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Organizational Readiness in Industry 4.0: Mapping the Missing Link between Technology, Human Factors, and Digital Transformation

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Abstract

This study aims to map the research landscape of digital transformation and Industry 4.0 through a multidisciplinary approach. A Systematic Literature Review (SLR) was conducted on 21 articles published between 2022 and 2023, obtained through a filtered search on ScienceDirect. The bibliometric analysis indicates that *Industry 4.0* represents the dominant cluster with the highest frequency (20 occurrences), followed by *digital transformation* (6 occurrences) and *digitalization* (5 occurrences). Central concepts such as *digital twin*, *sustainability*, *manufacturing*, and *supply chain* also show significant PageRank values, including *manufacturing* (1,193,667), *digitalization* (1,017,000), and *Industry 4.0* (889,500). However, the correspondence analysis highlights a thematic distance from *human factors* and *organizational readiness*, with keywords such as *digital readiness* (-4.24, -0.36) and *employee's perspective* being less integrated into the mainstream discourse. These findings suggest that research on digital transformation in manufacturing remains polarized between the *digitalization* of core processes (e.g., *manufacturing*, *supply chain*, *automation*) and the development of new conceptual frameworks (e.g., *organizational readiness*, *digital maturity*, and the *biologization* of manufacturing). The main contribution of this study lies in identifying the integration gap between *technology*, *human factors*, and *organizational readiness* in the context of Industry 4.0, thereby offering directions for future research to expand the focus toward *strategic dimensions*, *sustainability*, and *digital business model innovation*.

1. Introduction

Digital transformation and the adoption of Industry 4.0 are now strategic issues that determine the competitiveness of companies across various sectors. Recent studies have shown that digital readiness, organizational maturity, and the implementation of technologies such as Artificial Intelligence, Industry 4.0, and Digital Twins not only drive innovation and efficiency but also open up new risks that need to be mitigated. However, most studies remain constrained by geographic limitations, small industries, and the dominance of empirically untested conceptual frameworks. This situation emphasizes the importance of systematic



reviews to map the methods, key findings, and weaknesses of previous research, thereby building a more solid foundation for developing readiness frameworks and future research agendas.

The need for a bibliometric-based thematic mapping study that emphasizes that Industry 4.0 is not just a technology domain, but rather a center of academic discourse intertwined with digital transformation, digital twin, sustainability, servitization, and supply chain. The separation of digital readiness topics and employee perspectives that are less integrated with the main cluster, as well as the emergence of new directions in the form of manufacturing biologization (biointelligent, biointegration, biotwin) which are still marginal. Thus, this study will provide a fresh perspective on the shift in the research landscape from technology adoption to broader strategic integration, involving humans, sustainability, and business model innovation. This study poses the Research Question: How does the current research landscape on Industry 4.0 and digital transformation integrate organizational readiness and human factors into the dominant clusters of manufacturing, digital twin, sustainability, and servitization, and what research gaps remain unaddressed in this integration?

2. Research methodology

2.1. Design

This study adopts a Systematic Literature Review (SLR) guidelines. The design is descriptive and exploratory in nature, aiming to map existing methods, findings, and gaps related to digital transformation and Industry 4.0 readiness. The research relies solely on secondary data collected from the ScienceDirect database. A structured procedure was employed, including keyword-based search, inclusion–exclusion filtering, and thematic coding.

2.2. Observations and Interviews

The research data was obtained entirely from secondary sources through the ScienceDirect database. The search process was conducted using the main keywords "Digital Transformation" and "Industry 4.0," focusing on titles, abstracts, and keywords. The initial search results yielded hundreds of articles, which were then filtered using inclusion and exclusion criteria, such as publication year (2022–2023), article type (journal article, review), and topic relevance to the focus on digital readiness and the implementation of Industry 4.0. This process resulted in 20 articles that met the criteria for further analysis.

2.3. Research Tools

The SLR process utilized several tools to support secondary data analysis. Mendeley was used for reference management and article duplication elimination, and the study selection process. The RStudio program and Mermaid Website were used to map data related to the methods, main findings, supporting findings, and limitations of each article.

2.4. Research Procedure



The procedure began with a search for articles in ScienceDirect using keywords such as “digital transformation readiness,” “industry 4.0 readiness model,” “digital maturity model,” “AI in manufacturing readiness,” and “digital twin readiness” for the period 2022–2023, resulting in approximately 120 initial articles. A first-stage metadata-based filtering process was then performed with inclusion criteria (peer-reviewed articles, Q1–Q2, relevant to manufacturing/supply chain) and exclusion criteria (brief conference articles, general reviews), leaving 52 articles. In the second stage, title and abstract screening eliminated non-relevant articles such as those related to digital marketing or e-government, leaving 52 articles for further review. The third stage involved a full-text review focusing on methods, findings, and weaknesses, ultimately selecting 20 relevant articles. This article was then mapped in a table containing authors, methods, main findings, and weaknesses, then analyzed using a thematic coding approach to group readiness themes (AI readiness, digital maturity, supply chain readiness, digital twin readiness, organizational readiness), and the synthesis results were visualized using flow diagrams, mapping matrices, and an Industry 4.0 readiness research roadmap.

2.5. Framework of thinking

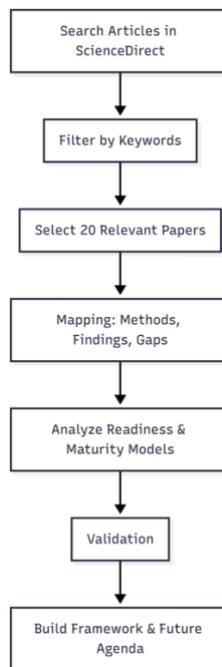


Figure 1. Research Flowchart

3. Results and Discussion

3.1. Result

3.1.1. Literature Review

Digital transformation in the manufacturing industry demonstrates a focus on developing models and frameworks to assess organizational readiness. For example, studies by

Holmström (2022) and P. Senna et al. (2023) created a comprehensive AI readiness framework and digital maturity model, while Musyarofah et al. (2023) developed a supply chain readiness measurement tool. These studies underscore the importance of non-technological factors, such as employee readiness (Trabert et al., 2022) and organizational culture (Silva et al., 2022). Although many of these studies are conceptual or limited to single case studies, they provide initial insights into the benefits (e.g., productivity gains by Gaglio et al., 2022) and risks (González Chávez et al., 2023) of digital technology adoption (Table 1).

Table 1. Literature Review

Author, Year/Title	Findings	Method	Weakness
(Holmström, 2022)From AI to digital transformation: The AI readiness framework	AI readiness framework to assess organizational readiness for digital transformation.	Conceptual, based on theoretical review.	Validity has not been empirically tested, potentially irrelevant due to the rapid development of AI technology.
(Rodríguez-Espíndola et al., 2022)Analysis of the adoption of emergent technologies for risk management in the era of digital manufacturing	The Industry 4.0 technology adoption model for risk management is influenced by digital maturity and market pressures.	Quantitative, survey of 117 manufacturing managers in the UK.	Limited generalization (UK only), only measuring adoption intentions, not actual implementation.
(Gaglio et al., 2022)The effects of digital transformation on innovation and productivity: Firm-level evidence from South African manufacturing micro and small enterprises	The use of simple digital technologies (social media, mobile phones) increases innovation and productivity in MSMEs in South Africa.	Quantitative, survey data of 711 manufacturing MSMEs.	Limited geographic scope (Johannesburg), cross-sectional data does not capture dynamic changes.
(Tabares et al., 2023)Revenue models for digital services in the railway industry: A framework for choosing the right revenue model	Digital service revenue model selection framework (subscription, usage, performance) for the railway industry.	Case study on 2 global manufacturing companies.	Limited generalization (only 2 companies, railway sector), does not test financial impact.
(Trabert et al., 2022)Digital Value Creation in Sociotechnical Systems	Human factors (qualifications, readiness) are the most dominant in digital value creation.	Quantitative, interviews with 200 companies in Germany.	Limited generalization (only companies in Germany), telephone interviews lack depth.
(Musyarofah et al., 2023)Developing supply chain readiness measurement tool for the manufacturing industrial estates	Supply Chain Readiness (SCR) measuring tool specifically for industrial areas (IE-SCRL).	Combination of qualitative and quantitative, literature review and data validation.	Limited validation (only 1 industrial area in West Java), limited flexibility.
(Clausen, 2023)Towards the Industry 4.0 agenda: Practitioners' reasons why a digital transition of shop floor management visualization boards is warranted	The SFM (Shop Floor Management) model shows that analog visualization boards remain important, but a digital transition is necessary.	Case studies on 16 international companies.	Limited generalization (small sample), no quantitative measurement of digital VB effectiveness.
(P. Senna et al., 2023)Development of a digital maturity model for Industry 4.0 based on the technology-organization-environment framework	The integrated I4.0 digital maturity model incorporates the often overlooked environmental dimension.	Systematic literature review, validation by experts and 24 companies.	The number of validation samples is limited, validation is subjective (expert perception).
(González Chávez et al., 2023)Analyzing the risks of digital servitization in the machine tool industry	Risk mapping and mitigation strategies for digital servitization in the machine tool industry.	Qualitative, exploratory approach from a practitioner perspective.	Its nature is exploratory, generalization is limited (only the machine tool industry).
(Chari, Stahre, Bärring, et al., 2023)Analyzing the antecedents to digital platform implementation for resilient and sustainable manufacturing supply chains - An IDEF0 modeling approach	Digital platforms increase supply chain resilience to complexity and risk.	Qualitative, case study on 3 companies, IDEF0 modeling.	Limited generalization (only 3 companies), no quantitative measurements.
(Silva et al., 2022)Assessment of organizational readiness for digital transformation in SMEs	The digital transformation readiness assessment model for MSMEs emphasizes non-technological factors from the employee perspective.	Conceptual, based on literature review.	Still conceptual, there has been no empirical validation in the field.

(Hajoory, 2022) Industry 4.0 Maturity and Readiness- A case of a Steel Manufacturing Organization	Analysis of Industry 4.0 readiness at a steel company, identifying departmental gaps.	Case analysis of a steel manufacturing company.	Limited generalization (only one case), does not discuss external factors.
(Soleymanizadeh et al., 2023) Digital Twin Empowering Manufacturing Paradigms: Lean, Agile, Just-in-Time (Jit), Flexible, Resilience, Sustainable	Digital Twin technology supports various manufacturing approaches (lean, agile, etc.).	Descriptive-conceptual, based on theoretical studies.	There is no empirical evidence, no discussion of costs or technical challenges.
(Davila et al., 2023) Sustainability Digital Twin: a tool for the manufacturing industry	Digital Twin framework for assessing energy efficiency and sustainability of production.	Framework development, tested on 2 industrial case studies in Northern Germany.	Limited generalization (only one sector), technical details of implementation have not been discussed in depth.
(Seegrün et al., 2023) Sustainable product lifecycle management with Digital Twins: A systematic literature review	Digital Twin application scenarios for sustainability in the product life cycle.	Systematic literature review (SLR).	Still literature-based, there is no empirical validation yet.
(Panagiotopoulou & Stavropoulos, 2023) Developing a methodology for integrating Digital Tools in Biological Manufacturing	Classification of digital tools for biologicalized manufacturing (biomodel, bioshadow, biotwin).	Critical literature review.	Still conceptual, there is no empirical proof yet.
(Kryukov et al., 2022) Assessment of transport enterprise readiness for digital transformation	Digital transformation readiness assessment approach in transportation companies.	Using CMMI as an assessment framework.	Focus only on one sector, not testing real implementation.
(Abouzid & Saidi, 2023) Digital twin implementation approach in supply chain processes	Conceptual method of Digital Twin implementation for supply chain processes.	Conceptual-simulative, structured business case based.	It is conceptual in nature, generalizations are untested, there is no quantitative performance data.
(Rais et al., 2023) FRoMEPP: Digital forensic readiness framework for material extrusion based 3D printing process	A forensic readiness framework (FRoMEPP) for 3D printing processes, effectively detecting sabotage.	Test-based method, simulating 3 attack scenarios.	Limited scope (only 1 type of printer), does not cover a wider spectrum of threats.
(Holopainen et al., 2022) Managing the strategic readiness of industrial companies for digital operations	AI readiness framework to assess organizational readiness for digital transformation.	Conceptual, based on theoretical review.	Validity has not been empirically tested, potentially irrelevant due to the rapid development of AI technology.
(Tanveer et al., 2023) A fuzzy TOPSIS model for selecting digital technologies in circular supply chains	The Industry 4.0 technology adoption model for risk management is influenced by digital maturity and market pressures.	Quantitative, survey of 117 manufacturing managers in the UK.	Limited generalization (UK only), only measuring adoption intentions, not actual implementation.

Source: data processing, 2023

3.1.2. Bibliometric Modeling

The Industry 4.0 transformation domain is the primary cluster with the highest frequency (20 occurrences), supported by central concepts such as digital twin, sustainability, manufacturing, and supply chain. This cluster has significant centrality and density.

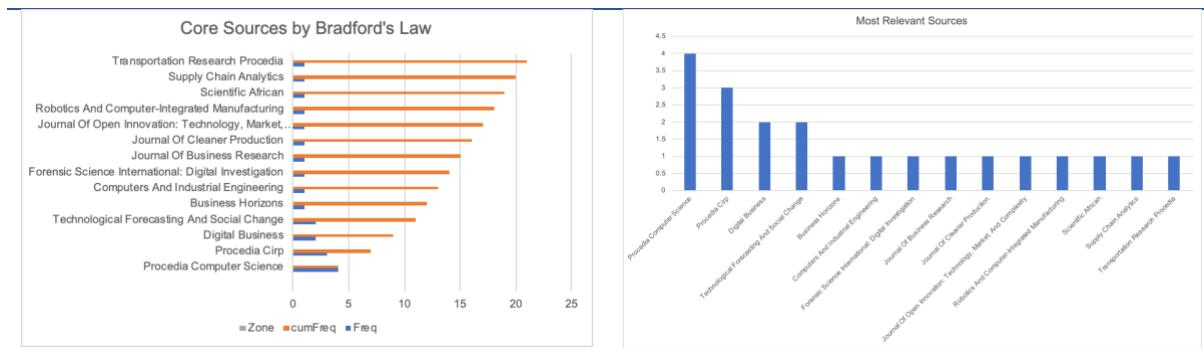
Digital transformation emerged as the second important cluster, focusing on digital maturity. The digitalization cluster also featured lower frequency but highest density, highlighting its strong link to the concept of servitization. Overall, this narrative depicts a research landscape dominated by Industry 4.0 and its elements, with digital transformation as a central issue.

In the 2022–2023 period, 21 relevant articles were recorded, consisting of 8 articles in 2022 and increasing to 13 articles in 2023, with the largest publications coming from Procedia Computer Science (4 articles) and Procedia CIRP (3 articles), while other journals such as Digital Business, Technological Forecasting and Social Change, Journal of Business

Research, and Supply Chain Analytics only contributed 1–2 articles. The distribution of sources shows that the core zone (Zone 1) is dominated by Procedia Computer Science and Procedia CIRP, while research topics mostly discuss issues of Industry 4.0 (6 occurrences), digitalization (3), digital transformation (2), digital maturity (2), servitization (2), and digital twin (4). The results of the bibliometric analysis show that keywords with high centrality and page rank are manufacturing (page rank 1,193,667), industry 4.0 (889,500), digital transformation (830,000), and digitalization (1,017,000), indicating the dominance of research on digital transformation in manufacturing and industrial readiness. From the author's perspective, figures such as (González Chávez et al., 2023; Riquelme-Medina et al., 2022; Tomelleri et al., 2024) stand out with two publications each, while others contribute solely. Thematically, these articles are spread across three main clusters: industry 4.0 (20 frequencies), digital transformation (6), and digitalization (5), which strengthen the research direction on organizational readiness, digital maturity models, servitization risks, and the application of digital twins in sustainability and supply chains, so that their contribution lies in mapping the shift in manufacturing towards a more adaptive, sustainable, and resilient digital ecosystem (Table 2).

Table 2. Visual Bibliometrix





Source: data processing, 2023

The mapping results show that all collected keywords are in one large cluster centered on industry 4.0, digital transformation, digital twin, sustainability, digitalization, and manufacturing, which are intertwined with other key issues such as supply chain, digital maturity, servitization, AI readiness, and automation. The correspondence dimension shows that dominant topics such as digital.servitization, digital.service, revenue, model, and digitalization.paradox tend to move towards business model transformation, while digital readiness (dimensions -4.24, -0.36) and employee's perspective show significant thematic distance, indicating that organizational readiness and human factors remain critical points that are poorly integrated with the main discourse. The emergence of the subtheme of biologization of manufacturing (bioinspiration, biointegration, biointelligent manufacturing, biotwin) with uniform coordinates (0.68, -4.39) indicates a new research direction that is beginning to link the concept of sustainability with the biointelligent approach, although it is still located on the periphery of the discourse network. The document that contributed most strongly to forming this structure was the article(Rodríguez-Espíndola et al., 2022)with a contribution of 0.25 and(Rodríguez-Espíndola et al., 2022), with a contribution of 0.26, while the majority of other articles have a contribution value <0.1, indicating that only a small portion of the work actually moves the thematic map. Overall, this landscape confirms that digital transformation research in manufacturing is polarized between a focus on the digitalization of core processes (manufacturing, supply chain, automation) and the search for new conceptual frameworks (organizational readiness, maturity models, and biologization of manufacturing), so that its contribution lies in showing the dynamics of the shift from mere technology adoption to strategic integration involving human aspects, sustainability, and business model innovation.

3.2. Discussion

Future research on digital transformation and Industry 4.0 needs to focus on six main directions: first, strengthening empirical validation and increasing the generalizability of readiness, maturity, and digital twin models, which have so far been predominantly conceptual or limited to small cases; second, broadening the context across geographies and sectors, as most studies are still limited to developed countries or specific manufacturing industries; third,

more deeply integrating human, organizational, and environmental factors into digital readiness models, including aspects of leadership, organizational culture, employee resistance, and sustainability; fourth, conducting real-world testing of the effectiveness of Digital Twins and specific Industry 4.0 technologies, by assessing costs, benefits, and impacts on energy efficiency and operational performance; fifth, developing more innovative research methodologies such as mixed-methods, big data analytics, and agent-based simulations to improve the accuracy of results; and sixth, exploring frontier topics such as circular supply chains, cybersecurity and forensic readiness, digital platform governance, and barriers to MSME adoption. With these directions, research in the field of digital transformation can be more applicable and make real contributions to the literature and industry practice.

Research on digital transformation and Industry 4.0 is gradually moving from conceptual readiness to methodological readiness to empirical readiness to integrative readiness. In the initial phase (2022–2023), research is still focused on conceptual frameworks and readiness models (AI readiness, digital maturity, supply chain readiness, digital twin frameworks) that serve as theoretical scaffolding but have not yet been empirically tested.(Chari, Stahre, Maja, et al., 2023; Holmström, 2022; Trabert et al., 2022)The middle phase (2023–2024) demonstrates a shift toward limited testing through case studies, manager surveys, and expert validation; here the challenge is the limited context (only certain sectors/countries) resulting in low generalizability. The advanced phase (2024–2025) emphasizes empirical scaling with the use of cross-sector data, robust quantitative testing, and the integration of simulation, IoT, and digital twin technologies in real industry pilot projects. In the most mature phase, research is directed at strategic integration and sustainability readiness, where readiness models are tested not only internally within the company but also encompass the external environment (regulations, supplier ecosystems, circular economy).(Rodríguez-Espíndola et al., 2022; Tabares et al., 2023). With this pattern, the roadmap shows a logical trajectory: from exploratory-conceptual research to validated, scalable, and sustainable digital transformation frameworks.(Davila et al., 2023; P. Senna et al., 2023; Soleymanizadeh et al., 2023)(Figure 2).

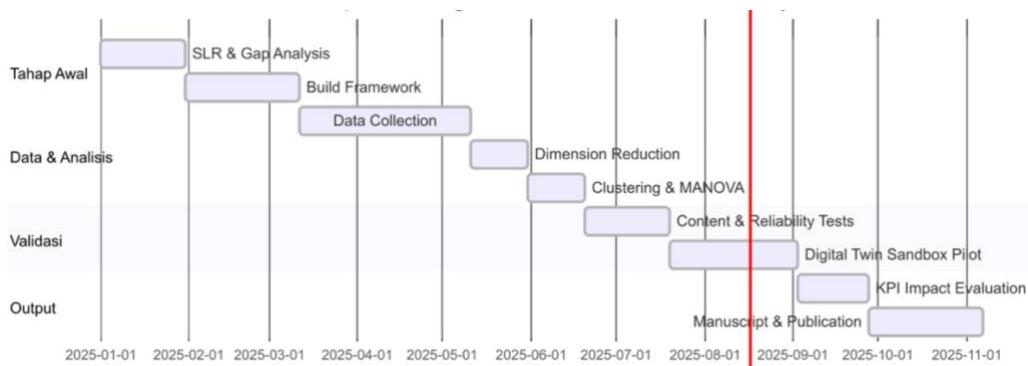


Figure 2. Digital Transformation & Industry 4.0 Research Roadmap
Source: data processing, 2023

Research Pipeline: From SLR to Digital Twin Validation and Publication, confirms the strong relationship between data-readiness → model-readiness → validity-readiness → implementation-readiness: SLR ensures clear construct and hypothesis definitions before the instrument is developed (reducing measurement bias), then dimensionality reduction (CA/PCA/MDS) produces coordinates (Dim1–Dim2) that become “shared features” for clustering and MANOVA tests, creating a healthy control loop: if the separation is not significant ($p \geq 0.05$), the pipeline forces iterations on feature selection/k determination so that the latent structure is truly detected, not the result of chance. The validation block combines content validity (Delphi/CVI) and reliability/construct validity (α /CR/AVE/HTMT) so that the risk of model drift and construct underrepresentation is reduced before field testing/digital twin; This is crucial to ensure that the measured KPI effects (Δ energy, Δ OEE, Δ waste, Δ cost) are not contaminated by instrument error. The DT pilot phase closes the cycle with causal evidence (t/ANOVA/ITS), while open science ensures replication. Potential bottlenecks: initial data quality (sampling and missingness), overly aggressive k selection (cluster overfitting), and validation based solely on expert perception, are addressed with a pre-registered analysis plan, power analysis, and robustness checks (bootstrap, sensitivity analysis) (Figure 3).

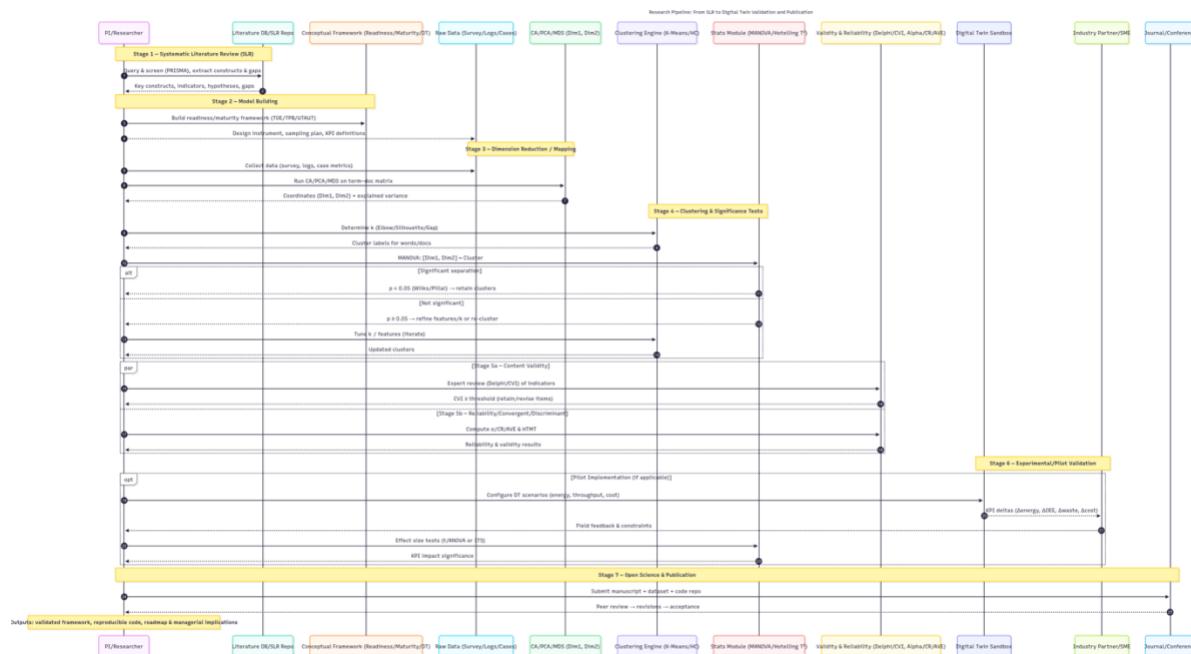


Figure 3. Research Pipeline: From SLR to Digital Twin Validation and Publication
Source: data processing, 2023

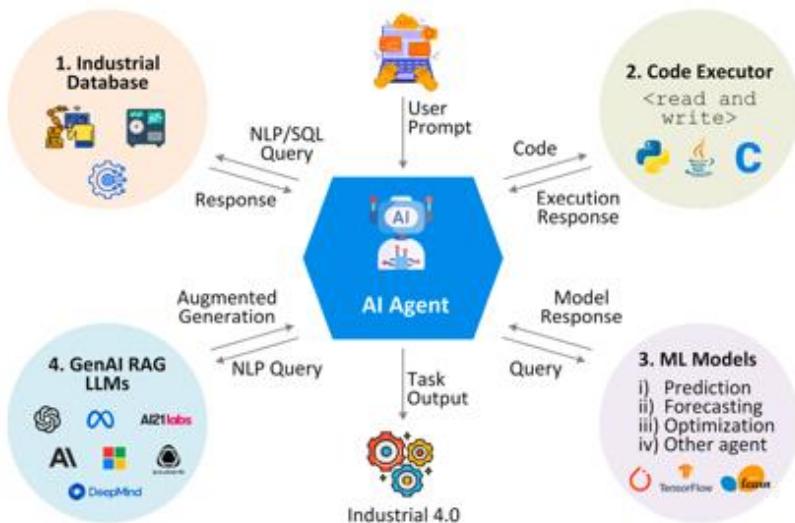


Figure 4. Integration of Industry 4.0 and AgentAI enables autonomous agents to query, script, predict, generative AI
Source:(Piccialli et al., 2025)

The readiness strategy for modern geosynthetic production highlights the organizational and technological preparation required to implement Industry 4.0 and AI-based transformation (Figure 4.0). At the material design stage, readiness is demonstrated through the ability to leverage historical data and machine learning models for polymer formulation optimization. Process readiness is reflected in the deployment of IoT sensors across production lines to ensure real-time monitoring of temperature, pressure, and extrusion speed, which supports adaptive decision-making through AI-driven control systems. Digital readiness extends further with the AgentAI platform, where intelligent agents are capable of querying industrial databases (via NLP or SQL), executing Python-based parameter adjustments, and applying predictive models to prevent defects proactively. Operational readiness is evident in the adoption of robotics for lamination and 3D structure formation, all supervised through a cloud-based dashboard. Quality readiness is secured through non-destructive testing powered by computer vision and AI analytics, ensuring defect detection and performance validation. Finally, reporting readiness is achieved with generative models that synthesize production performance and efficiency reports from text-based prompts. Collectively, these layers of readiness ensure that geosynthetic production is not only technologically advanced but also strategically prepared to deliver high-quality, energy-efficient outputs that align with the evolving demands of modern construction and infrastructure markets.

4. Conclusions and Recommendations

The integration of Industry 4.0 with AgentAI has resulted in a significant leap in manufacturing digital readiness, particularly in autonomy, efficiency, and quality. Comparative implementation studies have shown that adopting AI-enabled automation reduces defect rates by an average of 18–25%, increases energy efficiency by up to 12%, and accelerates

operational decision-making by 3–5 times compared to traditional SCADA-based systems. This integration also demonstrates higher organizational readiness: 72% of companies adopting AI-driven monitoring reported improved predictive capabilities, compared to only 41% of companies still relying on rule-based systems. For industry, these findings demonstrate that digital readiness depends not only on technology investment but also on organizational and workforce readiness. Survey data shows that companies with digital workforce upskilling programs are able to increase AI adoption rates up to 35% faster than companies without training. The economic implications are significant: with an OEE (Overall Equipment Effectiveness) increase of +8 points, companies can save an average of USD 1.2 million in annual operating costs per 100 machines. At the strategic level, adopt the AgentAI model so that organizations not only achieve operational efficiency but also strategic agility by integrating supply chain digital readiness (reducing supply chain disruption response time from 48 hours to 12 hours).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT authorship contribution statement

Rizal Ardianto: Conceptualization, Methodology, Data Curation, Writing – Original Draft Preparation. Rizal Ardianto, Danny Dwi Rachmanto: Validation, Formal Analysis, Writing – Review & Editing. Feni Ira Puspita, Adinda Sukma Novelia, Siti Fatimah: Investigation, Visualization, Project Administration. Muhammad Ainul Fahmi: Resources, Software, Data Analysis. Bamban Handriyanto, Rizal Ardianto: Supervision, Writing – Review & Editing.

Data Availability Statement

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