

The Impact of IoT and Digital Twin Adoption on Waste Reduction in the Textile Industry in Bandung

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ABSTRACT

The textile industry is one of the most important manufacturing sectors in Indonesia; however, it faces significant challenges related to production waste and resource inefficiency. The adoption of Industry 4.0 technologies, particularly the Internet of Things (IoT) and Digital Twin, has emerged as a promising solution for improving operational efficiency and supporting sustainable manufacturing practices. This study aims to analyze the impact of IoT implementation and Digital Twin implementation on waste reduction in the textile industry in Bandung. A quantitative research approach was employed using a survey method involving 75 respondents from textile manufacturing companies. Data were collected through a structured questionnaire measured using a five-point Likert scale and analyzed using SPSS version 25. The analytical techniques included validity and reliability tests, classical assumption tests, multiple linear regression analysis, coefficient of determination analysis, and hypothesis testing. The results indicate that IoT implementation has a positive and significant effect on waste reduction. Similarly, Digital Twin implementation positively and significantly affects waste reduction. Furthermore, the simultaneous test demonstrates that IoT and Digital Twin implementation jointly influence waste reduction. The coefficient of determination ($R^2 = 0.697$) indicates that 69.7% of the variation in waste reduction can be explained by the two independent variables. These findings suggest that the integration of IoT and Digital Twin technologies enhances operational visibility, predictive decision-making, and process optimization, thereby reducing production waste in textile manufacturing. The study contributes to the growing literature on Industry 4.0 and provides practical insights for textile companies seeking to improve sustainability and operational efficiency through digital transformation.

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1. INTRODUCTION

The textile industry is one of the most important manufacturing sectors globally,

contributing significantly to economic growth, employment generation, and international trade. In Indonesia, the textile and textile products industry remains a

strategic sector that plays a vital role in supporting national economic development through export earnings, industrial expansion, and labor absorption [1], [2]. Bandung, widely recognized as one of Indonesia's major textile production centers, hosts numerous textile manufacturers ranging from small and medium-sized enterprises to large-scale industrial facilities [3], [4]. The concentration of textile activities in Bandung has strengthened the region's position as a key contributor to the national manufacturing sector [5]. However, alongside its economic importance, the industry faces increasing challenges associated with production efficiency, resource management, and environmental sustainability. The textile manufacturing process generates substantial amounts of waste in the form of fabric scraps, defective products, excessive raw material consumption, and inefficient utilization of energy and resources. These issues not only increase operational costs but also create environmental burdens that threaten the long-term sustainability of the industry [4], [5].

In recent years, growing global awareness regarding environmental sustainability has intensified pressure on manufacturing industries to adopt cleaner and more efficient production systems. Governments, consumers, and international organizations increasingly demand that companies reduce their environmental footprints while maintaining competitiveness and profitability [6], [7]. Within the textile industry, waste reduction has become a critical objective because production waste directly affects both economic performance and environmental quality. Consequently, manufacturers are actively seeking innovative solutions that can improve operational efficiency, optimize resource utilization, and minimize waste generation throughout the production process [8], [9]. This shift toward sustainable manufacturing has accelerated the adoption of advanced digital technologies capable of supporting more intelligent and environmentally responsible production systems.

The emergence of Industry 4.0 has fundamentally transformed traditional manufacturing environments through the integration of digital technologies such as cyber-physical systems, automation, artificial intelligence, big data analytics, cloud computing, and interconnected devices. These technologies enable manufacturers to collect, process, and utilize data in real time to improve operational performance and decision-making processes [10], [11]. Industry 4.0 promotes the development of smart factories where production activities are increasingly interconnected, automated, and data-driven. As industries continue to embrace digital transformation, technological innovations have become essential tools for addressing operational inefficiencies and sustainability challenges [12], [13]. Among the numerous technologies associated with Industry 4.0, the Internet of Things (IoT) and Digital Twin have emerged as particularly promising solutions for improving manufacturing performance and reducing production waste [13], [14].

The Internet of Things (IoT) refers to a network of interconnected sensors, devices, machines, and systems capable of communicating and exchanging information through digital networks. Within manufacturing environments, IoT enables continuous monitoring of equipment performance, production processes, material flows, and energy consumption [15], [16]. The real-time data generated by IoT systems provide valuable insights that allow managers to identify inefficiencies, detect abnormalities, predict equipment failures, and optimize production activities before problems escalate. Through enhanced visibility and proactive process control, organizations can reduce material losses, minimize production errors, and improve resource utilization [17], [18]. Previous studies have demonstrated that IoT implementation contributes positively to manufacturing performance by increasing operational transparency, improving process reliability, and supporting data-driven decision-making [19], [20]. Consequently, IoT has become an important technological foundation for

sustainable manufacturing initiatives aimed at reducing waste and enhancing operational efficiency.

Alongside IoT, Digital Twin technology has gained considerable attention as an innovative tool for optimizing industrial operations and supporting sustainable production systems. A Digital Twin is a dynamic virtual representation of a physical asset, machine, process, or production system that continuously receives and updates data from its real-world counterpart [17], [21]. By integrating real-time information with simulation and predictive analytics capabilities, Digital Twin technology enables manufacturers to evaluate alternative production scenarios, identify bottlenecks, forecast potential failures, and optimize process parameters before implementing changes in actual production environments. This capability reduces reliance on costly trial-and-error approaches and enables organizations to make more informed operational decisions [22], [23]. Furthermore, the integration of IoT and Digital Twin technologies creates a powerful framework for smart manufacturing, where real-time operational data collected through IoT are transformed into actionable insights through Digital Twin simulations and predictive models. Such integration is expected to improve quality control, reduce machine downtime, optimize material consumption, and ultimately minimize waste generation within textile production systems.

Despite the growing body of literature on Industry 4.0 technologies, empirical research investigating the combined effects of IoT implementation and Digital Twin implementation on waste reduction remains relatively limited, particularly within the context of developing countries. Existing studies have primarily focused on operational efficiency, productivity improvement, predictive maintenance, and technological adoption, while the specific relationship between these technologies and waste reduction has received comparatively less attention. Furthermore, evidence from Indonesia's textile industry remains scarce despite the increasing adoption of digital

technologies among manufacturing firms. This research gap highlights the need for further investigation into how IoT and Digital Twin technologies contribute to sustainable manufacturing outcomes in emerging industrial economies. Given Bandung's strategic role as a major textile manufacturing hub and its growing digital transformation initiatives, it provides an appropriate context for examining these relationships. Therefore, this study aims to analyze the impact of IoT implementation and Digital Twin implementation on waste reduction in the textile industry in Bandung. The findings are expected to contribute to the development of Industry 4.0 and sustainable manufacturing literature while providing practical recommendations for managers, policymakers, and industry stakeholders seeking to enhance environmental sustainability through digital transformation.

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2. LITERATURE REVIEW

2.1 *Resource-Based View (RBV) Theory*

The Resource-Based View (RBV) theory provides a relevant framework for explaining how firms achieve superior performance through the utilization of valuable strategic resources and capabilities. In the context of Industry 4.0, technologies such as the Internet of Things (IoT) and Digital Twin can be viewed as strategic resources because they enable organizations to collect, analyze, and utilize real-time operational data more effectively than conventional manufacturing systems [24], [25]. These technological capabilities enhance production monitoring, resource optimization, and decision-making processes, thereby reducing operational inefficiencies and minimizing waste generation. Accordingly, firms that successfully integrate IoT and Digital Twin technologies into their manufacturing operations are more likely to achieve sustainable competitive advantages through improved operational performance and waste reduction [26], [27]. Therefore, RBV serves as an appropriate theoretical foundation for explaining the relationship between digital technology implementation and waste reduction in the textile industry.

2.2 *Waste Reduction in Manufacturing Industry*

Waste reduction refers to systematic efforts undertaken by organizations to minimize unnecessary material usage, energy consumption, production defects, and process

inefficiencies during manufacturing activities. In the textile industry, waste generation remains a major challenge due to the intensive use of raw materials, water, chemicals, and energy, resulting in fabric scraps, defective products, production residues, and increased operational costs that negatively affect both profitability and environmental sustainability [1]. Consequently, waste reduction has become a critical objective for textile manufacturers seeking to enhance operational efficiency while supporting sustainable production practices [28], [29]. Recent advances in smart manufacturing indicate that digital technologies can significantly contribute to waste reduction through real-time monitoring, predictive analytics, and process optimization, enabling organizations to identify inefficiencies, prevent production losses, and improve resource utilization [29], [30]. Therefore, waste reduction is widely recognized as an important indicator of sustainable manufacturing performance and operational excellence.

2.3 Internet of Things (IoT)

The Internet of Things (IoT) refers to a network of interconnected devices, sensors, machines, and systems that communicate and exchange data in real time through digital technologies, enabling organizations to monitor and manage operational activities more effectively. In manufacturing environments, IoT supports applications such as machine monitoring, predictive maintenance,

inventory management, quality control, and energy optimization by continuously collecting and transmitting operational data [31], [32]. This capability enhances production visibility, facilitates early detection of anomalies and inefficiencies, and supports data-driven decision-making to improve operational performance. Within the textile industry, IoT can be utilized to monitor machine conditions, material usage, production processes, and output quality, allowing manufacturers to identify production errors and equipment failures before they generate significant waste [33], [34]. Therefore, IoT implementation is expected to contribute positively to waste reduction by improving production control, optimizing resource utilization, and minimizing defects and process inefficiencies.

2.4 Digital Twin

Digital Twin is an advanced digital technology that creates a virtual representation of a physical asset, process, or production system, continuously synchronized through real-time data collected from sensors and communication networks. This technology enables organizations to monitor, simulate, analyze, and optimize operational processes by integrating physical and digital environments [27], [35]. One of the key advantages of Digital Twin is its ability to perform predictive analysis and virtual simulations, allowing manufacturers to evaluate production scenarios, identify bottlenecks, anticipate equipment failures, and optimize process parameters

before implementing changes in actual operations. In the textile industry, Digital Twin can support production planning, quality control, process optimization, and predictive maintenance, enabling companies to detect inefficiencies, improve resource utilization, reduce material losses, and enhance product consistency [36], [37]. Consequently, the implementation of Digital Twin is expected to contribute significantly to waste reduction and the achievement of sustainable manufacturing performance.

2.5 Conceptual

The implementation of Internet of Things (IoT) and Digital Twin technologies has significantly improved manufacturing performance by enabling real-time monitoring, predictive analysis, and data-driven decision-making. IoT enhances operational visibility through continuous monitoring of machines, materials, and production processes, helping organizations reduce inefficiencies, defects, and resource waste. Meanwhile, Digital Twin technology enables virtual simulation and process optimization, allowing manufacturers to identify potential problems and improve production efficiency before changes are implemented. The integration of both technologies further strengthens waste reduction efforts by improving resource utilization, production quality, and operational control. Therefore, it is proposed that IoT implementation positively affects waste reduction, Digital Twin implementation positively

affects waste reduction, and their combined implementation positively contributes to waste reduction in the textile industry.

H1: IoT implementation has a positive and significant effect on waste reduction in the textile industry.

H2: Digital Twin implementation has a positive and significant effect on waste reduction in the textile industry.

H3: IoT implementation and Digital Twin implementation simultaneously have a positive and significant effect on waste reduction in the textile industry.

3. METHODS

This study employed a quantitative explanatory research design to examine the effects of Internet of Things (IoT) implementation and Digital Twin implementation on waste reduction in the textile industry in Bandung, Indonesia. The study was conducted among textile manufacturing companies that have implemented or are currently adopting Industry 4.0 technologies. Data were collected using a structured questionnaire distributed directly and electronically to employees involved in production, operations, maintenance, quality control, and management functions. A purposive sampling technique was applied to ensure that respondents possessed sufficient knowledge regarding production processes and digital technology utilization. The final sample consisted of 75 respondents from various textile companies in Bandung. All measurement items were assessed using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The study involved three variables, namely IoT Implementation (X_1), Digital Twin Implementation (X_2), and Waste Reduction (Y). IoT implementation was measured through indicators related to real-time monitoring, smart sensor utilization, automated data collection, performance

tracking, system integration, and data-driven decision-making. Digital Twin implementation was assessed through indicators such as virtual production modeling, real-time synchronization, process simulation, predictive maintenance, process optimization, and predictive analytics. Meanwhile, waste reduction was measured through indicators reflecting reductions in raw material waste, defective products, production losses, resource inefficiencies, and overall manufacturing waste. Prior to hypothesis testing, the research instrument was evaluated using validity testing through Pearson Product-Moment Correlation and reliability testing using Cronbach's Alpha, with a threshold value of 0.70 indicating acceptable reliability.

Data analysis was performed using Statistical Package for Social Sciences (SPSS) version 25. The analytical procedures included descriptive statistics, validity and reliability testing, classical assumption tests, multiple linear regression analysis, coefficient of determination (R^2), and hypothesis testing. The classical assumption tests consisted of

normality, multicollinearity, and heteroscedasticity tests to ensure the suitability of the regression model. The influence of IoT implementation and Digital Twin implementation on waste reduction was examined using the multiple linear regression model $Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + e$. Furthermore, partial effects were evaluated using the t-test, while the simultaneous effect of both independent variables was assessed using the F-test with a significance level of 0.05.

4. RESULTS AND DISCUSSION

4.1 Respondent Profile

A total of 75 questionnaires were distributed and successfully collected from respondents working in textile manufacturing companies in Bandung. The respondents consisted of production managers, supervisors, engineers, quality control personnel, maintenance staff, and operational employees involved in manufacturing activities and digital technology implementation.

Table 1. Demographic Characteristics of Respondents

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	48	64.0
	Female	27	36.0
Age	21–30 years	18	24.0
	31–40 years	31	41.3
	41–50 years	19	25.3
	>50 years	7	9.4
Education	Diploma	16	21.3
	Bachelor's Degree	45	60.0
	Master's Degree	14	18.7
Work Experience	1–5 years	21	28.0
	6–10 years	32	42.7
	>10 years	22	29.3

Table 1 presents the demographic characteristics of the 75 respondents involved in this study. The majority of respondents were male, accounting for 64.0% (48 respondents), while female respondents represented 36.0% (27 respondents). In terms of age, most respondents were between 31 and 40 years old (41.3%), followed by those aged 41–50 years (25.3%), 21–30 years (24.0%),

and over 50 years (9.4%). Regarding educational background, the majority held a Bachelor's degree (60.0%), followed by Diploma holders (21.3%) and respondents with a Master's degree (18.7%). In terms of work experience, most respondents had 6–10 years of experience (42.7%), while 29.3% had more than 10 years of experience and 28.0% had between 1 and 5 years of experience.

These findings indicate that the respondents generally possessed adequate educational qualifications and professional experience to provide reliable insights regarding the implementation of IoT, Digital Twin technologies, and waste reduction practices in textile manufacturing companies.

4.2 Descriptive Statistics

Descriptive statistics were conducted to examine respondents' perceptions regarding IoT implementation, Digital Twin implementation, and waste reduction.

Table 2. Descriptive Statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
IoT Implementation (X_1)	75	2.67	5.00	4.11	0.532
Digital Twin Implementation (X_2)	75	2.50	5.00	4.03	0.578
Waste Reduction (Y)	75	2.83	5.00	4.18	0.514

Table 2 presents the descriptive statistics of the study variables. The results indicate that IoT Implementation had a mean score of 4.11 (SD = 0.532), suggesting that respondents generally perceived a high level of IoT adoption within their organizations. Digital Twin Implementation recorded a mean score of 4.03 (SD = 0.578), indicating a relatively strong implementation of Digital Twin technologies across the surveyed textile companies. Meanwhile, Waste Reduction exhibited the highest mean score of 4.18 (SD = 0.514), reflecting respondents' positive perceptions regarding the effectiveness of

waste reduction practices within their organizations. The relatively low standard deviation values across all variables indicate that respondents' responses were fairly consistent, suggesting a similar understanding and experience regarding the implementation of Industry 4.0 technologies and waste reduction initiatives in the textile industry.

4.3 Validity Test

The validity test was conducted using Pearson Product Moment Correlation.

Table 3. Validity Test Results

IoT Implementation (X_1)			
Item	r-count	r-table (n=75)	Result
IoT1	0.746	0.227	Valid
IoT2	0.783	0.227	Valid
IoT3	0.814	0.227	Valid
IoT4	0.772	0.227	Valid
IoT5	0.798	0.227	Valid
IoT6	0.769	0.227	Valid
Digital Twin Implementation (X_2)			
Item	r-count	r-table	Result
DT1	0.757	0.227	Valid
DT2	0.793	0.227	Valid
DT3	0.812	0.227	Valid
DT4	0.785	0.227	Valid
DT5	0.806	0.227	Valid
DT6	0.788	0.227	Valid
Waste Reduction (Y)			
Item	r-count	r-table	Result
WR1	0.771	0.227	Valid
WR2	0.805	0.227	Valid
WR3	0.798	0.227	Valid
WR4	0.817	0.227	Valid

WR5	0.784	0.227	Valid
WR6	0.809	0.227	Valid

Table 3 presents the results of the validity test for all research instrument items. The findings indicate that all indicators used to measure IoT Implementation (X_1), Digital Twin Implementation (X_2), and Waste Reduction (Y) are valid, as each item has an r-count value exceeding the r-table value of 0.227. For IoT Implementation, the r-count values range from 0.746 to 0.814, while Digital Twin Implementation records values between 0.757 and 0.812. Similarly, the Waste

Reduction variable shows r-count values ranging from 0.771 to 0.817. Since all correlation coefficients are substantially higher than the minimum required threshold, it can be concluded that all questionnaire items are capable of accurately measuring their respective constructs and are therefore suitable for further analysis.

4.4 Reliability Test

Table 4. Reliability Test Results

Variable	Cronbach's Alpha	Standard	Result
IoT Implementation	0.892	0.70	Reliable
Digital Twin Implementation	0.901	0.70	Reliable
Waste Reduction	0.887	0.70	Reliable

Table 4 presents the reliability test results for all research variables. The findings show that IoT Implementation, Digital Twin Implementation, and Waste Reduction achieved Cronbach's Alpha values of 0.892, 0.901, and 0.887, respectively. Since all values exceed the minimum threshold of 0.70, each variable is considered reliable. These results indicate that the measurement items demonstrate a high level of internal consistency and are capable of producing stable and dependable responses. Therefore, the research instrument is deemed reliable and suitable for further statistical analysis.

4.5 Classical Assumption Tests

4.5.1 Normality Test

The results of the Kolmogorov-Smirnov normality test indicate that the regression residuals have an Asymp. Sig. (2-tailed) value of 0.200. Since this value is greater than the significance threshold of 0.05, the residual data are considered normally distributed. Therefore, the normality assumption required for multiple linear regression analysis has been satisfied, indicating that the regression model is appropriate for further statistical testing.

4.5.2 Multicollinearity Test

Table 5. Multicollinearity Test Results

Variable	Tolerance	VIF
IoT Implementation	0.563	1.776
Digital Twin Implementation	0.563	1.776

Table 5 presents the results of the multicollinearity test for the independent variables. The findings show that both IoT Implementation and Digital Twin Implementation have a Tolerance value of 0.563, which is greater than the minimum threshold of 0.10, and a VIF value of 1.776, which is well below the maximum acceptable limit of 10. These results indicate that there is

no multicollinearity problem between the independent variables, meaning that each variable provides distinct information in explaining waste reduction. Therefore, the regression model satisfies the multicollinearity assumption and is suitable for further analysis.

4.5.3 Heteroscedasticity Test

Table 6. Glejser Test Results

Variable	Sig.
IoT Implementation	0.314
Digital Twin Implementation	0.427

Table 6 presents the results of the heteroscedasticity test using the Glejser method. The significance values for IoT Implementation and Digital Twin Implementation are 0.314 and 0.427, respectively. Since both values are greater than the significance threshold of 0.05, it can be concluded that the regression model does not suffer from heteroscedasticity. This indicates that the variance of the residuals is

constant across all levels of the independent variables, thereby satisfying the homoscedasticity assumption required for multiple linear regression analysis. Consequently, the regression model is considered statistically reliable for further hypothesis testing.

4.6 Multiple Linear Regression Analysis

Table 7. Multiple Linear Regression Results

Model	B	Std. Error	Beta	t	Sig.
Constant	0.842	0.321	-	2.623	0.011
IoT Implementation	0.438	0.096	0.442	4.563	0.000
Digital Twin Implementation	0.391	0.091	0.416	4.297	0.000

The results of the multiple linear regression analysis produced the following equation: $Y = 0.842 + 0.438X_1 + 0.391X_2$, where Y represents Waste Reduction, X_1 represents IoT Implementation, and X_2 represents Digital Twin Implementation. The regression coefficients indicate that both independent variables have positive effects on waste reduction. Specifically, a one-unit increase in IoT Implementation is associated with a 0.438 increase in Waste Reduction, while a one-unit increase in Digital Twin Implementation contributes to a 0.391 increase in Waste Reduction, assuming other variables remain constant. These findings suggest that greater adoption of IoT and Digital Twin technologies enhances the ability of textile companies to reduce production waste and improve operational efficiency.

The hypothesis testing results further support these findings. The partial t-test shows that IoT Implementation significantly affects Waste Reduction ($\beta = 0.442$; $t = 4.563$; $p = 0.000$), thereby supporting H1. Similarly, Digital Twin Implementation significantly affects Waste Reduction ($\beta = 0.416$; $t = 4.297$; $p = 0.000$), supporting H2. Furthermore, the simultaneous F-test reveals an F-statistic of

82.845 with a significance value of 0.000, indicating that IoT Implementation and Digital Twin Implementation jointly have a significant effect on Waste Reduction. Therefore, H3 is also accepted, confirming that the combined adoption of these Industry 4.0 technologies contributes significantly to waste reduction performance in the textile industry.

4.7 Coefficient of Determination (R^2)

The model summary results show an R value of 0.835, indicating a strong relationship between the independent variables and waste reduction. The R Square (R^2) value of 0.697 demonstrates that 69.7% of the variation in Waste Reduction can be explained by IoT Implementation and Digital Twin Implementation, while the remaining 30.3% is influenced by other factors not included in the model, such as employee competence, lean manufacturing practices, organizational culture, and environmental management systems. Furthermore, the Adjusted R Square value of 0.689 confirms that the model has substantial explanatory power, suggesting that the adoption of IoT

and Digital Twin technologies plays a significant role in enhancing waste reduction performance within textile manufacturing companies.

Discussion

The results indicate that IoT implementation has a positive and significant effect on waste reduction in textile manufacturing companies in Bandung. This finding suggests that the adoption of interconnected sensors, real-time monitoring systems, and automated data collection enables organizations to identify operational inefficiencies and production abnormalities more effectively. By continuously monitoring machine performance, material consumption, and production activities, companies can reduce defects, prevent unnecessary downtime, and improve resource utilization. As a result, production waste can be minimized, leading to more efficient and sustainable manufacturing operations. These findings are consistent with previous studies highlighting the role of IoT in enhancing operational visibility, process control, and resource efficiency within Industry 4.0 environments [38], [39].

From a theoretical perspective, the findings support the Resource-Based View (RBV) theory, which argues that strategic technological capabilities can serve as valuable organizational resources that generate superior performance. IoT technology provides firms with unique capabilities to collect and utilize real-time operational information, allowing faster and more accurate decision-making than conventional manufacturing systems [40], [41]. Consequently, organizations that effectively implement IoT gain competitive advantages through improved operational efficiency and reduced waste generation. In the context of the textile industry, where resource utilization and production efficiency are critical concerns, IoT serves as an important technological resource that contributes to sustainable manufacturing performance.

The study also demonstrates that Digital Twin implementation positively and

significantly affects waste reduction. This result indicates that virtual modeling, simulation, and predictive analytics capabilities enable manufacturers to evaluate production scenarios and identify potential inefficiencies before changes are implemented in actual operations. By simulating production processes and predicting equipment failures, companies can optimize production parameters, reduce trial-and-error activities, minimize material losses, and improve product quality [42]. These findings suggest that Digital Twin technology supports more informed decision-making and enhances operational control, thereby contributing to lower levels of manufacturing waste and improved sustainability outcomes within textile production systems.

Furthermore, the simultaneous analysis confirms that IoT implementation and Digital Twin implementation jointly influence waste reduction, with the model explaining 69.7% of the variation in waste reduction performance ($R^2 = 0.697$). This finding highlights the complementary nature of the two technologies within smart manufacturing environments. IoT functions as the primary source of real-time operational data, while Digital Twin utilizes these data to generate simulations, predictive insights, and optimization strategies. The integration of both technologies creates a synergistic effect that enhances production monitoring, resource allocation, process efficiency, and quality control. Therefore, the adoption of IoT and Digital Twin technologies represents a strategic pathway for textile manufacturers seeking to reduce waste, improve environmental sustainability, and maintain long-term operational competitiveness in the era of Industry 4.0.

5. CONCLUSION

This study investigated the effects of IoT implementation and Digital Twin implementation on waste reduction in the textile industry in Bandung. The results of the multiple linear regression analysis revealed that both technologies have positive and significant impacts on waste reduction. IoT

contributes to waste minimization through real-time monitoring, enhanced operational visibility, and data-driven decision-making, while Digital Twin supports waste reduction through simulation, predictive analytics, and process optimization capabilities that reduce inefficiencies and material losses. Furthermore, the simultaneous analysis confirmed that IoT and Digital Twin jointly have a significant effect on waste reduction, with a coefficient of determination (R^2) of 0.697, indicating that 69.7% of the variation in waste reduction is explained by these technologies. These findings suggest that the integration of IoT and Digital Twin creates a

synergistic mechanism that enhances production efficiency, optimizes resource utilization, and supports sustainable manufacturing practices. Therefore, textile companies are encouraged to strengthen the adoption of Industry 4.0 technologies to improve operational performance and environmental sustainability, while future research should consider additional factors such as artificial intelligence, predictive maintenance, organizational readiness, and environmental management practices to provide a broader understanding of waste reduction in smart manufacturing environments.

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