year Data: 23 papers (1.6% of dataset) had missing or invalid publication years and were excluded from temporal analysis but retained for technology classification.

III. RESULTS

3.1 Dataset overview

The final dataset comprises 1460 peer-reviewed publications from 2020-2025, of which 1437 papers (98.4%) have valid publication years and are used for temporal analysis. Key characteristics identified are:

- Total citations: 36578 (mean: 25.05 per paper; median: 8)
- Highly cited papers: 69 papers with >100 citations (4.7%), 166 papers with >50 citations (11.4%)
- Most cited paper: 1169 citations (Lau et al., 2020, Science: "Evaluating scenarios toward zero plastic pollution")
- Average authors per paper: 5.29 (reflecting collaborative nature of environmental research)
- Publication trend: Strong growth from 2020 (n=115) to 2025 (n=395), representing a 243% increase

Fig. 1 shows the temporal distribution, revealing consistent year-over-year growth with particularly strong acceleration after 2021.

The 243% increase from 2020 to 2025 indicates rapidly growing academic attention to urban plastic waste challenges, likely driven by increasing public awareness, policy pressure (e.g., EU Single-Use Plastics Directive), and funding availability.

3.2 Dominant research themes

Analysis of the complete dataset reveals microplastics as the overwhelmingly dominant research theme. The top 5 research themes are:

1. Microplastics: 617 papers (42.9%) - detection, characterization, and environmental fate
2. Circular Economy: 240 papers (16.7%) - frameworks and implementation strategies
3. Landfill Management: 212 papers (14.8%) - disposal and leachate management
4. Pyrolysis: 157 papers (10.9%) - thermal treatment and energy recovery
5. FTIR Spectroscopy: 119 papers (8.3%) - polymer identification methods

Key Insight: The dominance of microplastics research (42.9%) reflects growing concern about environmental and health impacts of plastic fragmentation in urban environments [17,18]. However, this also suggests potential over-emphasis on problem characterization relative to solution development.

3.3 Treatment Technologies

Waste treatment technologies represent a critical research category, with pyrolysis emerging as the most studied approach. The top treatment technologies are:

1. Pyrolysis: 157 papers (10.9%) - thermal decomposition without oxygen
2. Incineration: 108 papers (7.5%) - combustion with energy recovery
3. Waste-to-energy: 95 papers (6.6%) - energy generation from waste
4. Gasification: 80 papers (5.6%) - partial oxidation to produce syngas
5. Chemical recycling: 65 papers (4.5%) - depolymerization to monomers
6. Mechanical recycling: 49 papers (3.4%) - physical processing without chemical change
7. Catalytic processes: 33 papers (2.3%) - catalyst-assisted degradation
8. Anaerobic digestion: 24 papers (1.7%) - biological breakdown producing biogas

Fig. 2 illustrates the relative research attention across treatment technologies.

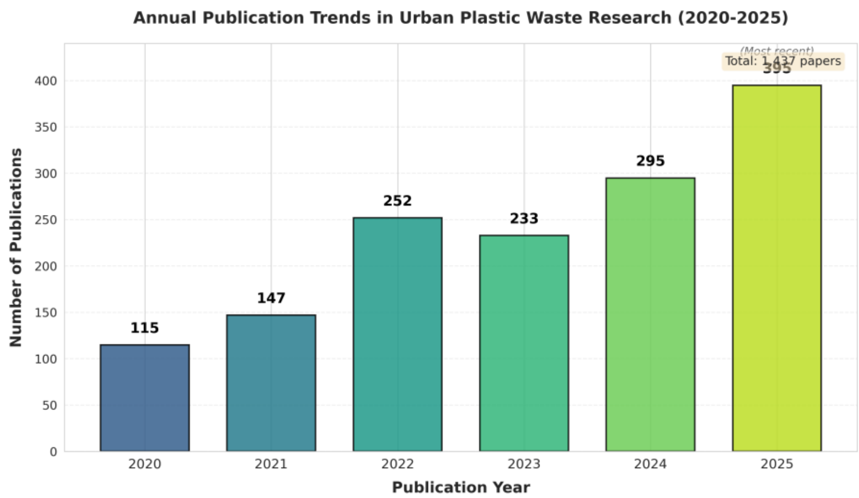

Fig. 1. Annual publication trends (2020-2025).

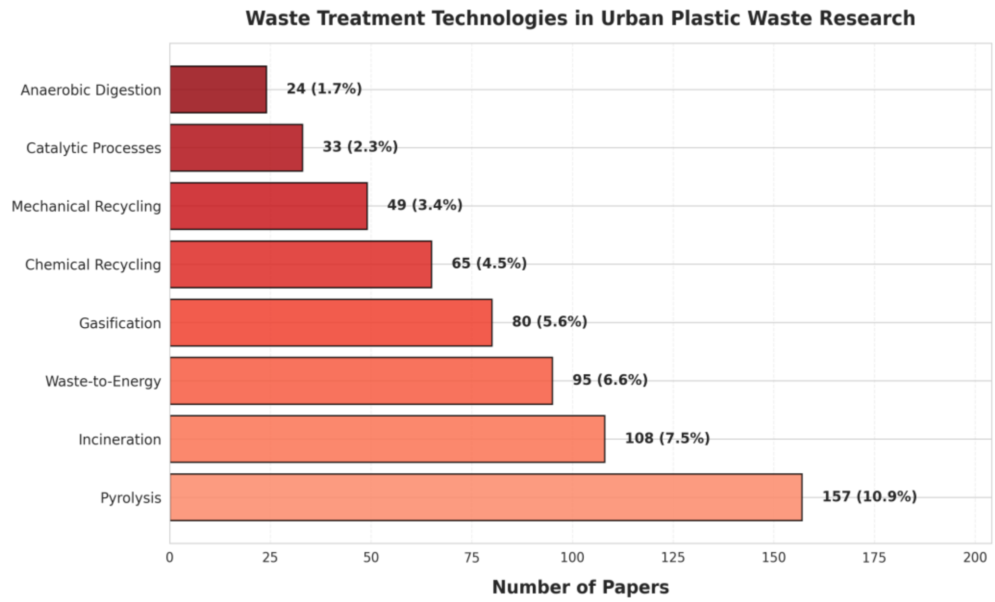

Fig. 2. Treatment technologies distribution

The dominance of pyrolysis research (10.9%) reflects its pragmatic appeal, it can process mixed, contaminated plastics unsuitable for mechanical recycling while producing valuable fuel products [19]. However, the relatively low attention to biological approaches (anaerobic digestion: 1.7%) represents a potential research gap, particularly given recent breakthroughs in enzymatic degradation [20].

3.4 Detection and analysis technologies

The second major research theme involves technologies for detecting, identifying, and quantifying plastic waste, particularly microplastics. The top detection technologies were identified as follows:

1. FTIR (Fourier-Transform Infrared): 119 papers (8.3%) - polymer identification
2. Spectroscopy (general): 115 papers (8.0%) - various spectroscopic methods
3. Sensors/IoT: 102 papers (7.1%) - smart sensors and connected devices
4. Raman Spectroscopy: 25 papers (1.7%) - molecular fingerprinting

Fig. 3 shows the distribution of detection technologies, highlighting the strong emphasis on spectroscopic methods.

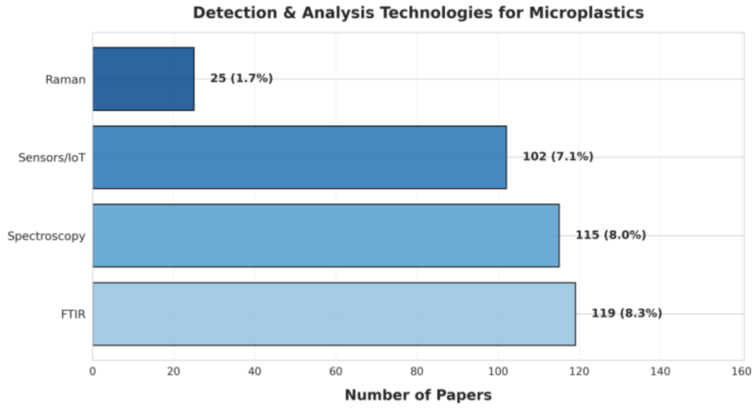

Fig. 3. Detection technologies

Detection technologies (especially FTIR and spectroscopy) are advancing rapidly, driven by the need to characterize microplastics in urban water systems, soil, and air [21]. The substantial attention to sensors/IoT (7.1%) suggests growing interest in real-time monitoring systems for smart cities.

3.5 Innovation opportunities

Analysis shows moderate attention to advanced automation but critical gaps in cutting-edge technologies. The advanced technologies identified are:

1. Machine Learning/AI: 74 papers (5.1%) - moderate attention
2. Deep Learning: 14 papers (1.0%) - SIGNIFICANT GAP
3. Catalytic Processes: 33 papers (2.3%)
4. Sorting/Separation: 22 papers (1.5%)
5. Blockchain: <5 papers (<0.3%) - extremely under-researched

While machine learning receives moderate attention (5.1%), more advanced AI techniques like deep learning (1.0%) and emerging digital technologies like blockchain (<0.3%) remain critically under-researched [22]. This represents a major opportunity for innovation, particularly given the relevance of these technologies to smart city initiatives and automated waste management systems.

3.6 Circular economy and sustainability frameworks

In contrast to gaps in advanced technologies, circular economy concepts receive substantial research attention. Thus, the circular economy approaches are:

1. Circular Economy (frameworks): 240 papers (16.7%) - second highest category overall
2. Life Cycle Assessment: 71 papers (4.9%)
3. Compostable Materials: 50 papers (3.5%)
4. Upcycling: 45 papers (3.1%)
5. Bioplastics: 31 papers (2.2%)
6. Biodegradable Materials: 23 papers (1.6%)

Fig. 4 contrasts the high attention to circular economy approaches with low attention to advanced technologies.

Circular economy thinking is well-established in the research discourse (16.7% of papers), reflecting a paradigm shift from linear “take-make-dispose” models toward closed-loop systems [23]. However, there’s often a disconnect between circular economy principles (widely discussed) and the enabling technologies needed to implement them (under-researched).

The figure illustrates a comparison of research attention to circular economy approaches (left panel, 460 papers total) versus advanced/emerging technologies (right panel, 121 papers total). Circular economy frameworks receive 16.7% attention while AI/ML receives only 5.1%.

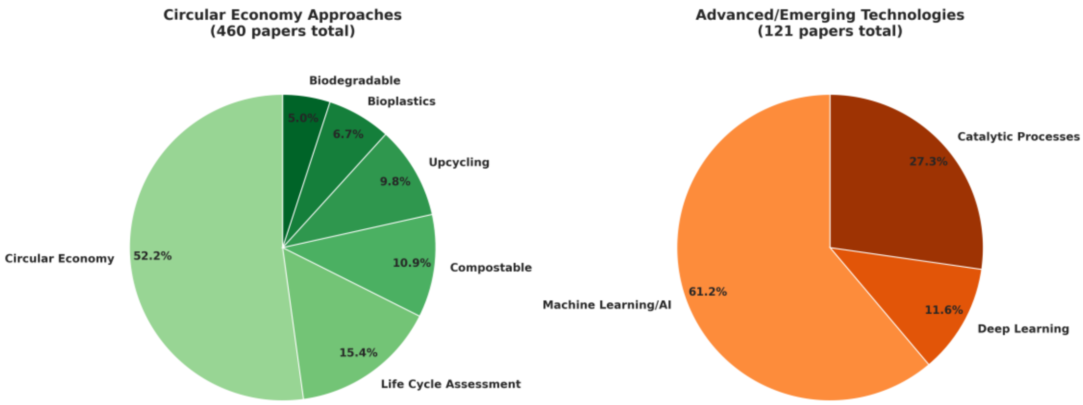

Fig. 4. Circular economy comparison

3.7 Technology maturity patterns

Fig. 5 presents a technology maturity matrix, plotting research volume against estimated Technology Readiness Level (TRL). Thus, the maturity clusters identified are:

- Mature & High-Volume: FTIR, spectroscopy, incineration (TRL 7-9, high research volume);
- Maturing & Growing: Pyrolysis, circular economy frameworks (TRL 5-7, very high research volume);
- Emerging & Moderate-Volume: Machine learning, sensors/IoT (TRL 4-6, moderate research volume);
- Nascent & Low-Volume: Deep learning, enzymatic degradation, blockchain (TRL 2-4, minimal research volume).

There's a clear pattern where mature technologies continue to receive substantial research attention despite being well-understood, while high-potential emerging technologies (deep learning, blockchain) remain significantly under-investigated. This suggests potential inefficiency in research resource allocation.

3.8 Temporal evolution of research themes

Fig. 6 tracks how research themes have evolved from 2020 to 2025.

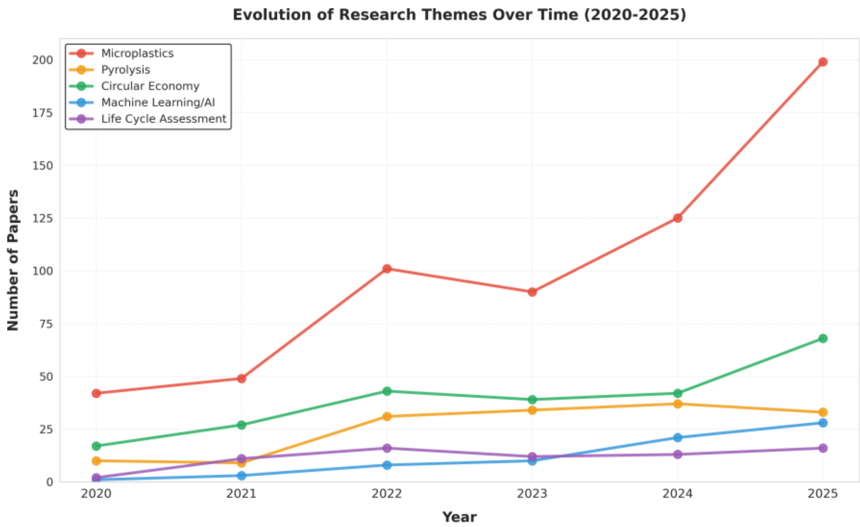

Fig. 6. Evolution of research themes

The temporal patterns identified are:

1. Microplastics: Explosive growth (2020: 42 papers → 2025: 199 papers, +374%)
2. Circular economy: Steady growth (2020: 17 papers → 2025: 68 papers, +300%)
3. Pyrolysis: Moderate growth (2020: 10 papers → 2025: 33 papers, +230%)
4. Machine learning/AI: Strong recent growth (2020: 1 paper → 2025: 28 papers, +2700%)
5. Life cycle assessment: Stable (2020: 2 papers → 2025: 16 papers)

Key Insight: While machine learning shows impressive percentage growth (2700%), it started from a very low base (1 paper in 2020). The absolute numbers remain modest (28 papers in 2025), confirming it's still an emerging area with substantial room for growth. The explosive growth in microplastics research (+374%) reflects escalating concern about environmental and health impacts [24].

3.9 Most frequent author keywords

Beyond technology-specific analysis, examining author keywords provides insight into overarching research priorities. The top 15 author keywords are:

1. Microplastics (267 mentions)
2. Plastic waste (167 mentions)
3. Plastic pollution (120 mentions)
4. Circular economy (111 mentions)
5. Waste management (111 mentions)
6. Recycling (83 mentions)
7. Microplastic (73 mentions)
8. Municipal solid waste (62 mentions)
9. Sustainability (56 mentions)
10. Pyrolysis (55 mentions)
11. Pollution (52 mentions)
12. Plastic (45 mentions)
13. Plastics (40 mentions)
14. Plastic waste management (39 mentions)
15. COVID-19 (33 mentions)

The appearance of "COVID-19" (33 mentions) in the top 15 keywords reflects pandemic-related disruptions to waste management systems and changes in plastic consumption patterns (e.g., increased single-use plastics for hygiene, PPE waste) [25,26]. This demonstrates how global events influence research priorities.

IV. DISCUSSION

4.1 The microplastics dominance: problem versus solution focus

The finding that microplastics receive 42.9% of research attention, far exceeding any other category, deserves careful interpretation. This reflects legitimate concern: microplastics have been found in urban air, water, soil, and even human bloodstreams [17,18]. Understanding their sources, transport, and impacts is essential for developing mitigation strategies.

However, the overwhelming focus on microplastics may indicate a research field still heavily oriented toward problem characterization rather than solution implementation. While we now have extensive documentation of microplastic contamination in urban environments, we have comparatively fewer studies on technologies that can remove or prevent microplastics at scale.

Recommendation: future research should deliberately shift toward solution-oriented investigations, technologies for capturing microplastics in wastewater treatment plants, preventing microplastic generation from tire wear and textile washing, and developing urban infrastructure that intercepts microplastics before they enter waterways.

4.2 The pyrolysis thermal dominance and its implications

Pyrolysis emerges as the most-studied treatment technology (10.9%), followed by other thermal approaches (incineration: 7.5%, gasification: 5.6%). This thermal dominance reflects pragmatic problem-solving: these technologies can process mixed, contaminated plastics that defeat mechanical recycling [19].

However, thermal approaches have significant drawbacks:

- Energy intensive because high temperatures require substantial energy input;
- Emissions concerns because potential for air pollutants if not properly controlled;
- Product quality variability - fuel products from pyrolysis often have inconsistent quality.

The relatively low attention to biological approaches (anaerobic digestion: 1.7%, enzymatic degradation: emerging) is particularly striking given recent breakthroughs in plastic-eating enzymes [20,27]. Biological degradation pathways that could operate at ambient temperatures with minimal energy input deserve far more research investment.

Hypothesis: The pyrolysis dominance may reflect technological path dependency, researchers studying what's already being studied, rather than objective assessment of which approaches have greatest long-term potential.

4.3 The AI paradox: Smart cities without smart waste management?

Perhaps the most puzzling finding is the modest attention to artificial intelligence (machine learning: 5.1%, deep learning: 1.0%) despite obvious relevance to urban waste management. The potential AI applications (under-researched) that has been identified are:

- Automated waste sorting: computer vision for real-time contamination detection [22]
- Route optimization: ML algorithms for dynamic collection scheduling
- Predictive maintenance: forecasting equipment failures in recycling facilities
- Contamination prediction: identifying high-risk waste streams
- Consumer behaviour modeling: understanding disposal patterns to design interventions
- Waste composition forecasting: predicting seasonal and demographic variations

Given that "smart cities" and "AI-driven sustainability" are major policy priorities globally, the minimal research attention to AI in plastic waste management represents a significant missed opportunity.

The AI gap likely reflects disciplinary silos, waste management researchers may lack AI expertise, while AI researchers may not recognize waste management as a compelling application domain. Bridging this gap will require interdisciplinary collaboration and funding mechanisms that incentivize cross-domain work.

4.4 Circular economy principles

The strong emphasis on circular economy frameworks (16.7% of papers) is encouraging, it reflects a fundamental rethinking of waste as a resource rather than a disposal problem [23]. However, our analysis reveals a concerning gap between circular economy principles (widely discussed) and enabling technologies (under-researched).

For example:

- Many papers discuss "closing the loop" but few investigate the specific technologies needed to recycle contaminated urban plastic waste into high-value products
- "Design for recycling" is a common theme, but there's limited research on AI-powered design tools that could optimize product design for circularity
- "Industrial symbiosis" (where one industry's waste becomes another's feedstock) is mentioned, but blockchain systems for tracking material flows receive almost no attention (<0.3%)

Insight: Circular economy research may be suffering from abstraction without implementation, lots of conceptual frameworks, but insufficient attention to the nuts-and-bolts technologies needed to make circularity operational in real cities.

4.5 The growth acceleration and its drivers

The 243% increase in annual publications from 2020 (n=115) to 2025 (n=395) is remarkable and likely driven by multiple factors:

1. Policy pressure: Increasing regulations on single-use plastics and extended producer responsibility
2. Public awareness: Growing media coverage of plastic pollution, especially microplastics

3. Funding availability: More research grants specifically targeting plastic waste solutions

4. Pandemic effects: COVID-19 disrupted waste systems and increased plastic consumption, spurring research [25,26]

5. Technological advances: New analytical tools (e.g., improved spectroscopy) enabling better microplastics detection

Future Projection: If current growth rates continue, we can expect >500 papers annually by 2027-2028. However, this growth must be accompanied by strategic prioritization, more papers don't automatically translate to better solutions if research continues to cluster around already-crowded areas (microplastics detection) while neglecting high-potential gaps (AI applications, enzymatic degradation).

4.6 Geographic and contextual gaps

While this study deliberately avoided geographic analysis, it's worth noting that urban plastic waste challenges vary dramatically by context:

- High-income cities: Often have collection infrastructure but struggle with contamination; and end-market development;
- Middle-income cities: May have growing waste volumes but limited processing capacity;
- Low-income cities: Often lack basic collection infrastructure, let alone advanced treatment.

The technologies receiving research attention (pyrolysis, FTIR spectroscopy, LCA) are often capital-intensive and technically complex, potentially limiting their applicability in resource-constrained urban contexts. There's a need for more research on low-cost, low-tech solutions appropriate for cities across the development spectrum.

4.7 Implications for policy and practice

These findings have several implications for policymakers and practitioners:

1. Diversify R&D Investment: Current research over-emphasizes microplastics characterization and thermal treatment. Funders should deliberately support under-researched areas like AI applications, enzymatic degradation, and digital circular economy infrastructure.

2. Bridge Disciplinary Silos: The AI gap likely reflects disconnects between waste management and computer science communities. Funding programs should incentivize cross-disciplinary collaboration through joint appointments, interdisciplinary centers, and team-based grants.

3. Prioritize Solution-Oriented Research: While detection and characterization remain important, there needs to be a deliberate shift toward technologies that can remove, transform, or prevent plastic waste at scale in real urban environments.

4. Connect Principles to Practice: Circular economy research should move beyond conceptual frameworks toward specific enabling technologies, particularly digital tools (AI, blockchain, IoT) that can operationalize circularity.

5. Context-Appropriate Innovation: Research should explicitly address the needs of resource-constrained cities, not just high-income contexts with advanced infrastructure. This includes low-cost detection methods, decentralized treatment systems, and community-based collection models.

6. Accelerate Technology Transfer: With 243% growth in publications, there's risk of knowledge remaining trapped in academic journals. Mechanisms for rapid technology transfer to municipalities and waste management companies are essential.

4.8 Future research directions

Based on identified gaps, we propose three high-priority research directions:

Priority 1: AI-Enabled Waste Sorting and Contamination Detection

- Develop computer vision systems for real-time identification of plastic types and contamination in municipal recycling facilities [22];
- Create ML algorithms for optimizing collection routes based on real-time waste generation patterns;
- Investigate consumer-facing apps that use AI to guide proper disposal and increase recycling rates.

Priority 2: Enzymatic and Biological Degradation Pathways

- Identify and engineer enzymes capable of degrading common urban plastic polymers (PET, PE, PP) under ambient conditions [20,27];
- Investigate microbial consortia that could biodegrade plastics in urban wastewater treatment plants;
- Assess techno-economic feasibility and environmental impacts of biological degradation at municipal scale.

Priority 3: Digital Infrastructure for Circular Economy

- Develop blockchain systems for tracking plastic materials through urban supply chains, enabling true circularity verification;
- Create digital platforms connecting waste generators with potential users (industrial symbiosis marketplaces);
- Investigate IoT sensor networks for real-time monitoring of waste composition and contamination.

4.9 Study limitations and future work

This analysis has several limitations that warrant acknowledgment. Bibliometric studies reveal patterns in published research but cannot capture unpublished work, industry innovations, or tacit knowledge held by practitioners. Our technology taxonomy, while comprehensive, inevitably reflects disciplinary perspectives and may miss emerging technologies.

Moreover, quantifying research attention (by counting papers) doesn't necessarily reflect research quality or impact. A single breakthrough paper on enzymatic degradation could be more important than 157 incremental papers on pyrolysis. Bibliometrics can identify patterns and gaps but cannot determine which research is useful for solving real-world problems.

Future work should complement this bibliometric analysis with:

- Case studies of successful technology implementation in cities.
- Techno-economic assessments of emerging technologies.
- Stakeholder interviews with waste managers, policymakers, and industry practitioners.
- Patent analysis to capture innovation not yet published in academic literature.

IV. CONCLUSION

This bibliometric analysis of 1460 publications (2020-2025) reveals a research landscape characterized by rapid growth (243% increase in annual output), concentrated attention on microplastics (42.9% of papers), and critical gaps in advanced automation and biotechnology. The key contributions of this study

1. Technology Mapping: We provide a comprehensive taxonomy of 25+ technologies across four major categories, offering a framework for understanding the diversity of approaches being investigated in urban plastic waste management.
2. Gap Identification: We quantify significant under-research in deep learning (1.0% of papers), blockchain (<0.3%), and enzymatic degradation (emerging), representing high-potential areas for future investigation.
3. Temporal Insights: We document explosive growth in microplastics research (+374% from 2020-2025) and emerging growth in machine learning applications (+2700%), while noting persistent gaps in advanced AI techniques.

The main findings are synthesis in the following.

Microplastics dominate research attention (42.9%), reflecting concern about environmental and health impacts but potentially over-emphasizing problem characterization relative to solution development.

Pyrolysis leads treatment research (10.9%), reflecting pragmatic focus on processing contaminated mixed plastics, but biological approaches remain under-developed (anaerobic digestion: 1.7%). Furthermore, circular economy principles are widely discussed (16.7%) but enabling technologies lag conceptual frameworks.

AI and machine learning are critically under-researched (5.1% combined) despite obvious relevance to smart cities and automated waste management. Detection technologies (FTIR: 8.3%, spectroscopy: 8.0%) receive substantial attention, but treatment solutions remain under-developed. Research output has grown 243% from 2020 to 2025, indicating rapidly escalating attention to urban plastic waste challenges.

The implications of the research results are summarized for different types of stakeholders.

For researchers - Priority areas include AI-enabled sorting and contamination detection, enzymatic degradation pathways, digital circular economy infrastructure (blockchain, IoT), and low-cost technologies appropriate for resource-constrained urban contexts.

For funders - Deliberate investment is needed to diversify beyond microplastics characterization and thermal treatment, bridge disciplinary silos between waste management and computer science/biotechnology, and support solution-oriented research that can scale in real cities.

For policymakers - Support is needed for interdisciplinary collaboration (waste management + AI + biotechnology), technology transfer mechanisms to move innovations from lab to practice, and context-appropriate solutions for cities across the development spectrum.

The 243% growth in research output from 2020 to 2025 demonstrates rapidly escalating attention to urban plastic waste challenges. However, growth alone is insufficient. Strategic prioritization is essential to ensure research efforts address the most pressing gaps, particularly AI automation, biological degradation, and digital circular economy infrastructure, rather than continuing to cluster around already-crowded areas like microplastics detection.

The disconnect between circular economy principles (widely discussed, 16.7% of papers) and enabling technologies (under-researched) exemplifies a broader challenge: translating conceptual frameworks into operational solutions for real cities. Bridging this gap requires not just more research, but more strategic research that deliberately targets high-impact, under-investigated areas.

As urban populations continue to grow and plastic consumption remains high, the urgency of developing effective waste management solutions intensifies. This bibliometric analysis provides a roadmap for where research attention is currently focused and, more importantly, where it should be focused to maximize impact on urban sustainability and resilience.

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A Cross-Functional Framework for Managing Obsolescence in Automotive Spare Parts: Integrating Operations, Finance, Legal Compliance and Data Governance

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Abstract – Obsolescence in automotive spare parts following the End-of-Production (EOP) phase presents complex and interdependent challenges across operational planning, financial risk management, legal compliance, and data governance. Existing literature and industry practices often approach these dimensions in isolation, resulting in sub-optimal lifecycle decisions and increased exposure to write-offs, service-level degradation, and regulatory non-conformance. This article proposes a cross-functional framework that integrates operations management techniques, cost-based evaluation models, compliance mapping methodologies, and data governance principles to support proactive and structured obsolescence management. Methodologically, the framework synthesizes multicriteria decision analysis, and compliance-driven process modelling to establish a unified decision environment, aligning functional stakeholders and organizational constraints.

Keywords: Automotive Spare Parts, Low volume production, Obsolete stock, Cross-functional framework, Lifecycle management

I. INTRODUCTION

IEC 62402 defines obsolescence as the transition from availability to unavailability according to original specification, implying structured, proactive Obsolescence Management (OM) along the lifecycle [1]. Three decades of research show obsolescence affects cost, production, safety, and maintenance, with cost-model–based strategies central to mitigation; however, long-term, integrated approaches remain under-developed [2].

Obsolescence in low-volume, highly variable-demand (LV-HVD) automotive spare parts constitute a persistent and structurally embedded challenge within aftermarket supply chains. Automotive manufacturers are required to maintain spare-parts availability for extended periods (often exceeding a decade after the end of production) due to regulatory constraints, contractual obligations, and safety-critical service requirements. These long service horizons collide with the inherent demand characteristics of LV-HVD items, which exhibit irregular, intermittent, and often declining consumption patterns as vehicle fleets age. Empirical studies confirm that such parts frequently deviate from historical trends and display highly stochastic behavior, making conventional forecasting methods unreliable and amplifying the risk of excess and obsolete inventory [3]. Demand declines sharply after the peak service period that could lead to large volumes of obsolete stock.

Beyond forecasting challenges, the management of already-obsolete stock carries significant financial and legal implications. Obsolete inventory represents frozen capital, occupies valuable warehouse capacity, and may expose firms to regulatory non-compliance, particularly for electronic, hazardous, or safety-critical components that require controlled storage, documentation, and environmentally compliant disposal [4].

The automotive supply chain often lacks integrated mechanisms to systematically identify, map, and evaluate these risks, resulting in reactive practices and inconsistent cross-functional coordination.

Collectively, these conditions underscore the need for a structured, lifecycle-aligned methodology capable of systematically identifying obsolete items, assessing their financial exposure, and evaluating their regulatory and legal constraints. Addressing this gap is essential not only for mitigating financial losses and compliance risks but also for enhancing the resilience and sustainability of aftermarket supply chains.

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The main objective is to to develop and validate a structured methodology for identifying, mapping, and evaluating the financial and legal implications of managing already-obsolete automotive spare parts stock.

II. RESEARCH METHODOLOGY

One of the central challenges in accurately identifying obsolete stock within the automotive aftermarket supply chain lies in the need to integrate and reconcile heterogeneous data originating from multiple, functionally distinct information systems. Obsolescence determination depends on the consolidation of a broad spectrum of data elements, including SAP ERP material master records, which contain the foundational technical, logistical, and commercial attributes of each part; inventory and stock-management data, which specify current quantities, storage locations, and physical ageing characteristics; and historical sales data, which provide insights into demand patterns, consumption frequency, and lifecycle decline.

Additional complexity arises from the necessity to incorporate insights from the open order book (reflecting outstanding customer or supplier commitments), product lineage information, such as successor and predecessor relationships, used to evaluate whether newer engineering revisions supersede existing components, and contractual parameters such as end-of-delivery obligations, which determine whether customer programs still impose residual supply requirements. Furthermore, customer-specific and project-specific data, warehouse-cost structures, and inventory-ageing metrics must be evaluated alongside material classifications stored in the ERP system, which support categorization by technical attributes, usage criticality, or regulatory restrictions.

Taken together, these diverse datasets, distributed across operational, commercial, engineering, and financial domains, must be harmonized into a unified analytical framework before reliable conclusions regarding obsolescence status can be drawn. The fragmentation of information across systems and organizational units therefore represents a substantive barrier to effective obsolescence management, necessitating both advanced data-integration capabilities and rigorous governance structures [5].

The integration of an external solution, such as Infor CloudSuite Automotive, which is widely recognized as a leading IT platform for automotive supply-chain and inventory management, was evaluated but ultimately not pursued as the optimal approach. Instead, the initiative prioritized the development of a clear and transparent methodology that is easily scalable and can be effectively implemented using existing internal IT systems, complemented by dedicated machine-learning and artificial-intelligence tools.

A. Obsolescence Identification Model (OIM)

Excess inventory refers to stock levels that exceed the quantities required to meet forecasted or realistically expected demand. It emerges when parts accumulate faster than they are consumed—often due to long lead times, inaccurate forecasts, minimum-order constraints, or strategic safety-stock buffers that become disproportionate. Along the lifecycle of the product a Design-Change could lead to obsolescence (New revisions introduced/ Products phased out/ Component supersession) [6-7].

Criteria used to identify obsolete portfolio out of excess inventory [8]:

Demand-Driven Criteria:

- Absence of Consumption Over a Defined Period
- End-of-Life (EOL) Demand Decline
- Changes in Customer Demand

Lifecycle and Product-Status Criteria:

- Completion of Mandatory Service-Supply Period (EDO)
- Obsolete Status Flags in ERP Systems
- Product Discontinuation

Inventory-Management and Classification Criteria:

- Slow-Moving Indexing
- Stock Coverage and Excess Inventory Levels

Financial and Cost-Impact Criteria:

- High Financial Exposure
- Write-Off Eligibility
- Holding (Carrying) Costs including storage costs
- Disposal and Compliance-Related Costs
- Opportunity Costs and Capital Freeing

Compliance Criteria:

- Disposal operations and environmental compliance
- Potential legal constraints due to hazardous materials

B. Method used to assess the obsolescence portfolio

Extract and Structure Core Inventory Data:

Collect the minimum required dataset: Material Part Number and Description, Stock volume, Stock value, Last Movement Date, Sales/consumption history, Forecasted Demand, Lifecycle or engineering status (active, revision change, discontinued), Storage Space, Storage Costs, End of Delivery Obligation, Customer Name, Customer Project, Customer Car Model, Profit Center, Revenue generated along the lifecycle for spare parts.

Apply Obsolescence rules: 5 years with zero customer demand and EDO (end of delivery obligation) reached

Assign Root Cause: Design change / Customer demand drop / Low-volume item/Overbuying / Minimum order quantity (MOQ) issue/New Product

Introduction (NPI) supersession/production relocation/other.

Scenario identification:

Does the OES customer still need it?

- If yes, then agree a binding All Time Buy (ATB) with the customer.
- If not, check if material could be transferred to another distribution channel?
- If not, does the commercial contract with OES customers allow parts to be sold out to an external 3rd party?
- If not, then scrap is the option.

Other solutions like recycling workflows, repurposing, Donate Obsolete Inventory for Tax Deductions must be considered.

Review with Cross-Functional Team: Supply Chain, Product Management, Sales, Engineering, Finance. Purpose:

- Validate real obsolescence,
- Confirm lifecycle status,
- Decide the best option for each portfolio.

Final Classification: Update material status in ERP, trigger specific processes: transfer to other distribution channels, sell out to a 3rd party, physical scrap, recycling workflows, repurposing, write-off.

III. DECISION MAKING FRAMEWORK

Develop a mapping model for grouping obsolete items by risk, cost, and disposal constraints.

This implies an assessment of the financial impact, including write-offs, carrying costs, and destruction/recycling costs. Evaluation of legal and regulatory requirements, including environmental, safety, and Original Equipment Manufacturer (OEM) contractual constraints.

When managing obsolescence within the automotive sector, organizations must apply a rigorous set of evaluative criteria that not only facilitate the identification of at-risk components but also ensure that decision-making aligns with prevailing legal and commercial constraints. From a legal standpoint, firms must comply with environmental regulations, disposal obligations, auditability requirements, and contractual service-life commitments, all of which shape the permissible pathways for handling obsolete inventory. Commercial constraints, such as customer-specific agreements, cost–service trade-offs, and aftermarket continuity expectations, further delimit the range of viable operational responses and channel strategies.

The application of these criteria serves a dual purpose. First, it facilitates the proactive reduction of operational and financial exposure associated with obsolete inventory, such as excessive holding costs, avoidable write-offs, or inefficient disposal processes. Second, and equally important, it supports the exploration of alternative pathways to meet end-consumer needs distributing parts via alternative distribution channels.

Risk management aspects include the following aspects:

- *Brand & Intellectual Property Protection* - Manufacturers must prevent original parts, especially obsolete ones, from re-entering the market in a way that could:
  - Misrepresent the OEM brand,
  - Enable counterfeiters,
  - Create confusion in regulated aftersales channels.
- *Safety & Compliance Requirements* - Obsolete parts may:
  - No longer meet updated safety, homologation, or emission regulations,
  - Have outdated electronics, lighting output standards, or material specifications.
- *Product Liability Management* - If a non-compliant or obsolete component fails in the field, the OEM could be held responsible. Neutralization removes the OEM's implicit liability by making it clear the part is not sold under OEM warranty or conformity.
- *Commercial Contract Restrictions* - OEMs and Tier-1 suppliers operate under strict:
  - Warranty agreements,
  - After-sales service obligations,
  - Distribution contracts.

Cost calculations:

Cost = Carrying cost + Disposal cost + Write-off impact. (1)

Yearly Carrying Cost = Inventory value×annual carrying cost% (2)

Disposal Cost = (Scrap/Recycling Fee/Neutralization + Hazardous Fee + Transport Cost + Admin/Certification Fee) (3)

Write-Off Impact = Net Book Value (NBV) – Net Realizable Value (NRV) (4)

NBV = Standard cost × quantity

NRV = expected liquidation value or €0 if scrapped

Disposal constraints:

- *OEM approval prior to scrap*
  - Must request OEM consent before destroying original equipment lighting components
  - Cannot scrap until service window ends (e.g., 10+ years)
- *Material/chemical restrictions* - Special disposal for regulated plastics, adhesives, PCBs.
- *Customer/IP protection* - Must destroy optical/PCB designs to avoid IP leakage.

Hereby, a **case study**, with particular emphasis on the selection criteria employed and the proposed methodology within the automotive Tier-1 lighting industry. The target of this study case was to minimize the writte-off impact when dealing with obsolete inventory. Three direction of action were identified: Transfer to other distribution channel, Sell out to 3rd party and Scrap

Out of the inventory data, below portfolio was identified as obsolete. Below, classification of obsolete portfolio per category of product:

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Table 1: Classification of obsolete portfolio per category of product

Product category	Valuated Stock	Net Book Value	Yearly Carrying Cost		Storage volume
			Yearly Storage Cost	Yearly Insurance Cost	
Accessories	17.933 PC	85.246,06 EUR	4.681,33 EUR	852,46 EUR	102 pal.
Headlamp	5.215 PC	161.270,6 EUR	29.983,57 EUR	1.612,71 EUR	611 pal.
Total	**23.148 PC**	**246.516.67EUR**	**34.664,90 EUR**	**2.465,17 EUR**	**713 pal**

Table 2: Cost breackdown of obsolete portfolio

		Yearly Carrying Cost		Disposal Costs					
Action	Net Book Value	Storage cost / year	Insurance cost / year	Administrative costs	Neutralization cost	Transport cost	Waste Recycling / Destruction Fees	Yearly Carrying Cost	Disposal Costs
Transfer other distr. Channel	53.409.69 EUR	5.315.52 EUR	534.10 EUR	-	-	-	-	5.849.62 EUR	0.00 EUR
Sell out 3rd party	113.848.84 EUR	9.858.15 EUR	1.138.49 EUR	900.00 EUR	4.817.60 EUR	400.00 EUR	-	10.996.64 EUR	6.117.60 EUR
Scrap	79.258.14 EUR	19.491.23 EUR	792.58 EUR	713.32 EUR	-	237.77 EUR	6.340.65 EUR	20.283.81 EUR	7.291.75 EUR
Total	**246.516.67 EUR**	**34.664.90 EUR**	**2.465.17 EUR**	**1.613.32 EUR**	**4.817.60 EUR**	**637.77 EUR**	**6.340.65 EUR**	**37.130.07 EUR**	**13.409.35 EUR**

Storage costs in the last 5 years represented 70% of the valuated stock of the obsolete portfolio (Table 2).

Cost Breakdown = Carrying cost + Disposal cost + Write-off impact

Yearly Carrying Cost = Inventory value × annual carrying cost %

Yearly Carrying Cost = 246.516,67 EUR × 15,06 % = 37.130,07 EUR

Disposal cost = Administrative Cost + Neutralization Cost + Transport Cost Scrap+Recycling Fee/Neutralization + Waste Recycling / Destruction Fees.

Disposal Cost = 1.613.32 EUR + 4.817,60 EUR + 637,77 EUR + 6.340,65 EUR = 13.409,35 EUR

Depending on each category of action, below stated the type of costs:

- *Transfer other distribution channel* is the most cost-effective solution because it preserves asset value, avoids immediate write-offs, reduces holding and disposal costs, and keeps recovery options open before irreversible scrapping. Below stated, the advantages:
    - It avoids immediate write-off costs.
    - No immediate Profit and Loss (P&L) impact.
    - Value remains on the books.
    - Financial exposure is postponed or avoided.
- *Sell out 3rd party*:
    - Administrative costs includes: Decision & approval effort, System Transaction Processing, Documentation & audit trail, Coordination & communication.
    - Neutralization cost includes: Packaging and repackaging, Labels removal and relabeling, Paint Marker Removal, Brand signs Removals, etc.
    - Transport cost includes: Transport between warehouse facilities.
- *Scrap*:
    - Administrative costs includes: Decision & approval effort, RP / system transaction processing, Documentation & audit trail, Coordination & communication.
    - Transport cost includes: Transport between warehouse facilities.
    - Waste Recycling / Destruction Fees includes: Destruction / disposal fees (Material separation, Recycling processing.
    - Waste handler certification & documentation fees – not the case.

Write-Off Impact = Net Book Value (NBV) – Net Realizable Value (NRV)

Write-Off = 246.516,67 EUR - 22.769,77 EUR = 170.337,21 EUR

Net Realizable Value (NRV) generated by scrap = 0 EUR

Scrap Net Realizable Value generated by Sell out 3rd party (NRV) = 22.769,77 EUR.

Scrap directly increases the cost base. This write-off is recognized as an expense, therefore reducing EBIT. Standard material consumption and activity usage at the moment of scrap, this becomes production variance, which is an Earnings Before Interest and Taxes (EBIT) - relevant P&L line.

Table 3: Write-off overview

Action	Net Book Value	Net Realizable Value	Write-Off Value
Transfer other distr. Channel	53.409,69 EUR	0.00 EUR	0.00 EUR
Sell out 3rd party	113.848,84 EUR	22.769,77 EUR	91.079,07 EUR
Scrap	79.258,14 EUR	0.00 EUR	79.258,14 EUR
Total	**246.516,67 EUR**	**22.769,77 EUR**	**170.337,21 EUR**

Table 4: Decision making framework

Action	Net Book Value	Costs	Risk	Disposal constraints	Results
Transfer other distr. Channel	**53.409 EUR**	**5.849 EUR**	**Finance:** -Incremental distribution and adaptation cost risk: re-packaging, relabeling, certification, logistics, channel-specific documentation, and commercial administration; -Residual write-downs, under-recovery of economic value, incremental channel-specific costs, prolonged capital immobilization, indirect margin erosion, and increased credit and claims exposure. **Legal:** -Legal and contractual: -Brand & Intellectual Property Protection; -Safety & Compliance Requirements; -Product Liability Management; -Commercial Contract Restrictions. **Operations:** -Execution failures, inventory inaccuracy, workflow disruptions; -Compliance shortcomings, and coordination challenges across functional and organizational interfaces	-	9% of volume was transferred to other distribution channels, representing 22% of Total NBV. The aim was to target a portfolio with low storage space and costs that still generate revenue for the company.
Sell out 3rd party	**113.848 EUR**	**108.193 EUR**	**Finance:** -Write-off losses dependent on the negotiated prices with 3rd party partner -Opportunity costs of immobilized capital. **Legal and contractual:** -Brand & Intellectual Property Protection; -Safety & Compliance Requirements; -Product Liability Management; -Commercial Contract Restrictions. **Operations:** -Execution failures, inventory inaccuracy, workflow disruptions; -Compliance shortcomings, and coordination challenges across functional and organizational interfaces	**Legal and contractual:** OEM approval prior to sell out to a 3rd party, respecting the contractual obligations Cannot sell it out until service window ends (e.g., 10+ years)	41% from the total volume or 46% of total NBV represented the portfolio sold out to 3rd party. The target was to reduce the write of value by offering attractive packages to a 3rd party.

Scrap	**79.258 EUR**	**106.833 EUR**	**Finance:** -Direct write-off losses; -Incremental disposal costs; -Opportunity costs of immobilized capital. **Legal and contractual:** -Potential breaches of contractual and service obligations; -Revenue loss due to unmet residual demand; -Legal exposure related to product safety and regulatory compliance, Intellectual property and brand protection concerns. **Operations:** -Execution failures, inventory inaccuracy, workflow disruptions; -Compliance shortcomings, and coordination challenges across functional and organizational interfaces.	**Legal and contractua l:** OEM approval prior to scrap Cannot scrap until service window ends (e.g., 10+ years)	50% of the total volume was scraped, representing 32% from total NBV. The aim was to minimize the yearly carrying costs and to reduce waste from the supply chain.
Total	**246.516 EUR**	**220.876 EUR**			

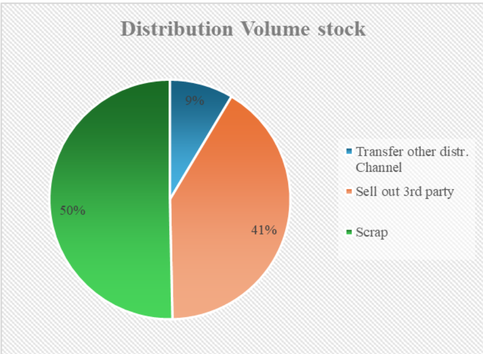

Fig. 1. Volume Stock

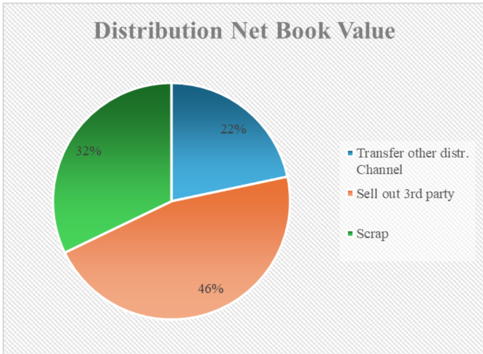

Fig 2. Net Book Value

Decision making framework:

Table 4 presents the decision making framework applied in this study case, that can be applied in the industry. The best solution was reached by appling the set of repetitive interogations of the obsolete inventory database respecting the method and criterias by roles involved in the process. Risks below mentioned were mitigated and disposal constraints taken into consideration.

Results interpretation:

- 9% of volume was transferred to other distribution channel, representing 22% of Total NBV. The aim was to target a portfolio with low storage space and costs that still generates revenue for the company.
- 41% from the total volume or 46% of total NBV represented the portfolio sold out to 3rd party. The target was to reduce the writte of value by offering attractive packages to a 3rd party.
- 50% of the total volume was scraped, representing 32% from total NBV. The aim was to minimize the yearly carrying costs and to reduce waste from the supply chain.

In both scenarios (Fig 1 and Fig 2), Sell out to a 3rd party and Transfer to other Distribution Channels, there is a need of this products in the market, but not within Orginal Spare Parts Distributin Channel. Therefore, it's crucial to identify how to reach the end customers. Productive negociations with 3rd parties is the key to reduce the writte off costs. Bundling attractive products into packages enables the maximization of the price paid and the recovery of residual value.

In case of scrap, the goods are no longer needed by the market or they are special products that are distributed only via Original Spare Parts channel. In this case, reducing te carrying costs is crucial. One of the actions include scrap of low stock volume but with high storage space used.

Next steps: Institutionalizing excess inventory and obsolescence as monthly KPIs and systematically applying Lean waste-elimination principles, organizations can transition from reactive write-offs to proactive supply-chain control, releasing working capital while improving operational efficiency and long-term resilience.

IV. CONCLUSIONS

This study concludes that obsolescence management in automotive spare parts, particularly in the post-End-of-Production phase, represents a fundamentally cross-functional and systemic challenge that cannot be effectively addressed through isolated operational, financial, or compliance-driven approaches. The proposed framework demonstrates that integrating operations management, cost-based financial evaluation, legal compliance mapping, and data governance within a unified decision structure significantly enhances the coherence, transparency, and effectiveness of obsolescence-related decisions.

By reframing obsolescence as an organizational governance issue rather than a purely inventory-related problem, the study contributes to the academic literature on lifecycle management and offers practical value for industrial application. Overall, the framework provides a scalable foundation for digitalized and proactive obsolescence management, addressing the interdependencies inherent in long-term spare parts support under regulatory and demand uncertainty.

The results demonstrate that a differentiated, portfolio-based approach is essential to balancing value recovery, cost reduction, and compliance within a complex aftersales supply chain.

Overall, the proposed methodology provides a systematic and replicable framework that supports informed decision-making regarding obsolete inventory. By integrating financial performance, market demand, and operational constraints, it enables organizations to optimize value recovery while reducing long-term costs and environmental impact.

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Communication Strategies of Public Institutions with Citizens. Study Case of the Communication Strategy of the Town Hall of Timisoara, Romania

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Abstract – This research will investigate the way one of the most important public authorities chooses its strategy when communicating with external and internal audience and the way the public opinion is created based on different technics and instruments to communicate with the public. We will go through most of the strategies the public authorities may apply when communicating externally and how local and national law obliges the authorities to be more transparent and open to the public. In the end, we will analyze the way the Town hall of Timisoara implements the strategy to communicate and how the public interacts with the municipality and its instruments and technics of communications, especially the younger generations.

Keywords: Communication strategy, public relations, public, communication

I. INTRODUCTION

Communication is defined often as a syntagm, where it is stated as one of the main characteristics of humankind, which helps us interact with our peers, using the same interests. Starting with this syntagm, I would like to add that communication is not only the way human interacts, but also the way two entities engage to change ideas, messages and emotions, using different language formats. Humanity used the language to evolve and thus, were made present in all of three temporal lines, making communication a primordial necessity. “The word 'communication' originates from the Latin noun *'communicatio,'* which means sharing or imparting.

From the root communis (common, public), it has no relation to terms such as union or unity, but rather is linked to the Latin *munus* (duty, gift), and thus has relatives in such terms as common, immune, mad, mean, meaning, municipal, mutual, and German terms such as Gemeinschaft (community) and Meinung (opinion). Its root senses involve change, exchange, and goods possessed by more than one person. The Latin verb *'communicare'* means to make common.” (Bendela, 2022, 3) There is no other similar element, that even while having strict rules and rigorous planification, strategic content and intradisciplinary implication, evolves daily and interacts with all human domains, being the significant part of all the systems and subsystems of their own components.

II. LITERATURE REVIEW

a. Conceptual Framework

The concept of communication was analyzed professionally from the perspective of psychosociological implication, by the representatives of School of Palo Alto, who are responsible for formalizing the important axioms of communication, considered as main rules of each communication specialist or one interested in the domain of communication. The valuable application of these five axioms enables the message to reach the interlocutor in a positive way, not only having a productive communicative act, but having a benefic effect over the social relation with the partner of discussions as well. “These axioms make up the grammar of conversation, or, to use another analogy that runs through the book, the rules of the game” (Watzlawick, 2008, 166).

Axioms and even more are presented in Fig 1. The recommendations are that these five axioms are used not only in verbal communication, but also in written communication, mostly used by media specialists. The following image, attached below, will provide the most important five axioms exposed by specialists from School of Palo Alto, the rules taught in every public university from Romania as the base of communication and management, and as public relations for public organizations activity. They provide important values about the human language and the context itself, depending not only on the components, but also on the means, channels and meaning, used in verbal and nonverbal communication.

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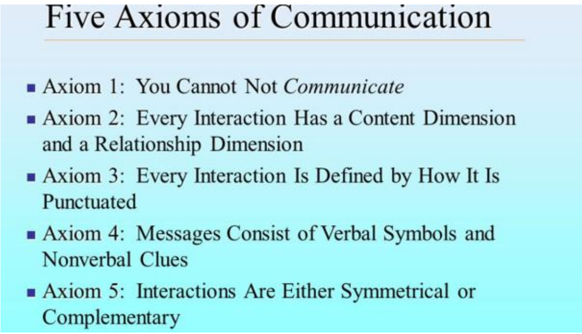

Fig. 1. Axioms of Interpersonal Communication.
(Juliana, 2020, https://interpersonalcommunicationaxioms.weebly.com/home/the-axioms-in-depth).

This chapter will take on the method of interference in the process of communication in the institutional context, using mainly the communication approach within public administrative institutions. Although the process of communication within an institution depends entirely on human implication, there exists a set of differences in the case of its application in professional settings, differences characterized by an emotional side, that truly depend on the position held within the organization.

Institutional communication is based upon language usage, for transmitting a message not only at the interorganizational rank but also at the extra organizational grade, by institutions at the public administrative level. This instrument serves as proof of the usefulness and efficiency of the existence of some administrative units of the territory, under which there always exists a public, represented by citizen, as represented by a process in which decisional premises are transmitted from one member of the institution to another, so that the activity of the institution is realized in good conditions.

Other theories will come with a different contradictory explanation of the same concept, notably the institutional communication is explained as public communication, communication of public institutions and even communication in legal practice. "Public communication is the form of communication specific to the work of public institutions in general interest. The messages conveyed include information of public interest, making citizens aware of the existence of public sector organizations, how they operate and what they do, and the legality and appropriateness of decisions taken. At the same time, public communication aims to make known the needs and wishes of the population so that public institutions, through their role and powers, can meet them, thus achieving a general interest" (Gherman, 2021, 22).

However, because of the roots of the public antique rhetoric, and the evolution of objectives of each public authority, the process of communication is limited and controlled by strict rules and regulations applied in the organizational context, with the purpose of making efficient the activities carried out for the well-being of the institution and its development. There is where the bond between the interpersonal communication and administrative authorities take place, connecting the dots between the public consultation process, and the intentional nature of the process with the people involved in it, which still remains the main method of productive dialog between the organization and its desired audience, which services are intended to be used by.

According to (Bendela, 2022, 3), "the term has such a wide extension that it can be used:

- In biology (communication between cells);
- In neurology (the communication of the brain with all the other organs), in computer science (communication between computers, man, and computer);
- In linguistics (communication through speech);
- In sociology (communication within a community or society), etc."

The recommendations require that the public authority not only makes information available to the interested parties, for example the directives and decisions must not be limited to only be presented as final law, but also, it involves seeking the opinions and following the conclusions made on an specific aspect, to influence the formulation and direction of local planks and policy proposals. "The obligation of transparency refers to the public authorities' duty to inform the public about draft legislation and subject it to public debate, to allow access of citizens and legally established associations to administrative decision making and the minutes of public meetings" (Ranta, 2011, 208).

b. Key aspects of Institutional Communication

Institutional communication within local public authorities is chosen based on the specific task, and according to the content of the message, encompassing the three methods of communication: verbal, written and mixed, with the specific intention of promoting a positive public image of the institution's own activities. That is the reason why the management of the public organization is important to be strategically chosen, as it influences the image of the whole employees of the institution. The public opinion is changed based on how the organization is creating and maintaining its public relations, as the responsibility of the PR and Communication department.

To ensure that the institution communicates efficiently, handbooks and guidelines are created by the specialists through government funded projects, which specify the best-known categories of public communications: (1) Providing public data to citizens as a principle of transparency; (2) Establishing public meetings and consultations in the context of the dialog with the public; (3) Efficient delivery service; (4) Presenting and promoting the services specifical for the organization profile; (5) Public information campaigns; (6) Open local websites for online services; (7) PR and promoting public institution activities and image.

As stated above, the main reason for these activities is to maintain an ethical and favorable image of the public authority in the subconscious of the target community, as the top-of-mind awareness. This strategy is applied in public relations activities, as a management decision, which might often transform into publicity or advertising. The important step which should be taken is to control and have a strict managerial plan of communication, as far as the objectives of advertising and public relations serve different approaches to the institution.

A distinct aspect of public relations, rather than advertising, in the communication process of authority is the ability to tell the truth, to achieve credibility and visibility, even when it does not work in institution's favor. "As a function of management, communication is the process of ensuring the correct flow of information within the organization and in its relations with the external environment; in the latter case, the aim is above all to obtain useful information about relevant organizations and to disseminate promotional information about one's own organization" (Gherman, 2021, 22).

We should take into consideration that, when choosing the tactics of communicating with the public, the management should note every aspect of these specific categories of communications and the different approaches they highlight. Table 1, enclosed herewith, delineates the differences between the categories of communication, exposed above, advertising and public relations.

Institutional communication is based on a strict set of values, without which the institution's internal communication is blocked. Building on this idea, we can distinguish between several categories of formal communication within the institution, namely: bottom-up communication, top-down communication, and horizontal or lateral communication, as described in other sources consulted, all of which are specific to the effectiveness of public authority and the institution's organizational structure that is, specific to established hierarchical relationships.

Messages transmitted through these types of communication are governed by norms dictated by the employee's status and formal role. These norms are also influenced by a series of factors specific to formal communication, such as organizational structure, organizational norms, information flow and technologies, and the location of the workplace or office.

Thus, downward communication involves top managers in the communication process with the operational staff; upward communication involves conveying the message to a higher hierarchical level; and horizontal communication takes place among staff in departments at the same level, excluding senior managers.

Table 1: Different perspectives between advertising and public relations

#	**Public Relations**	**Advertising**
1	Implements the brand popularity index	Incorporates the brand awareness index
2	Has a specific social role	Has an economic role
3	Exerts an indirect economic influence	Exerts an indirect social influence
4	It is achieved through two-way communication	It is achieved through monologue
5	Based on opinion polling	Based on market research
6	Is an attribute of a democratic social system	Is the base of the totalitarian system
7	Falsehood is totally unacceptable	Falsehood is propagated to the public

The main objective of this internal communication is to facilitate the transmission of the organization's culture to the external public and thereby establish a connection between the public services provided in the general interest of the public sphere and the society composed of individuals, organizations, and groups, part of social norms and regulations.

Anticipating the institution's side after disseminating the message, there are distinguished five roles of citizens in society, based on their way of reacting to institutions' messages. A model of effective municipal governance includes five key roles for citizens:

- Citizens as stakeholders.
- Citizens as representatives and advocates of group interests.
- Citizens as initiators of dialogue.
- Citizens as evaluators.
- Citizens as partners.

In all public institutions, it is recommended to develop a communication strategy with citizens, because citizens are the very people upon whom these legally recognized institutions rely to function. Accordingly, these communication strategies should be developed only after a thorough understanding of the institution's current situation and only after consulting experts in the field of public information. Communication strategies involve the use of communication channels and methods, as well as the institution's objectives, designed to maintain a positive image that inspires trust and goodwill among citizens.

Based on these results, the authority decides the technique and the strategy which should be applied in the community. "Communication with citizens is achieved through: the media, official newsletters, websites, information centers, exhibitions, information activities, debates, communication sessions, research programmes, cultural and educational activities, NGOs, citizens' advisory committees, participation in competitions, own publications, posters, written and oral transmission of various types of information to and from the management and specialist structures of public administration institutions" (Gherman, 2021, 22).

c. Foundational Legal Frameworks in National View

Under Romania's legal system, Law No. 767/2003 sets forth certain rights, obligations, and principles pertaining to citizens, including the provision (Art. 31, para. 1) that "the restriction of a person's right to information may not be prejudiced," and (Art. 31, para. 2) "the responsible institutions, through their respective powers, are obligated to ensure that citizens are accurately informed about public affairs and matters of personal interest." Thus, based on Art. 31, para. 4, both private and public media outlets are obligated to ensure, through language and vocabulary that must be accessible and understandable to a broad audience, accurately informing the public, both internal and external.

Following the development of the concept of communication and information, it became necessary to introduce a general provision to operationalize the obligation of local public authorities to publish information of public interest, including the entire

process of communication between citizens and state public institutions is carried out by them. Thus, according to Article 3 of Law No. 544/2001 published in the Official Monitor of Romania, it is written that "any person shall have free and unrestricted access to any information of public interest" (Official Monitor of Romania, 2001), which constitutes one of the fundamental principles of relations between individuals and public authorities. The same Article 5 paragraph (4) provides that "access to information is achieved either through a) display at the headquarters of the public authority or institution, or through publication in the Official Monitor of Romania or in the mass media, in its own publications, as well as on its own website," (Official Monitor of Romania, 2001) or "b) consultation at the headquarters of the public authority or institution, in spaces specifically designated for this purpose." (Official Monitor of Romania, 2001) Often, it is precisely the transparent display of information to the public that allows for the creation of a positive image of the authority, as well as the manifestation of public interest in the decision-making process.

Information of public interest is provided either ex officio or upon request, and in accordance with Article 4 paragraph (1) of the national law, "public authorities and institutions are required to establish specialized information and public relations departments or to designate individuals with responsibilities in this area." (Official Monitor of Romania, 2001) In this way, Romania's legislative system provides for the operation of communication departments within public institutions. These communication offices are responsible for the ongoing collection and selection of information held by the institution to update publications accessible to the public, including the media. In this regard, a law was passed stipulating that ignorance of the law cannot be invoked by anyone as an excuse for violating it; that is, the laws must be known and respected, hence the obligation of governing bodies to systematically inform the public through various means, and the legislation must be explained in a manner understandable to the recipients.

To ensure, from a legal standpoint, that the authority exercises its assigned functions including communication, there has been established in accordance with the framework law, the concept of Control. Control takes two forms: internal and external, carried out by the institution itself and, respectively, at the initiative of decision-makers outside the bodies subject to such verification control. If an institution fails to perform or performs its duties improperly, including communication and information dissemination, it may be sanctioned through administrative or administrative-judicial channels, via administrative courts.

However, due to the ambiguity created by this law, we cannot refer to the administrative activities of the authorities strictly in terms of communication, but rather to the entire activity itself, taken as a whole. Another important point to note is thus the lack of a competent special control institution or body for this area at both the local and EU levels.

d. Preliminary Conclusions Related to the Literature Review Study

By analyzing different aspects of strategies adopted by the authorities in Romania, from an institutional perspective, both in terms of their approach to channels and means, as well as their goals and objectives, we can arrive at a valuable set of conclusions. By distinguishing the communication strategies, each of the public authorities can fix their actions by aiming at the main objectives of the plan, but it implies taking into consideration all the ideas from the specialists and spokespersons from that specific institution.

The two main objectives observed from the last years in Romania are being realized by either the Communication and Public relations office, referred to as a public information service office, an information and public relations office, or a communications department reporting directly to the organization's upper management, or the recruitment, within a competitive process, of a public communication specialist, known as the spokesperson.

The tasks of this two-way communication are influenced firstly by the strategic plan established in the institution, and secondly by the means, techniques and channels available regionally or locally to make the process of communication efficient. We thus distinguish between three categories of communication strategies applied by public authorities:

- Power authority strategies, which aim is to convince the public of institution's authority activities, whether traditional or newer activities and areas acquired in the context of dynamics and changes of the social system;
- Strategies of efficiency, which aim is to improve the effectiveness of various structural elements, both on the human elements that comprise them, as well as the institutional part within the public authorities;
- Communication strategies of trust, aiming to create a real genuine and constructive dialogue with the citizens, NGOs, public and private organizations and other stakeholders.

III.CASE STUDY- COMMUNICATION STRATEGIES APPLIED IN THE CITY OF TIMISOARA, ROMANIA

The city hall from Timisoara city is a public authority institution, holding specific assets and a budget altogether as a legal entity, being the representative of the Government at a local level. The authority guarantees the public order for its citizens and ensures that the law is abided. It is located on Constantin Diaconovici Loga no. 1 boulevard, Timisoara city, Timiș county, Romania. One of the main guiding principles at the activity basis represents the public consultation and citizen oriented solutions, with legality, transparency, free access to information, impartiality, objectivity, responsibility, impartiality, impartiality, impartiality, integrity, efficiency, specialization as stipulated in Law no 215, adopted on April 23, 2001, in Romania, stating the law of local public authorities and institutions and their activities. These principles are followed by in all the functions of the organization, carried out by eight departments and offices, organized into suboffices and divisions, taking into consideration the administrative tasks at local level, which are established with an approved organizational chart, including the hierarchy, the mayor, vice mayor and secretary of the Consilium. As is the case with other public authorities also, the city hall includes the citizens in its organizational chart, encountering different categories of audience, known as the five keys roles of the main target audience, explained above.

Analyzing the website of the city hall we observe that the chart disposed includes the Communication Service, with its suboffice, Mass-Media relations compartment, which provides the two-way communication between local public administration and citizens. The role of these departments is to convince the public that public decisions are in general public's interests and provide quality services to meet the needs of the community. In accordance with the law, the institution is responsible with public order by the mayor's decree, carried out by law enforcements, as local police, security guards, the fire departments, medical units, civil protection units, gendarmerie, and other agencies responsible with the public order as their main activity.

To demonstrate that the communication flow is involving both parts of the process and the message is correct based on verified information, it is important to study the presence of satisfaction and preference among citizens following the qualitative communication process carried out by the Timisoara city hall as well as the actions this institution implements to improve communication strategies, techniques and means of transmitting information already used. To facilitate this, the easiest way to evaluate the indicators of strategic communication is quantitative research, surveying the citizens using a questionnaire based on Google Forms, with 22 questions. It allows us to identify and estimate the level of interest and the role of citizens and institutions in the communication flow, which then links us to the competence of the management into approving and applying a communication strategy.

The research hypothesis is that the level of communication is noticeable, due to the clear and transparent access of information. Consequently, the residents are informed about the activities that are carried out in the city, and they have access to the decision-making process as equal participants. "In a representative democracy, in which citizens delegate their decision-making authority, access to information is crucial to lay the foundations for consent" (Iacob, Istrate, and Hrestic, 2021, 462).

On the other hand, the participants are equally low in the decision-making process due to the high level of theoretical specific concepts and a high level of information flow, coming from different senders, which limits the capacity of selecting the important and correct information and its resistance to fake news. Faced with endless contradiction, people have retreated into a cynic, apathic, hyper-fragmented belief in the public system, as the citizens surrender not to a single ideology, but to the impossibility of knowing how to select, and appreciate the value of the message, which leads to a low implication and a higher critique of the political system. In addition, there exists NGOs, comities with special ground in public administration institutions program, research and analytical programs which strive the attention, understanding and public memory to the main topics of the public administration institution.

The questionnaire was held on 50 residents from Timisoara, with different approaches and roles in the public administration communication strategies. The first part of the poll aims to find general information about the target group, as the representative sample for the population living in the city, middle age, both feminine and masculine genre. The results are also shown in the Romanian language, as the survey has been conducted in Romania. Timiș county in 2023 from May until end of June, and the respondents have the national language Romanian.

The most important part of the survey begins at the 8th question, stating the level of awareness regarding the communication actions and initiatives, measured by a scale, ranging from "Not at all" being the 1st to "To a very large extent" being the 6th, to openly state the level of extent they are informed by the city hall.

The results are shown in the Fig.2., attached below, as most people responded with the variable "To a small extent"-representing the majority with 46%, colored in orange. It is alarming to observe that 4%, colored in blue, of respondents stated that their level of awareness in communication with the city hall is none, meaning that they are not informed at all regarding the activities and actions of this institution. 28% of the total respondents declared that they are informed to a moderate extent, colored as green in the diagram below, and only 18% stated they are informed to a very small extent, colored in red below. Only 2% fall into the following category, largely informed and to a very large extent, with only one answer per category, colored in light blue and pink.

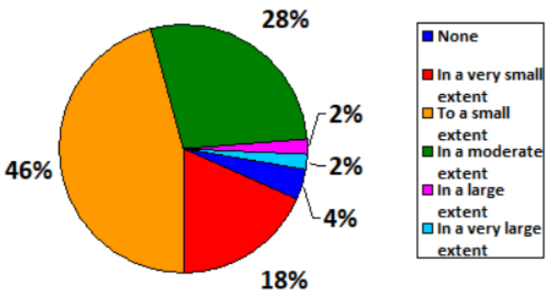

Fig 2. Level of awareness stated by respondents regarding the city hall's communication efforts.

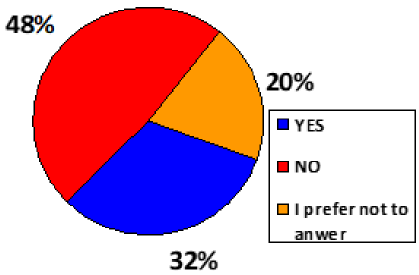

Fig. 3. Level of citizens' engagement stated by respondents in the city hall's call of decision-making process.

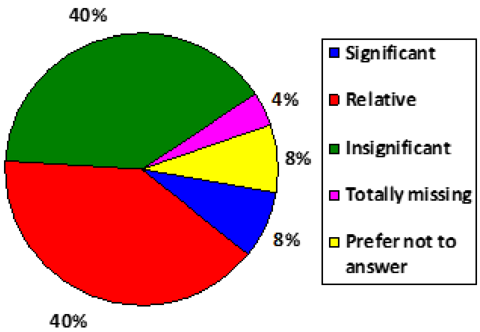

Fig. 4. Level of awareness stated by respondents regarding the city hall's communication efforts.

Another aspect of communication process is the level of citizen involvement in the process of decision-making from Timisoara (Romania). The answers were collected in question no 9, with the results disposed of in Fig. 3., above. When asked about the decision-making process and their involvement in it, more than half of respondents answered with a negative intention. Approximately 48% of the respondents, majority being the oldest generation-meaning the respondents over 35 years old, stated that they do not answer the municipality's public call to involve in the dialogues related to public issues. While 30% of the respondents, marked in the diagram Fig.3. with blue color, answered with Yes, being highly active in the decision-making process, finding solutions and proposing ideas, other 20% of respondents prefer not to answer to the authority's initiatives. This suggests that over 68% of respondents are still reticent in the initiatives of the institution when it comes with the intention of getting the citizens involved in decisions of public interest.

Some perspective delimitates that in contrast with the previous diagram, the results from question no 10, results being presented in the Fig. 4., suggest that over half of the respondents involve in the democratic process, as 48% responded with being "relatively" and "significantly" involved in this process. Those who considered that the degree of involvement is insignificant accounted for more than 20 out of 50 respondents, representing 40%. The diagram attached above, in Fig. 4., shows that only 4% of citizens are not involved in the decision-making process, as part of the democratic action, while the rest of 8% of citizens preferred not to answer.

When respondents were questioned about the issues they identified as being the main problem in society, there is where all the respondents personally faced reality. This question suggests that even when citizens are not involved in the democratic process, they face the actions or lack of actions from the municipality. They feel the need to solve the problems by being dissatisfied with the insufficient solutions or involvement of the institution. Every respondent faced one or more problems personally, and the diagram Fig. 5., attached below, suggests that the most significant issue in Timisoara (Romania) is lack of parking spaces for cars and bicycles. Thus, most citizens chose this issue as one of the main problems that authorities should focus on, this option being selected by over thirty respondents, meaning 60%.

Another majority was concerned about the infrastructure issues from the city, such problems as road access, road quality, public transportation, traffic lights and road crossing were considered when selecting this option, because over 32% of respondents selected it as the main problem of the city. Thermal-related issues option, as well as Healthcare facility and Temporary residence permit or documentation, was selected by only 2 citizens, summing 4% of the respondents of this questionnaire for each component.

The main issue taking over in the Romanian society, mediatized and commented repeatedly in the media is the sanitation issue, which mainly affects children enrolled at school in rural areas. This issue was selected as one of the problems of Timisoara by over 7 citizens, meaning 14% and mentioned also in the diagram Fig.5., from below, with red color.

Regarding the issues with education facility, surprisingly 22% of the respondents, representing 11 citizens, selected this option, the third most popular category, in a time when diplomas are seen not as important achievements and only 3 citizens mentioned that they do not face any of the problems below or any category presented, representing 6%, even more than the other 3 options disposed above. The results from this diagram (Fig 5), can help us conclude that population faces a wide range of issues in the community and surely, they expect solutions from the city government, as this is the institution's priority, to serve the public interest.

Statistics from question no 17 applied in the questionnaire are analyzed from the perspective of what extent public administration is engaged in a consistent dialogue with civil society. The results are disposed of in the figure attached, namely Fig.5, as the extent of involvement of the institution in public communication.

Most responses focus on the appropriate extent of implication of city government, with 50% of respondents selecting the option with a neutral position, marked in yellow. 28% of the respondents, the column marked in blue, assumed that the city hall is involved in a dialogue with society to a small extent, 6% from the interviewees suggested the implication as being in a very small extent, see the green column, while 10% felt that the institution is largely involved, marked in red in the Fig. 6. A minority of 2%, as we see the orange column, believe that there is no involvement from the institution in communicating with the public at this time, and only 4% felt the involvement of institutional communication in their life to a very large extent, presented with light pink in the diagram.

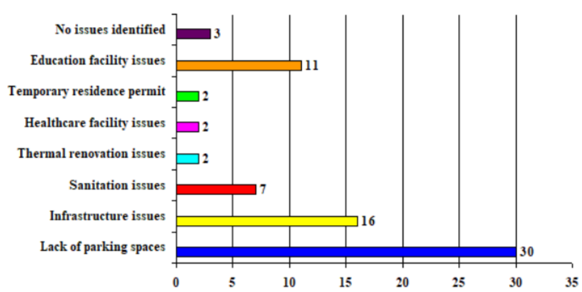

Fig. 5. Main issues identified as problems by the citizens in Timisoara city.

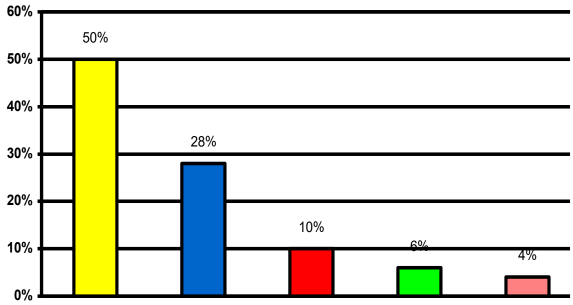

Fig. 6. The extent of involvement of the institution in public communication.

To highlight the negative aspects of the communication strategies selected by the upper management from the city hall of Timisoara, Romania we asked the respondents to outline the main problems they identified in this process which undermine the institution's image and the communication strategy they implemented. The answers focused on simple aspects, for instance bureaucracy, paving the green parks and spaces of recreational activities, intentionally hiding the information and no interest in providing any public information in an accessible speech style. Fake information, which leads to fake news, overly outdated means of infrastructure and resources, as the new management strategies, are among the responses collected in a fairly large number to this question, leading to complicated working methods and unsatisfied employment of the organization and external audience of the institution. By eliminating these issues and preventing the factors that create them, the satisfaction level for both parties included and involved in the communication process, the corruption phenomena, manipulation are likely to decrease or disappear.

IV. CONCLUSIONS

Answering the objectives of this paper, we successfully identified the level of awareness of the citizens about the communication strategies the city hall of Timisoara (Romania) used in the past to emphasize the main issues of the city. The citizens are aware of their role in society, as this impacts the strategy the municipality solves the issues and communicates about the best solutions, identified only after analyzing the way it impacts community.

The problem of communication strategies used ineffectively impacts the public and makes communication take place only as a one-way process, not a two-way strategy. Feedback is necessary as a step in improving the way authorities are perceived to their usefulness and qualitative value, even when image crisis is intense.

In addition, we can recommend increasing the interaction of modern and digital means of communication, namely internet media and websites, so the information will be updated and likely to hit the target audience. Noticeably, such actions as activities for both young and older generation, namely the Open doors day, Bring your child to work day, Earth Day, and other known important actions specific to public organizations and corporations also, implementation of which brings a high impact of trust in the public authorities.

If the institution is taking into consideration upgrading and modernizing the aspect of strategy communication and has the intention to provide good services for the public's interest, it will perform at the qualitative level of internal management and external audience.

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Integrating ISO 18828-2 Standard in Production Planning – A Study About Optimizing Work Instructions in Industrial Engineering Processes

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Abstract – The present paper offers a practical analysis of implementing the ISO 18828- 2 standard in the activities of industrial engineering production planning, emphasizing on the reviews of the work instructions used in production planning. The study was based on the technical and operational documentation available in the logistics department in Production Planning, of a company selling rubber-based products for the automotive industry. In line with the requirements of ISO 18828-2, standardized information models have been established, resulting in an improvement in the coherence of the documentation, a decrease in operational errors and better support with the interoperability of IT systems. The results prove the importance of unitary structuring of work instructions and re-emphasize the role of the standard in increasing production planning process.

Keywords: ISO 18828-2, work instructions, production planning, interoperability, industry digitalization, Industry 4.0

I. INTRODUCTION

I. I Context and definitions

Nowadays, in production planning, the quality of the technical data plays an essential role in making the processes more efficient. Work-instructions constitute essential operational documentation because they describe the way that technical / technological activities are supposed to be performed. The absence of standardization leads quite frequently to an incorrect interpretation, variations in the ways of working and execution errors. The ISO 18828-2 standard belongs to an international series of standards that focus on the evaluation of the applicability of information technology in production and establishes a coherent framework for the description of the industrial engineering processes. The main objective of the standard is to ensure and establish the interoperability of data between various software systems and at various levels within an organization.

1.2 The simple principles of the ISO 18828-2 standard

According to the standard, work instruction must include at the minimum:

- Metadata (author, revision history, date, unique identifier in the quality management system);
- A clear description of the activity (step-wise approach of the process);
- Required resources (equipment, tools, materials);
- Input and output information;
- Constraints and safety instructions;
- Verification criteria and tolerances;
- Logical interrelationship between the activities / steps.

The information structure is based on a modular model, compatible with the MES, ERP and similar modern applications. The ISO 18828 series is associated with production engineering and has amongst its purposes the standardization of the information flow between processes, systems and applications. The second part of ISO 18828-2:2016 - Part 2: Reference process for seamless production planning has as its objectives the definition and modelling of information pertaining for the fundamental processes of production planning.

The standard also describes formal relations between the stakeholders involved in planning offering a clear vocabulary and models to support interoperability. Through this endeavor, a framework to integrate systems for production handling that limits ambiguity and avoids interpretation errors is created. In line with the requirements of ISO, the standard excludes a clear set of activities associated with production planning such as handling orders, MPR/MRP II, manufacturing procedures or digital simulations. This separation is essential for understanding the scope of the standard and prevent misinterpretations.

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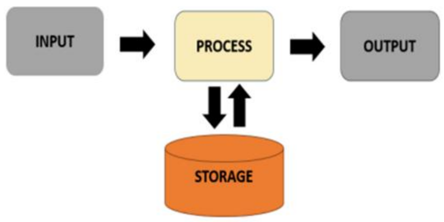

Fig. 1 The structure of the process, from inputs to outputs (source: internal)

The standard is exclusively focused on the conceptual processes related to planning and modeling the information associated with planning. In Fig. 1 we can see the structure of the process from input to output.

1.3 Relevance for production planning

Production planning is strictly linked to the quality of the work instructions. Incomplete documentation may lead to:
- Errors in execution;
- Higher analysis times;
- Process roadblocks;
- Gaps in internal assessments.
- Integration issues with industrial applications.

Standardization of documentation is supporting a more stable, predictable and efficient production process.

1.4 Benefits of ISO 18828

Adopting ISO 18828-2 presents advantages for each organization:
- Improved accuracy by clarification of misunderstandings;
- Increased automation rate for information flow
- Real time monitoring opportunities;
- Standardized communication flow between departments;
- Reduction of operational expenses.

These benefits are vital for organizations that operate in the context of Industry 4.0 digitalization.

Using ISO 18828-2 can offer big benefits to companies working in today's industrial settings.

The standard helps make things clearer by reducing confusion and making sure everyone understands the tasks better. This leads to a more consistent implementation of production planning activities across various departments and user groups. It also allows for more automation in how information is shared by organizing data in a standard, easy-to-read format that makes it easier to connect with digital systems like ERP and MES. Another key advantage is being able to watch production planning happen as it happens and track it more closely, which helps spot problems quicker and makes it easier to fix them efficiently.

Furthermore, the standard enhances communication between departments by ensuring a unified documentation structure and common terminology, which reduces the risk of misinterpretation and information loss. It also contributes to a reduction in operational expenses by minimizing errors, rework, and time spent on interpreting inconsistent documentation.

From an Industry 4.0 perspective, ISO 18828-2 plays an important role in enabling interoperability between human-centered processes and digital manufacturing systems. By standardizing information structures, it supports the transition toward data-driven production planning environments, where efficiency, transparency, and integration are key performance factors.

These combined benefits are essential for organizations operating within the context of Industry 4.0 digitalization, where interoperability, data consistency, and process efficiency represent key factors for competitiveness and sustainable development.

1.5 The challenges of implementation of the standard

A successful implementation of the standard requires:
- A deep impact analysis of the activities required
- Clear coordination between engineering, manufacturing and IT
- Personnel training
- Deployment of internal software tools (like SAP)
- Revising the internal documentation

Laking a unified approach in the organization, can pose significant issues in transitioning to a standardized mode of operation based on the ISO.

II. METHODOLOGY

During this study, multiple documents and materials have been analyzed to get the overview. This flow can be seen schematically in Fig. 2.
- Used documentation and materials;
- Existing work-instructions;
- Process diagrams;
- ISO 18828 standard requirements;
- Software for process modeling;
- Technical analysis tools.

In Fig. 3 we have a reference from the standard that refers to production planning.

2.1 Procedures

Methodology has included three main steps:

A. Review of current work-instructions
- Gap analysis
- Analysis of internal audit findings
- Analysis of the deployment of work instructions by its intended users

B. Mapping the ISO 18828-2 requirements

- Extracting the necessary stakeholders
- Definition of the metadata
- Organizing the IT structure

C. Redesign of operations

- Re-writing the activities in a standard format
- Considering and including quality criteria
- Introducing resources and verification
- Standardizing terminology

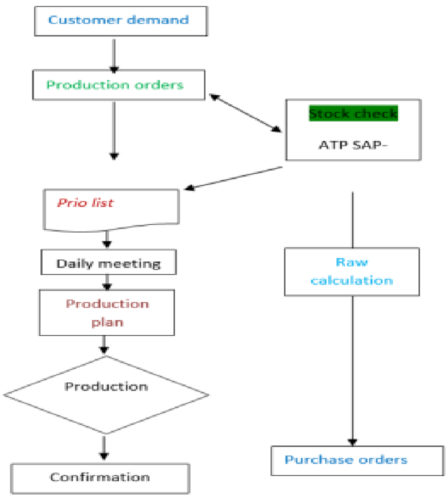

Fig. 2 The workflow for production planning (source: internal)


INTERNATIONAL STANDARD

ISO 18828-2

Industrial automation systems and integration — Standardized procedures for production systems engineering —

Part 2:
Reference process for seamless production planning

ISO

Fig. 3 ISO 18828-2 standard: Reference process for seamless production planning (source: ISO 18828-2:2016 - Industrial automation systems and integration - Standardized procedures for production systems engineering - Part 2: Reference process for seamless production planning)

2.2 Reduction of Non-Value-Added Activities

For the evaluation of the improvements the following were used:

E1 – Number of operational errors

E2 – Completion of work instructions (%)

E3 – Average interpretation time (s)

E4 – Interpretabilities with existing software systems (score 1-5)

The completion score has been calculated by this formula:

$$C = \frac{\text{Number of completed elements}}{\text{Number of required elements}} X\ 100$$

III. ANALYSIS RESULTS

After the analysis, the following were observed:

- Lack of metadata
- Incomplete information regarding resources
- Inconsistencies between departments
- Higher analysis times
- Frequent operational errors

The data in figure 4 demonstrates notable enhancements across all assessed performance metrics after the adoption of ISO 18828-2. A significant decrease in operational errors (E1) is evident, with a marked reduction from a high frequency prior to implementation, reaching an estimated 20% decrease following standardization. This shows that the production planning activities were carried out in a more stable and controlled way. The completeness of the documentation (E2) went up a lot, from about 60% to over 90%.

This shows that having clear, standardized instructions makes the data easier to understand and helps different departments use information in a more consistent way. The time it took to interpret (E3) was also greatly decreased because the instructions were organized in a clear and step-by-step way, making it easier and quicker to understand and work with technical details.

In addition, interoperability with IT systems (E4) improved from a low level, characterized by fragmented systems, to a high level of integration, supporting better alignment between documentation and digital platforms such as ERP and MES systems. Finally, data consistency has evolved from a variable state to a standardized format, confirming the effectiveness of ISO 18828-2 in harmonizing information flows within production planning processes.

Indicator	Before Implementation	After Implementation	Improvement
Operational errors (E1)	High frequency	Reduced (~20%)	Significant decrease
Documentation completion (E2)	~60%	>90%	Strong improvement
Interpretation time (E3)	High (manual analysis needed)	Reduced	Faster processing
IT-interoperability (E4)	Low (fragmented systems)	High (integrated systems)	Improved integration
Data consistency	Variable	Standardized	More stable output

Fig.4 Impact of ISO 18828-2 implementation on production planning performance indicators

3.1 Improvement action items

The following standardization measures have been implemented:

- Complete definition of metadata;
- Sequential description of activities;
- Introduction of verification criteria;
- Terminology standardization;
- Reorganizing the logical flowcharts;
- Creation of new work instructions compatible with the company QMS.

The analysis results have led to the reduction in operational errors by 20%, increase in documentation completion by over 90% and a reduction in the analyses of work instructions and of the data from the software systems.

IV. DISCUSSION

The findings from this study show that how work instructions are organized has a clear effect on how well production planning activities run. The implementation of ISO 18828-2 has not only enhanced documentation clarity but also served as a catalyst for aligning operational practices with digital transformation goals. One of the most significant observations is that the standardization effort reduced variability in interpretation among different users of the same documentation. Prior to the implementation of ISO 18828-2, work instructions were interpreted differently depending on the experience level and departmental background of the users.

After the standardization process, the introduction of structured metadata, sequential task descriptions, and unified terminology significantly reduced ambiguities and improved the consistency of production planning.

Another relevant aspect is the improvement in interoperability between human-readable documentation and IT systems. By aligning the structure of work instructions with modular and data-driven principles, the integration with systems such as ERP and MES became more consistent.

This shows that having standard documents isn't just about making things clear for people to work but also helps connect the choices people make with the machines that do tasks automatically. The reduction in operational errors (approximately 20%) highlights the practical impact of structured information.

The increase in how often people finish documentation (>90%) also shows that users are changing their behavior.

Standardization promotes a more structured approach to documenting processes, fostering a culture of accuracy and accountability within the organization.

V. LIMITATIONS OF THE STUDY

Even though there are good results, there are some things that need to be mentioned. The study is based on a single organizational environment within the automotive rubber products sector.

The second point is that the use of ISO 18828-2 was checked during a brief time of operation. Because of this, things like how long the improvements last, people getting used to changes, or keeping up with rules over time, weren't completely understood.

The performance indicators used (E1–E4) mainly focus on operational efficiency and documentation. These factors are important, but they don't completely show the bigger effects on the whole organization, like how happy employees are, how well different teams work together, or how much money is saved in the long run. The study also assumes that the IT infrastructure remains stable throughout the implementation process. In organizations implementing concurrent system upgrades or digital transformation initiatives, outcomes can differ due to the complexities of overlapping changes and integration challenges.

In organizations undergoing simultaneous system upgrades or digital transformation initiatives, outcomes may vary due to the complexities introduced by overlapping changes and integration challenges.

VI. RECOMMENDATIONS AND FUTURE WORK

Based on what this study found, there are several areas where things could be improved or developed in the future. Firstly, expanding the implementation of ISO 18828-2 across multiple departments and production sites would provide a more comprehensive evaluation of its effectiveness.

A multi-site comparative study could highlight differences in adoption rates and identify best practices for scaling standardization efforts.

In addition, future studies could explore the integration of ISO 18828-2 with advanced digital technologies such as AI-driven planning systems or predictive maintenance tools.

In these contexts, standardized work instructions can function as structured input data for machine learning algorithms, thereby further improving decision-making processes. It would be beneficial to develop a more detailed quantitative model for evaluating the impact of standardization.

This might also involve other measures like cost for each planning cycle, how quickly decisions are made, and how well different software systems work together. Another relevant direction is the investigation of human factors in the adoption of standardized documentation.

Even though there are clear technical improvements, how well the organization accepts these changes and how easily users can adjust to them are very important for the long-term success of these projects. So, in future studies, it's important to look at how well training works, how people resist change, and how much users are involved.

In the end, the development of ISO standards within the context of Industry 4.0 shows that there is an increasing need for ongoing improvements and updates.

As production systems become increasingly interconnected and data-driven, future versions of ISO 18828 may need to incorporate elements related to real-time data exchange, cloud-based planning systems, and digital twin integration.

VII. FINAL REMARKS

The implementation of ISO 18828-2 shows that structured information management is a key enabler of efficient production planning in modern industrial environments. Besides its function as a documentation framework, the standard also aids in aligning operational processes with digital transformation strategies. The results of this study show that even small changes in how documents are organized can lead to clear improvements in how operations are conducted. However, the full potential of such standards is achieved only when they are integrated into a broader organizational strategy that includes IT systems, human resources, and continuous improvement mechanisms.

Future industrial environments will increasingly depend on real-time data exchange and automated decision-making systems. In this situation, standard work instructions could change from being fixed written documents into living digital tools that keep getting updated and stay in sync with the production systems.

This change will make ISO-based structuring methods even more important in smart manufacturing systems.

CONCLUSIONS

Integrating the ISO 18828-2 standard in production planning represents an efficient solution for the increase of the work-instruction quality and for improving operational performance. The standard defines a reference planning process that enables seamless, consistent, and auditable planning, directly impacting the quality and clarity of instructions used by operators on the factory floor.

Integrating ISO 18828-2 standard in production helps optimize work instructions through several key mechanisms:

- Consistency and standardisation - By enforcing a standard structure for planning processes (Level 1–5), work instructions are developed using a common language and format, reducing ambiguity for operators.
- Integration with MBOM - The standard ensures that work instructions are directly derived from the Manufacturing Bill of Materials (MBOM) and Process Chains (sequence of activities), ensuring the materials listed in instructions are accurate and up to date.
- Linking resources to operations - ISO 18828-2 encourages detailed identification of “operating resources” (both movable and immovable), ensuring that necessary tools and fixtures are explicitly listed in the work instructions.
- Seamless change management - It supports the integration of change management (via related ISO 18828-5), meaning changes in product design or production systems are systematically updated in the work instructions.
- Improved efficiency - By using this framework, planners can identify bottlenecks and optimize the sequence of assembly tasks, leading to clearer, more efficient instructions that reduce task time.

The results of the study show that structuring the data according to the model leads to:

- Reduction of process related failures;
- More explicit and detailed documentation;
- Reduction of discrepancies between operators;
- Improved integration with it systems;
- Unification of internal communication.

Thus, the uniformization of work instructions has become a crucial factor for organizations focused on digitalization and Industry 4.0. Integrating the ISO 18828-2 standard into production planning offers an efficient solution to improve the quality and consistency of work instructions, while also supporting operational performance in industrial settings.

The study showed that organizing production planning information using standard models helps create a more controlled and clear way for data to move between departments and systems. Furthermore, the analysis indicates that the implementation of standardized work instructions is directly linked to reducing process-related errors, minimizing interpretation differences among operators, and enhancing the clarity of technical documentation. These improvements are especially useful in places where things are complicated and depend a lot on having good planning information, like in the automotive supply chain.

Another important outcome of the study is the improved interoperability between documentation processes and digital manufacturing systems. By aligning work instructions with the ISO 18828-2 structure, organizations can create a more efficient connection between human decision-making activities and automated industrial systems, which is an essential objective of Industry 4.0 transformation initiatives. The observed improvements in documentation completeness and reduction of operational errors indicate that standardized work instructions also have a behavioral impact on users.

Employees are more likely to follow a clear plan when the information is easy to understand, which helps make their work more consistent and ensures everyone takes responsibility for their tasks.

From a strategic perspective, the implementation of ISO 18828-2 should not be seen as a one-time documentation update, but rather as part of a continuous improvement cycle.

As production systems become more digital and linked together, it will be very important to keep information organized in a standard and flexible way to make sure industrial processes can grow and change easily.

The study confirms that even minor enhancements in documentation structure can yield measurable operational benefits. However, the full benefits of ISO 18828-2 can only be realized when it is paired with proper organizational alignment, employee training, and integration into wider digital transformation plans.

In conclusion, there can be summarized that the main benefits of integrating ISO 18828-2 in production for industrial engineering purposes are:

- Enhanced quality - Reduced errors due to clearer, more accurate instructions derived from a rigorous planning framework.
- Reduced training time - Standardized work instructions make it easier for new operators to understand tasks.
- Auditable processes - The formal, multi-level structure provides a clear audit trail for the planning process.
- Digital integration - The standard is designed for modern manufacturing systems (e.g., ISO 10303-238 / STEP-NC), facilitating digital delivery of work instructions.

The ISO 18828 series, particularly parts 1–4, can be implemented together to enhance overall production performance

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Circular Supply Chains for Industrial Symbiosis: Product Redesign, Reuse and Transformation Pathways

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Abstract: Product redesign, reuse and transformation pathways are important in the circular economy chain. Therefore, it is important to identify the connection between them. The research presents a systemic review of specialized literature using the most current research undertaken. The research results show that cross-domain interactions are missing or partially addressed. The link between transformation pathways and the other four domains has received little attention. This paper provides a comprehensive picture of the importance of circularity and industrial symbiosis.

Keywords: Sustainability, Circular Economy, Resource management, Product Redesign, Reverse Logistics, Eco-Design

I. INTRODUCTION

The linear economic model is defined by the consecutive processes of extraction, production, and disposal. This model faces persistent examination as resource limitations, environmental deterioration, and climate necessities call for alternative methods of production and consumption (Rashid & Malik, 2023). In this context, the circular economy (CE) has become a compelling concept. It perceives waste as a resource and promotes the continual extraction of value through recycling, remanufacture, reuse, and regeneration (Ellen MacArthur Foundation, 2019).

Within the topic of circular economy, two concepts have garnered significant academic focus: circular supply chains (CSCs) and industrial symbiosis (IS). The first one focuses on how to close internally and externally the material loops among enterprises. In this context, concepts such as reverse logistics and closed-loop flows emerge (Garcia-Buendia et al., 2024). In contrast, industrial symbiosis examines circularity from an ecosystem perspective. It facilitates the collaboration of firms in exchanging waste streams, energy, and by-products to promote industrial synergy (Palagonia et al., 2025).

Other key aspects closely linked to circular supply chains and industrial symbiosis include product design, available technologies, and organizational and institutional conditions, all of which influence whether the transition from linear to circular systems can be successfully achieved.

Although there is a substantial number of publications on these topics individually, comprehensive evaluations that concurrently assess the literature on circular supply chains, industrial symbiosis, product redesign, product reuse, and transformation routes are remarkably limited. Each of these subjects possesses considerable internal depth, yet the boundaries between them remain intact. Consequently, significant cross-domain questions, such as the influence of product design decisions on supply chain structures in relation to industrial symbiosis involvement, have not been investigated.

The transition from linear to circular economic models has had great interest in the development of circular supply chains within the process of industrial symbiosis. This aims to ensure collaboration between organizations and increase efficiency in resource use and waste reduction. Therefore, this study seeks to

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analyze the conceptual and empirical connections between circular supply chains, industrial symbiosis, product redesign, product reuse, and transformation pathways. The objectives of the paper are the following:

- To synthesize the current state of knowledge across the five thematic domains,
- To map the existing relationships between and across the five domains,
- To map the open research gaps that existing literature has not yet addressed.

The paper is structured as follows. Section 2 describes the methodology adopted for the literature search and selection process, detailing the databases consulted, search terms applied, and inclusion criteria used. Section 3 presents the literature review, which synthesizes the current state of knowledge across the five disciplines. Section 4 provides an analytical examination of the examined studies. Section 5 finishes the study by summarizing the principal findings.

II. BRIEF DESCRIPTION OF THE METHODOLOGICAL APPROACH

This paper presents a literature review on the main concepts. It synthesizes the existing knowledge and identifies research gaps. The process included three stages: literature identification, screening, and thematic synthesis.

As mentioned, the first phase was to identify relevant literature. Therefore, we have used Scopus and Web of Science databases. These two were selected because they contain reputable peer-reviewed publications. We also used Google Scholar to identify other studies and book chapters. We have applied following Boolean search across titles, abstracts, and keywords: "circular supply chain" OR "circular supply chain management" AND "industrial symbiosis" OR "product redesign" OR "product reuse" OR "transformation pathway" OR "reverse logistics". Also, we have restricted the search to peer-reviewed articles and book chapters published between 2020 and 2026 in English. This period was chosen to capture the most recent publications in this field.

Secondly, we have screened the relevance of the papers. Titles and abstracts were assessed against the thematic scope of the paper. Only studies that directly engaged with at least one of the five target domains were retained. Subsequently, full texts were analyzed to verify relevance and evaluate the quality.

Finally, each paper was categorized into one or more domains according to its principal contribution and the manner of its engagement with that domain. Afterwards, we looked at linkages between different domains and searched connections between pairs of domains. Those were either explicit, tacitly acknowledged, or not found in the literature that was evaluated.

III. LITERATURE REVIEW

The examined literature encompasses five interconnected domains, circular supply chains, industrial symbiosis, product redesign, product reuse, and transformation pathways, each of which cultivates significant knowledge while staying isolated from the others.

A. *Circular Supply Chains*

Circular supply chains differ from traditional supply chains because they combine restorative and regenerative cycles at the same time. This is achieved by closed-loop flows, where materials are reintegrated into the same system and waste is directed to alternative industries or applications. As a result, waste production and the need for new materials are cut down. Resource efficiency is also an objective of CSCs because they put value creation and waste elimination at the center of supply chain design. This means that at every stage of the life cycle, operational priorities are shifted to protecting and recovering the value of materials, components, and products. This necessitates that all participants in the chain commit to sustainability (Montag, 2023).

The circular supply chain is a system wherein product design, information and communication technologies, and value proposition collectively govern all supply chain activities. At the end of their cycle, materials and products are redirected into the system via a series of recovery loops, such as repair, reuse, refurbish/remanufacture, recycle, or cascade. The coordination of reverse flows needs recovery and return management systems, as well as good distribution and collection that unifies forward and reverse logistics, alongside network management decisions on facility placement, transportation, and inventory. Additionally, stakeholder involvement includes everything, such as roles, incentives, and ownership structures that determine how actors interact with the system (Amir et al., 2023).

The adoption of circular supply chain management (CSCM) improves resource and supply chain efficiency, while also fostering economic growth and value creation. In addition to operational advantages, CSCM enhances end-of-life strategies by facilitating more efficient recovery, reuse, and reintegration of materials and components. Hence, the overall competitiveness of the enterprises and networks is improved. Collectively, CSCM is not only an environmental management instrument but also a holistic strategy for sustainability that provides value across economic, environmental, and social spheres (Lahane et al., 2020).

The creation of a circular supply chain mostly relies on the commitment of senior management and shareholders to incorporate circular economy ideas into business strategy and to effectively direct the network of upstream and downstream partners in accordance with that strategic vision. Meaning, companies need to collaborate with suppliers and partners to advance green technology and eco-innovations. These are the basis for industrial symbiosis connections. Such relationships transform into structured collaborations whereby the waste or by-products of one company serve as inputs for another. This establishes industrial symbiosis networks that reduce waste disposal costs, diminish the demand for new raw materials, and facilitate mutually advantageous transactions (Maranesi & De Giovanni, 2020).

B. Industrial symbiosis

Industrial symbiosis is far more than a meso-level strategy within the circular economy. It is a systemic mechanism that works on micro, meso-, and macro levels and involves a wide range of actors, such as consumers, businesses, supply chains, ecosystems, and governments. IS requires collaboration of all stakeholders, rather than functioning in isolation at a single level. So, this multilevel and multi-actor approach uses fewer resources, cuts down waste, and makes the economy more sustainable. This makes industrial symbiosis a key strategy for moving toward a fully circular economy

As mentioned before, industrial symbiosis is a collaborative model in which companies deliberately share materials, energy, water, and byproducts, transforming waste streams from one firm into valuable inputs for another. These create environmental benefits such as reduced raw-material consumption, lower emissions, and better resource efficiency. Life-cycle assessment (LCA) is the main method for evaluating environmental benefits. It assesses the comprehensive cradle-to-grave impacts of items and activities before and following the symbiotic connection. Hence, LCA may demonstrate that the industrial symbiosis model is superior to a traditional production method (Neves et al., 2020). Moreover, it should also be noted that the process of industrial symbiosis comes with challenges as well as benefits. Most often there are organizational, technological, and institutional barriers (Palagonia et al., 2025).

The enablers and constraints of industrial symbiosis do not function uniformly across sectors, since their significance fluctuates based on the industry, the nature of the material or energy stream, and the exchange structure. Policy support, engaged partners, and geographical proximity are the main drivers. On the contrary, the main barriers are technological constraints, lack of trust between firms, the long distances, and economic constraints. To address these challenges, collaborative networks, unified waste policies, inter-firm protocols, financial instruments, and coordination with the government are needed (Henriques et al., 2021).

As mentioned above, polices promote industrial symbiosis. The most effective strategies integrate economic incentives and regulatory tools. Landfill taxes, bans on the disposal of organics, and pay-as-you-throw programs are examples of instruments that promote better waste hierarchy practices. Indirect policy mechanisms, such as land-use planning, waste legislation reforms, and renewable energy feed-in tariffs, while not specifically designed for this purpose, can create significant symbiotic synergies. Collaborative platforms for firms to trade by-products, flexible and long-term funding mechanisms, and centralized cooperative authorities with the expertise to assist in legal, technical, and administrative processes are also important (Lybaek et al., 2021).

C. Redesign

Choices made during the design phase significantly influence a product's environmental impact. Most of the product's effects are determined during the design phase. To achieve substantial advancements in sustainability, circularity principles must be integrated into goods from this stage. Radical redesign offers the greatest environmental advantage. On the other hand, incremental methods such as minimizing material usage, increasing reuse, and improving recovery offer only marginal improvements. The best redesign method encounters challenges in material recovery, which indicates the necessity of employing multiple strategies to properly address end-of-life material loops and achieve sustainability (Tan et al., 2024).

Circular product design refers to disassemblability, re-assimilability, durability, and modularity. Also, these are the dominant drivers of circular economy performance at the product level. If one of these attributes is improved, all recovery strategies across the R framework (upgrade, repair and maintenance, reuse, refurbishment, remanufacturing, and repurposing) are strengthened. Well-designed products do not serve a single recovery pathway but expand the range of options available to supply chain actors at every stage of the product's life. This reinforces the idea of seeing circular design as a strategic lever rather than a technical requirement (Mesa & González-Quiroga, 2023).

In addition, product redesign has become a strategic requirement for manufacturers because of the increased consumer expectations, product complexity, and time-to-market demands. All these compel firms to continuously improve existing products to remain competitive. Design for Manufacturing and Assembly supports early-stage cost reduction by simplifying component structures and improving how products are manufactured and assembled. In addition to this, Design for reliability complements it by addressing lifecycle performance and failure reduction, which helps firms uncover potential issues early and lower the overall cost of a product across its full operational life (Juniani et al., 2021).

On the contrary, some scholars say that Design for disassembly generates meaningful economic benefits because it improves sales growth and profitability, but it does not demonstrate a significant positive effect on environmental performance such as energy consumption, carbon emissions, or raw material use (Triguero et al., 2023).

D. Reuse

Within the circular supply chain framework, product reuse occupies a central position in the waste hierarchy as one of the cores "R-imperatives". Alongside refuse, reduce, and repair, they collectively define the short-loop actions through which products and components are kept active for as long as possible. Reuse is a short-loop method that intentionally slows down the flow of materials through the system. This keeps more of a product's value and extends its useful life before any restorative or regenerative actions are needed (Montag, 2023).

Reuse represents a significant yet underutilized circular manufacturing strategy, capable of extending product lifespans, minimizing waste production, and decreasing overall resource consumption. This would create economic, environmental, and social advantages. However, the successful implementation relies on product design that facilitates disassembly and multiple life cycles and operational processes with automated disassembly, as well as customer and market acceptability.

The latest might be achieved through education, certification, and trust. Undoubtedly, adoption is still limited because of the high initial costs, the lack of standards, and unclear core-acquisition timing. To solve these problems, there must be collaboration between industries, traceability, agreed quality standards, and complex incentives (Psarommatis et al., 2025).

E. Transformation pathways

There are many kinds of transformation pathways. When it comes to climate and energy pathways, they refer to the structured, long-term routes through which energy systems and societies shift away from fossil fuel toward sustainable, low-carbon alternatives. This requires not only technological transitions but also institutional, behavioral, and economic changes.

A supply-side pathway or a demand-driven pathway can reduce greenhouse gas emissions. The first is based on nuclear energy, carbon capture and storage, and biomass. The second pathway is based on solar power, heat pumps, and electric vehicles (Korkmaz et al., 2020).

Digital transformation requires two ways of approach: the implementation of flexible organizational structures that contribute to a rapid transition or the approach of digital business ecosystems. This process should be continuous and remove rigid structures from companies (Hanelt et al., 2021). Moreover, implementation must be context-specific and customized to the distinct characteristics and requirements of each unit (D'Amato, 2021).

Furthermore, the transition to a circular economy is not a linear sequence but a configuration that aligns with specific operational conditions, markets, and organizational competencies. It represents a type of comprehensive innovation aimed at fundamental company transformation. It necessitates companies to reevaluate their operations, value propositions, and connections with partners and customers in a cohesive and mutually reinforcing manner (Zils et al., 2025).

IV. RESEARCH GAP AND FUTURE RESEARCH AGENDA

The systematic analysis of the five topics indicates that, while each area has, independently, a significant body of literature, the cross-domain integration is still absent.

The most significant relationships identified in the literature are between circular supply chains and industrial symbiosis, as well as between product redesign and reuse. The first pair presents a direct connection between supply chain strategy and the development of symbiotic networks, with reverse flow coordination as the operational mechanism for inter-firm waste exchange.

The second pair demonstrates that circular design qualities, including modularity, disassemblability, and durability, facilitate reuse and recovery procedures. However, the relationship between circular supply chains and industrial symbiosis mostly emphasizes network building and material flow logistics, while the influence of product qualities on potential exchanges remains generally overlooked.

While the relationship between redesign and reuse is well known at the product level, it remains unconnected from the network and system-level conditions. Thus, even the well-covered relationships fall short of a completely integrated description.

Table 1. Well covered pairs

Domain Pair	**Key linkage**	**References**
Circular supply chains and Industrial symbiosis	Upstream/downstream collaboration transforms waste streams into shared inputs; reverse flow coordination enables inter-firm exchange	Maranesi & De Giovanni (2020); Amir et al. (2023); Lahane et al. (2020)
Product redesign and Reuse	Modularity, disassemblability, and durability directly enable reuse and multiple recovery strategies across the 6R framework	Mesa & González-Quiroga (2023); Psarommatis et al. (2025); Tan et al. (2024)

Table 2. Partial covered pairs

Domain Pair	Key linkage	References
Circular supply chains and Product redesign	End-of-life strategies and 6R recovery loops mentioned, but design decisions are not traced back to supply chain structure	Montag (2023); Lahane et al. (2020)
Circular supply chains and Reuse	Reuse positioned as a short-loop value retention strategy within CSC frameworks, without operational integration detail	Montag (2023); Amir et al. (2023)
Industrial symbiosis and Transformation pathways	Multi-level governance and policy instruments discussed as systemic enablers, but transition mechanisms remain descriptive	Henriques et al. (2021); Lybæk et al. (2021); D'Amato (2021)

Table 3. Conceptual model that highlights relationships between redesign, reuse, reverse logic and supply chain

Component	Relationship
Product Redesign → Reuse	If a circular product is designed, then it is easy to reuse
Reuse → Reverse Logistics	The products used require a competitive and up-to-date reverse logistics system.
Reverse Logistics → Industrial Symbiosis	Through reverse logistics, certain materials are recovered and pushed by other companies to use them
Industrial Symbiosis → Circular Supply Chain	Industrial symbiosis is closely related to reverse logistics
Circular Supply Chain → Sustainability	The impact is reduced and the principles of sustainability are supported.

The literature addresses partially three domain pairs. Circular supply chain frameworks recognize product redesign and reuse as pertinent tactics. However, the design decisions facilitating recovery and the operational conditions for reuse are not linked to the actual configuration of supply chains. The literature on industrial symbiosis also talks about systemic transition through governance and policy mechanisms, but these usually only talk about the conditions that lead to the creation of symbiotic systems, not how they change and grow over time.

The reviewed literature provides significant insights into many domain intersections. Nonetheless, five domains remain insufficiently explored and represent essential opportunities for future investigation. The relationship between industrial symbiosis and product redesign has been insufficiently examined, particularly regarding how design-for-disassembly decisions influence companies' capacity to exchange waste among themselves. Similarly, industrial symbiosis has rarely been examined as a structural enabler of reuse operations, despite the ability of symbiotic networks to alleviate existing barriers to reuse implementation. Moreover, the connections between transformation pathways and most of the domains are missing. Future research should concentrate on these intersections, as addressing these gaps is essential for developing a good understanding for product-level decisions, inter-firm network configurations, and systemic transitions.

Following the analysis of the specialized literature, the conceptual model in Table 3 can be developed.

Based on this model, a linear circular supply chain performance model can be developed. For this definition we use (R = product redesign, U = product reuse, L = reverse logistics efficiency, S = level of industrial symbiosis, C = circular chain performance, E = environmental impact). C has a higher value if the product is circular. The more the product is reused, the higher the value of U. If the logistics chain is efficient, then the value of L is higher. Finally, the level of symbiosis is higher if there is a lot of collaboration between companies. If C is higher than E has a lower value.

Therefore, the proposed linear model is:

$$C=\alpha R+\beta U+\gamma L+\delta S \qquad (1)$$

For a product A designed for circularity, the following values were obtained using a Likert scale from 1 to 10 for the variables and linear regression for the coefficients.

So, we have: R=8 (reuse level), U=7 (reuse), L=6 (reverse logistics), S=9 (industrial symbiosis)

And for the coefficients: α=0.3, β=0.25, γ=0.2, δ=0.25

Using equation 1 we obtain:

$$C=0.3*8+0.25*7+0.2*6+0.25*9 = 2.4+1.75+1.2+2.25=7.6$$

The interpretation of the result obtained is that the performance of the logistics chain is 7.6, close to the maximum value of 10. Therefore, an efficient circular economy system and industrial symbiosis are indicated.

V. CONCLUSION

This study examines five interconnected domains: circular supply chains, industrial symbiosis, product redesign, reuse, and transformation pathways, as well as the links between them. The review suggests that the information of each domain is substantial, but linkage between them is limited. The most recognized connection is between circular supply chains and industrial symbiosis. The second most explored connection is between product redesign and reuse, with circular design elements directly supporting multiple recovery options. Other intersections were found in the literature between circular supply chains and redesign and reuse, as well as between industrial symbiosis and transformation routes. However, these links are less studied.

Overall, there is a consensus on the need for transition towards circular frameworks. However, the practical implementation of this and its consequences for product design, product reuse, and inter-firm network structures are still uncertain. Our paper highlights the need for research that considers circular transition not as a background but as a field of study.

Future research may develop frameworks that combine circular supply chains, industrial symbiosis, and product-level initiatives into one unit. In this system, design choices, network configurations, and transition dynamics would be interdependent variables, not isolated factors.

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All for One? Responsibility Distribution in Sustainable Asset Management

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Abstract – The sustainable management of real estate in Romania depends on a clearer distribution of responsibility regarding building performance. ″All for one″ conceptual framework proposed in our paper, based on the Architecture Management Sustainability (AMS) model, synthesize the main structural fractures of the Romanian housing system and introduce two mirror figures: one fragmented and short-term, the other integrated and life-cycle oriented. Then highlights the implications for professional roles, contractual arrangements, and digital platforms that could support the transition to a strategic property management.

Keywords: Real estate management; responsibility distribution; Architecture Management Sustainability (AMS) model; fragmented ownership; Romania

I. INTRODUCTION

After the communist era, Romania developed one of Europe's most fragmented residential ownership structures, while it was still relying on the older multi-family housing built largely before 1990 [1]–[3]. More than 96% of residents own their homes. This combination makes coordinated interventions difficult, as buildings require energy improvements, technical improvements and better governance, and decisions are dispersed between many owners, associations with weak support, and reactive management practices.

In recent years, pressure has increased for sustainable transformation. Residential buildings are judged by energy performance, operating costs, resilience, indoor comfort, and long-term social effects, not by location or market value [4], [5]. Real estate management can no longer be reduced to ordinary administration, emergency repair, and minimal accounting.

The Romanian case reveals a deeper structural problem, that the responsibility for construction performance is divided between design, administration, ownership, and public regulation [1], [3], [6]–[9].

Architects usually leave the design and construction process, the property manager focusses on short-term operational problems, homeowners tend to give priority to immediate costs, and public authorities intervene in a balanced manner through fragmented programmes and regulations. Therefore, no actor assumes a clear responsibility for the full performance of the residential asset life cycle.

Our paper points out that this problem is not only technical but organizational, conceptual and so on. The article explores how responsibility is distributed in the governance of Romanian residential property based on the architecture management sustainability model (AMS).

The formula *"all for one"* is used as a conceptual lens for comparing these two contradictory situations: one fragmented and reactive, the other integrated and lifecycle-oriented [10], [11]. In the research approach, two objectives were followed:

1. Synthesis of the main structural shortcomings in Romania's housing system, which make sustainable management difficult, and
2. Introduction of two mirrors to illustrate different organizational roles, discuss their implications for professional roles, contractual logic and digital coordination tools.

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II. THEORETICAL BACKGROUND: STRUCTURAL FRACTURES AND AMS

A. *Structural fractures in the Romanian housing system*

The Romanian residential housing system is marked by several structural fractures that undermine coherent real estate governance (fig. 1), as follows:

1) The institutional fragmentation which responsibilities for housing policy, energy retrofit, urban planning and building control are spread across multiple ministries, agencies and local authorities, often with overlapping or inconsistent mandates [12]. All lead to programmes that are difficult to coordinate at the level of individual buildings or neighbourhoods.

2) The ownership, which mass privatisation in the 1990s created a landscape of highly atomised ownership, with hundreds of co-owners in a single multi-family building and weak collective decision-making structures [2]. In many associations, decision processes are slow, conflictual, and driven by immediate affordability rather than long-term value;

3) The qualitative fracture. In this issue much of the multi-family housing stock has poor energy performance, outdated installations and significant seismic and functional vulnerabilities, and there is no systematic, lifecycle-based maintenance culture, Fig. 1 [13].

Technical audits are not treated as precision tools, planned interventions are dominated by reactive repairs, and technological and legal fractures lead to a complicated situation. There are legislative gaps and ambiguities regarding homeowner associations, building management, and performance. Penalties and professional standards are minimal [14]–[18].

Decisions based on transparency and data are limited by the uneven adoption of digital tools (such as Building Information Modeling (BIM)), IoT, or online platforms dedicated to association management [13].

These gaps create an environment in which none of the actors has the mandate and capacity to oversee the building's life cycle in an integrated manner, and this structural context determined the starting point for the *"all for one"* framework in our work.

B. *Architect as value integrator*

To address the fragmentation in post-communist housing, Fig. 2, we developed the AMS model, a model that connects three interdependent areas: Architecture (sustainable design and life cycle intelligence); Management (real estate governance and operational planning); and Sustainability, based on ESG (long-term performance and value creation) [19]–[21].

Throughout the entire lifecycle of the construction, in AMS, architects are the value integrators who make decisions regarding design, management mechanisms, and specific sustainability objectives [22]. We consider that the role of value integrator does not replace property managers or public authorities. Continuity from concept to operation and renovation is complemented by the provision of integrated expertise.

The model assumes a circular relationship between design and management [23]. Architectural choices regarding the layout, structure, materials, and technical systems have influenced operational efficiency, maintenance costs, and user comfort for decades. On the other hand, operational feedback on energy consumption, failures, repairs and residents' satisfaction should inform future design interventions and upgrading strategies [4], [24]–[26].

When this cycle breaks down, the buildings tend to perform poorly and the responsibility for this poor performance remains wide. In previous research, the AMS framework has been conceptualized and supported by the literature on sustainable architecture, facility management, digitalization and real estate ESG governance [27], [28].

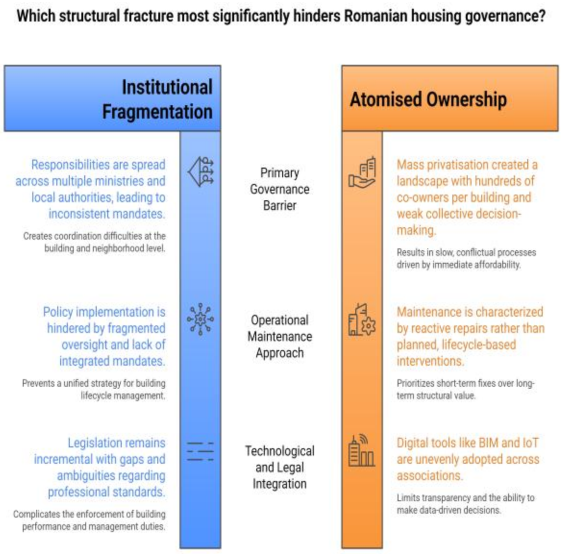

Fig. 1. Residential housing governance structural fractures

Fig. 2. The AMS

The paper uses the AMS as a benchmark model to rethink the distribution of responsibility in Romanian residential real estate, making life cycle performance a shared goal rather than an abandonment.

C. *From structural fractures to responsibility configurations*

The structural fractures described above mean that the responsibility for the performance of residential buildings is currently distributed in an implicit and uncoordinated way. Each actor (architect, engineer, property manager, homeowner association, public authority) acts within its own narrow mandate and time horizon, often without a clear view of the entire lifecycle.

The *"all for one"* framework proposed next in this document builds on the AMS logic to make these responsibility configurations explicit. By contrasting a fragmented, short-term configuration with an integrated, lifecycle-orientated one, the framework provides a conceptual tool for discussing which distribution of responsibilities is desirable and under what institutional and contractual conditions it could be implemented.

III. THE ALL FOR-ONE RESPONSIBILITY FRAMEWORK

A. *Rationale and design of mirror figures*

The *"all-for-one"* framework has been developed as a visual tool to clearly, rather than implicitly, distribute responsibility for the administration of residential property. The two mirrors (Fig. 3 and 4) are constructed around the same key actors (architects, engineers, property managers, homeowners' associations, residents and public authorities) and reorganise roles, connections, and time horizons in a different way.

The objective is to clarify what exactly changes when responsibility shifts from fragmented project-based logic to integrated lifecycle-oriented logic and not idealising one configuration and demonising the other. Fig. 3 shows a configuration very similar to the current model in many Romanian multi-family buildings, which means that responsibilities are officially distributed, poorly coordinated and each actor tends to act within a narrow mandate and short-term horizon.

Fig. 4 reflects AMS logic by connecting design, management, and sustainability throughout the construction life cycle, and by making the architect a value integrator who remains involved in crucial decision-making. When two figures are placed side by side, the gap in the existing system is seen and the levers available for progressive transition are visible.

B. *Fragmented and short-term responsibility configuration*

In fragmented configurations, the responsibility is formally divided and practically diluted. The architect focusses on the design and construction phases, implements the project, abandons the process at hand, has limited or no involvement in the decision to operate, maintain, or replace.

Many of the inconsistencies arise from property managers who most often have an average training course in this field. Tax collection, utility payment and response to urgent technical failures are constant concerns, and long-term multi-annual planning of interventions is too little addressed. Decisions are made in the short term and are often not the most efficient. Therefore, it can be said that public authorities are mainly regulatory authorities and rarely financiers.

Development programs are fragmented and do not reflect the needs and rhythms of each building. The first graphic depicts this situation through weak and inconsistent links between the actors and through arrows concentrated around a single moment, such as approval of projects or emergency repairs.

The long phases of the construction lifecycle (routine operations, monitoring, incremental renovations) are scarcely occupied with responsibilities, increasing the likelihood of underperformance and shifting responsibility when problems arise, Fig. 3. In this configuration, *"all for one"* becomes *"all against one"*: when the building cannot provide comfort, safety, or sustainability, each actor can point to someone else, Fig. 4.

C. *Integrated and lifecycle-oriented responsibility configuration*

A unified configuration redefines how responsibility is shared over time and coordinated rather than centralizing power in a single actor. Architects continue to exist beyond the transfer, at least at key transitional points, such as major renovations, changes in use, or important regulatory updates, and contribute to building design intelligence and knowledge.

Owners have evolved from guardians to strategic coordinators, planning, and justifying interventions using digital platforms and performance indicators. Owners' associations are supported by clearer rules, better information, and professional facilitating, which allows them to move from ad hoc decision-making to multi-year planning linking technical, financial, and social considerations [29].

The role of public authorities in planning the life cycle is more consistent through encouraging performance and integrating funding schemes. In Fig. 4, we highlighted the changes represented by the continuous and stronger links between actors and covered the building's life cycle with arrows. It can be easily observed how, in the later phases, the architect is a value integrator, connected to real estate managers, energy auditors, and association leaders, while in the project phase the connection is with engineers and contractors.

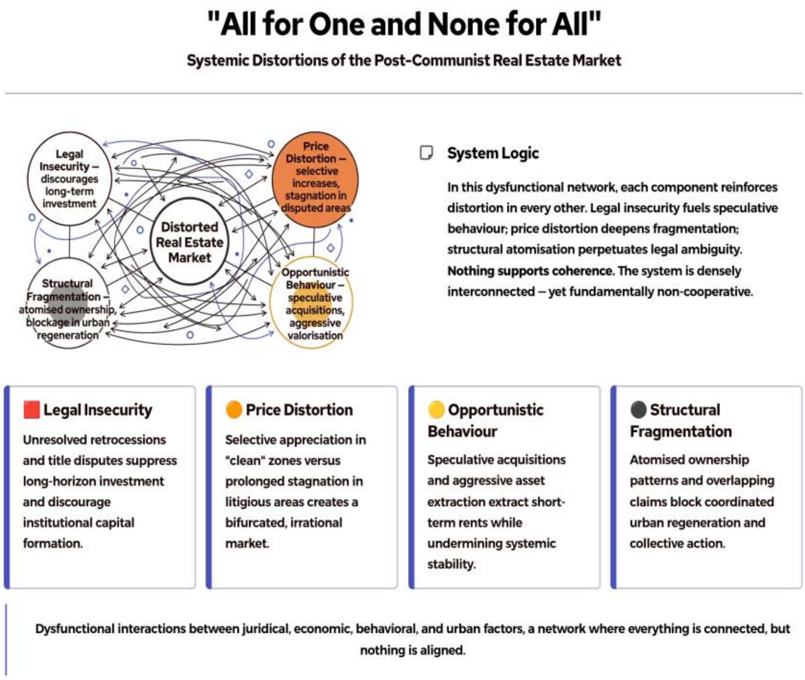

Fig. 3. Systemic distortions of the post-comunist real estate market

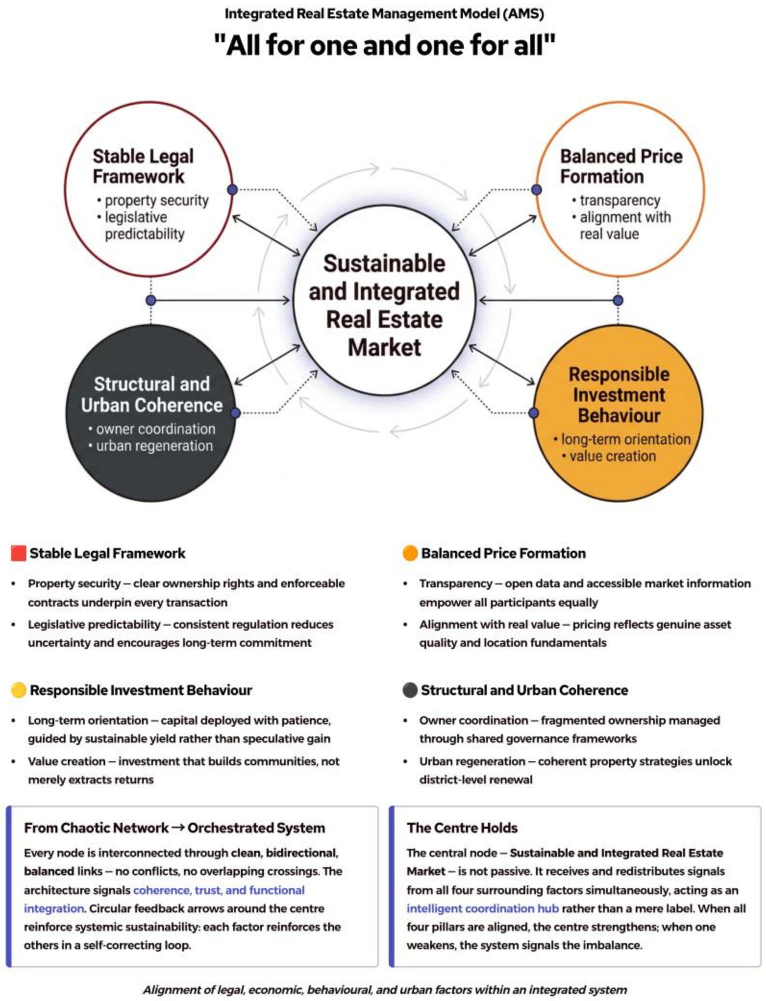

Fig. 4. Integrated real estate management model (AMS)

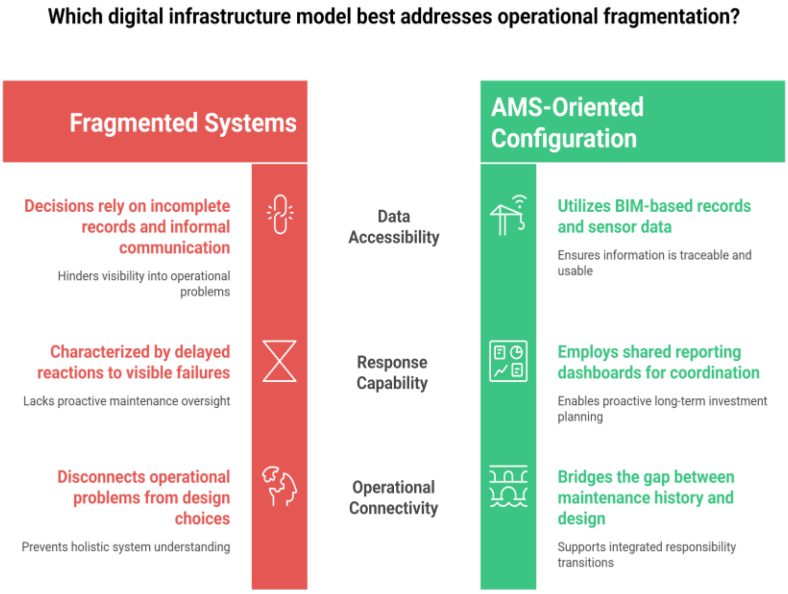

Fig. 5. Digital platforms and the fragmented operational

In addition, we explicitly draw the digital platforms and data flows, horizontal layers that support feedback and transparency and reduce the gaps between design intentions and operational realities on the ground. This configuration gives concrete content to the idea of *all for one*, which means that the responsibilities remain differentiated, that actors recognise a shared interest in the long-term performance of the building, and that their decisions are interdependent. The mirror between the two figures is therefore conceptual (not just graphic), and it contrasts with a system where responsibility is formally dispersed. The system is practically evaded with one in which responsibility is structured, shared, and traceable throughout the building lifecycle.

IV. IMPLICATIONS FOR ROLES, CONTRACTS AND DIGITAL PLATFORMS

A. *Redefining professional roles*

The transition from fragmented to integrated responsibility requires a redefinition of the roles of the main actors in the governance of residential property [21], [30]. In AMS logic, architects are no longer limited to the design phase but contribute to the performance of the life cycle by coordinating post-occupied feedback, retrofit strategies, and other specialists. We believe that this does not eliminate the role of property managers but requires stronger partnerships between design intelligence and operational management.

Real estate managers must also move beyond a narrow administrative function focused on bookkeeping, utility payments, and emergency responses. In the integrated configuration, they are coordinators of information, maintenance planning, and communication between residents, technical experts, and public authorities [17], [31], [32].

This expansion of the role means higher professional standards, clearer responsibilities, and better access to digital tools. At the same time, owners' associations and residents cannot remain passive beneficiaries of other people's decisions.

We believe that the evolution of roles needs to be rearranged, so that instead of merely providing approvals and reactive rejections of isolated expenses, the perceived improvement should move towards informed participation in medium- and long-term planning. With these changes, well-designed technical solutions will no longer fail in practice because the governmental environment would be stable.

B. *Contractual implications*

Contractual agreements that separate design, implementation, and operation into short, weakly interconnected episodes are those that reinforce the fragmentation of responsibility. It is known that, currently, the architect's responsibility ends upon delivery, while the property manager's mandate is limited to the usual compliance with immediate obligations [33].

Gaps in taking responsibility can be identified often, especially when aiming to optimize performance throughout the entire life cycle of a construction. We consider that for an integrated configuration; clear contractual tools are necessary which establish a durable and continuous link between design decisions and operational outcomes. For example: extending the consultative involvement of architects in major renovation projects, clearly defining the obligations stipulated in the technical documentation upon handover, introducing services that are performance-focused and connect management decisions to clearly measurable indicators. Such mechanisms will reduce the grey area of responsibilities and make their monitoring over time more accessible, even if they are introduced gradually. It should be noted that, for the adjustment of this contractual framework, in Romania many of the problems arise from the weakness of the relationships between the relevant actors.

We consider that it is necessary to describe clearly the tasks, the decision points, and the feedback loops, which can lead to the improvement of technical performance and the level of trust between owners, administrators, and specialists.

C. *Coordination infrastructure with digital platforms*

The transition towards integrated responsibility through facilitating access, traceability, and use of information can be supported with the help of digital platforms (Fig. 5).

An examination of fragmented systems reveals that, often, decisions are based on incomplete records, informal communication, and also delayed responses to visible failures.

All these triggers a difficult correlation of operational problems in design choices, maintenance history, or medium- and long-term investment planning.

Therefore, digital platforms, in an AMS-oriented configuration, can create the necessary basic infrastructure for coordination, Fig. 5 [18], [34].

The value of digital platforms lies in the ability to interconnect actors who work in isolation, thereby providing them access to the shared evidence base. Responsibility is difficult to transfer when information about costs, repairs, energy consumption, and planned interventions is transparent.

Likewise, we can state that strategic planning becomes realistic. Digitalisation should not be understood as a substitute for governance reform. We consider that the platforms can improve coordination only when roles, responsibilities, and decision procedures are already defined with enough clarity to make the data meaningful. In this sense, digital tools are not the starting point of integration, but one of its main enablers.

V. DISCUSSION, LIMITATIONS AND CONCLUSIONS

In this paper, we argue that the core difficulties in the management of sustainable residential real estate in post-communist Romania are not technical but structural and organizational. In the context of fragmented ownership, older multi-family buildings, lack of life cycle coordination and reactive management, responsibilities are distributed without true integration. In this context, the proposed single framework extended the AMS model by revealing responsibility configurations and showing that construction performance depends on the alignment of roles, decisions, and feedback throughout the life cycle.

The main contribution of the paper is therefore conceptual. Instead of proposing a new technical retrofit solution, it provides an interpretation framework for understanding why technically reasonable interventions often do not yield sustainable results when governance remains fragmented. Mirror figures help to translate this argument into a broader form of discussion because they show that there is no coordination, continuity, and traceability of the responsibility between actors. At the same time, the document has several limitations.

First, it is a conceptual contribution derived primarily from broader doctoral research and does not test the framework through a comprehensive empirical validation in representative samples of Romanian residential associations or housing portfolios.

Second, this argument is based mainly on the post-communist context of Romania, which strengthens the relevance of the context but limits the immediate generalisation to housing systems formed by different ownership structures, legal traditions, and professional cultures.

Third, these two figures clarify the responsible configurations at an analytical level, but they inevitably simplify the diversity of the actual structures, hybrid contracts, and informal practices that exist in actual buildings.

Another limitation is that the article has not yet operationalised the framework by measuring indicators, comparison points, or longitudinal case tests. As a result, the proposed model should be regarded as a structured basis for future empirical research and not as a fully verified prediction tool. Therefore, future research may be conducted through case studies, interviews, building governance analysis, and examination of digital platforms and performance-based residential management contractual arrangements.

Despite these limitations, the article brings an original perspective by linking architectural responsibility, property management and sustainability within a single lifecycle-oriented logic.

An original contribution of our paper is the adaptation of the AMS scheme to the specifics of Romania and the use of the phrase *all for one* to capture the contrast between integrated responsibilities and fragmented ones. All of this is done in a concise formula, and we consider it easy to reuse. Our proposal supports the shift from management focused on solving emergencies toward strategic management of the real estate portfolio, where assuming the common objective of all actors involved in the process is the long-term performance of the buildings.

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Validated Relational Infrastructure and Social Capital: A Conceptual Model for Facilitating Access to Economic Opportunities in the Local Entrepreneurial Ecosystem

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Abstract – This paper proposes a conceptual model, named We Connect, structured on five functional layers: local network, validated relationships, structured access to opportunities, interaction and development and scalability. Grounded in social capital theory, structural holes analysis, strategic networking research and entrepreneurial ecosystem frameworks, the model addresses the question: How can validated relationships and local collaborative infrastructure facilitate access to economic opportunities and reduce barriers in local entrepreneurial ecosystems? The paper adopts a conceptual-exploratory methodology, proposing an analytical framework applicable in the case of Timisoara and Romania West Region context. Results suggest that institutionalized relational validation can reduce information asymmetry, lower collaboration risk and generate cumulative social capital effects. Limitations and future empirical research directions are discussed.
Keywords: Entrepreneurship, ecosystem, social capital, relational infrastructure, economic opportunities, Western Region Romania

I. INTRODUCTION

The Western Development Region of Romania (NUTS code RO42) presents a compelling case for studying entrepreneurial ecosystem dynamics in mid-sized European cities. With a population of approximately 1.67 million (2021 census), a GDP of €31.6 billion (2024) and Timisoara as its economic capital – ranked third among Romanian cities by startup ecosystem vitality [23] – the region combines meaningful actor density with persistent structural underperformance in entrepreneurial collaboration and innovation output [15, 24].

The Regional Innovation Scoreboard 2025 of the European Commission identifies Vest (RO42) as the Romanian region that improved most strongly from 2018 to 2025 [15], yet knowledge-intensive collaboration remains constrained by relational infrastructure deficits documented across Central and Eastern European ecosystems [18]. At the national level, the GEM 2023/2024 Romania National Report records the lowest early-stage entrepreneurial activity (TEA) among all 45 surveyed economies (5.85% of adults) against a G7 average of 14.5% [4]. Equally significant is that 58.97% of Romanian adults cite fear of failure as a barrier to entrepreneurship [4, 7], a figure that research links not only to cultural dispositions but to the absence of reliable partnership validation mechanisms [7].

This structural paradox, a region with growing economic indicators but weak collaborative infrastructure, motivates the present paper. The problem is not primarily actor scarcity, but the absence of the relational architecture that converts actor density into collaborative value. Informal networks remain fragmented; partner quality is opaque; and opportunity flows are accessible primarily through pre-existing strong-tie networks, systematically excluding early-stage and peripheral actors [12, 19].

This paper proposes a conceptual model (hereinafter referred to as We Connect) to operationalize the concept of validated local relational infrastructure, capable of facilitating access to economic opportunities and reducing fragmentation in local entrepreneurial ecosystems. The model is grounded in established theory and calibrated to the specific structural conditions of Timisoara and the Western Region.

The central research question is: How can validated relationships and local collaborative

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infrastructure facilitate access to economic opportunities and reduce barriers in local entrepreneurial ecosystems? The paper's objectives are:

(1) To synthesize the theoretical framework on ecosystems, social capital and strategic networking;

(2) To identify and systematize structural barriers in local ecosystems with reference to the western region context;

(3) To propose a five-layer conceptual model as a structural response; and

(4) To evaluate the model's applicability and limitations.

II. THEORETICAL BACKGROUND

A. *Entrepreneurial Ecosystems*

The entrepreneurial ecosystem concept, systematized by Isenberg [10] and elaborated by Stam [19], Mason and Brown [13] and Autio et al. [2] frames entrepreneurial vitality as an emergent property of actor interdependence rather than individual capability. Isenberg [10] identifies six ecosystem domains: policy, finance, culture, support, human capital and markets. Critically, the relational dimension (the quality and density of actor connections) is recognized as a cross-cutting condition that either enables or constrains the functioning of all other domains.

Stam [19] distinguishes ecosystem outputs (firms created) from outcomes (economic value generated), arguing that outcome quality depends fundamentally on the relational framework. An ecosystem with active actors but weak connective infrastructure produces an "ecosystem failure": inputs without proportionate outputs. Spigel and Harrison [20] further demonstrate that ecosystems are constituted through ongoing relational practices (not static endowments) making relational infrastructure a key lever for ecosystem improvement.

Research on ecosystem resilience confirms that stronger network structures are associated with greater stability and performance, particularly in ecosystems dominated by SMEs [6]. The institutional work perspective [5] frames ecosystem development as a process of institutionalizing collaborative behavior, precisely what the proposed model seeks to operationalize. At the European level, the Regional Innovation Scoreboard 2025 [15] documents that innovation performance gaps among Romanian regions are attributable significantly to low levels of collaborative and knowledge-intensive activity, not solely to resource scarcity.

B. *Social Capital and Validated Relationships*

Social capital theory provides the foundational rationale for why relational structure determines economic outcomes. Coleman [3] defines social capital as resources embedded in relationships that facilitate action; Putnam [16] extends this to the collective level, demonstrating that communities with higher generalized trust and denser reciprocal networks consistently outperform on economic indicators. For entrepreneurial ecosystems, Putnam's insight implies that trust is not merely an ethical desideratum but an economic infrastructure component.

Granovetter's seminal work [8] on weak tie strength demonstrates that bridging connections (relationships between otherwise disconnected actors) are the primary channel through which non-redundant information and novel opportunities flow. This is directly relevant to ecosystem design: a relational infrastructure that systematically facilitates bridging connections generates higher informational value than one reinforcing existing cluster. In the Romanian context, research on social capital among SaaS entrepreneurs [17] confirms that network-mediated access to diverse knowledge resources is a significant predictor of innovative performance.

According to Burt's structural holes framework [12], the formalization of this dynamic: actors bridging disconnected groups gain informational and competitive advantages through brokerage. The proposed model institutionalizes this brokerage function at the ecosystem level, making it accessible to actors who lack the social capital to occupy brokerage positions individually. The concept of a validated relationship, operationalized in this paper, refers to a professional connection confirmed through:

(1) Network recommendations with verifiable identity;

(2) Documented post-collaboration feedback;

(3) Observed participation in ecosystem activities.

This operationalization directly addresses Akerlof's adverse selection problem [11], the quality uncertainty that inflates transaction costs and depresses collaboration rates.

C. *Strategic Networking and Relational Efficiency*

Strategic networking differs from generic networking by its orientation toward specific economic objectives: resource access, partnerships, market intelligence and opportunity recognition [1, 8]. Brass et al. [1] demonstrate across organizational contexts that network position, diversity and relationship quality are stronger performance predictors than network size alone. Their findings indicate that actors embedded in structurally diverse, quality-filtered networks access a broader resource base and achieve higher collaborative success rates.

The concept of relational efficiency, the ratio of relational investment to economic outcomes generated, is critical for ecosystem design. Evidence from Central and Eastern European ecosystems [18] suggests that relational efficiency in unstructured local ecosystems is systematically low: actors invest significant time and resources in networking activities that yield few actionable connections. This inefficiency is compounded when actors cannot reliably assess partner quality prior to commitment, leading to underinvestment in collaboration [11].

The institutionalization of collaboration, creating reproducible, legitimized patterns of collaborative behavior, is identified by Vangen and Huxham [14] as a necessary condition for sustained ecosystem development. An ad hoc networking event, however well-attended, does not produce institutionalized collaboration; a structured mechanism with validation, feedback and repeated interaction does. This distinction grounds the design logic of the proposed model.

D. *Architect as Value Integrator*

To address the fragmentation in post-communist housing, Fig. 1, we developed the AMS model, a model that connects three interdependent areas: Architecture (sustainable design and life cycle intelligence); Management (real estate governance and operational planning); and Sustainability, based on ESG (long-term performance and value creation).

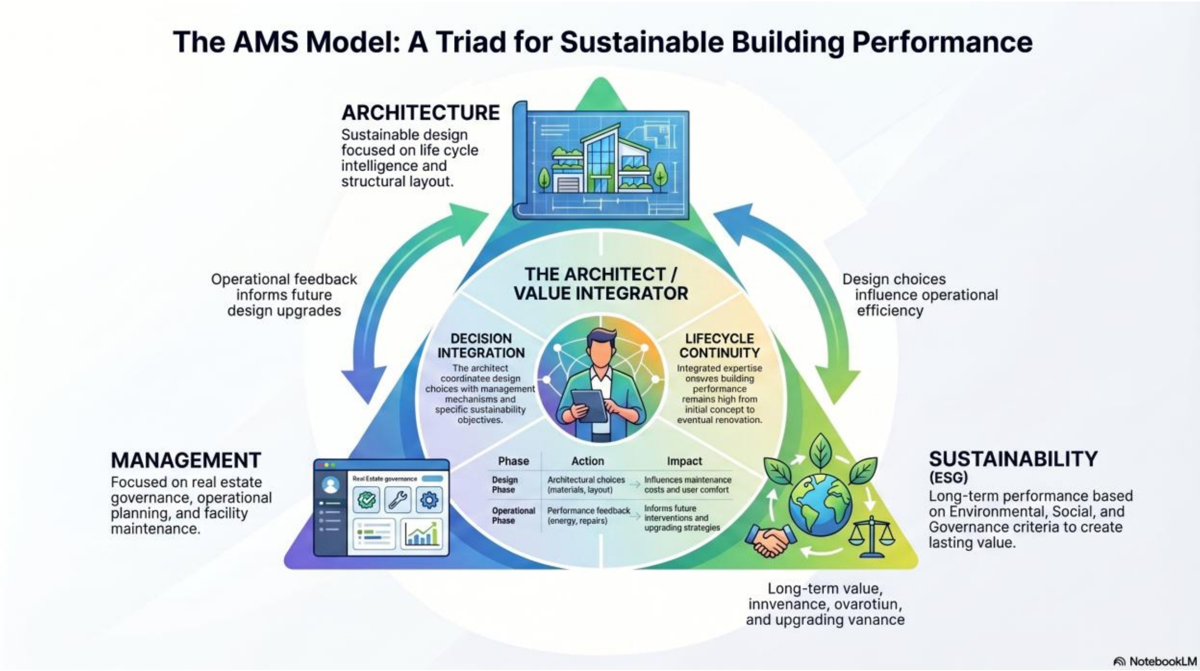

Fig. 1. The AMS model (authors own development using NotebookLM generative AI software as a synthesis)

Throughout the entire lifecycle of the construction, in AMS, architects are the value integrators who make decisions regarding design, management mechanisms and specific sustainability objectives. We consider that the role of value integrator does not replace property managers or public authorities. Continuity from concept to operation and renovation is complemented by the provision of integrated expertise.

The model assumes a circular relationship between design and management. Architectural choices regarding the layout, structure, materials and technical systems have influenced operational efficiency, maintenance costs and user comfort for decades. On the other hand, operational feedback on energy consumption, failures, repairs and residents' satisfaction should inform future design interventions and upgrading strategies [4].

When this cycle breaks down, the buildings tend to perform poorly and the responsibility for this poor performance remains wide. In previous research, the AMS framework has been conceptualized and supported by the literature on sustainable architecture, facility management, digitalization and real estate ESG governance.

III. BARRIERS IN LOCAL ENTREPRENEURIAL ECOSYSTEMS: THE WESTERN REGION CONTEXT

The following barrier taxonomy is grounded in the theoretical framework above and in empirical data characterizing the Romanian and Western Region entrepreneurial context. Four primary barrier categories are identified; they interact and reinforce one another, producing systemic fragmentation that persists independently of individual actor capability. Relational fragmentation and low actor visibility. In Timisoara’s startup ecosystem, ranked #649 globally and #3 in Romania with 43 documented startups [23], most economic actors operate with limited mutual visibility. The GEM 2023 Romania report finds that only approximately one in two Romanian adults knows someone who recently started a business [4] – a measure of network exposure that is among the lowest in the surveyed economies. This figure, while national, is symptomatic of the broader relational opacity that characterizes Romanian ecosystems: actors exist but are poorly mapped and mutually inaccessible.

Lack of collaborator validation and elevated risk perception. The 58.97% fear-of-failure rate documented by GEM 2023/2024 [4] reflects not only cultural attitudes but the absence of risk-reduction mechanisms in the collaboration environment. Research on Romanian entrepreneurship [7] confirms that fear of failure and limited access to reliable partnership information are structurally linked: when actor quality is unverifiable, the perceived risk of collaboration rises, reducing initiation rates. Akerlof's adverse selection dynamic [11] operates: the market for collaborations is depressed by quality uncertainty.

Information asymmetry and concentrated opportunity access. The European Innovation Scoreboard 2023 [24] places Romania's knowledge-intensive service employment at 26.5% of total employment, against an EU average of 35.8%, reflecting a structural concentration of high-value economic activity. Within regional ecosystems, opportunity flows, unmet demand, available resources, emerging partnerships, circulate predominantly through established strong-tie networks, systematically excluding actors with limited initial social capital, including recent graduates and early-stage entrepreneurs [12].

Weak collaborative culture and low institutionalization of networking. The ADR Vest Program Regional 2021-2027 [22] identifies the creation of a strong entrepreneurial culture and the increase of firm formation and survival rates as strategic priorities, implicitly acknowledging that collaborative norms remain underdeveloped in the regional ecosystem. The GEM Romania 2023 report scores Entrepreneurial Education at School at 2.7 out of 10, the lowest of all framework conditions [4], reflecting a systemic deficit in the formation of collaborative and entrepreneurial dispositions from which the professional population emerges.

These four barriers form a self-reinforcing cycle: fragmentation limits validation opportunities; lack of validation elevates risk and suppresses collaboration initiation; information asymmetry concentrates opportunity access among established actors; and weak collaborative culture reduces investment in relational infrastructure. Structural intervention at the ecosystem architecture level is required to break this cycle.

IV. CONCEPTUAL MODEL – WE CONNECT

A. Model Design Logic

The We Connect model (Table 1) is conceived as a local relational and economic infrastructure structured on five interdependent functional layers. Each layer directly addresses one or more barriers identified in Section III and the layers are designed to be mutually reinforced: the outputs of each layer create conditions for the effectiveness of subsequent ones. The model draws on the institutionalization framework of Vangen and Huxham [14], the brokerage mechanisms of Burt [12] and the ecosystem architecture principles of Feld [6a] and Spigel and Harrison [20].

B. Layer Descriptions

Layer 1 (Local Network) constitutes the model's foundational infrastructure: a structured, actively curated registry of ecosystem actors organized by functional categories, competencies offered, resources available, needs expressed, rather than institutional identity alone. Entry requires a minimum verification threshold. This registry addresses the visibility deficit documented above: it maps the ecosystem and makes its constituent actors mutually legible, enabling the subsequent validation and matching functions.

Layer 2 (Validated Relationships) is the model's central differentiating element. Validation operates through three cumulative mechanisms: (1) recommendations from existing verified members; (2) structured post-collaboration feedback accessible within the ecosystem; (3) a behavioral track record built through participation in ecosystem activities. Together, these generate an observable reputation signal that reduces the adverse selection problem identified by Akerlof [11]. This directly addresses the fear-of-failure dynamic documented by GEM [4]: when partner quality is verifiable, the perceived risk of new collaboration decreases.

Layer 3 (Structured Access to Opportunities) operationalizes the model's economic function through a demand-supply mechanism enabling members to declare needs and offers explicitly. This structured matchmaking converts latent complementarities, which exist in any actor-dense ecosystem but remain invisible without infrastructure, into active collaborations. Feld [6a] documents that explicit opportunity visibility is one of the highest-leverage interventions in ecosystem development, consistent with the information asymmetry barrier identified in Section III.

Layer 4 (Interaction and Development) provides relational densification through structured activities – thematically focused sessions with clear economic objectives, structured formats and post-event follow-up protocols. These activities differ from generic networking events in that they are designed to produce documented relationships within the ecosystem, not merely exchanged contact information. Brass et al. [1] confirm that interaction quality, the substantiveness of exchange and degree of mutual knowledge created – predicts subsequent collaboration more reliably than interaction frequency alone.

Layer 5 (Scalability) addresses long-term architecture. The registry, validation records and opportunity mechanisms are partially digitizable, enabling geographic extension from local to regional scale. This layer is directly relevant to the Western Region context: connecting the Timisoara ecosystem to those of Arad, Hunedoara and Caras-Severin (also in the West Region) through shared infrastructure would create a regional relational network aligned with the ADR Vest 2021-2027 strategic priorities [22].

Table 1. We Connect Model – Layer Structure and Addressed Barriers

Layer	Name	Main Components	Barrier Addressed
L1	Local Network	Curated actor registry: entrepreneurs, mentors, investors, suppliers, service providers	Fragmentation / low visibility
L2	Validated Relationships	Network recommendations, documented feedback, behavioral track record	Validation deficit / risk
L3	Structured Access to Opportuniti	Demand-supply mechanism, matchmaking, resource and expertise exchange	Information asymmetry
L4	Interaction and Development	Thematic workshops, results-oriented networking, post-event follow-up	Low collaborative culture
L5	Scalability	Local → regional → digital architecture, replicability	Systemic / long-term

Source: authors' own conception

V. IMPACT, APPLICABILITY and COMPARATIVE CONTEXT

A. Impact on Actor and Ecosystem Level

For individual SMEs and entrepreneurs, the proposed model reduces partner search and evaluation costs, lowers risk in new collaborations through validated reputation signals and increases access to opportunity flows previously accessible only through established networks. For early-stage actors, a population particularly affected by the GEM-documented barriers [4], access to a validated network provides a substitute for the social capital that would otherwise require years of informal relationship building to accumulate.

At the ecosystem level, the model's validation layer contributes to what Putnam [16] terms generalized trust, the expectation of reliable behavior from unknown actors, a documented predictor of aggregate economic performance. Ecosystems with higher trust levels generate more innovation and more productive collaborative activity [19]. The model's structured interaction layer (L4) increases relational density, which Stam [19] identifies as a key structural predictor of ecosystem outcome quality, which is currently low across Romanian regional ecosystems relative to EU averages [24].

B. Comparative Context: Similar Initiatives

The proposed model is not without precedent. The Romanian startup ecosystem has produced community-driven initiatives, including Timisoara Startups and analogous organizations in Cluj-Napoca and Iasi [21], that demonstrate the feasibility of structured ecosystem support in Romanian cities. The Romanian startup and VC ecosystem report [21] identifies Timisoara as one of four key startup cities in Romania, with local organizations "organizing networking activities, acceleration programs and coworking spaces". However, these initiatives have not systematically incorporated validated relationship mechanisms or structured opportunity matching, leaving the core information asymmetric barrier unaddressed.

At the European level, ecosystem infrastructure initiatives in comparable cities, including Tartu (Estonia), Graz (Austria) and Wroclaw (Poland), demonstrate that structured relational infrastructure at city scale can produce measurable increases in startup formation and inter-firm collaboration rates [6, 20]. The We Connect model draws on these precedents while adapting to the specific structural conditions of the Romanian Western Region.

C. Critical Mass and Implementation Conditions

The model's applicability is conditioned by three key factors. First, a critical mass of active participants: Feld [6a] estimates that 150-300 regularly active participants are sufficient to generate self-sustaining network effects in a medium-sized urban ecosystem, a threshold achievable in Timisoara given the documented density of SMEs, startup founders and professionals. Second, an institutional anchor willing to curate the registry and administer validation mechanisms, potentially provided by Politehnica University of Timisoara, ADR Vest, or an established professional association. Third, a minimum collaborative culture, which Layer 4 of the model is specifically designed to build over time.

VI. CONCLUSIONS AND LIMITATIONS

This paper has proposed the We Connect model as a structured conceptual response to a documented structural problem: the coexistence of actor density and collaborative underperformance in local entrepreneurial ecosystems, with specific reference to Timisoara and Romania's Western Region. The empirical grounding in GEM 2023/2024 data [4], European Innovation Scoreboard findings [15, 24], Regional Innovation Scoreboard 2025 evidence [15] and ADR Vest strategic priorities [22] establishes that the barriers addressed by the model are not hypothetical but are specifically documented in the target context.

The model's primary theoretical contribution is the operationalization of relational validation as a concrete multi-mechanism infrastructure function, translating the sociological concept of social capital into actionable ecosystem design principles. The adverse selection problem [11], the structural holes framework [1] and the trust-building requirements of collaborative institutionalization [5] are integrated into a five-layer architecture that addresses each identified barrier with a specific functional response.

The model's practical contribution is a structured implementation sequence, from foundational registry (L1) through validation (L2), matching (L3), interaction facilitation (L4) and scalability (L5), designed for incremental deployment. This sequence is aligned with the Vest Program Regional 2021-2027 objectives of increasing entrepreneurial culture, firm survival rates and regional collaboration [22], suggesting potential for institutional partnership.

Several limitations must be acknowledged. The model remains conceptual: its causal claims, which validated relationships reduce collaboration risk, that structured matching increases opportunity access, that Layer 4 activities increase relational density, require empirical testing. The proposed institutional anchor (university, ADR, professional association) introduces a governance dependency that could constrain implementation in contexts where such anchors are unavailable or unwilling. The validation mechanisms of Layer 2 carry an exclusion risk for actors without initial network connections, which may reproduce social capital inequalities the model aims to reduce.

Future research directions include:

(1) A mixed-methods empirical validation study applying survey instruments to entrepreneurs and SME owners in Timisoara and the Western Region;

(2) Comparative case analysis of structured relational infrastructure initiatives in analogous Central and Eastern European cities;

(3) Development of a validated measurement instrument for ecosystem-level relational capital to enable longitudinal impact assessment; and

(4) Governance model analysis to identify the institutional arrangements most conducive to model sustainability and inclusivity.

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Designing and Evaluating a Conversational AI Agent for Order Processing Automation: A Case Study at ICCO Smart Solutions Company

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Abstract - The paper provides an example for workflow automation applied to business using conversational artificial intelligence in an IT company in Romania. The example used in the paper is the order processing business process of ICCO Smart Solutions, an integrated security and automation systems supplier. Order processing includes clerical tasks such as reading documents, extracting information, verifying the completeness and accuracy of documents, and preparing internal documentation. The order flow assistant is the conversational AI agent that completes the tasks. Developed as a low-code prototype based on the ChatGPT Custom GPT this LLM-based agent was evaluated using a real commercial document in functional testing and using nine criteria of a well-defined task to be done using this document in performance testing. Results suggest that the LLM-based agent can not only furnish the structure of knowledge available and mark out knowledge gaps but also automate illustrating decisional authority at the level of the human operator.
Keywords: Conversational AI, business process automation, prompt engineering, Custom GPT, order management.

I. INTRODUCTION

Digital transformation has become a key planned priority and information technologies and artificial intelligence (AI) solutions, which in recent years have made it possible to optimize business processes, automate the performance of repetitive and routine tasks and improve the competitiveness of organizations, play an increasingly meaningful role in this transformation [5, 6, 8, 22].

Large language models (LLMs) and conversational software utilizing advanced natural language processing (NLP) are being used to address particular real-world business problems such as document analysis, extraction of information from documents, and decision support, among others, rather than simply remaining in experimental environments [4, 7, 9, 27].

For companies that deal with a lot of commercial documents, having people check, enter and transfer data repeatedly is time-consuming, prone to user error and does not make it easy to find where any commercial information has been stored. So it is useful to introduce dedicated AI agents to organize and process information.

This article presents the design and assessment of a conversational agent which can be used as an order management assistant in ICCO Smart Solutions, a Romanian provider of integrated security, communications and automation solutions. The proposed solution does not aim to replace humans from the decision-making process, but to assist them by automating standardizable repetitive tasks, while the decision-making remains in the users' hands [1].

The paper is structured as follows. Section II. describes theory on AI in organizations, business process automation and prompt engineering. Section III describes the case study and approach adopted. Section IV discusses how the Order Flow Assistant, the proposed agent, has been developed and then functionally tested. Conclusions, including limitations and future research directions, are presented in Section V.

II. THEORETICAL BACKGROUND

2.1 AI in organizations and business process automation

Several studies have examined the implementation of AI in organizations [5][9][19][32]. According to Davenport and Ronanki [9], the most successful AI business applications rely on achieving incremental automation of repetitively cognitively intensive tasks rather than replacing or substituting

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human decision making entirely. From a process perspective, BPM is defined as a structured approach to identifying, designing, executing, monitoring and optimizing business processes, while business process automation (BPA) is defined as the use of technology to automate repetitive business processes with minimal human intervention (Dumas et al. [10]). Automation thus allows employees to focus on activities with higher added value, such as analysis, coordination and client relations [13].

Generative AI also allows BPA toolkit to process unstructured inputs (such as natural language) and semi-structured documents, which have customarily been difficult to automate through rule-based approaches [7, 18, 29, 33].

2.2 Intelligent agents and LLM-based assistants

A smart agent is a software system that perceives its environment and takes actions to achieve some goals [24, 28]. Recently, a new family of agents has been enabled by LLMs, which are a type of foundation model, built on the transformer architecture [34], that can parse natural language prompts, process documents, and produce structured outputs [2][3][21][25]. Bhagwat [2] suggests that to be effective, AI agents should be provided with a high performing model and carefully designed instructions, tools and task boundaries. These agent workflows remain an active and rapidly evolving area of research [36].

2.3 Prompt engineering

Prompt engineering or prompt design is the act of creating a prompt that results in a desired and reproducible output from a particular LLM. Brown et al. [4] found that careful prompting created an improvement in particular models. They often include role conditioning, output constraints, and few-shot exemplars [31, 35]. A prompt can also replace programming in organizations: domain experts can specify custom tasks to be performed by the AI system without writing a program.

2.4 Regulatory considerations

The business process use cases of AI are regulated by the EU Artificial Intelligence Act [12] and the General Data Protection Regulation [11]. They require human oversight of, and transparency in, AI systems, as well as the lawful and fair processing of personal data. The proposed solution meets their requirements, and its human oversight feature is consistent with best practices in AI risk management [17, 23].

III. CASE STUDY AND METHODOLOGY

3.1 The analyzed company

ICCO Smart Solutions is a Romanian company, a part of ICCO Group, that provides integrated electronic security, communications and technical automation solutions [14, 15, 16]. It is headquartered in Brasov, Romania, and has offices in Bucharest and Timisoara. It has been operating since 2015 and its customers include both public and private entities. It has a steady copy of commercial documents and requests of varying complexity, from equipment transfer to servicing and projects.

3.2 The order management process

Order management is the starting point for the other processes within the company, a cross-departmental flow that generates added value [26]. The simplified process flow explained in this paper has four stages:

Client order → Registration → Logistics → Scheduling

In the first phase, the order is processed to identify and extract the required information (client, request type, request deadline, request location, and special requirements). It is followed by internal record keeping and entry in a standard format. In the logistics stage, available resources are examined [30], and in the scheduling stage, the intervention is planned.

3.3 Identified bottlenecks

The first phase is characterized by a large amount of repetitive manual work and the generation of orders in PDF, Excel formats, scans and e-mail that make the first phase strongly dependent on human experience. The greatest bottlenecks lie in the manual information extraction, the different input document structures to be processed, the lack of a systematic approach to incomplete information, and the lack of traceability along the process chain.

3.4 Methodological approach

The conducted approach is based on an organizational analysis and an applied design of a working prototype for the AI agent. This includes an analysis of the company and its order management process, requirement analysis, the design of the conceptual architecture of the agent, the implementation of a low code prototype using the ChatGPT Custom GPT platform, and a functional test of the agent with a real commercial document. This was chosen as it allowed quick validation of the concept without a separate software application.

IV. SOLUTION DESIGN AND FUNCTIONAL TESTING

4.1 Architecture of the Order Flow Assistant

We built the agent, Order Flow Assistant, using OpenAI's ChatGPT Custom GPT framework. This framework provides three capability layers: instructions (to specify the GPT's behaviour and ground rules), knowledge (for storing reference material), and tools (to analyse files and access the web, if applicable) [2, 7, 20]. As such, our agent is used solely as operational support and is unable to independently make decisions.

4.2 Prompt design strategy

The prompt was written with instructions specifying the role of the agent, the job it has to perform, the kind of documents it will read, the fields it should extract from those documents, how to tag fields that are missing without needing to invent information, and how the output should look (typed tables, internal draft notifications, preliminary order numbers and scheduling data). This prevents the generation of information that was not present in the input documents, thus avoiding hallucinations.

4.3 Human-in-the-loop responsibility distribution

To preserve human oversight, responsibilities are distributed between the AI agent and the human operator as summarized in Table 1.

Table 1. Responsibility distribution between user and AI agent

Activity	AI Agent	User
Document intake	assists processing	provides the document
Information extraction	performed automatically	verifies the result
Missing-data detection	flags	confirms / clarifies
Request classification	suggests	validates
Internal document drafting	produces a draft	approves use
Final operational decision	no decisional role	fully responsible

Table 2. Functional testing results - Order Flow Assistant

Evaluation criterion	Observed outcome	Level
Document type identification	Distinguished offer from firm order	High
Relevant data extraction	Client, value, deadline correctly captured	High
Completeness verification	Missing fields flagged without fabrication	High
Output consistency	Standardized, easily interpretable format	High
Operational classification	Logical category proposed	Good
Priority estimation	Heuristic level proposed	Good
Internal draft generation	Drafts of notification, order, scheduling produced	High
Practical administrative utility	Outputs reduce time and standardize tasks	High
Real operational integration	Standalone prototype, no ERP/DB connection	Limited

4.4 Functional testing

Testing the prototype was accomplished by using a document that the client Flextronics created as a real offer to relocate its access control system and to place a fire-emergency opening command. The agent needed to detect the document type, extract relevant data, verify that the information was complete, create a preliminary internal number, classify it operationally, determine its priority, create internal draft documents, and organise the data into a processing schedule.

4.5 Results

The agent is a ChatGPT Custom GPT called Order Flow Assistant. It comprises three layers: instructions (behaviors' rules, and guidelines), knowledge (supporting reference materials) and tools (interface to file analysis and the web where relevant). The agent is provided purely as an operational support tool and is not an independent decision-maker.

V. CONCLUSIONS

The paper proposed and evaluated a conversational agent called the Order Flow Assistant that supports order management at ICCO Smart Solutions. ICCO Smart Solutions' work process was analyzed and was found to have a lot of repetitive administrative responsibilities related to the order. Additionally, because of the heterogeneity of documents used as input, a lack of standardization was observed. The agent was built using low-code with the ChatGPT Custom GPT platform, allowing the agent designers to develop a functional prototype without the need for a dedicated software application.

The feasibility of the solution was demonstrated through functional testing of a real commercial document. The agent was able to identify the document type, extract the required information, highlight missing data and generate structured data for the next stages of the operation. The main advantages are a reduction in the time taken to process a document, a standardization of processing, better traceability, and a reduction of the risk of errors taking place in this stage.

However, a number of limitations exist: the agent's success depends on the structures and information found within the different documents, the prototype is functionally separate from the company's internal systems (e.g., ERP, logistics module), and all output needs to be validated by a human. The evaluation was performed on a single representative document and a broader sample of orders with various complexities would be required for a complete description of performance.

Future work may include integrating with the company enterprise systems, bigger libraries of prompts with new document types, internationalization to support multilingual clients and measurement of the impact on operations over time.

The results suggest that conversational AI should not be seen as a way to replace humans, but rather as an opportunity to redesign the way the information is processed by the organization, bring efficiencies to repetitive work and help human decision-making with smart digital tools.

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Digitalization of Financial Processes in Customers Relationships Management. The Case of Aquatim Company

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Abstract – The research study analysis the way that digital instruments sustain Aquatim S.A. financial activities and it's based by direct relationship with clients. The study starts with the idea of financial digitalization and that fact does not mean that only by paying invoices in an electronic way, is it a whole ecosystem based on a good structure and digitalization, that starts from consumption to educate the client, and it ends with tracking finished operations. The study is based by data base from digital economy and digital financial management and reports from Aquatim from 2024 and 2025. The practical part track available digital instruments, channel structure, Aquatim app and client financial path. The results show that digital tools are way more used in the relationship between company and users and fill the classic ways gaps and make the process easier to handle.

Keywords: digitalization, financial processes, online payments, digital channels, MyAquatim, relationship with clients

I. INTRODUCTION

Digitalization becomes an important part in companies, because it's easier to manage information, communication and relationships with clients. In the specialized literature, digital economy is associated by the appearance of new technologies and new ways that can transform economic activity and customers' feedback [1].

This change is important for big companies that work with a large or significant number of clients because they must do repetitive tasks like invoice issuance, information about the amount due and payment amount information. Aquatim keeps a strong relationship between the client and the way that it's used to track the information from index to receive the bill to verify the amount of pay and the way of payment and in the end, client can see even the history of consumption and latest payments. That's why financial digitalization is not all about the app, is about that ecosystem built around the whole company.

Relationship between digitalization and financial management is sustained by scientific literature. Duchlicher shows that the digitalization in a company level is based on how technologies and digital information are used in automatization processes and operations and software programs can sustain the part of evidence, analyze, build financial information [2]. Digital softwares are a key part of this process and it helps to manage and stock the information clearly.

II. CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1 Digitalization and company activity evolution

Digitalization is not limited by using apps, it can change the way that companies manage their activity and relationship with market. Popescu shows that digitalization has gained popularity in the las two decades and changed the way that people, customers and entrepreneurs communicate and relate with each other [1]. That idea is important, because the financial relationship between a company and client can work via digital channels, not just on printed documents or physical payment.

Digital technologies create new channels, like mobile apps, online portals and online payments. For clients, these channels mean access to information quickly, safe and in security manner and it saves a lot of time. For companies, all these things mean a well structure tracking system, ability to choose between cash or online payments and so on. In Aquatim's case, this change means a rise in online payments via MyAquatim app.

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Digitalization needs to be seen as a systemic change. The volume of economy in this digitalization era becomes more powerful in economic life and generates important changes in economy and management [3]. From that perspective, this analysis does not need to stop at financial instruments, digitalization needs to follow a way that can be integrated in real life processes and needs.

2.2 Digitalization in financial management

Financial management requires a set of right, up to date and easy to track information. A company needs to know what's invoiced, what's collected and what amount are due throught which channels payments are made. Duhlicher shows that path of company depends on how good management decisions on a good system are to collect the information and utilize it. That principle defines that digitalization is important in financial area.

In a practical way, financial digitalization could mean online invoices, online payment, access to your wallet and the history of your payments. These functions take part in financial activity and help the way that the client receives his information about the payments and verify the actual status.

Digital solutions are useful when the daily activity is simplified, not just adds a technical function. This idea is presented by financial management literature [2]. In case of Aquatim company it is important to mention that applications and online portal need to be used for their utility in daily tasks: access to invoices, bills, payments, invoice tracking.

2.3 Digital financial relationship between company and client

Financial relationship between company and client does not end in the moment of payment, in Aquatim's case, relationship starts with invoice issuance, consumption and index, and continues with access of invoice and ends up to actual payment and history tracking. If these steps are digitally integrated, clients have more control over their specific situation, and the company can manage clearly and easily the problems.

This method permits us to analyze a more simplified way of digitalization. Online payment is important, but it's not the only significant step. As important as online payment is sent by an index, receiving a invoice through e-mail verifying the wallet of payment and consulting the history of consumption. All these things together form a client's digital financial path

III. METHODOLGY

The research uses case study method, applied in Aquatim SA. This method fits and permits us to analyze a particular case, based on the available public date and digital instrumentation for clients.

These are 2 types of sources. First category is formed by theoretical report about digital economy and digital financial management. Second category is formed by report about Aquatim from 2024-2025, information about MyAquatim and client's path as a Aquatim client.

The practical part follows important database for digitalization of financial processes. The analysis focuses on digital instruments used on relationships with clients, functions of financial processes, average collections on every channel, utilization of MyAquatim app and financial digital path as a Aquatim client.

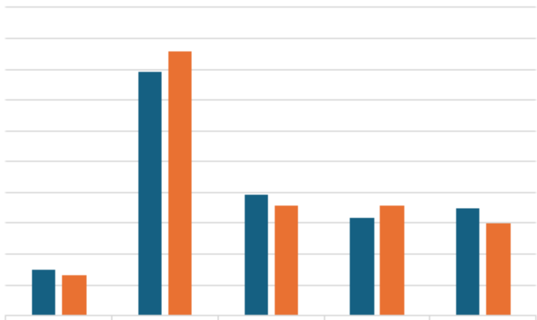
IV. THE APLICATION OF DIGITAL INSTRUMENTS AND MANAGEMENT OF FINANCIAL ACTIVITY

4.1 Digital instruments used by Aquatim in relationship with clients.

The presented information in Table 1 highlights digital instruments that have a different role. MyAqutim app and online portal "my account" are instruments more powerful than the rest, because they can deliver more operations. Online payment has a pointed role, based directly on collecting and the invoice through e-mail sustains the information phase. All these things together form a financial relationship that is easy to track, for clients and for company, too.

Table 1. Digital tools and their role in the financial process [4,5]

Digital tool	Use by customers	Role in financial process
MyAquatim app	Invoice access, index, payment, history of consumption, reports and errors of consumption	Integrates more operations on a single instrument for a financial relationship
Portal ''My account''	Login to your account, online payment, manage invoice via e-mail	Connects client information with payment and digital evidence
Online payment/ Create an account	Online invoice payment, with or without authentification	Diversifies methods of collecting
E-mail invoice	Receiving digital invoice	Easy to acces a document and reduce physical invoice need



	Treasury	Banks	Other forms	Online	Pay office
Collections by payment channel 2024	7,53%	39,59%	19,58%	15,85%	17,33%
Collections by payment channel 2025	6,50%	42,97%	17,79%	17,82%	14,89%

Fig. 1. Share of Aquatim collections by payment channel [4,5]

Fig. 2. Financial path as Aquatim's client [4,5]

4.2 Digitalization of collecting process

The chart in Fig. 1, show that banks remain the main channel on both years, that means they maintain same stable behavior about payments for a significant number of clients. Online payments rise, and that evolution shows us that digital options are more used. Online popularity does not need to be seen as something bad or too early change, it's normal in a good and healthy system.

An important aspect is that digitalization does not shut down the classic channels. The classic channels are in the same place, with a significant volume and it's normal because everybody is different, clients that prefer classic methods or clients that prefer online payments or digital solutions. For companies, advantage comes from existence of more options to choose from, that's why financial relationships become more flexible.

4.3 Utilization of MyAquatim app

MyAquatim mobile app, launched in 2024 and available for Android and iOS, was updated frequently in 2025. Right now, app has 16,300 users and offers quick access to a series of useful services for its clients. Via app, users could visualize and pay the invoices, activate electronic invoices, track their payments, send the indexes, history of consumption, send problems or troubles. A useful function is the receiving notification about the service shut down with water, for multiple addresses set by user [5].

4.4 Financial path as Aquatim's client

Based on instruments and analyzed functions, digital financial relationship between Aquatim and client could be presented as partnership. In this way is useful because shows the route of operations, not just existence of some services individually. Next figure summarizes main stages about digital financial relationship.

Fig. 2 shows that digitalization does not appear in the moment of payment. It starts when the index is sent and continues with the invoice and online viewing, then with online payment and payment record. At the final stage, consumption history is sent to client with the possibility to track the evolution of his relationship with company.

V. RESULTS OF RESEARCH AND LIMITS

Results of research highlight the fact that the digitalization of financial processes in Aquatim are built around extending digital channels used in relationships between clients and integrate the activities on their daily invoices, payments and tracking. In that way, digital instruments are used to simplify the interaction between company and client and to increase access for information and consumption management.

Important findings are on online payments rising, that shows a significant number of clients that choose over classic payments and go for digital solution. This evolution shows that digitalization is not about a technical role, it is an upgrade to the realization method between company and clients. Classic channels remain important; this process shows that digitalization evolution is gradually adopted and function to fill the existing methods of payment and communication.

A limitation about research is the public date information, because it is hard to find it available. Aquatim reports permit the observation of general evolution about online collections, but don't offer a detailed explanation for each digital instrument used. Also, information is not available about the level of app utilization, frequency and the number of documents sent only electronically. The data could allow a more precise analyzation about the impact of financial activity of a company

The element of originality on this research is based on analysis of digitalization as a part of complete financial path as a client, not just a method to pay the invoices. This perspective permits us to observe the relationship between consumption, invoicing, payment and tracking the financial relationship with company. In that way, the study reflects a clear of digital instruments contribution for a healthy, accessible and well-organized relationship between Aquatim and its customers.

VI. CONCLUSIONS AND FINAL OBSERVATIONS

Analyze show that digital financial processes at Aquatim SA contributes at modernization and upgrading the relationship between company and customers. Digital instruments that are used simplifies the accessibility for financial information, simplifies the accessibility in payments and accessibility in tracking transactions

Main conclusion is that digitalization helps Aquatim clients to go through every stage easily and secure. Informatin is accessible and easy to work with and up to date.

In the future I will be helpful that reports will contain detailed indicators about how to use digital channels, number of transactions made with eletronic methods, values of collections for every platform.

This data could permit a more detailed evaluation of digitalization impact and implementation in financial process of a company.

As a result, digitalization must not be seen as a technical solution, but as support for more efficient organization of financial activity. Case of Aquatim, the use of digital channels can have a significant impact by reducing the time needed for some operations, improve communication with users and ensuring a clearer record of financial relationship. Company can respond better to the current needs of customers, while maintaining the classic methods for those who choose to continue to use them.

This approach shows that digitalization process must be developed,based on the actual needs of customers and how they use the available servicies. It is nor enough for digital tools to simply exist, it is critical that they are user friendly, well explained, and integrated into the company's daily operations. In this way, digitalization can contribute not only to simplifying financial operations, but also to increasing customer trust in the services provided by Aquatim.

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Application of Cost of Quality Principles for Defect Reduction in an Electrostatic Painting Process: A Case Study

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Abstract – This paper examines the application of Cost of Quality (CoQ) principles in the electrostatic painting line of SC Ambasador Plus SRL. Quality costs were classified using the classical CoQ model, while Ishikawa and 5 Why analyses were used to investigate the causes of recurring coating defects. After implementing a dosing and pH monitoring system and an oven preheating verification procedure, uneven coating defects were reduced from around 11 to 5 defects per month (about 55%). The results show how CoQ analysis can be used to support defect reduction and quality improvement in production processes.

Keywords: Cost of Quality, electrostatic painting, defect reduction, process improvement, quality management.

I. INTRODUCTION

To survive in today's increasingly competitive industrial environment, companies are under pressure to constantly find solutions for improving their processes, while reducing operational costs, but without sacrificing product quality. One way to achieve this objective is by implementing Cost of Quality (CoQ) principles, which allow organisations to identify, classify and analyse the costs associated with quality management activities and quality failures. Once organisations know where the losses are occurring in terms of quality, they can make better decisions about where to improve processes and allocate resources.

The electrostatic painting process represents a relevant example of an operation in which quality and cost are closely connected. Although widely used for its protective and aesthetic advantages, the process is influenced by many technological and operational factors. Variations in surface preparation, chemical treatment, application settings, or curing conditions can lead to defects, rework, and material losses. For this reason, identifying their causes is important for improving overall process performance.

II. LITERATURE REVIEW

The concept of Cost of Quality (CoQ) is widely recognised as an effective tool to identify and manage quality-related costs in manufacturing companies. According to the Prevention-Appraisal-Failure (PAF) model, quality costs can be categorised into prevention costs, appraisal costs, internal failure costs and external failure costs. Such classification helps companies to locate the quality-related losses and to prioritise improvement actions accordingly [1,2].

Previous studies have shown that investing in preventive activities and process improvements can significantly reduce failure costs and improve overall operational performance [3,4]. In manufacturing, quality cost analysis is often combined with problem-solving tools, such as Ishikawa diagrams and 5 Why analysis, in order to identify the most important defects and their root causes.

Electrostatic powder coating is one of the newest coating processes, already implemented in various industrial areas due to its capacity to prevent powder coating loss, excellent coating effect and relatively low coating cost [5]. However, coating quality can be affected by numerous factors such as surface preparation, chemical treatment parameters, application conditions or curing temperature. Defects including uneven coating, orange peel, and surface contamination may lead to rework, material waste, and increased production costs [6,7]. JOBON Coating, a Chinese company specialised in the manufacturing of electrostatic coating equipment and industrial coating systems, has published a series of technical articles focused on specific categories of

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nonconformities frequently met in industrial electrostatic painting processes. The article regarding the main causes that lead to poor mechanical properties of electrostatic powder coatings analyses problems such as poor adhesion, low flexibility, insufficient impact resistance and inadequate hardness of the coating layer. The study proves that one of the main reasons for these defects is the inappropriate curing of the powder coating, either because the curing temperature is too low, the curing time is not enough, or on the contrary, the coating was over-baked. Inadequate curing prevents the powder from reaching its optimum mechanical properties and affects the durability and performance of the coated surface. The article also points out the importance of powder quality, stating that defects can be caused by issues with the curing agents, resins, fillers or pigments contained within the powder composition. Another major factor that was noted was the lack of surface preparation before painting. Contamination of the substrate surface with oil, dust or other contaminants can seriously reduce the adhesion of the coating [8].

For these reasons, using a CoQ approach is a useful way to understand where problems in the process come from, as it helps engineers identify hidden process bottlenecks and reduce unnecessary costs within the electrostatic painting process.

III. METHODOLOGY

In essence, the research combines a theoretical literature review with a practical case study, applying the concepts and findings from the literature to the electrostatic painting line of a local production facility.

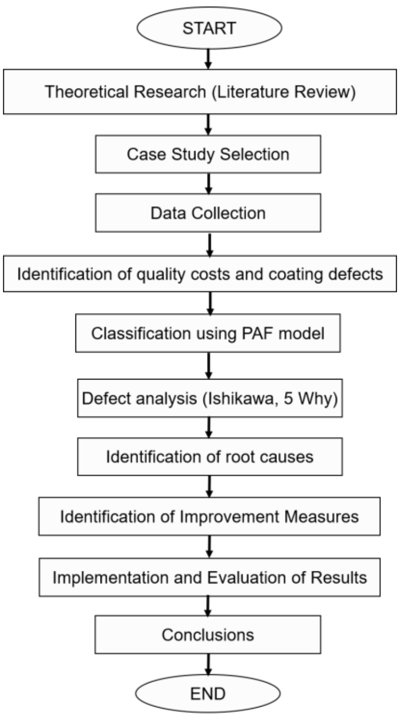

Fig. 1. General Research Methodological Flow

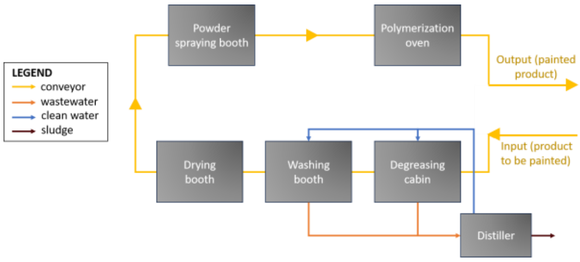

Fig. 2. Position and connection between the equipment of the painting line

The methodological flow started with theoretical research focused on CoQ management, quality improvement tools and electrostatic coating processes. Moreover, the research helped in identifying what are the most common electrostatic painting defects. The practical part of the research was conducted at SC Ambasador Plus SRL, using data collected through direct observation, production and quality records, and discussions with company personnel. Quality-related costs were classified according to the PAF model, and, afterwards, Ishikawa and 5 Why analyses were used to investigate the root causes of the most significant coating defects. Based on the findings, several improvement measures were proposed, out of which some were implemented and evaluated through a comparison of defect occurrence and quality costs before and after implementation.

Fig. 1 illustrates the general research methodology in a simplified form, outlining the main stages followed in the study. In practice, each stage included several intermediate analyses and decisions, and the improvement actions used throughout the study were chosen based on the findings obtained at each step. As new information became available, certain decisions were reviewed and adjusted accordingly. For this reason, the methodological flow is better understood as a flexible process that evolved throughout the research rather than as a fixed sequence of predefined activities.

A. *Case Study Description*

SC Ambasador Plus S.R.L. is a Romanian privately-owned (family) company founded in 1994. Its primary activity is the production and distribution, under the trademark "ELTIM", of a wide range of consumer goods, thermal installations, industrial equipment, fire safety machinery, food processing equipment, as well as medium- and low-voltage electrical apparatus [9].

The electrostatic painting line was implemented in 2021, representing one of the company's most modern and complex sectors.

Fig. 2 schematically presents the analysed electrostatic painting line, which operates as an integrated, continuous system composed of several sequential units: degreasing and phosphating, rinsing, drying, powder coating, polymerisation, and wastewater distillation. The process begins with surface preparation in a closed degreasing chamber using Bonderite M-FE 3960 W to remove oils, rust, and other contaminants that could affect coating adhesion [10]. The parts are then rinsed, dried at approximately 150 °C using forced hot air circulation, and transferred to a manual electrostatic powder coating booth equipped with filtration and powder recovery systems to improve efficiency and reduce waste. After coating, components are cured in a polymerisation oven at around 190°C, where controlled air circulation ensures uniform heat distribution and proper paint hardening. A distillation unit treats process wastewater by evaporation and condensation, enabling partial water reuse while generating around 400 kg of sludge annually [11].

In terms of production, the line produces around 310 parts per month, mostly standard products such as boilers, water heaters, heat recovery units and storage tanks, while custom-made products are produced on an irregular basis and therefore were excluded from this estimate. Although the painting process is generally well organised, during daily operations, the production line still produces some defective parts. Based on the quality observations and production records available, it was estimated that 5–7% of the total painted parts (in a month) had different coating nonconformities that require rework, correction, or rejection.

B. Data Collection

The data collection process involved a main limitation: the lack of dedicated CoQ records, as the company is a small enterprise, where tracking such information is usually not considered a priority. As a result, quality costs were not directly available from internal records and had to be estimated or deducted from indirect sources, such as production records, material consumption, energy usage, invoices, and information on defects, rework, and customer returns. These were complemented with observations from the production line and discussions with employees, to approximate the financial impact of quality issues as accurately as possible within the available data constraints.

C. Cost of Quality Classification

To better understand how quality affects the overall performance of the electrostatic painting process, several costs were identified and organised using the Cost of Quality framework. This classification helps differentiate between the costs allocated to prevent defects, the ones related to inspection and control, and costs caused by real failures in the process. By structuring the data in this way, it becomes easier to observe where the main financial losses occur and which areas of the process need improvement. Since the company does not have a formal CoQ tracking system, this classification also provides a clearer picture of the hidden costs associated with defects, rework, and inefficiencies.

Table 1 illustrates the estimated CoQ analysis conducted for the electrostatic painting line of SC Ambasador Plus SRL in 2025. Because the company does not maintain a fully separated accounting system dedicated exclusively to quality costs for the painting line, the values were estimated proportionally according to production volume, coated surface area, equipment usage frequency, maintenance interventions, labour involvement and historical defect occurrence. The column “Annual cost” shows the estimated annual cost value of each activity or defect source (expressed in RON), while the “Global rank” indicates the relative importance of each cost element in relation to all the other identified costs.

Table 1 The estimated CoQ analysis for the electrostatic painting line of SC Ambasador Plus SRL

Cost categ.	Sub-categories	Annual cost [RON]	Global rank
Prevention	Process design and preparation regarding quality assurance	5000	6
	Determining process and customer requirements	4000	7
	Staff training	7000	4
	Maintenance planning	8000	2
	Supplier quality assurance	4000	9
TOTAL PREV. COSTS		*28000*	
Appraisal	Inspection and testing of parts	10000	1
	Process monitoring	5000	5
	Laboratory and testing costs	2000	12
	Quality control activities	8000	3
TOTAL APPRAISAL COSTS		*25000*	
Internal Failure	Rework and corrections	2000	11
	Scrap and waste	3000	10
	Downtime and inefficiencies	4000	8
	Energy and material losses	1000	15
TOTAL INTERNAL F. COSTS		*10000*	
External Failure	Customer complaints	1000	14
	Warranty and compensation	1200	13
	Transport and logistics for returns	800	16
	Reputation impact	100	17
TOTAL EXTERNAL F. COSTS		*3100*	
Total quality costs		*66100*	

At first glance, the results indicate that the largest costs are associated with inspection and testing activities, preventive maintenance operations and staff training. One might assume this means the system is well controlled and failures are less important. However, this distribution is itself a red flag, as it signals that the organisation is spending a lot on preventing problems instead of eliminating their root causes. The classic CoQ model teaches that high prevention and appraisal costs together with recurring failures indicate an unresolved chronic defect driver [1,2], consisting in this case of painting defects.

D. Analysis of Electrostatic Painting Defects

As previously mentioned, it was estimated that defects occur in about 5-7% of the total painted parts (in a month). According to the practical observations on site, on the discussions with operators and the production manager, and on available reports, it was observed that the most common nonconformities were uneven coating, surface stains and orange-peel defects. Based on the monthly defect reports available from the electrostatic painting line, a pie chart was developed. To obtain a more representative view of the defect distribution, an average value was calculated based on the data collected over several months of production activity, data presented in the pie chart in Fig. 3.

The graphical representation in Fig. 3 shows that uneven coating defects represent the most frequent nonconformities, followed by surface stains, while orange peel defects are less frequent. The results confirm the practical observations on site and suggest that most of the coating defects might be related to operational inconsistencies that occur during repetitive production activities. Because uneven coating was identified as the most common defect and had a significant impact on the repainting activities, material consumption and the efficiency of the production process, it was selected for further root cause analysis. Therefore, an Ishikawa (cause-effect) analysis was developed, to identify and structure the main potential causes that lead to the occurrence of uneven coating defects in the electrostatic painting process of the company. The resulting analysis was built based on discussions and observations carried out together with the involved operators, the production director and the company administrator.

After the Ishikawa analysis, a 5 Why investigation was carried out to confirm or infirm if the main root cause of the uneven coating defect is operator related. The analysis showed the defect was primarily caused by operational and process control problems, not equipment failure.

The main causes found were that painted parts entered the curing oven before the required preheating temperature was reached, there was not enough pH control in the degreasing cabin during the production shift, and the spraying movements were improper. The investigation also revealed that these problems were more frequent at the end of the painting process, indicating the effect of insufficient process monitoring and reduced operational discipline.

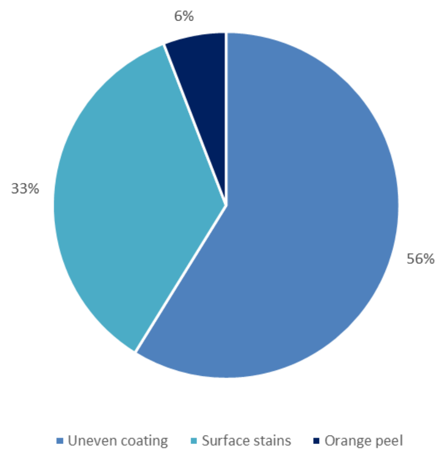

Fig. 3. Percentage Distribution of Monthly Coating Defects

E. Proposed Improvements Strategies

Based on the results from the CoQ analysis and the root cause investigations, several improvement measures were identified during a brainstorming session with the production manager and company administrator. The discussion focused on the main defects and operational issues highlighted by the previous analyses and aimed to find practical and realistic solutions. From the ideas generated, the most suitable measures were selected based on their expected impact on defect reduction and their feasibility under the company's operating conditions. These measures were then evaluated using a 2x2 Effort–Impact matrix model provided by Smartsheet, to prioritise implementation. The solutions were classified into four categories: Quick Wins (high impact, low effort), which should be implemented first, as they have a good cost-benefit ratio; Major Projects (high impact, high effort), which require greater investments but can bring significant long-term improvements; Fill-In Activities (low impact, low effort), which offer limited benefits but can support the main improvement actions; and Low-Priority Activities (low impact, high effort), which require considerable resources and generate relatively small improvements [12].

The analysis included both organisational actions (such as operator training, standardised checklists, and oven preheating verification) and technical solutions (such as pH monitoring, automated dosing, and process control improvements).

The matrix illustrated in Fig. 4 below shows that oven preheating verification, periodic pH monitoring, operator training, and standardised process checklists are quick-win actions, that could be easily implemented and with minimal investment. These actions directly address the main causes identified through the Ishikawa and 5 Why analyses. More advanced solutions, such as a digital defect and Cost of Quality monitoring system, an automated Bonderite dosing and pH control unit, and a poka-yoke oven locking system, were classified as high-impact but requiring greater investment.

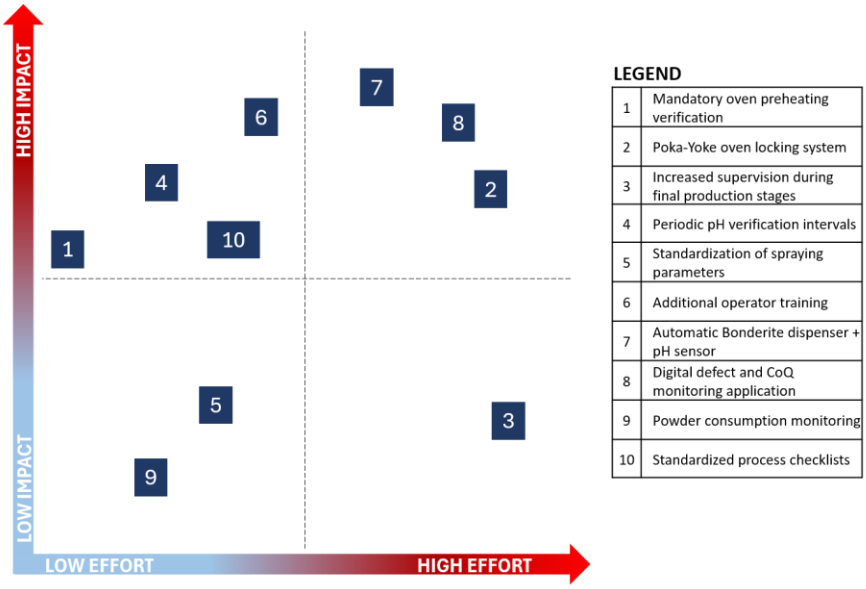

Fig. 4. Effort-Impact Matrix

Although these measures involve higher implementation costs, they offer improved process control and reduce dependence on operator intervention. Since the root cause analysis revealed that many defects are caused by human factors, particular attention was given to automation-based solutions that could reduce process variability and help standardise operating conditions. Since some of the proposed improvement measures required financial investment, they were further evaluated based on their expected costs, savings, and payback period, following the approach suggested by Țucu [4]. Among the analysed alternatives, the installation of an automatic Bonderite dosing and pH monitoring system was identified as the most promising solution, as it addresses one of the main root causes identified: insufficient control of the degreasing bath.

Table 2 The estimated quality-related losses generated by inadequate pH control in the degreasing process

Category	Item	Estimated Value (RON)
Annual quality-related losses associated with pH deviations	Rework caused by poor surface preparation	2,000
	Additional inspection and testing	1,000
	Powder and material losses	500
	Production interruptions	500
	Total annual losses	*4,000*
Investment costs	Automatic Bonderite dispenser	3,500
	Industrial pH sensor	1,500
	Installation and calibration	500
	Total investment	*5,500*

Table 3 Optimisation measures

Priority	Measure	Category
1	Mandatory oven preheating verification	Quick Win
2	Automatic Bonderite dispenser + pH sensor	Major Project
3	Digital defect and CoQ monitoring application	Fill-In Activity
4	Additional operator training	Quick Win

Table 2 illustrates the estimated quality-related losses generated by inadequate pH control in the degreasing process, together with the investment required for the implementation of the proposed automation solution. The annual savings were then calculated by estimating the proportion of quality-related losses that could reasonably be avoided by automating the dosing and monitoring process, resulting in annual savings of approximately 2,800 RON.

$$Annual\ savings = total\ annual\ losses \cdot 0{,}70 \quad (1)$$

The payback period was calculated by dividing the total investment cost by the estimated annual savings.

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Cash\ Inflows} \quad (2)$$

The estimated recovery period of the investment is approximately 2 years. Since the dispenser and pH sensor are expected to have a much longer lifetime than the recovery time, the investment is considered economically reasonable. Besides the direct cost savings, the system improves process stability, reduces dependence on operator intervention, and lowers the risk of defects caused by incorrect degreasing conditions.

Four optimisation measures were selected based on the results of the conducted analysis, to address the main root causes of defects. Together, they combine operational monitoring and automation-based actions to improve coating quality and reduce process variability (Table 3).

IV. RESULTS AND DISCUSSIONS

For the beginning, the first two of the proposed measures were implemented and tested in the electrostatic painting line of SC Ambasador Plus SRL.

Following the implementation of the Bonderite VMS pH Complete Panel [13], a noticeable reduction in coating defects related to surface preparation was observed. Based on production records, process observations, and operator feedback collected over a two-month period, the overall defect rate decreased from approximately 6% to 4.5% of monthly production. Uneven coating, the most frequent defect, decreased from around 11 defective parts per month to 6, representing a reduction of about 45%.

These results indicate that automated pH control improved the stability of the pretreatment process and reduced defect occurrence. To assess the economic impact of the measure, the reduction in defects was converted into internal failure costs. Based on observations from the production line, each defect requiring rework was estimated to generate an additional cost of approximately 35 RON through labour, energy consumption, and inspection activities.

Before the use of the Bonderite pH monitoring and dosing system, the average number of uneven coating defects was estimated at 11 parts per month, which means an internal failure cost of about 385 RON per month. After the automatic system was implemented, the number of such defects decreased to about 6 parts/month, thus decreasing the internal failure cost to approximately 210 RON/month.

This indicates a saving of approximately 2,100 RON/year, which proves the good contribution of the solution implemented into the reduction of quality-related costs in the process of electrostatic painting and can be compared with the previously done preliminary economic evaluation. Although slightly lower than the initial estimate of 2800 RON, this value represents roughly 75% of the expected savings and confirms the economic benefits of the system. The difference can be explained by the fact that the current calculation only considers savings from defect reduction, while the initial estimate also included reductions in material waste, inspection activities, and other process-related losses.

The second improvement measure, consisted of introducing a mandatory oven preheating verification procedure, has been implemented as well, as it required no additional equipment, relying on the existing temperature monitoring system. Operators were required to verify that the oven had reached the prescribed curing temperature before loading parts for polymerisation. Compared to the automated pH monitoring system, the impact of this measure was more limited. Observations during the testing period indicated that uneven coating defects were reduced by approximately one part per month, from six to five defects. This corresponded to an estimated annual saving of around 420 RON in internal failure costs.

The financial benefit is significantly lower than the implementation of the Bonderite dosing and pH monitoring system, however the measure required almost no investment and was implemented with existing resources and still contributed positively to the reduction of internal failure costs.

The results show that even small, incremental improvements can contribute to overall process efficiency. As shown in fig. 5, uneven coating defects decreased from around 11 per month before implementation to about 6 after introducing the Bonderite VMS pH Complete Panel. A further reduction to approximately 5 defects per month was achieved after implementing the oven preheating verification procedure.

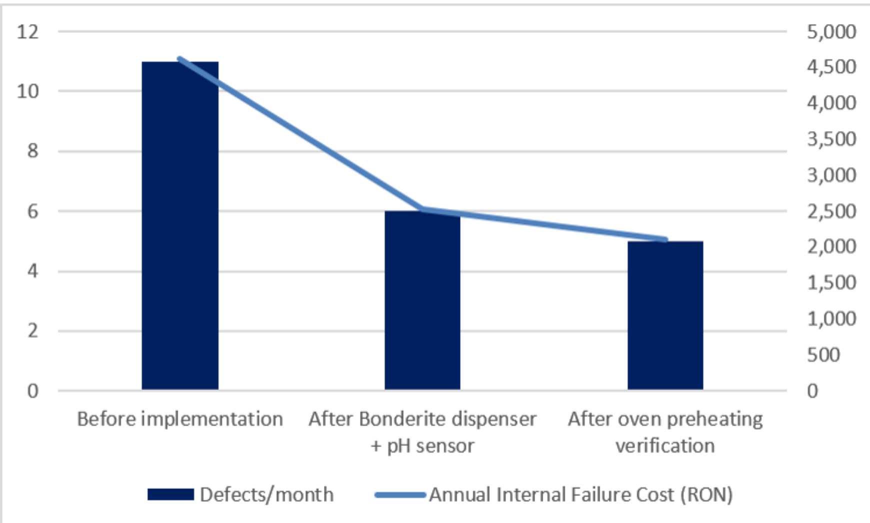

Fig. 5. Impact of implemented improvement measures on defect occurrence and quality costs

V. CONCLUSIONS

Based on the CoQ analysis, the focus was placed on reducing defects at their source rather than limiting prevention activities, as eliminating process variations was key to improving efficiency and reducing failure costs.

The results showed that automation-based measures (Bonderite VMS pH monitoring system) were the most effective in reducing coating defects, while procedural actions, such as oven preheating verification, had a more limited impact due to their dependence on operators. Overall, the study shows that addressing root causes through automation provides more consistent quality improvements and cost reductions. Future efforts should therefore focus more on automated and poka-yoke solutions.

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TRANSACTIONS on ENGINEERING AND MANAGEMENT

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Workforce Rebalancing and Process Optimization in Automotive Manufacturing Using Lean Six Sigma DMAIC

Ladislau Hajnal[1] and Adrian PUGNA[2]

Abstract – This study presents the application of the Lean Six Sigma DMAIC methodology for workforce rebalancing and process optimization in an automotive manufacturing assembly process. The analyzed production line consisted of sequential manual operations characterized by uneven workload distribution, idle time, and inefficient process flow. The research followed the Define, Measure, Analyze, Improve, and Control phases, using specific quality management tools such as SIPOC analysis, process mapping, Ishikawa diagram, hypothesis validation, and before-after performance comparison. The improvement actions focused on workstation rebalancing, task redistribution, layout optimization, and improved material flow. The results indicate that the proposed approach enabled improved operator utilization, reduced idle time, and maintained production throughput and quality performance. Furthermore, the implementation led to an 11.6% reduction in scrap-related losses and a slight improvement in Overall Equipment Effectiveness from 85.5% to approximately 86%. The study confirms that Lean Six Sigma DMAIC can be effectively used as a structured framework for improving resource utilization and process stability in automotive manufacturing environments.

Keywords: Lean Six Sigma, DMAIC, Workforce Rebalancing, Process Optimization, Automotive Manufacturing, Line Balancing.

I. INTRODUCTION

The automotive manufacturing industry operates in an increasingly competitive environment characterized by high customer expectations, stringent quality requirements, and continuous pressure to improve operational efficiency while reducing costs. To remain competitive, manufacturers must continuously optimize resource utilization, improve process stability, and eliminate non-value-added activities.

Workforce utilization plays a critical role in manufacturing performance, particularly in manual assembly systems where operator workload distribution directly influences productivity, cycle time, and process stability. Unbalanced workloads can generate bottlenecks, increase idle time, inefficient material flow, and reduced operational efficiency. Consequently, workforce rebalancing and process optimization have become strategic objectives in modern manufacturing environments.

Lean Manufacturing principles focus on waste elimination and continuous flow improvement whereas Six Sigma aims to reduce process variability and defects through data-driven decision-making [1]. The integration of both methodologies, commonly referred to as Lean Six Sigma (LSS), provides organizations with a structured framework for achieving operational excellence and sustainable process improvements [2].

Among the various Lean Six Sigma approaches, DMAIC (Define, Measure, Analyze, Improve, and Control) is one of the most widely adopted methodologies for process improvement. The DMAIC framework enables organizations to systematically identify inefficiencies, determine root causes, implement corrective actions, and sustain long-term improvements [3]. Previous studies have demonstrated the successful application of DMAIC in manufacturing environments for line balancing, cycle time reduction, productivity enhancement, and defect prevention [4], [5].

Despite the extensive implementation of Lean Six Sigma in manufacturing, workforce optimization in manual assembly systems remains a challenge, especially in automotive environments characterized by product diversity and changing production requirements. Traditional approaches often emphasize workforce reduction rather than the optimization and redistribution of tasks among workstations. Therefore, there is an increasing need for methodologies that support workforce rebalancing while maintaining production throughput and quality performance.

This study investigates the application of Lean Six Sigma DMAIC to an automotive assembly line characterized by workload imbalance and inefficient process flow. The objective of the research is to improve operator utilization through workstation rebalancing, layout optimization, and task redistribution while preserving process stability, throughput, and quality performance. The findings contribute to the growing body of knowledge regarding workforce optimization and demonstrate the applicability of Lean Six Sigma methodologies in automotive manufacturing environments.

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II. PROCESS DESCRIPTION AND RESEARCH METHODOLOGY

A. General context

The present study was conducted on an automotive manual assembly line responsible for producing battery monitoring components. The analyzed manufacturing system consists of sequential assembly operations involving cable preparation, crimping, shrink processing, bending, and final packaging activities. Initially, the production line operated with five direct operators assigned to dedicated workstations. Preliminary observations and time studies revealed significant variability in workload distribution, uneven workstation utilization, and idle periods that negatively affected process efficiency. The research follows the Lean Six Sigma DMAIC methodology to identify process inefficiencies, determine root causes, and implement sustainable improvements focused on workforce rebalancing and process optimization.

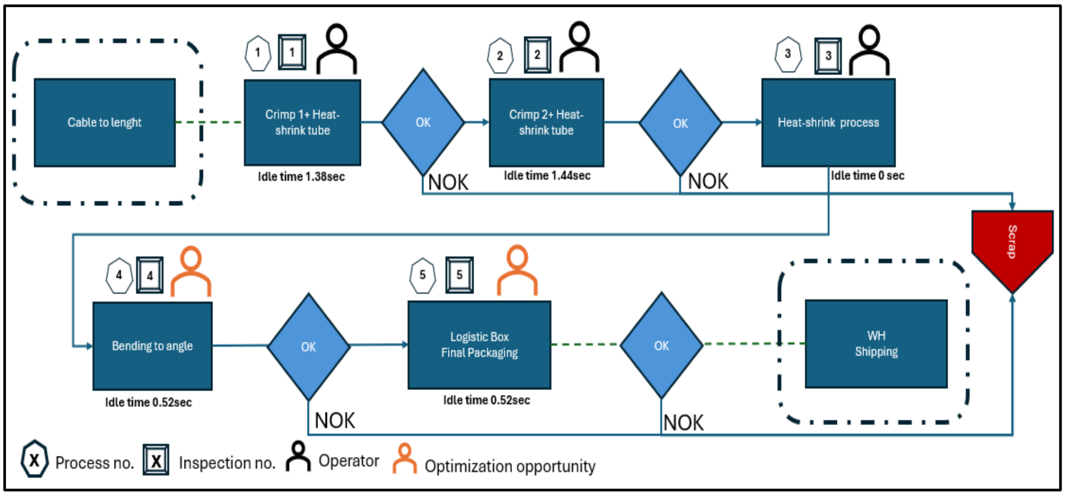

Fig. 1. Process Flow Chart of the Automotive Assembly Line.

Fig. 1 illustrates the sequence of assembly operations analyzed in this study and provides the basis for subsequent process optimization activities.

B. The manufacturing process description

The analyzed manufacturing process consists of five sequential workstations designed for the assembly of automotive battery monitoring components. The production flow begins with cable preparation and crimping operations and continues through heat-shrinking, bending, and final packaging activities. The product under investigation is intended for battery monitoring applications and requires high process stability and consistent quality performance due to its safety-critical function within the automotive electrical system.

Station 1 performs chassis-side crimping followed by heat-shrink tube application. This operation ensures reliable electrical and mechanical connection between the cable and the chassis-side terminal.

Station 2 is dedicated to sensor-side crimping and heat-shrink tube applications. Like the previous operation, this workstation is responsible for ensuring proper electrical continuity and insulation of the sensor-side connection.

Station 3 performs the heat-shrinking process, where controlled thermal energy is applied to contract the heat-shrink tube and provide mechanical protection and insulation of the crimped joints.

Station 4 is responsible for the bending operation, ensuring that the assembled component complies with the required geometrical specifications and installation constraints.

Station 5 performs logistic box preparation and final packaging activities before the product is transferred to the warehouse and subsequently to the customer.

The initial process configuration employed five direct operators assigned to dedicated workstations. Preliminary observations and time studies identified significant differences in workstation utilization, leading to bottlenecks, operator idle time, and inefficient material flow. These findings justified the application of Lean Six Sigma DMAIC methodology to improve process balance and optimize workforce utilization.

III. DEFINE PHASE AND PROBLEM STATEMENT

The Define phase of the DMAIC methodology focuses on identifying the existing inefficiencies of the assembly process and establishing clear project objectives. Initial observations revealed that the production line operated with five direct operators performing sequential assembly activities. However, the workload distribution among workstations was uneven, resulting in bottlenecks, operator idle time, and inefficient resource utilization.

The project objective was to achieve workforce rebalancing and process optimization while maintaining production throughput and quality performance. The improvement strategy aimed to redistribute tasks among workstations, optimize the production layout, and reduce non-value-added activities without negatively affecting operational stability.

To better understand the current state of the process, time studies and workstation analyses were conducted. The collected data indicated significant differences in operator utilization. Some workstations exhibited considerable idle periods, whereas others operated closer to the bottleneck cycle time. Such variability negatively influenced production flow and overall efficiency.

The analysis further revealed that inefficient material flow and workstation arrangement increased unnecessary movement and waiting times between operations. Consequently, the process exhibited characteristics commonly associated with unbalanced production systems, including uneven workload allocation and underutilization of available resources.

Based on these findings, the project established the following improvement objectives:

- Improve workstation balance and operator utilization;
- Reduce idle time across the production line;
- Optimize material flow and workstation arrangement;
- Maintain production throughput and quality indicators;
- Implement sustainable process improvements using Lean Six Sigma DMAIC methodology.

The Define phase provided the foundation for subsequent measurement and analysis activities by establishing the problem boundaries, project objectives, and critical process indicators used throughout the improvement initiative.

As illustrated in Fig. 2, the initial process exhibited significant variability in workstation utilization. Stations 1 and 2 recorded the highest idle times, reaching 1.38 s and 1.44 s, respectively. These findings indicate opportunities for workload redistribution and process optimization aimed at improving operator utilization and process balance.

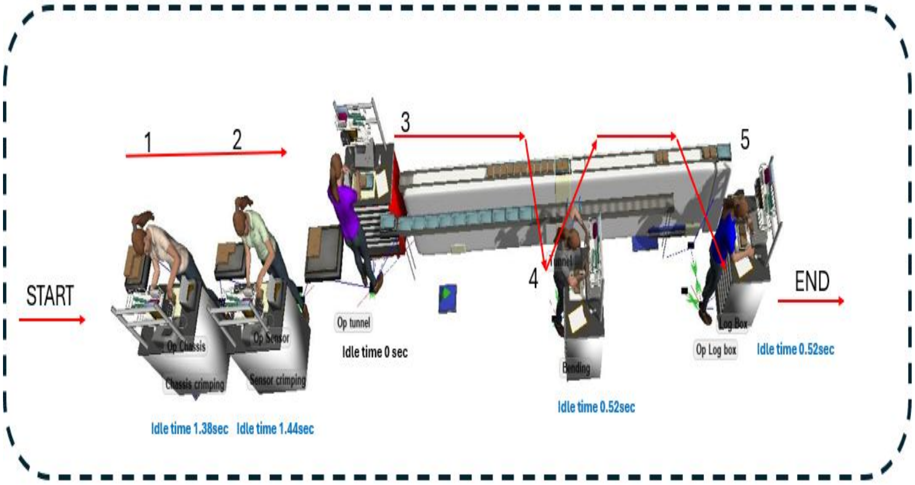

Fig. 2. Initial Idle Time Analysis of the Assembly Workstations.

IV. MEASURE AND ROOT CAUSE ANALYSIS

The Measure phase of the DMAIC methodology focused on collecting quantitative data to evaluate the current performance of the assembly process and identify opportunities for improvement. Time studies, workstation observations, and process flow analyses were conducted to establish a baseline for subsequent optimization activities.

The initial assessment revealed significant variability in workstation utilization. Idle time analysis demonstrated that Stations 1 and 2 exhibited the highest non-value-added time, whereas other workstations operated closer to the bottleneck cycle time. Such variability indicated an unbalanced production system and highlighted the need for workload redistribution and process optimization.

To further investigate the causes of process inefficiencies, an Ishikawa (Fishbone) Diagram was developed with the participation of cross-functional team members from industrial engineering, manufacturing engineering, quality, production, and technical services. The analysis categorized potential root causes into six major groups: Man, Machine, Method, Material, Measurement, and Environment.

The root cause analysis identified several factors contributing to process inefficiency. These included uneven task allocation between operators, inefficient workstation layout, excessive operator movement, and variability in process execution. In addition, the lack of balanced workload distribution generated idle periods at certain workstations while increasing utilization at others.

Based on the Ishikawa analysis, a set of hypotheses was established and prioritized according to their expected impact on process performance. The highest-priority hypotheses focused on layout redesign, travel distance reduction, and process flow optimization. Hypothesis validation confirmed that inefficient workstation arrangement and unbalanced task allocation represented the primary contributors to process inefficiency.

The results of the analysis provided the foundation for the Improve phase, where corrective actions aimed at workforce rebalancing and process optimization were developed and implemented.

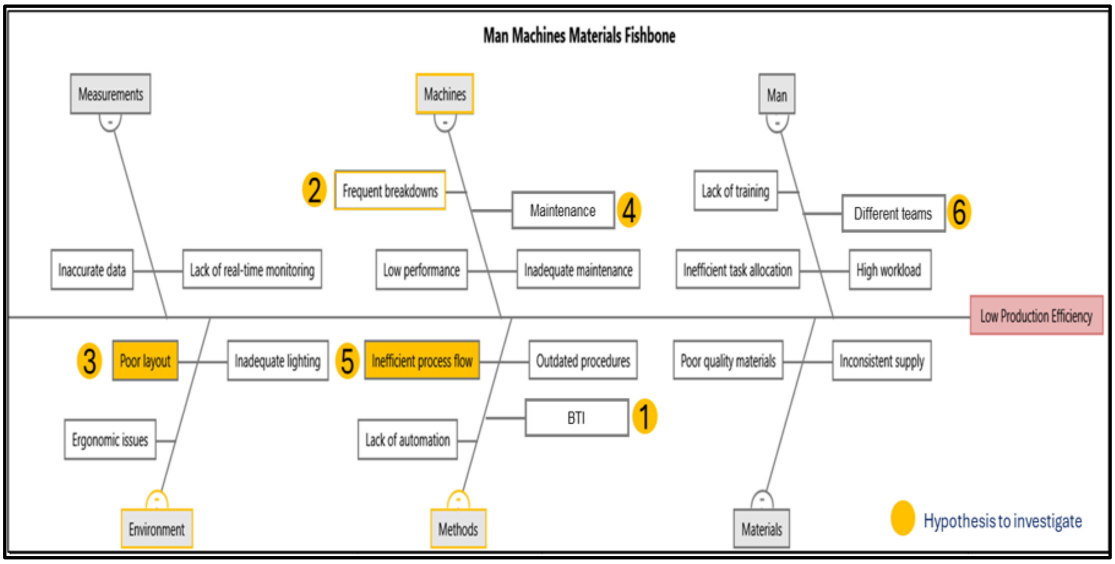

Fig. 3. Ishikawa Diagram for Root Cause Analysis.

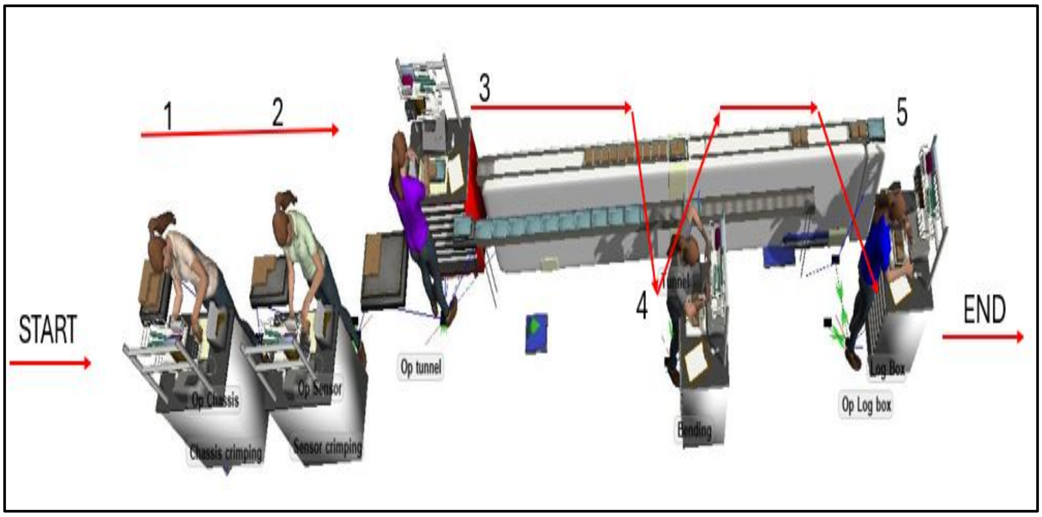

Fig. 4. Initial Assembly Line Layout Before Optimization.

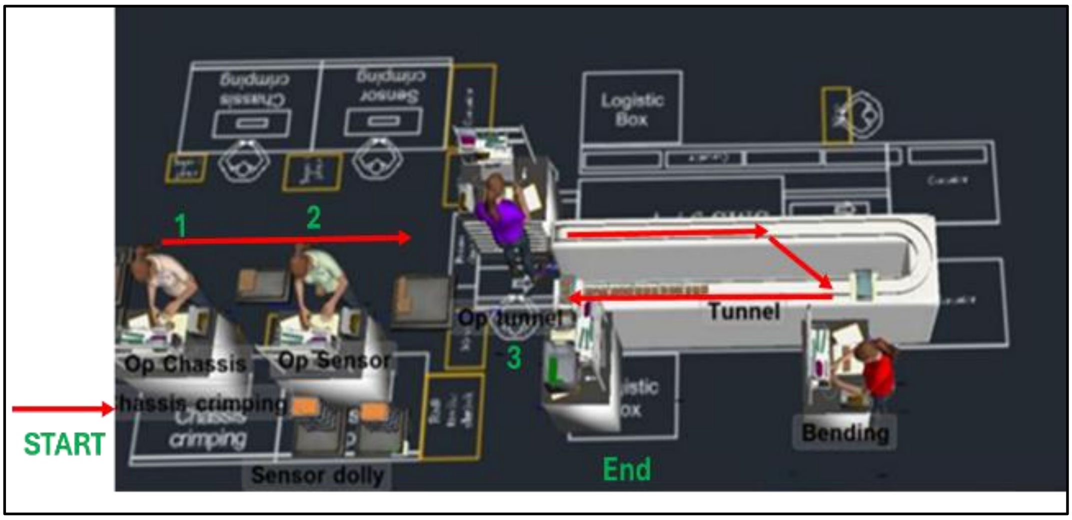

Fig. 5. Optimized Assembly Line Layout After Workforce Rebalancing.

Fig. 3 illustrates the root cause analysis conducted during the Measure phase. The identified causes highlighted the significant influence of workstation layout and workload allocation on overall process performance.

V. IMPROVEMENT IMPLEMENTATION

The Improve phase of the DMAIC methodology focused on implementing corrective actions aimed at eliminating process inefficiencies identified during the previous phases. Based on time studies, root cause analysis, and hypothesis validation, several improvement initiatives were developed and evaluated to enhance workstation balance and optimize resource utilization.

The primary objective of the improvement phase was to achieve workforce rebalancing through task redistribution and layout optimization while maintaining production throughput and quality performance. The proposed solutions targeted the elimination of non-value-added activities, reduction of operator movement, and improvement of material flow between workstations.

A key improvement consisted of repositioning the final packaging workstation closer to upstream operations to minimize transportation distances and reduce waiting time. In addition, a gravitational conveyor system was introduced to facilitate material transfer between stations and improve process continuity.

Task redistribution was performed to achieve a more balanced workload among operators. Activities previously concentrated at specific workstations were reassigned to neighboring stations based on available capacity and cycle time analysis. This approach reduced workstation variability and contributed to a more uniform distribution of tasks across the production line.

The implemented layout modifications significantly improved operator ergonomics and reduced unnecessary movement within the work area. Furthermore, the optimized process enabled better synchronization between workstations, resulting in improved process flow and enhanced operational stability.

The improvement actions were designed to ensure sustainability and support long-term process control. Standardized work instructions and visual management principles were incorporated to maintain the achieved performance and facilitate continuous improvement initiatives.

Overall, the Improve phase demonstrated that systematic application of Lean Six Sigma principles can effectively support workforce rebalancing and process optimization in automotive manufacturing environments without compromising production quality or throughput.

Figures 4 and 5 illustrate the implemented layout modifications and their impact on process flow. The optimized arrangement reduced operator movement, improved workstation interaction, and supported a more balanced distribution of tasks across the production line. Standardized work instructions and visual management principles were implemented as control measures to sustain the achieved improvements.

VI. RESULTS AND DISCUSSION

The implementation of the proposed improvements resulted in measurable enhancements in process performance and workforce utilization. The combination of workstation rebalancing, layout optimization, and task redistribution contributed to a more stable and efficient manufacturing process while maintaining production throughput and quality performance.

The results of the idle time analysis demonstrated that the initial process exhibited significant variability in workstation utilization. Following the implementation of corrective actions, operator workload became more evenly distributed, leading to improved workstation balance and reduced non-value-added activities. The introduction of a gravitational conveyor system and the relocation of the final packaging station significantly reduced transportation distances and unnecessary operator movement.

Process performance was further evaluated using key operational indicators. The Overall Equipment Effectiveness (OEE) showed a slight improvement from 85.5% to approximately 86%, indicating enhanced process stability and resource utilization. Although the increase appears moderate, it is important to note that even small improvements in OEE may generate significant operational benefits in manufacturing environments characterized by high production volumes.

The implemented changes also contributed to a reduction in scrap-related losses. Comparative analysis indicated an 11.6% decrease in scrap generation after implementation of the proposed solutions. This improvement suggests that enhanced process flow, better workstation synchronization, and standardized work practices positively influenced product quality and process consistency.

An additional outcome of the project was the successful achievement of workforce rebalancing without negatively affecting production throughput. The optimized process-maintained target production levels while improving operator utilization and reducing idle periods. These findings confirm that process optimization does not necessarily require additional automation or increased resources but can be effectively achieved through systematic analysis and continuous improvement methodologies.

The results obtained in this study are consistent with previous research highlighting the effectiveness of Lean Six Sigma DMAIC in improving manufacturing performance [1]–[5]. The findings further demonstrate that workforce rebalancing represents a sustainable approach for enhancing productivity in manual assembly systems operating in automotive manufacturing environments.

Overall, the implemented improvements provided evidence that Lean Six Sigma DMAIC can serve as an effective framework for balancing workloads, improving material flow, and supporting long-term operational excellence.

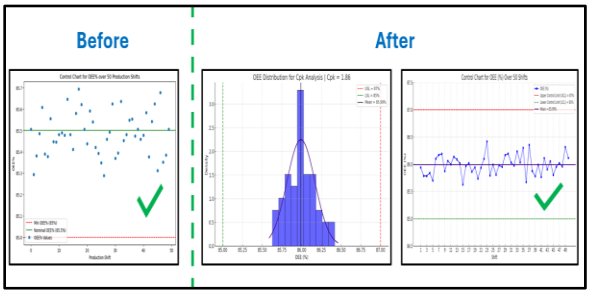

Fig. 6. Overall Equipment Effectiveness (OEE) Before and After Optimization.

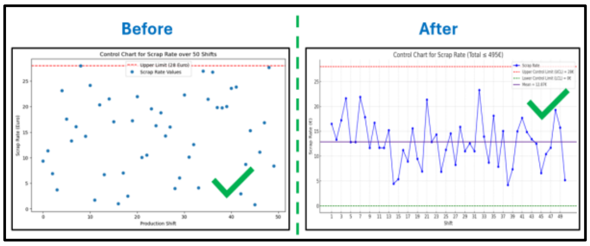

Fig. 7. Scrap-Related Losses Before and After Optimization.

Figures 6 and 7 illustrate the impact of the implemented improvements on process performance indicators. The observed enhancement in OEE and reduction in scrap-related losses confirm the effectiveness of workforce rebalancing and process optimization measures implemented during the DMAIC project.

VII. MANAGERIAL AND SCIENTIFIC CONTRIBUTION

From a managerial perspective, the implementation of Lean Six Sigma DMAIC demonstrated the potential to improve manufacturing efficiency through workforce rebalancing and process optimization. The study showed that significant performance improvements can be achieved without major capital investments or additional automation. By optimizing workstation layout, redistributing tasks, and improving material flow, organizations can enhance operator utilization while maintaining production throughput and quality performance.

The proposed approach also supports better decision-making by providing a structured framework for identifying inefficiencies and prioritizing improvement actions. The use of time studies, root cause analysis, and performance indicators enables manufacturing managers to make data-driven decisions and implement sustainable improvements. Furthermore, standardized work instructions and visual management principles contribute to long-term process stability and facilitate continuous improvement initiatives.

From an operational perspective, the implementation of a gravitational conveyor system and workstation repositioning reduced unnecessary movement and improved process synchronization. These improvements not only increased process efficiency but also enhanced ergonomics and workplace organization, supporting a safer and more productive work environment.

From a scientific perspective, this study contributes to the growing body of knowledge regarding workforce optimization in manual assembly systems. While previous research has extensively investigated Lean Six Sigma applications in manufacturing, relatively few studies have focused specifically on workforce rebalancing as a means of improving operational efficiency without compromising throughput and quality performance.

The research further demonstrates the applicability of Lean Six Sigma DMAIC as a systematic methodology for analyzing and improving manual assembly processes in automotive manufacturing environments. The findings confirm that process improvements achieved through workload balancing and layout optimization can generate measurable operational benefits while supporting sustainable manufacturing practices.

Finally, the proposed methodology can serve as a reference framework for future studies investigating workforce optimization, line balancing, and process improvement in similar industrial environments. The integration of digital manufacturing tools, real-time data collection, and Industry 4.0 technologies may further enhance the effectiveness of workforce rebalancing strategies in future applications.

VIII. LIMITATIONS AND FUTURE RESEARCH

The present study has several limitations that should be considered when interpreting the results. First, the research was conducted on a single automotive assembly line, which may limit the generalization of the findings to other manufacturing environments. Different production systems may exhibit distinct process characteristics, operator skills, and layout configurations that could influence the effectiveness of workforce rebalancing strategies.

Second, due to confidentiality requirements, detailed production data and company-specific information were anonymized. Consequently, certain operational indicators and process parameters were presented in a generalized manner to preserve industrial confidentiality while maintaining the scientific validity of the study.

Third, the evaluation focused primarily on operational performance indicators such as idle time, scrap-related losses, and Overall Equipment Effectiveness. Although these metrics provide valuable insights into process performance, additional indicators related to ergonomics, operator satisfaction, and long-term sustainability could further enrich the analysis.

Furthermore, the study emphasized practical implementation under real industrial conditions. As is often the case in manufacturing environments, constraints related to production schedules, resource availability, and operational priorities limit the duration of data collection and observation periods.

Future research should focus on validating the proposed workforce rebalancing methodology across multiple production lines and manufacturing sectors. Comparative studies involving different assembly systems could provide additional evidence regarding the transferability and scalability of the proposed approach.

Another promising research direction involves the integration of Industry 4.0 technologies, including real-time data collection systems, digital manufacturing platforms, and advanced analytics tools. The application of predictive models and digital twins may further enhance workforce allocation and process optimization capabilities in complex manufacturing environments.

Finally, the integration of artificial intelligence techniques for dynamic workload balancing and decision support represents a valuable area for future investigation. AI-assisted optimization methods may enable adaptive workforce rebalancing strategies capable of responding to changing production conditions in real time.

IX. CONCLUSIONS

This study investigated the application of Lean Six Sigma DMAIC methodology for workforce rebalancing and process optimization in an automotive manufacturing environment. The research addressed operational inefficiencies associated with uneven workload distribution, idle time, and inefficient material flow within a manual assembly process.

The systematic application of the DMAIC framework enabled the identification of root causes and the implementation of targeted improvement actions, including workstation rebalancing, layout optimization, task redistribution, and the introduction of a gravitational conveyor system. These actions contributed to improved process flow, enhanced operator utilization, and reduced non-value-added activities.

The results demonstrated measurable operational benefits. The implemented improvements led to an 11.6% reduction in scrap-related losses and a slight increase in Overall Equipment Effectiveness from 85.5% to approximately 86%, while maintaining production throughput and quality performance. These findings confirm that process optimization can be achieved through data-driven analysis and continuous improvement methodologies without requiring significant capital investment or additional automation.

From a practical perspective, the study provides a transferable framework that can be applied to similar manufacturing environments facing challenges related to workload imbalance and process inefficiency. From a scientific perspective, the research contributes to the existing body of knowledge on Lean Six Sigma applications by emphasizing workforce rebalancing as a sustainable strategy for improving manufacturing performance.

The increasing adoption of Industry 4.0 technologies, digital manufacturing systems, and artificial intelligence solutions creates new opportunities for the further advancement of workforce optimization strategies in modern manufacturing environments.Consequently, future manufacturing systems may increasingly rely on intelligent and adaptive approaches capable of dynamically balancing workloads and supporting operational excellence in real time. In conclusion, the findings demonstrate that Lean Six Sigma DMAIC represents an effective and scalable methodology for workforce rebalancing and process optimization in automotive manufacturing environments, supporting both industrial competitiveness and sustainable process improvement.

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Greenwashing, Green Marketing, and Evidence-Based Sustainability Communication - the ECO Nexus project

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Abstract – Although there is often no solid data foundation, the literature shows an increase in the use of 'green' and 'sustainable' labels due to the pressure exerted in aligning with the European Green Deal. The relationship between greenwashing, green marketing, and evidence-based marketing is explored through the ECO Nexus project. We propose a conceptual framework that targets the connection between the design of these green messages, the quality of environmental data, and the credibility of sustainability information. The results outline support transparent communication, verifiable through the subsequent creation of practical guidelines.

Keywords: Greenwashing, green marketing, ECO Nexus project, evidence-based sustainability communication, circular economy

I. INTRODUCTION

One of the most pressing challenges of our days, which the ECO Nexus project addresses, lies at the intersection of environmental governance and industrial transformation and refers to the capacity of Romanian companies to adopt circular economy principles [1], industrial symbiosis mechanisms [2]–[5], while maintaining efficient operational consistency and balance with the help of digital monitoring tools [6].

As the name suggests, in our project activities we focus on the water - energy - materials - fertilizers nexus [7], viewed as an integrated system [8], and the flows (of resources, waste and residual energy) are, and can be continuously exploited, beyond organizational boundaries, thus reducing production costs and the (negative) impact on the environment. One of the important activities of the project (a core component) aims at communicating sustainability results.

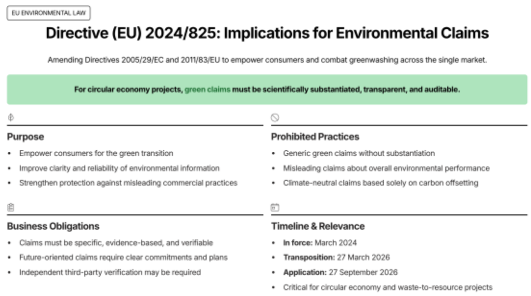

Fig. 1. Directive (EU) 2024/825 synthesis

We are also under high pressure from the regulations of the European Green Deal, namely the mandatory ESG reporting requirements set out in the Corporate Sustainability Reporting Directive (CSRD) and the new Directive 2024/825 (Fig.1). Considering these regulations, the directive framework stimulates sustainability communication but also establishes sanctions for unfounded claims.

In its research design, the project activities integrate a marketing and communication dimension. An explicit concern in the data collection tool administered to companies in the agro-industrial production sectors in the western region of Romania investigates the extent to which these companies are concerned with their environmental performance. We capitalize on the selected responses (our questionnaire is active and can be fully accessed at the following link: https://forms.gle/8a55hFpubMWMNFX3A), to carry out their quantitative and qualitative analysis on the following topic of interest: *To what extent does the existing data infrastructure support evidence-based sustainability communication and what is the gap in avoiding facilitating greenwashing?*

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In 2021, the European Commission conducted a screening of commercial websites [9], found that two out of three products analysed contained unverifiable environmental information or claims, and that, before any ESG risk, greenwashing [10] is a real threat to the credibility of green finance. This aspect leads to the eroding of consumer and investor trust in the field of sustainability communication. So that, our challenge is more than technical, it becomes communicative, because we need to ensure that the sustainability results [11], generated by the project are communicated in a specific, verifiable and transparent way.

Our paper is further structured into the following sections: the conceptual framework in section II defines greenwashing and green marketing and anchors the bibliographic reference base of the study, section III describes the methodology part, the results related to the selected questions from the data collection tool are discussed in section IV and, finally, we formulate the conclusions, limitations and future research directions.

II. CONCEPTUAL FRAMEWORK

It is well known that the American environmental activist Jay Westerveld was the one who introduced the term *greenwashing* into the specialized literature, 20 years ago. This phenomenon has undergone a remarkable evolution, so that it becomes mandatory and necessary to distinguish between the misleading promotion of a so-called "green" image and the "authentic green" ecological marketing [10], [12].

The *green marketing* term was introduced by Michael Jay Polonsky [13] in parallel with the phenomenon of greenwashing, in 1994, as *"the set of activities that satisfy human needs and desires with minimal impact on the natural environment."*

A PRISMA systematic review of the literature on the concept of greenwashing was conducted in 2020 by Netto et al. [14], who proposed a taxonomy structured into four main forms (Fig. 2). Then, in 2021 this perspective is expanded by Szabo and Webster [15], who demonstrate that the greenwashing phenomenon affects more than the company's ecological credibility, namely the emotional state of consumers, including the perception of the product, with direct implications for promotion and digital communication strategies.

By bibliometrically analyzing 419 articles published between 2004 and 2024, Persakis et al. (2025) conduct the most comprehensive and recent study confirming the main documented effects of greenwashing [16], namely the depreciation of brand value, an undermining of progress towards authentic sustainability and last but not least the erosion of consumer trust. Thus, priority research directions in this regard are identified, through normative regulation and psychological impact.

We believe that these three contributions are the ones that best substantiate the integrated analytical framework of our work. However, relevant to the ECO Nexus project [8], as will be presented in the discussion section, is the Open Data Institute (ODI) report [17], because it operates at the necessary level regarding data infrastructure and identifies this three systemic factors (Fig. 3): framework fragmentation, data opacity and accountability deficit.

Fig. 4 presents the conceptual architecture of our project model, which illustrates the main argument of the paper. The risk of greenwashing is moderated directly by the quality of evidence and through its monitoring tools, through the EMA/MFCA tools, and through the data platforms for industrial symbiosis, which meet in node 2 of the model the entire chain of the architecture is strengthened.

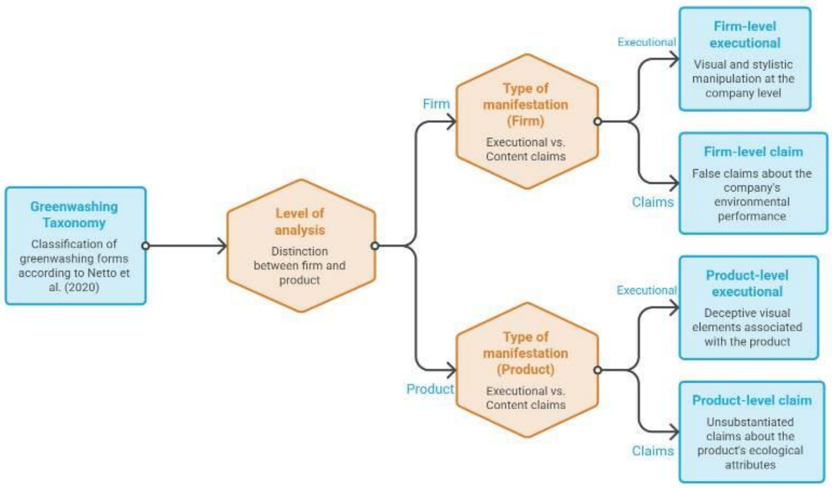

Fig. 2. Greenwashing concept according to Netto et al. (2020).

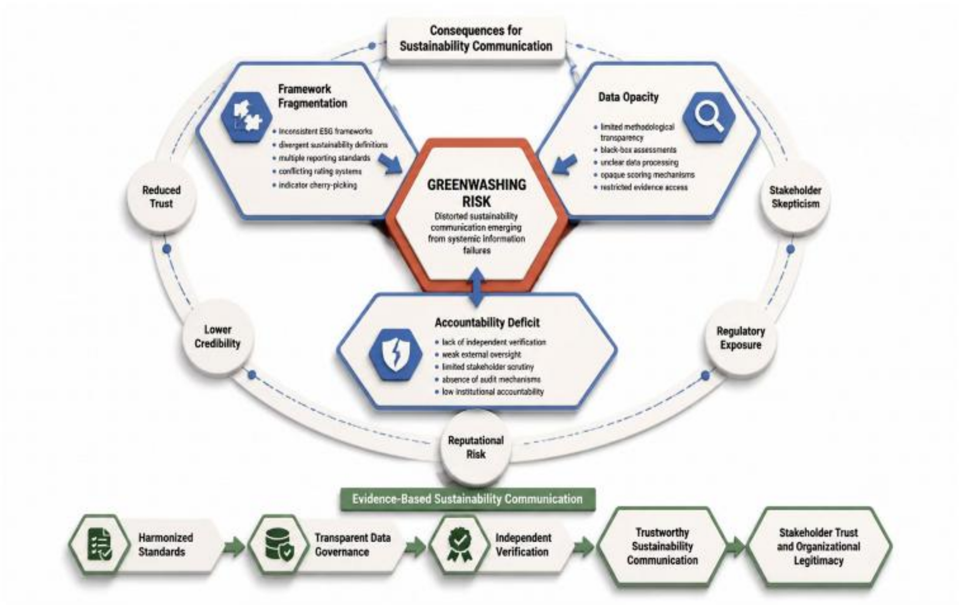

Fig. 3. Systemic enablers of greenwashing according to Stiglich et al. (2023).

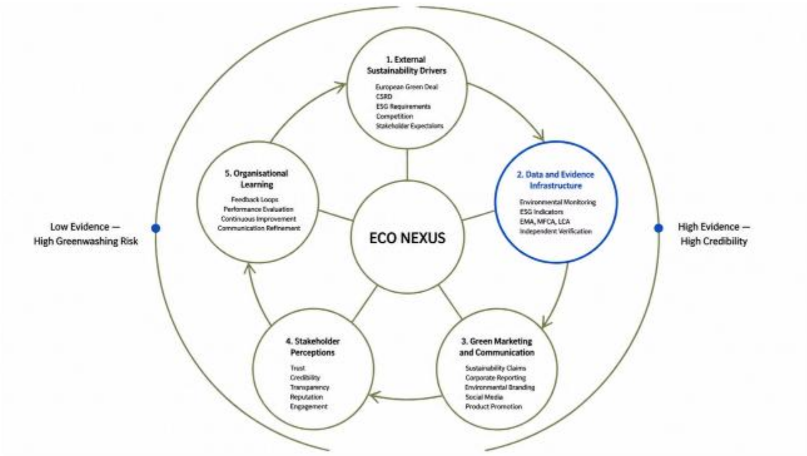

Fig. 4. Integrative framework of the ECO Nexus ecosystem model

III. METHODOLOGY

For our study we used a mixed approach, combining the structured literature review from section II with quantitative and qualitative analysis of primary data collected using the ECO Nexus questionnaire. Our data collection tool is composed of 7 thematic sections focused on 25 questions covering the following topics: organizational profile; circular economy and Green Deal; strategic objectives; impact of technologies and risk appetite; industrial symbiosis and collaborations; necessary support and collaboration with ECO Nexus; final comments. Participation was solicited through a dedicated and disseminated webinar for companies in the manufacturing and agro-industrial sectors and was applied online. For the analytical focus of our paper, questions and answers addressing the following topics were selected: (1) key environmental indicators and the extent to which companies track CO_2 emissions, water consumption, waste consumption; (2) environmental monitoring; (3) barriers to transparent communication of sustainability and (4) competitive advantage versus compliance obligations. These items were chosen because they map onto nodes 2 and 3 of the ECO Nexus Ecosystem Model (Fig.4) and facilitate grounded empirical evaluation of the analysis.

IV. DISCUSSIONS AND RESULTS

As previously stated, this section of our paper mainly relates to the relationship between data, green marketing and the risk of greenwashing, which will be interpreted directly through the model in Fig. 4 and nodes 2 and 3, which are dedicated to the data communication infrastructure. Fig. 5 summarizes in graphical form the four topics that we will address further.

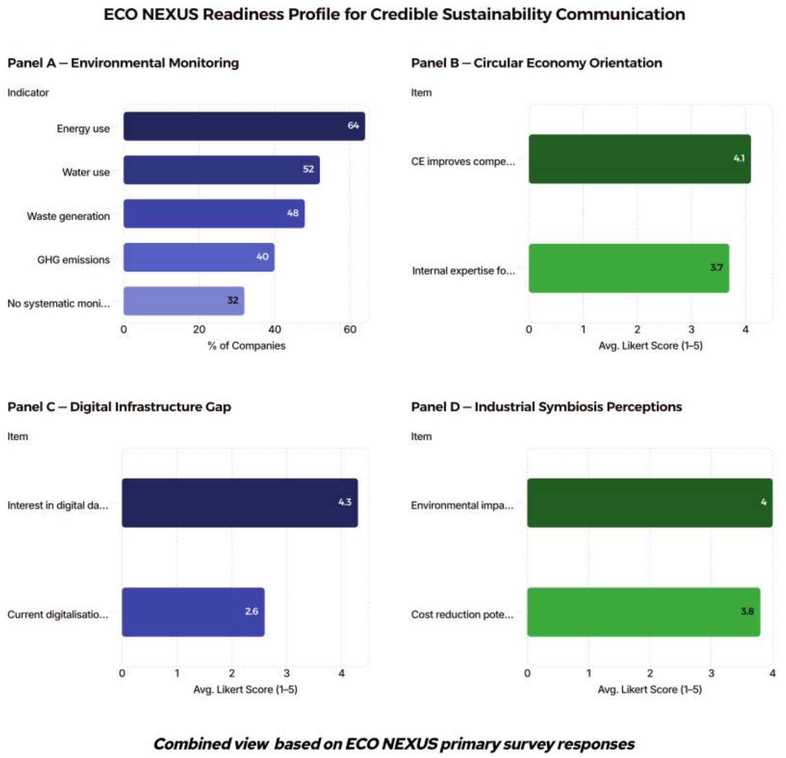

Fig.5. Sustainability communication ECO Nexus readiness profile.

A. *Environmental monitoring and the evidence base*

From the analysis of the responses regarding the monitoring of environmental indicators, we find that all companies are concerned about this aspect, and the distribution of the results confirms that there is a core of data, but it is far from universal. Almost two thirds declare that they monitor energy consumption as a priority, more than half water consumption and almost half waste generation. This information leads us to the idea that there are a series of data indicators that can be used both for reporting and for sustainability marketing, but because about a third state very clearly that they do not have a systematic monitoring of environmental performance, we conclude that these are only general estimates. The environmental claims regarding the degree of monitoring illustrated by Panel A are a proxy from the perspective of the ECO Nexus Ecosystem Model because the communication space is structurally vulnerable to the risk of greenwashing, even if positive intentions are revealed.

B. *Circular economy between opportunity and capacity limit*

The attitude towards the circular economy and the perceived internal capacity are found in Panel B. A scale of 1-5 was used, and for the topic of our paper the answers to these two statements are interesting: "Circular economy improves competitiveness", respectively "Internal expertise for circular solutions". The average of 4.1 result for the first statement indicates that the majority considers circularity as an opportunity for competitiveness, and the average of 3.7 for the second statement suggests a moderate and heterogeneous internal capacity between sectors. Which leads us to the idea that the ECO NEXUS Ecosystem Model positions the circular economy as a driver for the development of skills and data infrastructure that allows for evidence-based communication.

C. *The digital divide*

Regarding the results in Panel C, the analysis shows that there is a difference of almost 2 points between the expressed interest and the actual capacity regarding the current level of digitalization of environmental data. The recorded averages, respectively 4.3 for interest and 2.6 for digitalization, indicate a clear appetite for such data-driven approaches, but at the same time demonstrate the absence of the technical and organizational infrastructure to match the appetite.

If we look at the results obtained in terms of communication, the analysis confirms these barriers. Although this profile can lead us to greenwashing claims, at the same time we can also think of greenhushing communication (a deliberate under-communication of environmental claims) [18], [19]. Our model is designed to reduce such a gap, because it provides the necessary framework to integrate data into a format that can then be used for communication and decision-making.

D. *Perceptions of industrial symbiosis*

The perceptions of industrial symbiosis that we can observe on Panel D indicate an average of 4.0 for "Environmental impact reduction" and an average of

3.8 for "Cost reduction potential". Environmental benefits are therefore expected [20], at the same time as economic benefits [21]. It also shows the existence of a core of organizations that are in partnership and exchange resources. The results also indicate a specific problem, because the environmental value is distributed between partners. This risks an overestimation of the individual contribution of the partners. The ECO Nexus Ecosystem model aims at this aspect, and through a data infrastructure created at the network level, each partner will be able to communicate with credibility its own contribution to the results of the industrial symbiosis. This reduces the marketing narrative of both greenwashing and greenhushing, by achieving authentic collaborative communication.

Viewed in the four Panels of Fig. 5, the conclusion suggests that the analyzed sample is at the "intermediate readiness" level in terms of credible communication of sustainability, and the risk of greenwashing derives mainly from the tension created between aspirations, regulatory pressures and availability of data resources (the "infrastructure gap" observed in our study).

As a central message of the analysis, we can distinguish that organizations can reduce the risk of sustainability communication from a marketing perspective through phased investments in monitoring, digitalization and not by avoiding communication. We believe that the ECO Nexus Ecosystem Model offers the integrated transition framework who connects environmental practices, data infrastructure, but also market communication, all of which are aligned with the regulations and requirements of Directive (EU) 2024/825.

V. CONCLUSION

Making misleading or unfounded claims about the environment and its protection is a characteristic practice in the risk of greenwashing. Thus, the fact that remedial measures are needed is proliferated, and regarding the sustainability claim in corporate communication, the important thing is the green marketing strategy. Through this paper, we examined greenwashing and evidence-based sustainability communication, by panning a dual perspective. The conceptual framework is grounded in recent literature, one of the perspectives and the other is based on empirical data collected using the questionnaire that was administered to the project participants, directly during a webinar. Industrial companies from the Western Zone of Romania, participating in the ECO Nexus project, also answered questions related to environmental performance, circular economy maturity, digital innovation and industrial symbiosis. The analyzed results show how the sustainability claim is perceived, how credible it is and the fact that authentic green communication can truly be supported by a data infrastructure with the help of integrated digital tools.

We believe that the results of this analysis should be interpreted as an indicative model, due to the relatively small and context-specific initial and intermediate sample. This would be the main limitation of our study.

We also believe that in future research we will be able to capitalize on the findings of this study and expand the sample, compare the sectors and organizational profile of the respondents, and, of course, examine how digital data communication on sustainability is carried out.

VI. ACKNOWLEDGMENT

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The Impact of Artificial Intelligence on Accounting Information Systems: Optimizing Financial Decisions through Neural Networks and Virtual Cloud Assistants

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Abstract - The digital transformation of corporate financial departments requires a strategic transition from rigid local architectures to integrated ecosystems powered by cloud computing and artificial intelligence. This paper investigates the impact of embedding emerging technologies into Accounting Information Systems (AIS), focusing on three fundamental pillars: migration to the SAGA Cloud platform, automation of data workflows via Robotic Process Automation (RPA) tailored for the national RO e-Factura system, and the deployment of Artificial Neural Networks (ANN) to optimize management decisions. Utilizing a mixed methodology that combines qualitative operational process mapping with quantitative modeling research, this study demonstrates the efficiency of machine learning algorithms in cash-flow forecasting and accounting anomaly detection. The results reveal a significant reduction in source document processing times alongside a substantial increase in financial predictive accuracy. Furthermore, current technological boundaries and the ethical implications of delegating decision-making tasks to predictive algorithms are critically analyzed. This paper delivers an original contribution by proposing a unified digital governance framework for Romanian SMEs, proving that virtual assistants and neural networks do not replace human capital but rather redefine the strategic role of the modern accountant.

Keywords: Artificial intelligence, accounting information systems, SAGA Cloud, neural networks, RO e-Factura.

I. INTRODUCTION

Driven by accelerating globalization and contemporary economic dynamics, corporate financial management faces continuous pressure to streamline operational workflows and enhance decision-making rigor. Traditionally, Accounting Information Systems (AIS) have operated as passive tools for recording historical economic transactions. However, the imperative of digital transformation demands a paradigm shift: the evolution of AIS from historical data repositories to active decision-support systems capable of generating real-time forecasts and identifying operational risks before they materialize.

Integrating Artificial Intelligence (AI) into accounting architecture represents a major technological leap [8][11]. Machine learning algorithms and advanced neural networks can process massive volumes of financial and non-financial data, capturing complex non-linear correlations that classic econometric models fail to detect [3][7][10]. In the context of the Romanian market, this evolution is heavily catalyzed by structural fiscal reforms, such as mandatory digital reporting via the RO e-Factura system [12].

Small and medium-sized enterprises (SMEs) are particularly affected by this transition, as they often operate with limited financial and human resources while facing increasing regulatory requirements.

This research aims to analyze the mechanisms through which migrating to cloud-based ERP solutions (such as the SAGA Cloud platform), combined with Robotic Process Automation (RPA) and Artificial Neural Networks (ANN), contributes to the optimization of financial decisions [6][17]. The central hypothesis posits that an AI-augmented accounting ecosystem significantly boosts operational productivity and minimizes human error, transforming the accounting function from an administrative cost center into a strategic value driver for executive management.

II. METHODOLOGY / APPROACH

To ensure scientific validity and practical applicability, this study adopts a convergent mixed methodology structured across two complementary dimensions:

1. Qualitative and Conceptual Analysis: Comprehensive mapping of information flows within a traditional finance department versus a fully digitalized cloud environment (SAGA Cloud) was conducted. The process of retrieving, validating, and uploading invoices from the Romanian Tax Administration's (ANAF) Virtual

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Private Spaces via RO e-Factura was modeled using business process diagrams to identify operational bottlenecks and automation potential through RPA scripts.

2. Quantitative Research and Mathematical Modeling: For the predictive component, an Artificial Neural Network model based on a Multi-Layer Perceptron (MLP) architecture was developed [3][7][10].

A conceptual Artificial Neural Network (ANN) architecture was designed using a representative financial dataset scenario spanning 36 months. The mathematical model relies on Forward Propagation for signal transmission and weight adjustment via the Backpropagation algorithm [15]. For a given neuron j in the hidden layer, the net input is computed as follows:

$$z_j = \sum_{i=1}^{n} w_{ji}\, x_i + b_j \quad (1)$$

where w_{ji} represents the connection weight, x_i denotes the input variables (e.g., initial balance, historical collections, supplier maturities), and b_j is the bias term. The activation function utilized for the hidden layers is either the logistic function (Sigmoid) or the Rectified Linear Unit (ReLU), defined as f(z) = max (0, z).

To minimize cash-flow forecasting errors, the network optimizes a Mean Squared Error (MSE) cost function:

$$E = \frac{1}{2}\sum_{k=1}^{m}(t_k - y_k)^2 \quad (2)$$

where t_k represents the actual cash-flow value and y_k is the network's predicted output. Weights were iteratively updated based on the error gradient, applying an optimized learning rate η.

III. THE RESEARCH

a. The research development

The applied study was conducted within a digital accounting ecosystem consisting of the SAGA Cloud ERP platform, a custom-built virtual assistant designed for database querying, and an external predictive analysis module built in Python (utilizing TensorFlow/Keras and Pandas libraries).

In the first phase, the impact of migrating from the local SAGA Desktop version to SAGA Cloud was evaluated. The primary advantage identified is the centralization of financial data into a secure, remotely accessible architecture, eliminating data desynchronization risks across multiple business branches. Over this infrastructure, a tailored RPA script was deployed to run at scheduled intervals (e.g., daily at 08:00 AM) to query the RO e-Factura system API. The software robot automatically downloads the unique XML files issued by suppliers, verifies structural data integrity, converts the data fields, and registers them directly into the "Inflows/Purchases" module of SAGA Cloud as drafts, leaving only the final validation step to the expert accountant [9][18][19].

In the second phase, the cleaned accounting dataset (comprising historical purchase invoices, sales invoices, bank statements, and cash registries) was exported to feed the neural network. The input variables included historical collection vectors, economic seasonality components, average customer payment delays, and certain fiscal obligations derived from official tax declarations (Forms 300 and 394). The MLP network was configured with an input layer (12 predictors), two hidden layers (containing 24 and 12 neurons, respectively), and an output layer generating the estimated net cash flow for the upcoming 30-day window.

b. Research results and limitations

Simulation results suggest the potential superiority of the integrated AI approach. Regarding RO e-Factura automation via RPA in SAGA Cloud, a drastic reduction in manual data entry times was achieved: the average processing time per invoice dropped from 4.5 minutes (manual typing, checking CPV/NC codes, matching suppliers) to under 20 seconds (the time required solely for visual verification and final approval by the user). These findings are consistent with the efficiency improvements reported in Robotic Process Automation literature [9][18][19].

The conceptual neural network predictive model indicated promising results for short-term (30-day) cash-flow forecasting. The conceptual model indicates that forecasting errors could be significantly reduced compared to traditional approaches. This suggests potential advantages compared to traditional econometric forecasting approaches, which often struggle to capture non-linear customer payment behavior and exogenous economic shocks.

Despite providing undeniable competitive advantages, the study highlighted several notable limitations. First, artificial neural networks suffer from the "Black Box" phenomenon—while generating highly accurate predictions, their internal weight-allocation logic is difficult for managers to interpret directly, lacking transparent causal traceability [5][13]. Second, forecast quality is entirely dependent on historical data integrity (the "Garbage In, Garbage Out" principle). If source invoices are misclassified in the ERP or if massive macroeconomic anomalies occur that were absent from the training set, the model's accuracy degrades sharply.

Another limitation concerns the conceptual nature of the proposed framework, which requires validation through implementation in real-world organizational environments.

IV. ORIGINALITY OF THE PAPER

The originality of this research lies in its holistic and applied approach to digital transformation within the Romanian financial landscape. Unlike existing literature that often treats cloud computing, RPA, or neural networks in isolation, this paper proposes a functional, fully integrated architecture specifically calibrated for local SMEs.

The novelty element consists of modeling a complete automation loop where SAGA Cloud serves as a unified "Single Source of Truth," intelligently populated by software robots pulling data from government platforms (RO e-Factura) and analytically exploited via artificial neural networks. Furthermore, the paper introduces a cloud-based virtual assistant model capable of interpreting synthetic accounting indicators and translating complex mathematical forecasts into accessible managerial recommendations (such as flagging upcoming liquidity shortages and suggesting maturity renegotiations).

To the author's knowledge, few studies have examined the combined interaction between SAGA Cloud, RO e-Factura automation and AI-based forecasting within the Romanian SME context. This contribution extends prior accounting information systems research by integrating ERP platforms, AI forecasting and process automation into a single conceptual framework [2][11][14].

V. CONCLUSIONS

Implementing artificial intelligence within accounting information systems is no longer an optional luxury but a core strategic necessity for corporate resilience in a digitalized economy. Migrating to SAGA Cloud provides the required mobility and scalability infrastructure, while automating RO e-Factura streams removes redundant, routine manual labor with minimal operational risk.

This research suggests that artificial neural networks can be successfully leveraged in management accounting for cash-flow forecasting and decision support. Their capacity to learn from intricate data patterns allows corporate executives to act proactively, optimizing working capital and mitigating insolvency risks.

In conclusion, the future of the accounting profession lies at the intersection of economic sciences and information technology. The accountant's role is rapidly evolving from a traditional data entry clerk into a strategic analyst and business partner who interprets AI-generated scenarios to guide top-level management decisions [2][11]. Future research directions will focus on expanding the neural architecture by integrating Deep Learning models (such as Long Short-Term Memory networks) to analyze market sentiment and customer payment behaviors under high macroeconomic volatility conditions.

Rather than replacing accountants, artificial intelligence enhances their analytical capabilities and supports a transition toward a more strategic role in organizational decision-making [8][11].

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A Pragmatic Approach to Measuring Innovativeness and Business Performance Generated by Innovation in Software Development Companies

Doru ȘUPEALĂ[1]

Abstract – Measuring innovativeness is crucial for software companies, as traditional indicators often fail to capture the rapid, modular nature of digital products. Drawing on OECD standards and innovation literature, this article proposes an integrated framework that distinguishes organizational innovativeness (resources, capabilities, and processes) from innovation performance (outcomes like novelty, revenue, market access, and productivity). Building on prior research (Șupeală, 2022), the model incorporates software-specific operational measures, such as experimentation speed, delivery times, digital capabilities, and responsible AI use, without confusing them with commercial success. The proposed architecture advocates combining objective data with manager and employee perceptions, evaluating performance across multiple benchmarks (absolute values, internal targets, temporal trends, and competitive comparisons), and balancing financial and non-financial indicators. By moving beyond single metrics like patents or launch counts, this multidimensional approach offers a more nuanced evaluation of incremental and radical innovation, aligning with modern digital transformation literature (Dziallas and Blind, 2019).

Keywords - Innovation management; Innovation performance; Innovativeness; Software companies; Information technology; Digital transformation; Business Performance.

I. INTRODUCTION

Performance measurement plays a central role in management because it allows organizations to distinguish actual results from intuitive perceptions of success and to transform the information obtained into decisions about resources, priorities and future development. In the field of innovation, this function is all the more important as the effects of investments are often delayed, uncertain and distributed between technological, commercial and organizational results. Classical literature shows that innovation performance measurement should be integrated into the overall performance management system and should combine financial and non-financial indicators (Saunila and Ukko, 2013, 2014; Saunila, 2017; 2020). The need to use measurement is especially significant to support decisions in the early stages of innovation development.

However, a stricter differentiation between the two constructs is needed. **Organizational innovativeness** describes the ability of a firm to produce relevant change through resources, skills, research and development processes, experimentation, learning, collaboration and the implementation of ideas. **Innovation performance** describes the results of these activities: new or substantially improved products or processes, customer value created, market access, revenues associated with new products, productivity or economic returns. This distinction is compatible with the literature that treats innovation capability as an antecedent of performance and not as a synonym for it (Al-kalouti et al., 2020; Saunila, 2020; Șupeală, 2022).

The current international reference, the *Oslo Manual 2018* (OECD/Eurostat, 2018), locates business innovation around a new or improved product or business process that differs significantly from previous products or processes and that has been effectively introduced to the market or put into use. The manual thus emphasizes both the significant difference from the previous situation and the condition of implementation, avoiding equating a simple idea with a realized innovation. This clarification is important for software companies, where large volumes of ideas, prototypes or versions can exist without each of them constituting an innovation with organizational or commercial value. The measurement problem is amplified by the characteristics of digital products (Hund et al., 2021). Research on digital innovation highlights the "reprogrammability" and recombination

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of digital technologies, as well as the fact that the innovation process can become more distributed and less delimited than in the case of traditional material products (Nambisan et al., 2017; Liu et al, 2023). Consequently, the number of products, versions, modules or patents can be difficult to interpret without information on the degree of novelty, actual use, speed of development and value created. Research on information technology firms further confirms that digital orientation and digital capabilities influence digital innovation, and this may mediate the relationship between technological capabilities and organizational performance (Khin and Ho, 2019).

The relevance of the issue is also high for the Romanian context. According to recent European assessments, Romania continues to be in the category of economies with modest innovation performance, and the country report indicates low levels of research and development intensity and of the share of enterprises introducing product or process innovations compared to the EU average (European Commission, Directorate-General for Research and Innovation, 2026). Eurostat showed, for the period 2020–2022, very large differences between countries in the proportion of enterprises with innovation activities, Romania being at the lower end of the European distribution (Eurostat, 2025). This context makes it useful to develop sufficiently precise measurement tools to identify not only the existence of innovative activities, but also the mechanisms through which they are transformed into performance. The objective of this article is, therefore, to develop a coherent and applicable set of dimensions and indicators through which managers of software companies can longitudinally assess: (a) the organization's capacity to produce and implement innovations and (b) their economic and market effects. The aim is not to build a single universal index, but to provide a modular architecture that can be adapted to the size of the firm, its business model, technological maturity and the type of market served. Such an approach is consistent with the literature showing that measuring innovation involves a large number of indicators distributed throughout the innovation process and that their choice must be related to the purpose of the assessment (Dziallas and Blind, 2019).

II. THEORETICAL FOUNDATIONS OF MEASURING INNOVATIVENESS AND INNOVATION PERFORMANCE

The literature on innovation measurement uses a wide variety of indicators, reflecting both differences across industries and the fact that innovation is simultaneously a process and an outcome. A useful analytical framework distinguishes between **inputs, processes, outputs and outcomes** (Adams et al, 2006). Inputs include the financial resources, human capital, skills, information and ideas mobilized for innovation; processes describe the transformation of these resources through research and development, design, experimentation, collaboration and implementation; outputs are the newly created products, services, processes or knowledge; and outcomes capture their economic, competitive or social consequences (Dziallas and Blind, 2019).

In this research proposed framework, **innovativeness** is measured predominantly in the area of inputs and processes, while **innovation performance** is measured through outputs and outcomes. The separation should not be interpreted rigidly. For example, launch time can simultaneously be a result of process quality and a factor influencing commercial success. Similarly, the development of an artificial intelligence capability can represent an organizational resource, but its effects can manifest themselves through creativity, development speed or performance. Research on AI capability shows precisely the need to conceptualize it as a set of resources and skills, not as the simple presence of a technology (Mikalef and Gupta, 2021).

Using a single output indicator is problematic. Patents, for example, may be a relevant measure for some industries, but not all innovations are patented, and patenting does not guarantee implementation or economic success. This limitation is accentuated in the case of software companies, where product cycles can be short, offerings are frequently modular or customized, and value protection can be achieved through mechanisms other than patents. More generally, Dziallas and Blind's (2019) analysis of indicators used throughout the innovation process shows a considerable diversity of measures and implicitly argues against a single-criteria assessment. The same caution applies to the number of "new products". In software, a new version, a functionality, an additional module, and a truly new product can be administratively counted in very different ways. For this reason, the number of releases should be related to the degree of novelty and the effect on the user or market. The Oslo Manual 2018 is relevant precisely because it links innovation to the significant difference from the previous situation and to effective implementation (OECD/Eurostat, 2018).

For software companies, process measurement should also include dimensions specific to digital delivery. The DORA (2025) framework, specialized in Artificial Intelligence assessment, uses indicators such as change delivery time, implementation frequency, change failure rate, and recovery time, and the framework has been extended over time to capture both throughput and delivery system instability. These indicators do not directly measure innovation, but provide objective data on the organization's ability to transform technical changes into software available to users. A similar limitation should be applied to developer productivity metrics. The SPACE framework (Forsgren et al., 2021) shows that software productivity cannot be reduced to the number of commits, lines of code, closed tickets, or other easily quantifiable activities; the assessment should simultaneously cover satisfaction and well-being, performance, activity, communication and collaboration, as well as efficiency and flow. For the present framework, these dimensions are relevant as explanatory variables of innovativeness, especially when research aims to understand why two firms with similar resources achieve different levels of innovation.

2.1. Established innovation measurement models compatible with the software sector

One of the most important frameworks for collecting data on innovation at the enterprise level is the Oslo Manual, developed by the OECD and Eurostat (OECD/Eurostat, 2018). The fourth edition of the manual provides concepts and definitions applicable across a wider range of industries and systematically addresses the measurement of innovation activities, capabilities, knowledge flows, externalities and outcomes. The Community Innovation Survey proposed by Eurostat applies this conceptual framework at European level and collects, among other things, information on product and business process innovations, innovation expenditure, cooperation, barriers and the share of turnover from innovative products (Eurostat, 2025).

For measuring performance, **the share of sales generated by new or substantially improved products** remains a particularly useful indicator because it links the outcome of innovation to actual economic activity. In the classical literature, this measure appears both as a percentage of total sales and in adjusted forms, such as innovative product revenue per employee (Mairesse and Mohnen, 2002; Kafouros et al., 2008; Tsai, 2009). Currently, new product revenue should be reported in at least three forms: percentage of total turnover; value per employee (when productivity comparisons are relevant); and deviation from stated business objectives. When historical data are available, it is also useful to report the evolution against a base period. This architecture avoids the situation where an absolute increase in revenue is interpreted as superior performance, even though the size of the firm has increased over the same period.

Another essential dimension is the **degree of novelty**. Romijn and Albaladejo (2002) propose differentiating between products similar to existing ones, improved products, new products for the industry and new products at the global level. Baer and Frese (2003), Prajogo and Ahmed (2006), as well as Fischer et al. (2014) use related perceptual approaches. These scales can better differentiate incremental change from radical innovation than simply counting products. The current distinction in innovation statistics between novelty for the firm and novelty for the market (Eurostat, 2025) valuably complements this perspective. For the software sector, the assessment of the degree of novelty should take into account not only the technology, but also the business model configuration and the value for the customer. Research on digital innovation shows that innovative value can result from new combinations of technologies, data, platforms and organizational processes, even when the individual technical elements are not themselves completely new (Khin and Ho, 2019; Nambisan et al., 2017; Liu et al, 2023). Therefore, a novelty scale can be accompanied by an open-ended question in which the respondent specifies what is new: functionality, technical architecture, user experience, delivery process, revenue model or target market.

Perceptual models should, however, be used with caution. Pallas et al. (2013) measure both innovation performance, such as impact on sales and profit, and overall financial performance. Similarly, Ferraresi et al. (2012), Parida et al. (2017), and Hung et al. (2011) include combinations of process, product, and business impact indicators. The advantage of such scales is that they can be applied when detailed financial data is confidential; the disadvantage is that respondents may overestimate their own organization's performance.

The recent literature on digital capabilities provides a useful complement. Khin and Ho (2019) show, in a study of IT firms, that technological orientation and digital capability are associated with digital innovation, and this is linked to financial and non-financial performance. Mikalef and Gupta (2021) develop and validate an AI capability construct, emphasizing the importance of combining technological resources with organizational and human resources. These approaches justify the inclusion of indicators related to the ability to use data, AI, automated tools, and digital infrastructure in contemporary software firms. Research from Romania provides compatible results. Suciu (Vodă) et al. (2021) analyse the adoption of IoT technologies in enterprises in the Romanian IT industry and link technological adoption to innovation and sustainable development. Vuță et al. (2022), on a large sample of Romanian microenterprises and SMEs, examines digital transformation and the use of digital tools in difficult market conditions. Recently published Romanian and Central-Eastern European studies indicate, in turn, that the effect of digitalization on performance depends on how the organization transforms access to technology into usable capabilities (Ogrean and Herciu, 2022; Nicolau et al., 2022; Noja et al., 2026).

In this logic, software development performance can be used as a component of innovativeness assessment. The time it takes for a change to reach production, the frequency of deliveries, the rate of failed implementations and the speed of recovery provide operational data that can validate or contradict managerial perceptions of "agility" and "speed" (Jungnickel et al., 2020; DORA, 2025). However, these should not be transformed into a universal innovation score: a firm can very effectively deliver incremental improvements without generating radical innovations, just as a team on a very new technology project can temporarily have a less efficient delivery flow. Artificial intelligence requires the same caution.

The DORA (2025) report on AI-assisted software development treats AI as an amplifier of existing organizational conditions rather than an automatic determinant of performance. Therefore, "percentage of developers using AI" would be a weak indicator if analysed in isolation. More relevant are the observable changes in the experimentation cycle, product quality, delivery stability, time saved, novelty of solutions, and results for users.

From a management perspective, the recommended framework thus becomes **a multidimensional dashboard**, not a single index. Each organization can select indicators according to its own strategy, but it must maintain the representation of at least four levels: resources/capabilities, processes, innovative outputs and economic results. This architecture is congruent both with the literature on innovation indicators and with research that treats performance as a result of the interaction between capabilities, learning and innovation (Dziallas and Blind, 2019).

2.2. The need to use multiple sources of information, scales and assessment perspectives

A robust assessment should not depend solely on the responses of a company's management. Saunila (2017) shows that managers and employees may interpret innovation performance differently, differences that may stem from unequal access to information, distinct professional priorities, or the way in which results are communicated. Therefore, applying **equivalent items to different categories of respondent**s can allow the identification of a "perceptual gap" that is relevant in itself for management. In software companies, this logic can be extended to include operational data. For example, if managers assess the speed of delivery as very high, the assessment can be confronted with data from continuous integration and delivery systems. If employees perceive processes as excessively slow, indicators regarding lead time and recovery from incidents can show at what stage the blockage occurs. The use of standardized operational measures is compatible with the practice of DORA (2025), and the multidimensionality of the development experience is supported by SPACE (Forsgren et al., 2021).

The second form of triangulation concerns **the evaluation benchmarks**. The same indicator can be expressed as:

1. Absolute observed value;
2. Change from the previous period;
3. Performance against the internal objective;
4. Perceived or observed performance against competitors.

Using these benchmarks together limits misinterpretations. A 20% share of revenue from new products may be excellent for a mature company with long product cycles, but insufficient for a supplier in a rapidly changing market. Similarly, a higher launch rate than the previous year does not automatically demonstrate the success of the innovation if the new features are not adopted by users.

The third dimension is the **combination of quantitative and qualitative perspectives**. Financial and operational data provide reproducibility, but they do not always explain the mechanisms. Interviews and open-ended responses can clarify whether an increase in development time stems from technological complexity, bureaucratic process, lack of skills, or a deliberate investment in a new architecture. The literature on digital innovation insists on the interdependence between technology and organization, which makes it difficult to interpret isolated indicators (Nambisan et al., 2017).

Furthermore, data on digital transformation in SMEs suggest that simply participating in a digital ecosystem does not automatically produce superior results. In a recent study of SMEs in Romania, the relationship between integration into digital ecosystems and performance is explained by the development of data analytics and artificial intelligence capabilities, which indicates the need to measure intermediate mechanisms, not just the final outcome (Croitoru et al., 2026). Analyses of SMEs in Central and Eastern Europe also highlight uneven effects of digitalization and innovation on sales, investment and employment, depending on resources and context (Vuță et al., 2022; Aleca and Mihai, 2026). Consequently, the proposed model recommends a matrix in which each important construct is assessed, when data allow, through at least two sources and two types of scale. A perceptual indicator of agility can be associated with an objective measure of lead time (Jungnickel et al., 2020); strategic orientation towards innovation can be assessed by both managers and employees; the commercial success of a product can combine the achievement of revenue targets, the share of turnover and the assessment of the position against competitors. This controlled redundancy is not methodological waste, but a validation mechanism.

As a synthesis of the concepts presented, we propose in Figure 1 an integrated framework of the processes for measuring innovativeness and innovation-generated performance in software companies. The input–process–output–result structure is compatible with the multidimensional approach to innovation indicators and with the current OECD/Eurostat framework (2018), and the triangulation layer reflects the recommendation to combine different sources and benchmarks (Dziallas and Blind, 2019). For a later empirical version, this diagram can also become the basis of a model to be tested through academic research: **innovation capabilities → effectiveness of innovation processes → degree of novelty/innovative output → innovation performance**, with digital maturity or AI capability as explanatory or moderating variables. Recent research on dynamic capabilities, digital innovation and AI provides support for investigating such intermediary mechanisms (Ferreira et al., 2021).

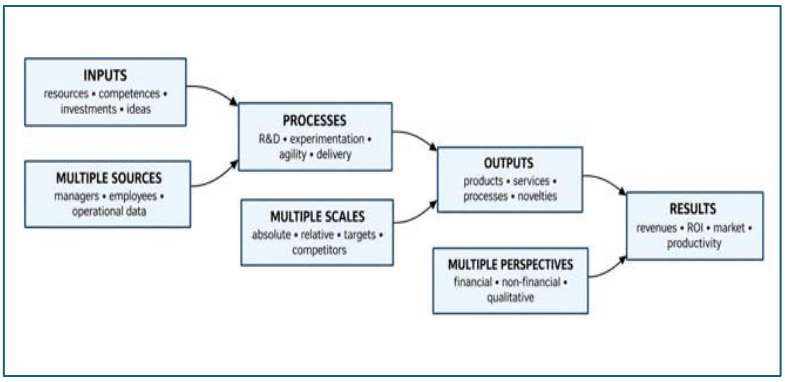

Fig. 1. Integrated framework for the process of pragmatic measuring innovativeness and innovation performance in software companies.

Table 1

Proposed measures for organizational innovation.

Innovativeness factor	Item formulation	Respondents and evaluation benchmarks	Academic reference
Comparative innovativeness	"Compared to other organizations I have worked in or know, this company demonstrates a high level of innovation".	Employees, managers; Likert scale or comparative response	Fischer et al. (2014); Saunila (2020)
Strategic orientation towards innovation	"Innovation is an explicit and consistently supported priority in the company's strategy".	Employees, managers; Likert scale 1–5	Pallas et al. (2013); OECD/Eurostat (2018)
Speed of R&D processes	"Research, experimentation and validation processes allow for rapid testing of new solutions".	Perception; internal objectives; temporal benchmark	Prajogo & Ahmed (2006); Dziallas & Blind (2019)
Speed of launch / market response	"The company transforms a validated idea into a functionality or offering available to users in a competitive range".	Perception; lead time; objectives; competitors	Ferraresi et al. (2012); DORA (2025)
Encouraging initiative	"Employees who propose and test new ideas receive practical support, not just declarative approval".	Employees and managers; Likert scale	OECD/Eurostat (2018); Fischer et al. (2014)
Implementing ideas	"A relevant proportion of validated ideas are transformed into changes actually used in products or processes".	Likert scale + estimated/observed percentage	Ferraresi et al. (2012); Parida et al. (2017)
Technological innovation and digital capability	"The organization can integrate new digital technologies and methods when they provide demonstrable value".	Employees, managers; Likert scale; operational evidence	Khin & Ho (2019); Mikalef & Gupta (2021)
The degree of novelty of the products	Classification of the most important innovation, on a scale: "no significant novelty", "new to the company", "new to the national/international market" and "change that redefines the market".	Employees, managers; ordinal scale + justification	Romijn & Albaladejo (2002); Fischer et al. (2014); OECD/Eurostat (2018)
Radical novelty	"To what extent does the innovation change the existing rules of the product, market, or business model?"	Ordinal scale, validated with examples	Carayannis & Provance (2008); Nambisan et al. (2017)
Evolution of investment in innovation	"Compared to income and the previous period, have the resources allocated to innovation increased, stagnated, or decreased?"	Financial data + perception	Calik & Bardudeen (2016); Eurostat CIS
Introduction of new products / processes	"During the reporting period, the organization has effectively put into use significantly new or improved products or processes".	Administrative data + managers	OECD/Eurostat (2018)
Additional software process indicators	Lead time, delivery frequency, recovery from failure, delivery stability, flow efficiency, collaboration and developer satisfaction.	Telemetry + employees + managers	Hung et al. (2011); Forsgren et al. (2021); DORA (2025)

Table 2

Proposed measures for innovation business performance.

Innovation performance factor	**Item formulation**	**Respondents and evaluation benchmarks**	**Academic reference**
Share of revenue from new products	"What percentage of the period's turnover comes from new or significantly improved products/services?"	Absolute data; targets; evolution; competitors	OECD/Eurostat (2018); Alegre et al. (2013)
New product revenue per employee	"What is the value of revenue attributed to new products relative to the number of employees?"	Financial data; evolution in time	Kafouros et al. (2008); Tsai (2009)
Competitive advantage associated with innovation	"To what extent have the innovations introduced improved differentiation or competitive position?"	Managers; customers; market data	Hung et al. (2011); Khin & Ho (2019)
Profitability associated with innovation	"What is the estimated or calculated contribution of new products to profitability?"	Financial data + management estimate	Pallas et al. (2013)
Revenue growth associated with innovation	"What portion of the revenue growth is associated with products or services introduced during the reference period?"	Absolute data; objectives; trend	OECD/Eurostat (2018); Parida et al. (2017)
Achieving market share goals	"Did the innovative products achieve the penetration or market share targets set before launch?"	Internal targets + market data	De Luca & Atuahene-Gima (2007); Ferraresi et al. (2012)
Achieving income goals	"Do the revenues generated by the new products meet or exceed the approved business case?"	Financial data; target	Pallas et al. (2013)
Achieving ROI goals	"Is the return on investment in the new product within the planned level and time horizon?"	Financial data; target	Ferraresi et al. (2012); Pallas et al. (2013)
Achieving profitability goals	"Does the margin/profitability of the innovative portfolio meet the established objectives?"	Financial data; target; benchmark	Pallas et al. (2013)
Reducing unit cost / cost-to-serve	"Did the process or product innovation reduce the cost of providing a comparable unit of value?"	Operational and financial data	Hung et al. (2011); OECD/Eurostat (2018)

III. CONCLUSIONS, MANAGERIAL AND PRACTICAL IMPLICATIONS

The literature review suggests that measuring innovation in software companies should avoid two extremes: on the one hand, using a single indicator that is easy to collect; on the other hand, building a system so complex that it can no longer be used managerially. The proposed solution is a modular architecture in which companies select a limited set of indicators from each stage of the chain **inputs → processes → outputs → results**, while maintaining the distinction between innovation capacity and innovation performance.

This approach is coherent with OECD/Eurostat standards (2018) and with the modern literature on innovation indicators. For software companies, the assessment should be complemented with delivery and development indicators, but without confusing technical efficiency with novelty or commercial success. DORA (2025) and SPACE (Forsgren et al., 2021) provide useful tools for operationalizing speed, stability, flow, collaboration, and developer experience, while the literature on digital capabilities and AI allows for the assessment of a firm's ability to transform technology into new products and processes (Filip et al., 2026).

Table 1 summarizes the main orientations towards the most relevant innovation drivers for the contemporary software industry. The indicators should be interpreted as a set of multiple options, which should be selected according to the specifics and context of the organization and then measured longitudinally.

Table 2 summarizes the main trends in the economic and commercial effects of innovation. The indicators should be interpreted as a portfolio: a firm may have an innovation with high strategic impact before it generates accounting profit, and an increase in revenue may have causes that are not related to innovation.

The practical application of the parameters in the two tables involves selecting a stable core of indicators to be tracked longitudinally. Continuously changing indicators would make it difficult to observe trends. Instead, the firm can keep a core of comparable measures and temporarily introduce additional indicators for new technologies or strategic objectives. In the case of AI, for example, adoption should be assessed by the effect on the process and outcome, not by the simple rate of use. The recent DORA (2025) report on AI in software development emphasizes that the effects depend on the organizational system in which the technology is introduced. In the same logic, Romanian research on digital ecosystems shows that access to a digital environment must be transformed into analytical and AI capabilities in order to materialize in performance results (Croitoru et al., 2026; Coman et al., 2026; Filip et al., 2026)

The proposed framework does not provide a "magic score" of innovation. Its contribution consists in structuring a repeatable evaluation process, through which managers can identify whether a problem is localized at the level of resources, process, quality and novelty of output or its conversion into economic results. This distinction facilitates decisions regarding investments, skills, development processes and product portfolio.

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