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Digital Readiness Assessment of PT. Kencana Tiara Gemilang Using the INDI 4.0 Framework: Strategies for Advancing Geosynthetic Manufacturing Toward Industry 4.0

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Abstract
This study evaluates the readiness of PT. Kencana Tiara Gemilang (PT. KTG) in adopting Industry 4.0 using the INDI 4.0 framework, with a result of Level 2 – Currently Adopting (score 1.848). The main strengths lie in the integration of basic technologies in geosynthetic production, including IoT, automation, and ERP, while significant weaknesses are found in the Management & Organization and People & Culture pillars. A readiness perception gap was identified between executives (score 2.14) and employees (score 1.85). Improvement strategies include strengthening a collaborative culture, establishing a digital transformation team, and gradually investing in technology infrastructure. The study emphasizes that the success of the Industry 4.0 transition requires synchronization of technology, management, and human resources. The results provide a relevant digital adoption stage model for polymer manufacturing, serve as a policy reference for medium-sized industry development, and fill a literature gap in the geosynthetic sector. Recommendations for future research include developing AI-based predictive maintenance, analyzing the ROI of IoT and ERP implementation, conducting global comparative studies, and carrying out qualitative studies on employee resistance to digitalization.

1. Introduction

Geosynthetics increase aggregate stiffness by 30% and reduce deformation by 40%, supporting the digitalization of soil structure monitoring in line with Industry 4.0 principles.(Tutumluer et al., 2025). With high-resolution optical sensors, geosynthetics can reduce seismic risks by up to 45% and CO emissions$_2$38% construction, supporting sustainable infrastructure management(Miyata, 2024). Furthermore, with precision industrial supply and processes, Industry 4.0 technologies such as IoT, AI, and CPS have been shown to improve operational efficiency and personalize production. However, this adoption also increases technical, organizational, and human resource complexity. Of 61,360 publications, 27 key studies indicate the absence of standard metrics to effectively manage this complexity. Furthermore, the integration of Industry 5.0 principles, which emphasize human-technology collaboration, remains weak.(Herrera-Vidal et al., 2025). Therefore, the development of an adaptive framework that is human-centered and supports the sustainability of the industry in the future.

The geosynthetics industry plays a strategic role in infrastructure, such as soil stabilization, slope reinforcement, and road construction. In the Singosari area of Malang Regency, which is developing as a new industrial area, the use of geosynthetic products such as geotextiles and geogrids is crucial to support the acceleration of infrastructure projects and construction efficiency.(Huang et al., 2025; Liu et al., 2025; Meitz et al., 2025; Tutumluer et al., 2025)However, the main challenge lies not only in the application of the material, but also in the readiness of the production system.(Mohd Fazi et al., 2019; Placci, 2019; Schwerha et al., 2020). Performance measurement and digital readiness are becoming essential to ensure that geosynthetic manufacturers and users are able to compete in an increasingly complex market.(Huh, 2023; Loizia et al., 2021; Psarommatis et al., 2023; Sekadakis et al., 2023)This is where INDI 4.0 comes into play: as a measuring tool for the readiness of the national industry for digital transformation, including the Plant Operations and Technology pillars, which are highly relevant in the geosynthetic production line.(Meitz et al., 2025; Muzamil et al., 2025)Through this approach, companies can accurately assess their level of digitalization, production efficiency, data integration, and automation potential.

The need for a geosynthetic company in Singosari to be prepared to face the challenges of Industry 4.0, and to what extent INDI 4.0 can be a guideline for accelerating the growth of high-tech-based industries in the region.(Piccialli et al., 2025). Study(Puppala et al., 2025),utilizing ASTM/AASHTO standardized testing with the potential for sensor integration and digital data logging for real-time monitoring of soil quality.(X. Li et al., 2025), relying on elastoplastic numerical simulations that can be optimized with cloud computing and artificial intelligence for long-term performance prediction. The study(Kolli & Prashant, 2025), introducing an innovative GRS joint design that can be precisely manufactured with additive manufacturing and tested through an IoT-based monitoring system.(L. Li et al., 2025),(Huang et al., 2025), And(Liu et al., 2025),Aligned with the Industry 4.0 paradigm through the application of data-driven design, sensor-integrated testing, and advanced material optimization. Geosynthetic design parameters can be modeled and optimized using a digital twin to precisely predict deformation and bearing capacity. A 12-month monitoring system based on pressure, temperature, and humidity sensors, a core IoT practice, for evaluating geosynthetic performance in extreme climates, allowing real-time data to inform predictive maintenance.(Errezgouny et al., 2025; Meitz et al., 2025; Zhang et al., 2022). The effectiveness of wicking-geogrid composites that can be developed through automated precision manufacturing and analyzed using big data for design-performance correlation. The role of digitalization, automation, and sensor integration in geosynthetic testing and design is a strategic foundation towards smart construction in the Industry 4.0 era. PT KTG, a local geomembrane manufacturer in Singosari, Malang, with a TKDN of >40%, has strategic potential in the national geosynthetic industry. However, readiness for Industry 4.0 is not yet fully optimal. Based on INDI 4.0, many manufacturing companies are still at levels 1–2. Without a comprehensive digital transformation, the opportunity to increase production efficiency by up to 30% and expand the global market could be hampered.

This study offers a precise strategy for digital readiness among PT. KTG's leaders and employees in facing Industry 4.0, with INDI 4.0 scores of 2.14 and 1.85, respectively. This difference demonstrates the challenge in aligning perceptions towards digital transformation, especially in the geosynthetic operational line. By integrating IoT, AI, and AgentAI technologies, the geosynthetic production process becomes more precise, adaptive, and efficient, from raw material planning, maintenance prediction, to automated quality control. The contribution of this research lies in the development of an operational transition model based on intelligent technology that can be replicated by other national construction industries.

This study aims to answer the key question of how to prepare geosynthetic manufacturing companies, particularly in the operational and supply chain lines, to transition from conventional systems to Industry 4.0-based digitalization. The main focus is directed at supply chain transformation in the geosynthetics sector through raw material requirements planning systems, production management, safety stock management, and the formation of SOPs and data flows based on digital technology. It is hoped that the results of this study will be able to formulate applicable strategic and technical steps to encourage efficiency, supply chain resilience, and the competitiveness of local geosynthetic products in the global market. Practically, this study contributes in the form of an implementable framework for the geosynthetics industry that wants to optimize the operational digitalization process, and theoretically enriches the literature on readiness and transition strategies towards Industry 4.0 in the material-based manufacturing sector.

2. Research methodology

2.1. Design

The descriptive quantitative research design used to measure the readiness of PT. KTG, a geosynthetic factory in Singosari District, Malang Regency, in facing the Industrial Revolution 4.0 uses the INDI 4.0 tools issued by the Ministry of Industry, so that all analysis and discussion refer to official government standards.(Flick, 2020)The research was conducted in two main stages: completing an online questionnaire to obtain initial quantitative data, and direct on-site observation to supplement the data with field verification.

2.2. Population and Sample

In this study, the population is defined as all 74 employees of PT. Kencana Tiara Gemilang (PT. KTG), covering all divisions and job levels from managers, supervisors, staff, to operators, thus representing the entire work ecosystem in the geosynthetics and agriculture industry run by the company. This population selection is relevant because PT. KTG is the first local geosynthetics producer in Indonesia with a strategic role in reducing import dependence and increasing national competitiveness.(Pandey & Pandey, 2015)The sampling technique used was purposive sampling, which selects a portion of respondents who are considered capable of providing the most relevant data to measure readiness to face the Industrial Revolution 4.0, taking into account the proportion of positions and direct involvement in the production and management processes. This approach ensures that the research results not only reflect the general condition of the company, but also describe specific readiness in strategic and operational aspects in the geosynthetics sector.

2.3. Operational Definition of Variables

The variables used in this research are as follows.

Table1. Operational Variables

Variables	Conceptual Definition	Operational Definition	Indicator	Measurement Scale
Industry 4.0 Readiness	The level of company capability in adopting technology, systems, and work culture based on Industry 4.0 principles according to the standards of the Ministry of Industry	The level of readiness of PT. KTG was measured through a questionnaire based on the five pillars and 17 fields of INDI 4.0, with weighted scoring results according to the Ministry of Industry guidelines.	INDI 4.0 total score, score per pillar, strongest pillar, weakest pillar	Interval
Geosynthetic Production Process	Technical stages of production of polymer-based geosynthetic materials for infrastructure and environmental applications	The number of stages in the production process starting from raw material formulation, extrusion, cooling, surface treatment, quality control, to packaging and storage	Number of stages, level of automation, QC parameters	Ratio
Geosynthetic Product Range	Types of geosynthetic products produced and their applications in the field	The variety of products produced by PT. KTG includes Geomembrane, Woven Geotextile, Geocell, and their technical applications.	Number of product types, number of applications	Ratio

Source: Processed Primary Data, 2022

2.4. Observations and Interviews

PT. KTG has 74 employees with a staff to operator ratio of 1:3, of which 25% were selected as questionnaire respondents, including managers, supervisors, staff, and operators from all departments. After coordinating with the company, HR distributed questionnaires via Google Forms equipped with PPTs regarding the Industrial Revolution 4.0 and INDI 4.0, with a filling time of 1–2 weeks. The first two weeks collected 10 respondents, then the time was extended by one week and expanded to operators and production departments until 14 respondents were collected. The incoming data was summarized, calculated, and analyzed temporarily in preparation for the factory visit which included observation of the geosynthetic production process, work area, data verification, and respondent interviews.

2.5. Research Tools

This process is quite challenging, as it requires creating a list of questionnaire questions. The questions must be consistent with the INDI 4.0 tool's requirements. What makes it easier is that INDI 4.0 has already created a guide for the list of questions. From this guide, minor changes and modifications are made to adapt to the target industry.

2.6. Research Procedure

This study focuses on the implementation of INDI 4.0 at PT. KTG, a geosynthetic manufacturer in Singosari District, Malang Regency, to measure the company's digital readiness in facing the Industrial Revolution 4.0. The stages began with a preliminary study through literature, news, and official INDI 4.0 guidelines, followed by the development of a questionnaire tailored to the characteristics of the geosynthetic industry. Data collection from various levels, complemented by field observations to understand the production process, from polymer processing to the formation of geosynthetic structures.(Bi et al., 2021; Kotler et al., 2017)The data processing results in a readiness index that is analyzed per pillar, guiding improvement plans such as the integration of IoT, AI, and automation to improve efficiency, raw material security, and quality control accuracy. The implementation strategy involves adjusting SOPs, updating production data streams, and synchronizing work equipment, ensuring PT. KTG can adapt quickly to the challenges of the smart technology-based global market.

2.7. Framework of thinking

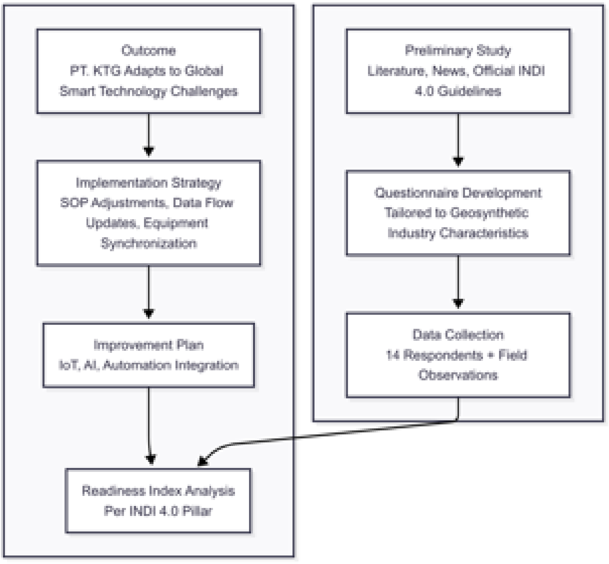

Figure 3.1. Research Flowchart

3. Results and Discussion

3.1. Result

3.1.1. Research Object Profile

PT. Kencana Tiara Gemilang (PT. KTG) is a national manufacturing company focused on the geosynthetic industry, a field that is increasingly crucial in sustainable infrastructure development. Established in 2014 and located in Malang, East Java, PT. KTG produces various polymer-based engineering materials such as Geomembrane, Woven Geotextile, and Geocell. These products play a vital role in water management, environmental protection, and soil reinforcement in various construction projects, from ponds to roads to slope conservation. With the implementation of the ISO 9001:2015 quality management system and a portfolio of projects in various regions of Indonesia, PT. KTG strengthens its position as a pioneering local geomembrane manufacturer with international standards.

The sample determination in this study used a purposive sampling technique, considering the limited employee population of PT. KTG (73 people) and the respondent criteria had been set to suit the objectives of evaluating readiness to face Industry 4.0. Involving 14 respondents across positions and departments, the data collection process was carried out over three weeks through three main stages: the preparation of a questionnaire based on the five pillars and 17 fields of INDI 4.0, online distribution of the questionnaire, and direct coordination with HRD to ensure respondent representation. The results of the questionnaire showed significant variations in the answers, which were then processed through weighted scoring according to the Ministry of Industry guidelines. The final calculation resulted in a score of 1.848 which places PT. KTG at Level 2 – Moderately Adopting Industry

4.0, with the two weakest pillars being Management & Organization and People & Corporate Culture. This indicates that increasing internal capabilities through strengthening managerial and collaborative work culture is a strategic step that can be taken immediately to raise the level of readiness towards the Mature category in digital transformation.

3.1.2. Geosynthetic Product Production Process

The geosynthetic production process at PT KTG, specifically for geomembrane and geotextile products, begins with the formulation of polymer raw materials, which primarily consist of high-quality polyethylene resin that meets national and international technical standards. These raw materials then undergo a high-pressure extrusion process using automated machines capable of precisely controlling thickness, width, and tensile strength through digital temperature and pressure sensors. After the sheet formation process, the material is calibrated and cooled with an automatic cooling system that maintains the product's structural integrity. The formed geosynthetic sheets undergo a surface treatment process to enhance resistance to UV rays and chemicals, and are laminated if needed for specific applications such as fish ponds, landfills, or the heavy construction sector. Next, the Quality Control unit tests technical parameters such as permeability, elongation, puncture resistance, and tensile strength using a digital testing system integrated with a real-time database. All production data is automatically recorded into the ERP system, enabling monitoring and tracking of the quality of each production batch. Finally, packaging is carried out mechanically, and the products are stored in a warehouse based on an integrated logistics system that supports timely delivery. This entire process demonstrates how the integration of digital technology across the entire production chain can improve efficiency, quality consistency, and the company's readiness to adopt Industry 4.0 principles in a gradual but targeted manner.

Figure1Geosynthetic Product Production Process

3.1.3. Various Geosynthetic Products and Their Applications

The geosynthetic industry in Indonesia is currently experiencing rapid growth along with the increasing demand for polymer-based technical solutions. However, this growth is also accompanied by the emergence of many competitors, both local producers and importers from abroad, particularly from China. Several large companies such as Multi Bangun Rekatama Patria, Geostar Techno Maxima, and Toma Karya Geolindo have become competitors to be reckoned with. This challenge drives PT. KTG to continue innovating, not only in improving product quality, but also in the efficiency of the production process and the accuracy of distribution. In the Industrial Revolution 4.0, PT. KTG has begun to adopt automation and digitalization to ensure long-term resilience and competitiveness in this technology-intensive industry.

	
(a) Geocell Application (Retaining wall)	(b) Geowoven Application

Figure 1Geocell and Geowoven Applications

PT. KTG also produces Geocell (Geoprocell) and Woven Geotextile (Geowoven) which offer multifunctional solutions in the construction and soil conservation sectors. Geocell is made of HDPE with a three-dimensional structure that can withstand shear forces and prevent erosion, very suitable for retaining walls, steep slopes, and mine access roads. Meanwhile, Geowoven is designed from polypropylene slit-film tape that has high tensile strength and filtration capabilities, ideal for material separation, road reinforcement on soft soils, and irrigation channel protection. With a continuously expanding product line and designed according to field engineering needs, PT. KTG plays a strategic role in supporting stronger, more efficient, and environmentally friendly infrastructure projects throughout Indonesia.

3.2. Discussion

In measuring PT. KTG's readiness to face Industry 4.0 using INDI 4.0, differences in perception were found between employees and company leaders. The average score given by employees was 1.85, while leaders gave a higher rating of 2.14. Although both are in the Level 2 category or "Moderately implementing Industry 4.0", this difference in scores indicates a gap in understanding of the company's actual condition. The pillars with the most significant differences were Products and Services and People and Culture, where leaders tended to be more optimistic about the company's progress than employees. The results of in-depth interviews revealed that leaders are aware that the company still has many limitations, especially in terms of technology, unintegrated information systems, and limited human resource adaptability to digital change. Leaders believe that digital transformation requires significant investment and a long adaptation time, especially when some employees are comfortable with the old system and are less motivated to develop new skills.

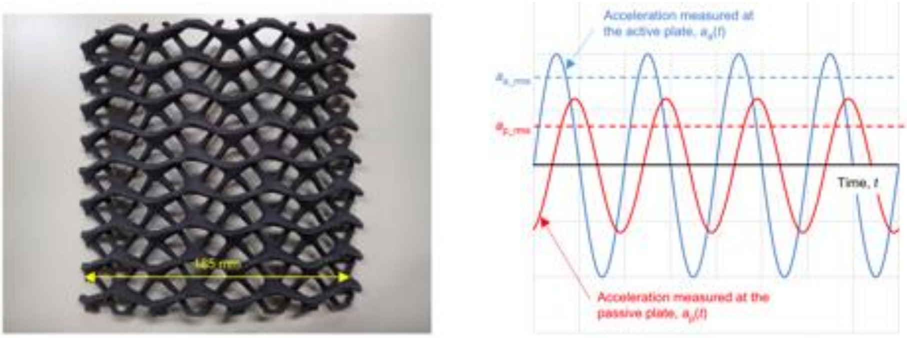

Figure 2. Three-dimensional geosynthetic material made from polyolefin elastomer is used in laboratory testing with acceleration measurements on passive plates.

Source:(Miyata, 2024)

An effective maintenance strategy is key to ensuring operational continuity and product quality. Maintenance approaches begin with corrective maintenance, which is implemented after damage occurs, either immediately on vital components or deferred for non-critical damage. However, this approach often results in high downtime and production disruptions. Therefore, companies are shifting to preventive maintenance, which is implemented before damage occurs through two main methods: predetermined maintenance and condition-based maintenance. Predetermined maintenance is performed based on a fixed schedule, such as machine operating hours or the number of production cycles, while condition-based maintenance relies on periodic or continuous monitoring of the actual condition of the machine, using temperature, vibration, or pressure sensors. With the adoption of Industry 4.0 technology, maintenance strategies are evolving toward predictive maintenance, which utilizes the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to predict potential damage before it occurs. Through the integration of these intelligent systems, companies can reduce the risk of sudden damage, extend equipment lifespan, streamline resource use, and maintain supply chain stability. This strategy is crucial for the geosynthetics industry, which relies on precision and continuity of manufacturing processes to meet infrastructure market demand.

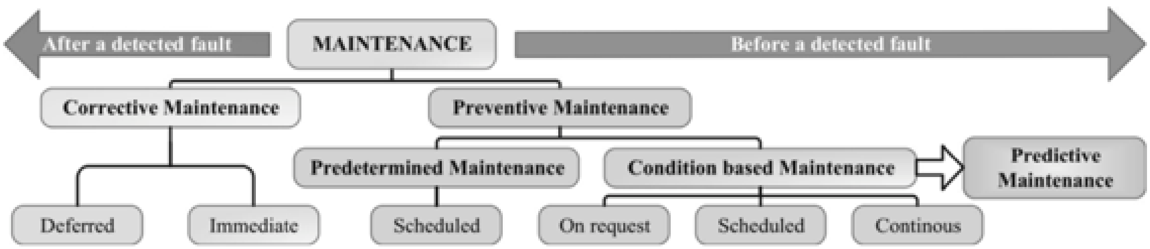

Figure 3Post-Production Maintenance Policy

Source:(Meitz et al., 2025)

In response to this situation, the improvement strategy is directed comprehensively at three critical pillars. First, in the Organization and Culture pillar, companies need to actively socialize the digital transformation vision to all employees and build a work culture open to learning and innovation. Regular training activities, cross-divisional discussions, and incentives for skills development must be strengthened to make employees more adaptable to the digital era. Second, from the Management and Organizational perspective, it is necessary to establish an internal transformation team with the mandate and resources to oversee system changes, set implementation priorities, and periodically evaluate achievements. Third, in the Technology aspect, companies need to start investing gradually, such as building an integrated database, adopting a simple ERP, and gradually upgrading production equipment.

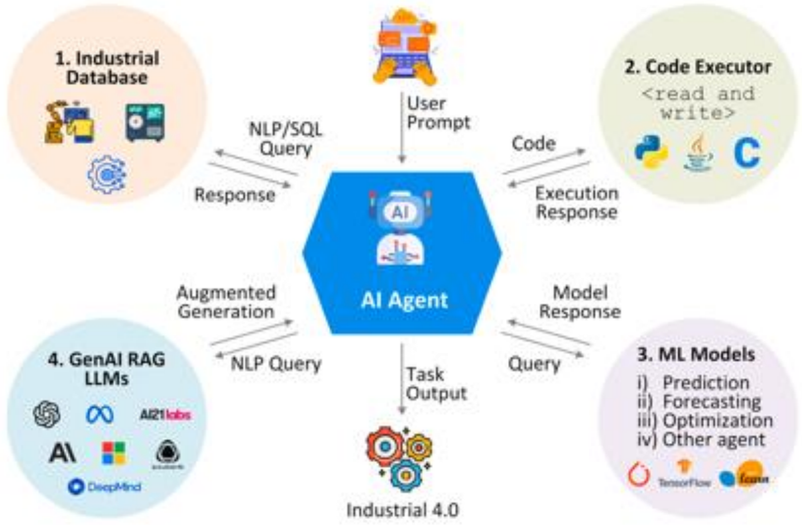

Figure 4. The integration of Industry 4.0 with AgentAI enables autonomous agents to query industrial databases using NLP or SQL, execute scripts for data operations, interact with predictive machine learning models, and engage generative AI through prompt-based Source:(Piccialli et al., 2025)

Integration strategyThe modern geosynthetic production process has undergone a significant transformation through the adoption of Industry 4.0 and artificial intelligence (AI) technologies, starting with historical data-driven material design using machine learning to determine the optimal polymer formulation for polyolefin elastomers. IoT sensors embedded throughout the production line monitor temperature, pressure, and extrusion speed in real time, enabling automated, adaptive decision-making through an AI-based control system. The AgentAI system enables digital agents to send NLP- or SQL-based queries to industrial databases to retrieve structured production data, run Python scripts to set and adjust production parameters, and utilize predictive models to prevent product defects before they occur. The lamination and three-dimensional structure formation of geosynthetics are precisely controlled by automated robotics monitored through a cloud-based dashboard. Finally, product quality is verified with non-destructive testing powered by computer vision and AI image analysis, while production performance and efficiency reports are automatically synthesized by a text-prompt-based generative model. This comprehensive integration results in high-quality, energy-efficient geosynthetics that are adaptive to the needs of the modern construction and infrastructure market.

Furthermore, implementing barcode and GPS-based tracking technology can improve service transparency for customers. Operationally, it's crucial for companies to prepare operators capable of managing automated machines and update cross-functional SOPs to improve efficiency. This strategy not only addresses short-term needs but also lays the foundation for elevating PT. KTG's readiness to a more mature level for Industry 4.0.

The results of this study indicate that digitalization readiness in geosynthetic manufacturing companies, particularly in the operational and supply chain lines, still faces various challenges in the transition from conventional systems to full integration based on Industry 4.0. In a case study of PT KTG located in Singosari, Malang, it was found that the digitalization process can have a significant impact on the efficiency of production and distribution management. The technology-based system allows for accurate calculation of raw material requirements, automated production planning, and determination of safety stock to prevent the risk of stockouts, which have been a major obstacle in the procurement and delivery of geosynthetic products such as geomembranes and geotextiles.

This digital transformation requires companies to revise Standard Operating Procedures (SOPs), update internal data flows, and integrate work equipment with Internet of Things (IoT)-based digital systems and Enterprise Resource Planning (ERP) software. These findings align with expectations that the implementation of Industry 4.0 will not only boost production efficiency but also increase responsiveness to market demand and the competitiveness of local products.

In terms of contribution, this research provides an implementable model for geosynthetics companies in Indonesia in facing the era of industrial digitalization. Furthermore, academically, these results enrich the literature review on operational transition strategies for civil engineering materials-based manufacturing to the Industry 4.0 ecosystem, which has so far been rarely discussed specifically in this sector. Thus, companies like PT KTG can become pioneers in the development of a modern construction materials industry that is efficient, adaptive, and oriented towards future technologies.

4. Conclusions and Recommendations

The study shows that PT. Kencana Tiara Gemilang (PT. KTG) is at Level 2 – Moderately Adopting Industry 4.0 with a score of 1.848. Its main strength lies in the integration of basic technologies in the geosynthetic production process such as IoT, automation, and ERP systems, while its main weaknesses are in the Management & Organization and People & Corporate Culture pillars. There is a perception gap between leaders (score 2.14) and employees (score 1.85) regarding digital readiness. Recommended strategies include strengthening a collaborative work culture, establishing a digital transformation team, and gradual investment in technology infrastructure. These findings confirm that the transition to Industry 4.0 in the geosynthetics sector cannot rely solely on technology adoption, but requires synchronization between technology, management, and human resource readiness. For industry practitioners, these results provide a relevant digital adoption stage model for polymer-based manufacturing. For the government, this study can serve as a reference for policies to foster medium-sized industries to be able to catch up digitally by focusing on weak pillars. For academics, these results fill the literature gap regarding the implementation of Industry 4.0 in the civil engineering materials industry, which is still rarely studied. Further studies could focus on developing AI- and big data-based predictive maintenance models for the geosynthetics industry, analyzing the ROI (Return on Investment) of IoT and ERP implementations in the supply chain, and comparing local geosynthetics companies with foreign manufacturers regarding digital transformation strategies. In-depth qualitative research is also needed to understand employee resistance to digitalization, allowing for more effective interventions.

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. Hari Irawan: Validation, Formal Analysis, Writing – Review & Editing. Ruri Artanti Prahastuti: Investigation, Visualization, Project Administration. Muhammad Ainul Fahmi: Resources, Software, Data Analysis. Julianus Hutabarat: Supervision, Funding Acquisition, Writing – Review & Editing.

Data Availability Statement

None.

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