# Framework for Digital Transformation in Industry 4.0: Insights Data Driven Analysis in the Indonesia Manufacture Sector

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**ABSTRACT**

This study presents a structured grey literature review to develop a digital transformation framework for Industry 4.0 in Indonesia's manufacturing sector. The analysis draws from national policy documents such as Making Indonesia 4.0, the Indonesia Industry 4.0 Readiness Index (INDI), and the Performance Accountability Report (LAKIP), complemented by qualitative insights from Focus Group Discussions with stakeholders from Digital Industry 4.0 Center (PIDI 4.0) and Badan Standardisasi dan Kebijakan Jasa Industri (BKSJI). Using grounded theory techniques—open, axial, and selective coding—relevant themes were extracted from these non-academic sources and organized into four perspectives: Adaptation, Technologies for Transformation, Key Success Factors, and Implementation Steps. These were operationalized into 25 dimensions and four detailed activity tables. A gap analysis with PIDI 4.0 partner industries was conducted to validate the framework and reveal implementation challenges such as fragmented strategies, limited technical skills, and a lack of performance monitoring. The review method integrates institutional evidence and stakeholder knowledge into a practical model for digital transformation, offering transferability to other developing countries. This research highlights the methodological value of grey literature in constructing context-sensitive frameworks for complex industrial innovation.



## 1. Introduction

While Indonesia's manufacturing sector is transitioning towards Industry 4.0, the adoption rate remains relatively low. Only 21% of the country's 32,193 manufacturing companies have adopted Industry 4.0 technologies, primarily in sectors such as automotive, electronics, chemicals, textiles, and food and beverage. Agriculture and small and medium-sized enterprises (SMEs) lag behind in this technological shift [1]. Recognizing the need to expedite the adoption of Industry 4.0, the Indonesian government has taken a proactive approach. A key initiative is "Making Indonesia 4.0," a national roadmap designed to guide the country's digital transformation. The Ministry of Industry has also established the Indonesia Industry 4.0 Readiness Index (INDI 4.0) to assess companies' preparedness for Industry 4.0 technologies. Furthermore, the Ministry provides training and support through the Digital Industry 4.0 Center (PIDI 4.0) to assist companies in their transition [2]. Figure 1 illustrates the roadmap for the Indonesian manufacturing industry.

Globally, the manufacturing sector is at a pivotal point with Industry 4.0 technologies reshaping production paradigms. However, the process of digital transformation differs markedly between developed and developing countries. Developed nations benefit from superior infrastructure quality, skilled human resources, and supportive cultural attitudes toward technology adoption [3]. Thus, their Industry 4.0 frameworks often focus on optimizing technological integration. Conversely, developing countries like Indonesia face infrastructural limitations, vendor dependency, and cultural barriers that complicate their digital transformation frameworks [4]. Most existing frameworks are developed based on conditions in developed countries, which reduces their applicability in contexts such as Indonesia. Díaz-Arancibia et al. [5] emphasize the need for an adaptive perspective to unify digital transformation frameworks suitable for developing countries. This highlights a critical gap and the necessity for a structured framework that addresses Indonesia’s specific challenges while leveraging local opportunities [6].

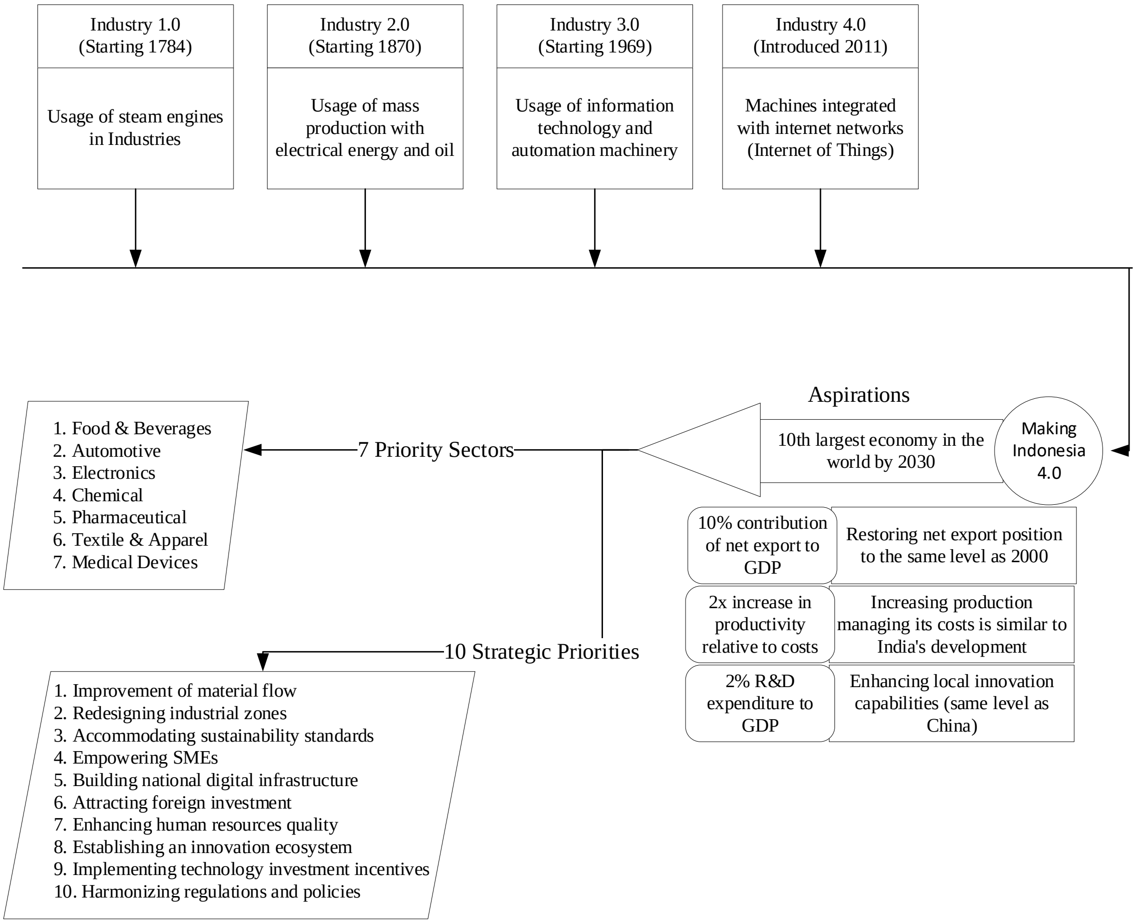


**Figure 1.** Roadmap for the Indonesian Manufacturing Industry

Notably, much of Indonesia's policy landscape on Industry 4.0 remains undocumented in academic literature, making grey literature, such as government reports, industry whitepapers, and institutional documents, an essential source for a comprehensive understanding and analysis. This reliance underscores the importance of integrating formal and informal sources to capture the complete picture of Indonesia's digital transformation efforts [7].

The framework developed in this study aims to provide a practical and contextually relevant tool to support Indonesia’s manufacturing sector in transitioning more effectively and efficiently to Industry 4.0. The development process involved a systematic approach, beginning with situational analysis through surveys, expert interviews, and discussions to identify existing barriers. This was followed by material preparation with the research team, and subsequent phases of guidance, monitoring, implementation, and evaluation within industrial settings, ensuring continuous improvement and validation of the framework [8].

The primary objective of this research is to develop a comprehensive digital transformation framework tailored to the Indonesian manufacturing sector that addresses its unique challenges while capitalizing on local strengths [9]. The novelty of this study lies in creating a framework that is not only practical for the local context but also provides insights with potential global relevance. By adhering to established principles of conceptual framework construction, this study offers a robust theoretical foundation guiding the design and implementation of Industry 4.0 systems [10]. Figure 2 illustrates this

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conceptual framework, serving as a blueprint for understanding, interpreting, and evaluating the complexities inherent in the digital transformation process.

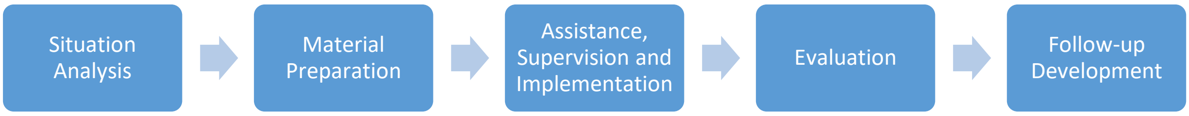


**Figure 2.** Conceptual Framework

Establishing this structured conceptual framework is vital for a successful Industry 4.0 transition, offering a solid foundation for deploying advanced technologies. This approach empowers Indonesian manufacturing industries to effectively leverage government initiatives and incentives, thereby maximizing the benefits of digital transformation under Industry 4.0.

## 2. Methods

Qualitative research focuses on gaining deep insights into a phenomenon using non-numerical data like text and images, employing an inductive approach to develop theory through case studies, observation, interviews, and narrative analysis [11]. For example, in analyzing the implementation of digital transformation in Indonesia, researchers might explore grey literature like the *Peta Jalan Indonesia Digital 2021–2024* [12] and *Indeks Daya Saing Digital Indonesia (INDI)*, which provide narrative and contextual data on policy direction, digital ecosystem readiness, and sectoral strategies. This method emphasizes credibility and transferability, making it suitable for exploring complex processes such as Industry 4.0 transformation. In this context, a qualitative approach was chosen over quantitative methods to thoroughly explore Industry 4.0's transformation in Indonesia. The research methodology involved three stages [13], beginning with case studies and observations using grey literature from previous frameworks, INDI 4.0 assessments (2021–2024), and Performance Accountability Report of Government Agencies – Ministry of Industry 2023 [14] to ensure relevance to Indonesia's manufacturing industries [15].

The second stage consists of a Focus Group Discussion (FGD), conducted by the research team in collaboration with stakeholders from the Ministry of Industry—specifically, the *Indonesia Digital Industry Center (PIDI 4.0)* program, the Standardization and Industrial Services Policy Agency (BKSJI), and industry partners affiliated with PIDI 4.0. The FGD is scheduled for June 2024 in Ciawi, Bogor, West Java. The objective is to gather insights into the challenges, opportunities, and determinants influencing the adoption of Industry 4.0 technologies in Indonesia. In addition, the FGD aims to validate the proposed framework by obtaining feedback on its comprehensiveness, relevance, clarity, and applicability within the Indonesian manufacturing context. The discussion also seeks to uncover unanticipated factors based on participants' expertise and foster consensus on key priorities, barriers, enablers, and strategies for effective digital transformation [16].

In the third stage, data from the FGD was analyzed through a three-step qualitative coding process—open, axial, and selective coding—to derive the conceptual framework. This approach identified key themes such as technology adoption challenges, workforce readiness, and infrastructure gaps, which were then grouped into broader categories like technological enablers and regulatory support. The most recurring and significant themes formed the core pillars of the framework, ensuring it was empirically grounded in stakeholder insights and aligned with the strategic and contextual realities of Industry 4.0 transformation in Indonesia's manufacturing sector [17].

To construct detailed activity table corresponding to each framework perspective, qualitative data from FGD transcripts were further analyzed using the grounded theory approach. The process began with open coding to extract recurring phrases, ideas, and actions described by participants. These were then organized using axial coding to form meaningful dimensions under broader conceptual categories (e.g., adaptation, technologies, success factors). Finally, selective coding was applied to identify and prioritize representative key activities associated with each dimension. These systematic coding stages formed the technical foundation for translating abstract themes into practical, actionable components, as presented in the resulting tables [18].

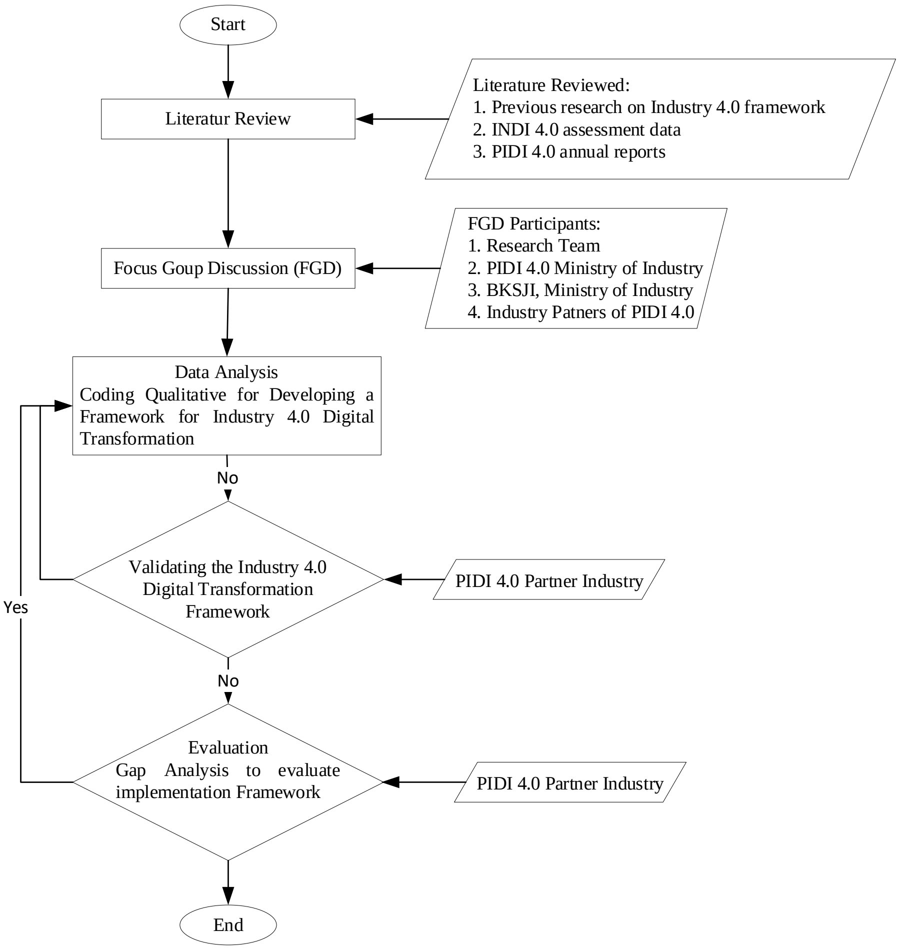


**Figure 3.** Research Methodology Flowchart

Subsequently, the framework was validated with PIDI 4.0 industry partners that had undergone Industry 4.0 transformations, ensuring its practical relevance, clarity, and applicability to the Indonesian manufacturing sector [19]. A Gap Analysis was then conducted, comparing the pre- and post-implementation performance of PIDI 4.0 partner industries. This analysis assessed the effectiveness of the framework in achieving digital transformation goals and identified areas for improvement. The results of this Gap Analysis provided insights into challenges encountered during implementation and served as a basis for refining the framework and offering strategic recommendations to enhance Industry 4.0 adoption in Indonesia [20]. Figure 3 illustrates the research process through a flowchart diagram.

## 3. Results and Discussions

In the first stage, this study collected data from various sources, including previous research, INDI 4.0 data (2021–2024), and Performance Accountability Report of Government Agencies – Ministry of Industry 2023 [14], to ensure the relevance of the Industry 4.0 framework in the context of Indonesia's manufacturing sector. Based on the literature, [21] proposed a framework with nine key blocks, such as Big Data and Cloud, emphasizing vertical system integration. Studies [22] and [23] in Europe highlighted the importance of supporting technologies, such as adaptive robotics and cybersecurity. The framework [24] assesses manufacturing readiness through four layers covering all operational aspects. In developing countries like Turkey, [25] identified limitations in technology, resources, and infrastructure as key challenges. Overall, adopting Industry 4.0 requires coordinated strategies and policies, particularly in developing countries like Indonesia, to support effective digital transformation.

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The second stage involved a Focus Group Discussion (FGD) with the Ministry of Industry, BKSJI, and PIDI 4.0 partners, which identified key challenges and opportunities in adopting Industry 4.0 in Indonesia's manufacturing sector. The FGD outlined strategic approaches, success factors, and the phases of digital transformation, emphasizing the need for technological readiness, workforce skills, and clear regulations. It also highlighted the differences between developed and developing countries, where Indonesia faces gaps in digital strategies and infrastructure [26].

To transform the insights gained from the FGD into a coherent and actionable conceptual framework, a grounded qualitative analysis approach was employed. This process consisted of three sequential coding steps. First, open coding was conducted to extract raw data elements and highlight recurring issues from the FGD transcripts, such as resistance to change, insufficient training, digital infrastructure challenges, and fragmented digital strategies [27]. Next, through axial coding, these codes were grouped into broader thematic categories, such as regulatory support, technological readiness, and organizational alignment. Finally, selective coding was used to identify the most dominant and integrative themes that frequently appeared across multiple stakeholder perspectives. This iterative and evidence-driven approach allowed the construction of a framework that accurately reflects the key drivers, enablers, and barriers of Industry 4.0 transformation in Indonesia's manufacturing sector [28].

The conceptual framework was directly derived from these coding results and consists of four overarching perspectives: (1) Adaptation — encompassing policy, infrastructure, and organizational transformation; (2) Technologies for Transformation — focused on key enabling technologies (KETs); (3) Key Success Factors (KSFs) — emphasizing strategy, governance, and change management; and (4) Implementation Steps — capturing action-oriented pathways recommended by FGD participants. Each of these perspectives maps directly to major thematic clusters that emerged from the FGD and represents collective expert insights from public and industrial stakeholders [29].

Following the framework development, validation was conducted with PIDI 4.0 industry partners that had already implemented Industry 4.0 initiatives. This involved detailed discussions and site visits. Feedback from these partners led to refinements for better clarity and applicability, resulting in a more concise and practical framework for use in the Indonesian manufacturing sector [30]. The final framework integrates critical elements of adaptation, including digital infrastructure development, technological innovation, governance regulation, stakeholder collaboration, cybersecurity, and organizational change management [31]. It emphasizes the role of Key Enabling Technologies (KETs) such as Big Data, Cloud Computing, Robotics, 3D Printing, and IoT in driving intelligent manufacturing systems [32]. The Key Success Factors (KSFs) consist of a robust digital transformation strategy, prioritization of initiatives, effective communication, and performance governance mechanisms [33]. The final dimension, Implementation Steps, identifies operational priorities including productivity tracking automation, employee upskilling, system integration (ERP), maintenance optimization, and energy efficiency. Together, these four perspectives and their dimensions form a comprehensive roadmap to guide Industry 4.0 transformation [34].

The final step involved a Gap Analysis applied to PIDI 4.0 industry partners. This analysis revealed several key discrepancies between the conceptual framework and the on-the-ground implementation. Many firms lacked integrated digital strategies, and while awareness of technologies like IoT and robotics existed, actual implementation was hindered by limited technical capacity. Additionally, change resistance and the absence of structured employee training posed significant barriers. However, tools such as automated tracking were in place, but deeper integration (e.g., ERP, customer portals) remained underdeveloped. Importantly, the framework lacked clearly defined performance indicators, limiting the ability to monitor progress. As a result, refinements are proposed to enhance the framework with more holistic strategies, technology expansion, structured change management, and built-in performance evaluation tools [35]. Figure 4 presents the proposed conceptual framework, encompassing the three perspectives discussed.

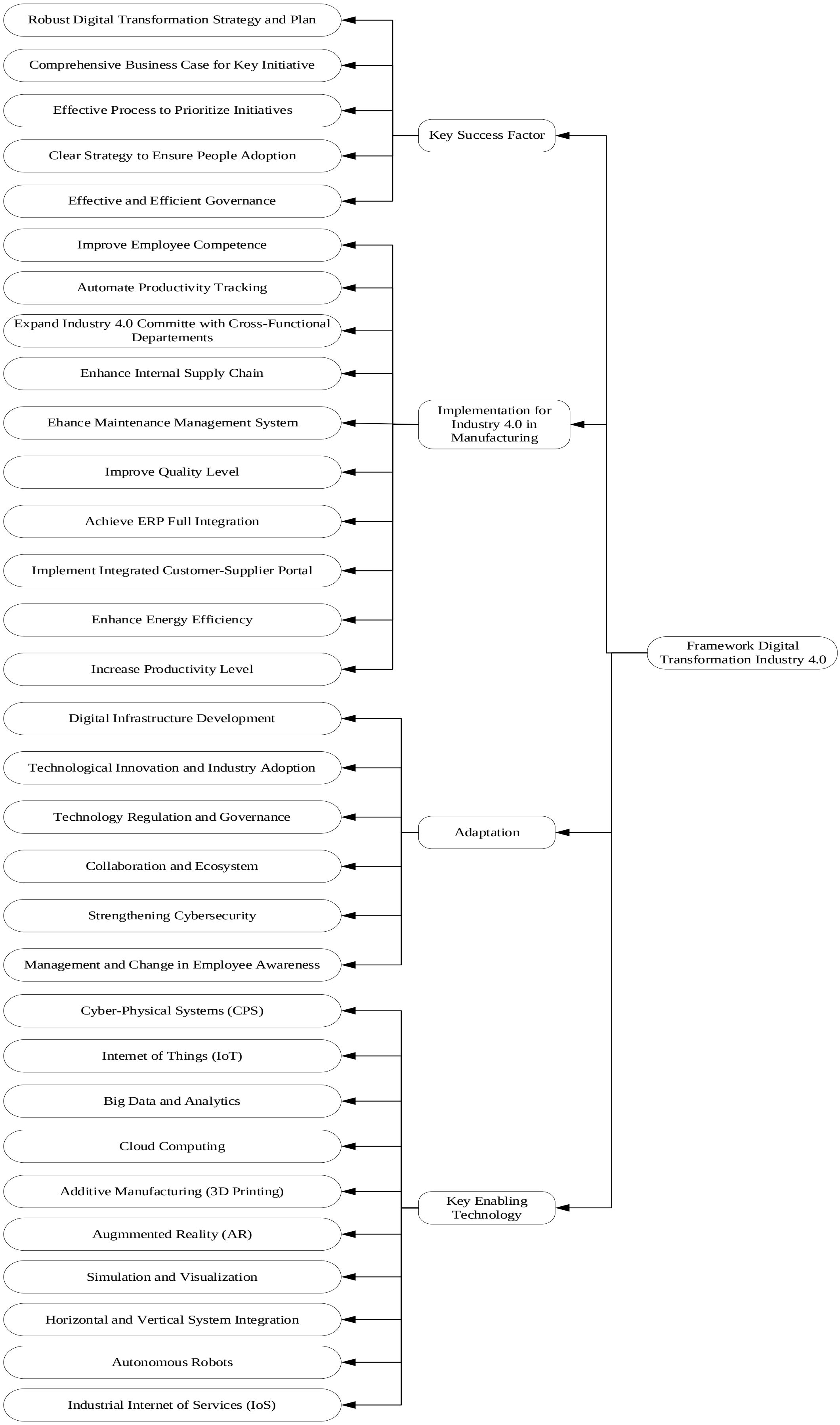


**Figure 4.** Conceptual Framework for Industry 4.0 Digital Transformation

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**Table 1.** Key Activities for the Adaptation Dimensions

| Perspective | Dimensions | Key Activities |
|---|---|---|
| Adaptation | Digital Infrastructure Development | The development of fast and affordable internet networks is a key step. The focus is on providing connectivity in remote and rural areas through the development of optical fiber infrastructure and 5G networks. |
| | | Facilitate the construction of secure local data centres and promote the adoption of cloud computing to store and process industrial data, enhancing efficiency and accessibility. |
| | Technological Innovation and Industry Adoption | Focus on the adoption of core technologies such as IoT, AI, machine learning, big data, and robotics for process automation, supply chain optimization, and efficiency improvements in the manufacturing and agriculture sectors. |
| | | Provide incentives and technological assistance to Small and Medium Enterprises (SMEs) to adopt digital solutions in their operations, such as e-commerce platforms, digital payments, and business process automation. |
| | Technology Regulation and Governance | Establish flexible regulations that still protect data security and privacy. Encourage the adoption of international standards in cybersecurity to safeguard digital infrastructure. |
| | | The government needs to accelerate the licensing process and deregulation to enable innovation and the adoption of new technologies, such as in the development of fintech, smart mobility, or renewable energy. |
| | Collaboration and Ecosystem | Strengthen collaboration between the government, private sector, and academia to share resources and create a robust innovation ecosystem. Encourage joint projects in technology research and infrastructure development. |
| | | Develop technology hubs and industrial clusters that allow local companies to access global technology and create a supportive, innovative environment. |
| | Strengthening Cybersecurity | Adopt international cybersecurity standards, and raise awareness of the importance of cybersecurity among the government, businesses, and the general public. |
| | | Strengthen law enforcement related to cybercrime and data theft by enhancing investigation capacities and providing protection for users. |
| | Management and Change in Employee Awareness | Conduct public awareness campaigns on the importance of digital transformation at all levels of society to encourage technology adoption. |
| | | Launch change management programs that support organizations and individuals in adapting to new technologies through adequate training and socialization. |

Building upon these findings, the Industry 4.0 Digital Transformation Framework was refined and finalized. It comprises four interconnected perspectives and 25 key dimensions, providing an integrated structure for managing transformation initiatives in the manufacturing sector. To enhance the operational utility of this framework, each perspective was further translated into detailed activity tables to guide execution and business process alignment in real-world settings [36].

This operationalization was achieved through a structured coding process applied to the FGD transcripts. Specifically, open coding was used to identify raw insights and frequently mentioned issues from participants. These were then grouped through axial coding into thematic dimensions reflecting strategic focus areas, such as adaptation, enabling technologies, success factors, and implementation processes. Finally, selective coding helped extract the most impactful and actionable content from each theme, formulating 25 validated dimensions associated with one or more key activities [37]. The result of this rigorous process is presented in four structured tables (Tables 1–4), each corresponding to one of the framework's main perspectives.

**Table 2.** Key activities for the KET perspective dimensions

| Perspective | Dimensions | Key Activities |
|---|---|---|
| Key Enabling Technology | Cyber-Physical Systems (CPS) | Integration of physical and computational components enables intelligent interaction and control. |
| | Internet of Things (IoT) | Networks of physical objects are connected and embedded with sensors, software, and electronic for data exchange. |
| | Big Data and Analytics | Large volumes of data are collected, analysed, and transformed into valuable insights for decision making. |
| | Cloud Computing | Data storage and processing are delivered through internet-based services, promoting scalability and flexibility. |
| | Additive Manufacturing (3D Printing) | Layer-by-layer construction enablers the creation of complex geometries, reducing costs and enhancing customization. |
| | Augmented Reality (AR) | Virtual information is superimposed onto the real world, enhancing interaction and providing real-time guidance. |
| | Simulation and Virtualization | Digital models and visual representations allow the testing optimization of processes and products. |
| | Horizontal and Vertical System Integration | Integration of system within an organization (vertical) and across organization (horizontal enhances collaboration and efficiency. |
| | Autonomous Robots | Robots that can operate and interact with their environment without direct human control, improving productivity and safety. |
| | Industrial Internet of Services (IoS) | Services are digitally integrated with industrial processes, enabling new business models and value creation. |

Ultimately, this refined framework not only captures high-level strategic directions but also provides practical guidance through concrete actions, ensuring its relevance across diverse manufacturing settings in Indonesia. The first perspective, Adaptation, is especially critical for ensuring smooth transitions during transformation and minimizing operational disruption. It includes six detailed dimensions: digital infrastructure development, technological innovation and adoption, regulation and governance, collaboration and ecosystem building, cybersecurity, and change management [38]. Each dimension is operationalized through specific key activities, as outlined in Table 1.

The digital transformation framework focuses on six critical areas for adaptation. First, Digital Infrastructure Development prioritizes affordable, high-speed internet and extends connectivity to remote areas through fiber optic and 5G infrastructure, supported by secure local data centers and cloud computing. Second, Technological Innovation and Industry Adoption integrates key technologies like

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IoT, AI, and robotics, supporting SMEs to adopt digital solutions. Third, Technology Regulation and Governance promotes flexible regulations and streamlined licensing to foster innovation in fintech and renewable energy. Fourth, Collaboration and Ecosystems encourages partnerships among government, industry, and academia to create innovation hubs. Fifth, Strengthening Cybersecurity focuses on adopting international standards and improving legal enforcement against cybercrime. Lastly, Management and Change in Employee Awareness emphasizes public awareness campaigns and change management programs to facilitate adaptation to new technologies [39]. This framework aligns with established practices and highlights Key Enabling Technologies (KETs) such as Big Data, Cloud Computing, IoT, Robotics, and others as vital for modernizing manufacturing, with specific activities outlined to enhance their adoption in Indonesian industries. Table 2 provides a comprehensive overview of these activities.

The adoption of Key Enabling Technologies (KETs) is essential for Industry 4.0 transformation, enabling smart manufacturing environments where machines, production modules, and products can autonomously exchange information and control processes. This fosters an intelligent ecosystem that enhances productivity and efficiency while providing economic and social opportunities for companies [40]. Effective implementation requires a tailored approach, avoiding unnecessary technology adoption, and ensuring alignment with the company's vision and mission to support growth [41]. The Key Success Factors (KSF) perspective includes five dimensions: a robust digital transformation strategy, comprehensive business cases for key initiatives, effective prioritization processes, a clear strategy for people adoption, and efficient governance. Each dimension involves specific key activities, detailed in Table 3, that guide successful digital transformation.

**Table 3.** Key activities for the KSF perspective dimensions

| Perspective | Dimensions | Key Activities |
|---|---|---|
| Key Success Factors | Robust Digital Transformation Strategy and Plan | Define digital transformation strategic objectives<br>Identify initiatives to reach the objectives<br>Allocate necessary human and financial resources |
| | Comprehensive Business Case for Key Initiatives | Clearly define the initiative's objectives, scope, and approach<br>Outline expected deliverables and business outcomes<br>Provide cost-benefit analysis and net present value |
| | Effective Process to Prioritize Initiatives | Assess the impact (e.g., cost savings, revenue) and effort (e.g., time, resources) of each initiative<br>Position initiatives on a 2x2 matrix and focus on high-impact, low-effort project |
| | Clear Strategy to Ensure People Adoption | Conduct an impact assessment<br>Develop a comprehensive change management plan, including communication, training, and resistance management |
| | Effective and Efficient Governance | Assign accountability for the success of each initiative<br>Establish weekly meetings and user-friendly dashboards at the program and initiative levels<br>Visually display dashboards on a wall for easy tracking and management |

Each Key Success Factor (KSF) dimension includes essential activities for ensuring successful digital transformation, such as setting strategic goals, allocating resources, conducting cost-benefit analyses, prioritizing high-impact projects, developing change management plans, and establishing accountability. Javaid Butt [42], emphasize that a robust digital transformation strategy requires a deep understanding of how technology can create value for the business and its customers. Success depends not only on technology but also on the organization's ability to manage change and integrate new technologies effectively. McKie et al [43] add that organizations with higher technology adoption levels are more adaptable and responsive to market changes, thereby gaining a competitive edge. Consequently, implementing KSFs is critical for Industry 4.0 transformation. The final perspective, Implementation for Industry 4.0 in Manufacturing, outlines ten dimensions detailing the necessary steps for digital transformation within the Indonesian manufacturing sector, with the key activities listed in Table 4.

**Table 4.** Key activities for the implementation for industry 4.0 in manufacturing perspective dimensions

| Perspective | Dimensions | Key Activities |
|---|---|---|
| Implementation for Industry 4.0 in Manufacturing | Improve Employee Competence | Implement AR/VR and learning management system for training |
| | | Encourage self-training and development of industry 4.0 mindset |
| | Automate Productivity Tracking | Utilize PLC, HMI and IoT technology |
| | | Train employees on PLC, IoT and Industry 4.0 mindset |
| | Expand Industri 4.0 Committee with Cross-Functional Departments | Train employees on industry 4.0 mindset and basic data analytics |
| | | Collaborate with the Industry 4.0 ecosystem |
| | Enhance Internal Supply Chain | Implement QR, RFID and Warehouse Management System technology |
| | | Train employee on RFID/IoT and Warehouse Management |
| | Enhance Maintenance Management System | Implement Computerized Maintenance Management System (CMMS) and Condition-Based Maintenance |
| | | Train employee on CMMS, Total Productive Maintenance (TPM), and data analytics |
| | Improve Quality Level | Implement Camera Inspection and Quality Management System technologies |
| | | Train employees on camera inspection and data analytics |
| | Achieve ERP Full Integration | Integrate MES and ERP system |
| | | Train employees on ERP and MES software |
| | Implement Integrated Customer-Supplier Portal | Develop Supplier Integration System and Digital Customer Order System |
| | | Train employees on web-based system integration and data analytics |
| | Enhance Energy Efficiency | Implement Energy Monitor and Control technologies |
| | | Train employees on IoT, energy management and data analytics |
| | Increase Productive Level | Implement Digital Work Instruction and Manufacturing Execution System |
| | | Train employee on digital standard operating procedures and MES software |

Each dimension within the Implementation for Industry 4.0 in the Manufacturing perspective aims to enhance efficiency, productivity, and human resource competency. Implementation steps should be tailored to the specific needs and vision of each company. Prioritization of implementation efforts is recommended. This implementation approach aligns with previous literature, including McKie et al [43] on competency enhancement, Serrano-Ruiz [44] on productivity tracking automation, Barata et al [45] on supply chain improvement, Ghobakhloo et al [46] on energy conservation, and Jaskó Szilárd [47] on

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the integration of ERP and Manufacturing Execution Systems (MES). All these studies connect to the broader theme of Industry 4.0 transformation.

A Gap Analysis conducted with PIDI 4.0 partner companies revealed critical discrepancies between the conceptual framework and its field-level implementation. First, the absence of integrated digital strategies across departments led to fragmented technology adoption, highlighting the need for cross-functional coordination and enterprise-wide planning. Second, although awareness of enabling technologies such as IoT, robotics, and big data is relatively high, adoption remains limited due to insufficient technical skills and organizational understanding—suggesting a strong need for workforce reskilling and technical support. Third, resistance to change remains a significant barrier, underlining the role of structured change management programs in digital transformation strategies. Fourth, system integration (e.g., ERP, customer-supplier portals) is at a nascent stage, requiring further investment and interoperability standards. Lastly, the lack of performance evaluation mechanisms inhibits effective monitoring of progress, making it difficult for companies to adapt their strategies dynamically. These findings reinforce the need for a refined framework with a holistic approach, inclusive of broader technology applications, structured training, integrated systems, and embedded KPIs for continuous performance measurement [48].

In reviewing implementation across partner industries, the findings align not only with academic studies but also with grey literature, including agency reports, government frameworks (e.g., PIDI 4.0, INDI) [12], and institutional documents [14]. This convergence underscores the importance of integrating structured grey literature review methodology into future work. Although this study applied selective literature review strategies to incorporate relevant policy and institutional references, further research should apply a formalized search strategy—including predefined inclusion criteria, source databases, and quality assessments—if the article is to be reframed as a grey literature review.

Moreover, the developed Industry 4.0 Digital Transformation Framework shows adaptability for other developing economies, provided that contextual challenges are addressed. Similar issues—such as fragmented adoption, limited infrastructure, and resistance to change—have been observed in Turkey [25]. Studies in Europe, Canas et al. [22] and by Sun et al. [23] emphasized the importance of enabling technologies (e.g., AI, IoT, big data) and government-backed innovation ecosystems. These findings are consistent with the Indonesian context, where institutional capacity, infrastructure gaps, and limited performance monitoring hinder widespread adoption.

In summary, while the PIDI 4.0 framework offers a solid foundation tailored for Indonesia's manufacturing sector, its scalability depends on strategic government intervention, capacity-building programs, and localized implementation strategies. For broader applicability, the framework must be continuously adapted using evidence from both empirical implementation and policy-oriented grey literature, underpinned by a systematic methodology for evidence integration [49].

## 4. Conclusion

This study developed a comprehensive and contextually grounded framework for Industry 4.0 digital transformation, specifically tailored to the Indonesian manufacturing sector. By employing a qualitative methodology supported by grounded theory and grey literature analysis—including national roadmaps, readiness indices (INDI), and government reports (LAKIP)—the research identified four core perspectives: Adaptation, Technologies for Transformation, Key Success Factors, and Implementation Steps. These were further operationalized into 25 dimensions and structured into four actionable tables to support real-world execution.

Validation through Focus Group Discussions and gap analysis with PIDI 4.0 industry partners revealed both strengths and critical implementation barriers, such as fragmented digital strategies, limited technical capacity, and inadequate performance evaluation. As a response, the framework was refined to integrate holistic strategies, structured training, system integration, and measurable KPIs.

The resulting framework not only enhances the practical readiness of Indonesian industries to adopt Industry 4.0 but also serves as a replicable model for other developing countries facing similar challenges. Future research is encouraged to expand the model through cross-sector validation and to embed systematic review methods for grey literature to strengthen its academic and policy impact.

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**References**

[1] I. Mahriv, N. Alifatuzzahra, and N. Nurbaiti, "Kesiapan perusahaan di indonesia dalam menghadapi revolusi industri 4.0," *MENAWAN: Jurnal Riset Dan Publikasi Ilmu Ekonomi*, vol. 2, no. 1, pp. 287–294, 2024.

[2] R. D. Cahya and M. Yasin, "Strategi Industri Manufaktur Dalam Meningkatkan Percepatan Pertumbuhan Ekonomi di Indonesia," *Jurnal Ekonomi Bisnis dan Kewirausahaan*, vol. 1, no. 4, pp. 19–22, 2024.

[3] O. Ali, A. Shrestha, V. Osmanaj, and S. Muhammed, "Cloud computing technology adoption: an evaluation of key factors in local governments," *Information Technology & People*, vol. 34, no. 2, pp. 666–703, Apr. 2020, doi: 10.1108/ITP-03-2019-0119.

[4] T. Haryanti, N. A. Rakhmawati, and A. P. Subriadi, "A comparative analysis review of digital transformation stage in developing countries," *Journal of Industrial Engineering and Management*, vol. 16, no. 1, p. 150, Mar. 2023, doi: 10.3926/jiem.4576.

[5] J. Díaz-Arancibia, J. Hochstetter-Diez, A. Bustamante-Mora, S. Sepúlveda-Cuevas, I. Albayay, and J. Arango-López, "Navigating Digital Transformation and Technology Adoption: A Literature Review from Small and Medium-Sized Enterprises in Developing Countries," *Sustainability*, vol. 16, no. 14, p. 5946, Jul. 2024, doi: 10.3390/su16145946.

[6] E. N. Yunus, "The mark of industry 4.0: how managers respond to key revolutionary changes," *International Journal of Productivity and Performance Management*, vol. 70, no. 5, pp. 1213–1231, Jun. 2021, doi: 10.1108/IJPPM-12-2019-0590.

[7] J. Schöpfel and H. Prost, "How scientific papers mention grey literature: a scientometric study based on Scopus data," *Collection and Curation*, vol. 40, no. 3, pp. 77–82, Jul. 2021, doi: 10.1108/CC-12-2019-0044.

[8] K.-C. Chen and Z.-J. Gao, "Integrated Group-based Valuable Sensor Selection Approach for Remaining Machinery Life Estimation in the Future Industry 4.0 Era," in *2020 International Symposium on VLSI Design, Automation and Test (VLSI-DAT)*, IEEE, Aug. 2020, pp. 1–4. doi: 10.1109/VLSI-DAT49148.2020.9196260.

[9] S. Bag and J. H. C. Pretorius, "Relationships between industry 4.0, sustainable manufacturing and circular economy: proposal of a research framework," *International Journal of Organizational Analysis*, vol. 30, no. 4, pp. 864–898, Jun. 2022, doi: 10.1108/IJOA-04-2020-2120.

[10] N. Dragicevic, A. Ullrich, E. Tsui, and N. Gronau, "A conceptual model of knowledge dynamics in the industry 4.0 smart grid scenario," *Knowledge Management Research & Practice*, vol. 18, no. 2, pp. 199–213, Apr. 2020, doi: 10.1080/14778238.2019.1633893.

[11] H. Cinelli, "Mener un terrain de recherche qualitatif, apports des méthodes ethnographiques," *Sages-Femmes*, vol. 19, no. 6, pp. 52–55, 2020.

[12] BPSDMI Kemenperin, "Strategi dan Kebijakan Unit Pendidikan BPSDMI Dalam Mendukung Transformasi Industri 4.0," Jakarta, May 2024.

[13] I. Janis, M. Alias, M. Zulkipli, and F. Muhammad-Sukki, “Using Illustrations to Make Decisions on the Most Appropriate Qualitative Research Methodology: The Industry 4.0 Scenario,” *Int J Qual Methods*, vol. 19, p. 160940692090724, Jan. 2020, doi: 10.1177/1609406920907247.

[14] M Rum, “Laporan Akuntabilitas Kinerja Instansi Pemerintahan Kementerian Perindustrian Tahun 2023,” Jakarta, Feb. 2023.

[15] N. Saputra, R. E. Putera, A. Zetra, Azwar, T. R. Valentina, and R. A. Mulia, “Capacity building for organizational performance: a systematic review, conceptual framework, and future research directions,” *Cogent Business & Management*, vol. 11, no. 1, Dec. 2024, doi: 10.1080/23311975.2024.2434966.

[16] F. Gillani, K. A. Chatha, S. S. Jajja, D. Cao, and X. Ma, “Unpacking Digital Transformation: Identifying key enablers, transition stages and digital archetypes,” *Technol Forecast Soc Change*, vol. 203, p. 123335, Jun. 2024, doi: 10.1016/j.techfore.2024.123335.

[17] S. Tumen Akyildiz and K. H. Ahmed, “An Overview of Qualitative Research and Focus Group Discussion,” *International Journal of Academic Research in Education*, vol. 7, no. 1, pp. 1–15, Dec. 2021, doi: 10.17985/ijare.866762.

[18] P. Candra Susanto, L. Yuntina, E. Saribanon, J. Panatap Soehaditama, and E. Liana, “Qualitative Method Concepts: Literature Review, Focus Group Discussion, Ethnography and Grounded Theory,” *Siber Journal of Advanced Multidisciplinary*, vol. 2, no. 2, pp. 262–275, Sep. 2024, doi: 10.38035/sjam.v2i2.207.

[19] K. Semenkov, V. Promyslov, A. Poletykin, and N. Mengazetdinov, “Validation of Complex Control Systems with Heterogeneous Digital Models in Industry 4.0 Framework,” *Machines*, vol. 9, no. 3, p. 62, Mar. 2021, doi: 10.3390/machines9030062.

[20] H. Shafei, A. R. Radzi, M. Algahtany, and R. A. Rahman, “Construction 4.0 Technologies and Decision-Making: A Systematic Review and Gap Analysis,” *Buildings*, vol. 12, no. 12, p. 2206, Dec. 2022, doi: 10.3390/buildings12122206.

[21] C. Yang, S. Lan, L. Wang, W. Shen, and G. G. Q. Huang, “Big Data Driven Edge-Cloud Collaboration Architecture for Cloud Manufacturing: A Software Defined Perspective,” *IEEE Access*, vol. 8, pp. 45938–45950, 2020, doi: 10.1109/ACCESS.2020.2977846.

[22] H. Cañas, J. Mula, F. Campuzano-Bolarín, and R. Poler, “A conceptual framework for smart production planning and control in Industry 4.0,” *Comput Ind Eng*, vol. 173, p. 108659, Nov. 2022, doi: 10.1016/j.cie.2022.108659.

[23] X. Sun, H. Yu, W. D. Solvang, Y. Wang, and K. Wang, “The application of Industry 4.0 technologies in sustainable logistics: a systematic literature review (2012–2020) to explore future research opportunities,” *Environmental Science and Pollution Research*, vol. 29, no. 7, pp. 9560–9591, Feb. 2022, doi: 10.1007/s11356-021-17693-y.

[24] Z. M. Çınar, Q. Zeeshan, and O. Korhan, “A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises: A Case Study,” *Sustainability*, vol. 13, no. 12, p. 6659, Jun. 2021, doi: 10.3390/su13126659.

[25] H. Yüksel, “An empirical evaluation of industry 4.0 applications of companies in Turkey: The case of a developing country,” *Technol Soc*, vol. 63, p. 101364, Nov. 2020, doi: 10.1016/j.techsoc.2020.101364.

[26] K. Govindan and G. Arampatzis, “A framework to measure readiness and barriers for the implementation of Industry 4.0: A case approach,” *Electron Commer Res Appl*, vol. 59, p. 101249, May 2023, doi: 10.1016/j.elerap.2023.101249.

[27] J. M. Stratil *et al.*, "Advancing the WHO-INTEGRATE Framework as a Tool for Evidence-Informed, Deliberative Decision-Making Processes: Exploring the Views of Developers and Users of WHO Guidelines," *Int J Health Policy Manag*, Oct. 2020, doi: 10.34172/ijhpm.2020.193.

[28] O. A. Shonubi, "Advancing organisational technology readiness and convergence of emerging digital technologies (AI, IoT, I4.0) for innovation adoption," *International Journal of Technology and Globalisation*, vol. 9, no. 1, pp. 50–91, 2024, doi: 10.1504/IJTG.2024.142621.

[29] V. Reyes, E. Bogumil, and L. E. Welch, "The Living Codebook: Documenting the Process of Qualitative Data Analysis," *Sociol Methods Res*, vol. 53, no. 1, pp. 89–120, Feb. 2024, doi: 10.1177/0049124120986185.

[30] D. S. Yim, W. Kim, S. Kang, and E. J. Kim, "The Development Strategy for Indonesia Digital Center PIDI 4.0 toward Digital Transformation," in *2023 Portland International Conference on Management of Engineering and Technology (PICMET)*, IEEE, Jul. 2023, pp. 1–7. doi: 10.23919/PICMET59654.2023.10216890.

[31] U. S. Rangaswamy, "Industry 4.0 disruption: assessing the need for adaptive capability," *Development and Learning in Organizations: An International Journal*, vol. 35, no. 6, pp. 7–10, Oct. 2021, doi: 10.1108/DLO-01-2021-0003.

[32] A. Sigov, L. Ratkin, L. A. Ivanov, and L. Da Xu, "Emerging Enabling Technologies for Industry 4.0 and Beyond," *Information Systems Frontiers*, Jan. 2022, doi: 10.1007/s10796-021-10213-w.

[33] R. Pozzi, T. Rossi, and R. Secchi, "Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies," *Production Planning & Control*, vol. 34, no. 2, pp. 139–158, Jan. 2023, doi: 10.1080/09537287.2021.1891481.

[34] F. Dillinger, B. Tropschuh, M. Y. Dervis, and G. Reinhart, "A Systematic Approach to Identify the Interdependencies of Lean Production and Industry 4.0 Elements," *Procedia CIRP*, vol. 112, pp. 85–90, 2022, doi: 10.1016/j.procir.2022.09.041.

[35] D. R. Adhikari and P. Shrestha, "Knowledge management initiatives for achieving sustainable development goal 4.7: higher education institutions' stakeholder perspectives," *Journal of Knowledge Management*, vol. 27, no. 4, pp. 1109–1139, Mar. 2023, doi: 10.1108/JKM-03-2022-0172.

[36] M. Ghobakhloo and M. Iranmanesh, "Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs," *Journal of Manufacturing Technology Management*, vol. 32, no. 8, pp. 1533–1556, Oct. 2021, doi: 10.1108/JMTM-11-2020-0455.

[37] P. F. D. Scheelbeek, Y. A. Hamza, J. Schellenberg, and Z. Hill, "Improving the use of focus group discussions in low income settings," *BMC Med Res Methodol*, vol. 20, no. 1, p. 287, Dec. 2020, doi: 10.1186/s12874-020-01168-8.

[38] A. Abdurrahman, A. Gustomo, E. A. Prasetio, and S. Rustiadi, "Designing an Open Innovation Framework for Digital Transformation Based on Systematic Literature Review," *Journal of Information Systems Engineering and Business Intelligence*, vol. 8, no. 2, pp. 100–108, Oct. 2022, doi: 10.20473/jisebi.8.2.100-108.

[39] M. Fakhar Manesh, M. M. Pellegrini, G. Marzi, and M. Dabic, "Knowledge Management in the Fourth Industrial Revolution: Mapping the Literature and Scoping Future Avenues," *IEEE Trans Eng Manag*, vol. 68, no. 1, pp. 289–300, Feb. 2021, doi: 10.1109/TEM.2019.2963489.

[40] M. Javaid, A. Haleem, R. P. Singh, and R. Suman, "Enabling flexible manufacturing system (FMS) through the applications of industry 4.0 technologies," *Internet of Things and Cyber-Physical Systems*, vol. 2, pp. 49–62, 2022, doi: 10.1016/j.iotcps.2022.05.005.

[41] A. Shaikh, S. Shinde, M. Rondhe, and S. Chinchanikar, "Machine Learning Techniques for Smart Manufacturing: A Comprehensive Review," 2023, pp. 127–137. doi: 10.1007/978-981-19-0561-2_12.

[42] J. Butt, "A Conceptual Framework to Support Digital Transformation in Manufacturing Using an Integrated Business Process Management Approach," *Designs (Basel)*, vol. 4, no. 3, p. 17, Jun. 2020, doi: 10.3390/designs4030017.

[43] M. G. McKie, R. Jones, J. Miles, and I. R. Jones, "Improving Lean Manufacturing Systems and Tools Engagement Through the Utilisation of Industry 4.0, Improved Communication and a People Recognition Methodology in a UK Engine Manufacturing Centre," *Procedia Manuf*, vol. 55, pp. 371–382, 2021, doi: 10.1016/j.promfg.2021.10.052.

[44] J. C. Serrano-Ruiz, J. Mula, and R. Poler, "Development of a multidimensional conceptual model for job shop smart manufacturing scheduling from the Industry 4.0 perspective," *J Manuf Syst*, vol. 63, pp. 185–202, Apr. 2022, doi: 10.1016/j.jmsy.2022.03.011.

[45] J. Barata, J. C. S. Cardoso, and P. R. Cunha, "Mass customization and mass personalization meet at the crossroads of Industry 4.0: A case of augmented digital engineering," *Systems Engineering*, vol. 26, no. 6, pp. 715–727, Nov. 2023, doi: 10.1002/sys.21682.

[46] M. Ghobakhloo and M. Fathi, "Industry 4.0 and opportunities for energy sustainability," *J Clean Prod*, vol. 295, p. 126427, May 2021, doi: 10.1016/j.jclepro.2021.126427.

[47] S. Jaskó, A. Skrop, T. Holczinger, T. Chován, and J. Abonyi, "Development of manufacturing execution systems in accordance with Industry 4.0 requirements: A review of standard- and ontology-based methodologies and tools," *Comput Ind*, vol. 123, p. 103300, Dec. 2020, doi: 10.1016/j.compind.2020.103300.

[48] V. Kumar, R. Shankar, and P. Vrat, "An analysis of Industry 4.0 implementation-variables by using SAP-LAP and e-IRP approach," *Benchmarking: An International Journal*, vol. 29, no. 5, pp. 1606–1639, Apr. 2022, doi: 10.1108/BIJ-03-2021-0153.

[49] H. Cañas, J. Mula, M. Díaz-Madroñero, and F. Campuzano-Bolarín, "Implementing Industry 4.0 principles," *Comput Ind Eng*, vol. 158, p. 107379, Aug. 2021, doi: 10.1016/j.cie.2021.107379.

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