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The Impact of Robotic and 3D Printing Technologies on the Profitability of Sri Lanka's Textile Industry: Addressing Labor Cost Challenges and Raw Material Dependency

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ABSTRACT

The textile and apparel industry plays a vital role in Sri Lanka's economy, contributing significantly to employment and export earnings. However, rising labour costs, over-reliance on imported raw materials, lack of technological innovation, and global economic pressures pose substantial challenges to the sector. This study investigates the impact of robotic and 3D printing technologies on the profitability and development of Sri Lanka's textile industry, filling a significant research gap on their usage in developing economies. The study employed a quantitative research design using a sample of 300 employees selected from total employees of 400,000 attached to the textile industry in Sri Lanka by using simple random sampling technique. A structured questionnaire assessed four critical factors: reliance on imported raw materials, labor costs, robotic technology, and 3D printing technology. Data analysis employed regression analysis, correlation, and descriptive statistics. The findings show a strong positive correlation between profitability and both robotic and 3D printing technologies, suggesting that greater adoption improves cost control, product innovation, and operational efficiency. While resilience on imported raw materials showed a positive impact, labor costs indicated a significant negative relationship with profitability. According to the regression analysis, 3D printing technology had the highest positive impact on profitability. The study recommends offering financial incentives, specialized training and pilot programs to expand the technology adoption. Moreover, the study suggests fostering partnerships between businesses and universities, improving local material sourcing, and developing supportive government policies.

Key words: Robotic technology, 3D printing technologies, Labor Cost Challenges and Raw Material Dependency.

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1. Introduction

The textile and apparel industry is the cornerstone of Sri Lanka's economy, contributing significantly to employment, export revenue, and industrial development. The sector remains one of the primary sources of foreign exchange, representing 44% of the country's export revenue and employing over 400,000 individuals

directly as of 2024 (Fibre Fashion, 2024). The industry has been instrumental in helping Sri Lanka recover from the economic downturns caused by both internal political unrest and global crises such as the COVID-19 pandemic.

At global level, adoption of cutting-edge technologies such as robotics and 3D printing proved to be the potential to revolutionize the production process by reducing labour costs, improving precision, and enhancing production efficiency. Robotics can automate tasks such as sewing, cutting, and fabric testing, while 3D printing allows for rapid prototyping and customization, reducing material waste and production time (Buchanan & Berkstresser, 1986; Muralidhara & Banerjee, 2022).

Despite the significance of the textile industry in Sri Lanka, the sector faces significant challenges including increasing labor costs, a heavy dependence on imported raw materials, supply chain disruptions, and a limited incorporation of advanced manufacturing technologies (Samarasinghe, Ariadurai and Perera, 2015; Makalanda, Nirmali and Perera, 2025). Competitors on the global stage have swiftly embraced automation, robotics, and digital manufacturing, highlighting an urgent need for Sri Lanka to modernize its production systems to maintain competitiveness. Emerging technologies such as robotic systems and 3D printing present considerable opportunities to enhance productivity, reduce cost inefficiencies, and drive product innovation. Yet, the impact of these technologies on firm-level profitability within the Sri Lankan textile industry warrants further investigation.

Several key research gaps highlight the need for this study. While previous studies on robotic technology (Buchanan and Berkstresser, 1986) and 3D printing technology (Muralidhara and Banerjee, 2022) discuss its potential to enhance productivity and revolutionary innovation in manufacturing, there is a lack of theoretical exploration regarding how this technology specifically interacts with the economic and labor dynamics of developing countries like Sri Lanka. While empirical evidence exists in global markets (Automate.org, 2020), there is limited empirical data on the adoption and effectiveness of robotic technology and 3D printing technology in Sri Lanka's textile industry. Moreover, methodological gaps also persist as most research use simple descriptive techniques rather than exact statistical models that require accurately assessing the impacts of technology. Further, Sri Lankan firms may not be achieving the potential performance improvements seen in other countries due to slower adoption rates or contextual challenges. Furthermore, most research on 3D printing focuses on its technical aspects, leaving a gap in understanding its economic and operational implications through comprehensive industry surveys or economic modeling. The nascent adoption of 3D printing in Sri Lanka's textile industry suggests that performance improvements (e.g., cost reductions, product innovation) have yet to be fully realized.

Additionally, while the challenges of inclined labor costs (Pavesic, 1999) and supply chain vulnerabilities (Nosch & Gillis, 2007) are well-theorized further exploration is required to understand how technological interventions can mitigate these rising costs in developing economies. Limited empirical research has been conducted on how Sri Lankan textile firms manage increasing labor expenses through technology adoption, particularly in comparison to countries that have embraced robotics. And empirical research is required to investigate how dependence on imported raw materials affects the cost structures and profitability of Sri Lankan textile firms (Rammandala, 2022). Further studies are also needed to explore alternative strategies, such as the development of local materials or the adoption of advanced technologies like 3D printing, to reduce this dependency. Employing supply chain modeling or simulations could offer insights into the potential for local sourcing, as Sri Lanka's heavy reliance on imports continues to impact the industry's overall profitability and growth.

Hence, the current study was conducted to address the research question: 'What is the impact of Robotic and 3D Printing Technologies on the Profitability and Development of Sri Lanka's Textile Industry?"

Research Objectives:

1. To analyze the extent of robotic technology adoption in Sri Lanka's textile industry and its impact on operational efficiency and labor costs.
2. To evaluate the role of 3D printing in enhancing product innovation and reducing material costs in the textile sector.
3. To investigate the relationship between technological adoption (robotics and 3D printing) and the profitability of textile firms.
4. To explore strategies for reducing dependence on imported raw materials through the use of advanced technologies.
5. To provide policy recommendations for encouraging technological adoption in the Sri Lankan textile industry.

Research Questions:

1. How does the adoption of robotic technology influence labor costs and operational efficiency in Sri Lanka's textile industry?
2. What are the benefits and challenges of using 3D printing technology in textile production, particularly in reducing material costs?
3. To what extent can the adoption of these technologies improve the profitability of Sri Lankan textile firms?
4. How can Sri Lanka's textile industry reduce its dependency on imported raw materials through technological innovation?
5. What are the key barriers to adopting robotic and 3D printing technologies in Sri Lanka's textile sector, and how can these barriers be overcome?

2. Literature Review

Previous studies have explored the challenges and opportunities within Sri Lanka's textile industry. Dheerasinghe (2015) identified internal challenges such as a shortage of skilled labor, dependency on imported materials, and inefficiencies in supply chains. Perera (n.d.) emphasized the importance of leadership and governance in overcoming these challenges to ensure the long-term sustainability of the sector. Rammandala (2022) highlighted external economic pressures, including inflation and energy shortages in key export markets, which have exacerbated operational difficulties.

Technological advancements, particularly robotics and 3D printing, have been proposed as solutions to many of the industry's challenges. Zhao et al. (2024) reported that robotics could automate repetitive and labor-intensive tasks, thereby reducing the industry's dependence on human labor and improving overall productivity (Zhao et al., 2024). Similarly, 3D printing technology has been shown to streamline the production process by enabling rapid prototyping and reducing material waste (Kantaros et al., 2025).

Despite these potential benefits, the high initial cost of adopting new technologies and the need for specialized skills to operate these systems remain significant barriers, especially for small- and medium-sized enterprises in Sri Lanka. Nonetheless, the successful integration of these technologies could significantly enhance the sector's global competitiveness.

Theoretical Gaps

The literature on the Sri Lankan textile industry often lacks comprehensive integration of advanced technological frameworks such as Industry 4.0 principles, including robotics and 3D printing, which could revolutionize manufacturing processes. While traditional models have explored labor, material costs, and

market dynamics, there is a lack of focus on how emerging technologies can reshape the operational landscape of this industry (Kulakli, Arikan and Birgün, 2024). Further, many theories are based on Western or highly developed Asian markets like China, which may not be entirely applicable to Sri Lanka's unique socio-economic context. The theoretical frameworks currently in use do not fully explain how localized industrial challenges, such as reliance on imported raw materials or skilled labor shortages, interact with the implementation of disruptive technologies.

Empirical Gaps

Many empirical studies on Sri Lanka's textile industry focus on historical data and trends, overlooking the recent global challenges such as the COVID-19 pandemic, supply chain disruptions, and geopolitical uncertainties that affect trade (Herath, Fernando and Pramudika, 2024). The literature lacks up-to-date empirical investigations that assess the real-time impact of revolutionary technologies like 3D printing and robotics in the Sri Lankan context. For instance, while 3D printing is being rapidly adopted globally, studies have not sufficiently examined its actual application, cost-benefit analysis, or scalability within Sri Lankan textile firms. Existing empirical research also inadequately considers how global shifts, such as rising labor costs and energy crises in key markets, are impacting the performance of Sri Lankan manufacturers (Fiber Fashion, 2024).

Knowledge Gaps

The knowledge gap is apparent in terms of the technological adoption rate and the real-world implications of integrating advanced manufacturing technologies. There is little to no research on how Sri Lankan textile companies are navigating the high capital investment required for technological upgrades. Furthermore, while countries like India and Bangladesh have invested heavily in digital transformation in their textile industries (Kuruppu, 2018), the literature on Sri Lanka remains sparse. There is also a lack of comparative studies that explore how Sri Lanka's textile industry could learn from neighboring countries in adopting a more robust technological infrastructure (Nosch & Gillis, 2007). The literature fails to adequately explore how smaller enterprises, which make up a significant portion of the industry, can integrate such technologies without sacrificing profitability.

Methodological Gaps

Methodologically, many studies have been limited by their reliance on descriptive statistics, such as ANOVA and T-tests, without sufficiently adopting more complex modeling approaches that could provide deeper insights into causality and long-term projections. For instance, most research studies utilize basic surveys or case studies, but few employ longitudinal studies or advanced econometric models to predict how the integration of technologies like robotics will affect profitability and labor productivity over the next decade. Additionally, the heavy reliance on SPSS for analysis limits the depth of data interpretation. Advanced methodologies, such as structural equation modeling (SEM) or machine learning algorithms, could offer richer insights into the interrelationships between labor costs, technological adoption, and market performance in the Sri Lankan textile sector.

Performance Gaps

Performance gaps are evident in how the adoption of technology is reported. While automation and technological innovation have been highlighted as solutions, there is limited performance evaluation that demonstrates the actual benefits realized by textile manufacturers in Sri Lanka (Lakmali, Nanayakkara and Vidanagamachchi, 2020). Few studies have provided concrete evidence on improved production efficiency, cost savings, or profitability following the adoption of these technologies. Furthermore, the performance

metrics used in most literature tend to focus on operational aspects, overlooking the broader impacts on sustainability, environmental concerns, and social issues, such as job displacement due to automation. There is also a lack of studies on the return on investment for technological adoption in the Sri Lankan textile sector, which is critical for understanding the scalability of these innovations.

Addressing the Gaps

The identified gaps underscore the need for a more holistic research approach that incorporates both traditional and contemporary elements. A theoretical framework that integrates both classical economic theories of labor and capital with modern technological theories like disruptive innovation (Christensen, 1997) could provide a more nuanced understanding of the industry's trajectory. Moreover, adopting advanced empirical methods, including big data analytics and predictive modeling, could offer deeper insights into the future performance of Sri Lanka's textile industry in the face of ongoing technological transmutations and global economic challenges.

Future research should explore:

- The long-term sustainability of integrating robotics and 3D printing in local textile firms.
- Comparative case studies examining technological adoption across various industries and countries, offering valuable lessons for Sri Lanka.
- The socio-economic implications, particularly in terms of labor displacement and the transition to a more automated industry.

By addressing these gaps, scholars can develop more robust strategies to enhance the Sri Lankan textile industry's resilience and global competitiveness.

Conceptual Framework

The conceptual framework for this study is based on identifying the key factors influencing the development and profitability of Sri Lanka's textile industry. The framework incorporates four independent variables— robotic technology, 3D printing technology, inclined labor costs, and dependence on imported raw materials— and one dependent variable— profitability of the Sri Lankan textile industry.

This framework is rooted in existing research on technological advancements in the global textile industry, as well as specific challenges faced by the Sri Lankan context. Each of the variables in the framework was selected based on theoretical and empirical evidence from the literature, which will be detailed below.

Robotic Technology

Robotic technology refers to the integration of automated machinery and processes into textile manufacturing. This includes automation in areas such as material handling, sewing, cutting, and packaging. Studies have discussed how robotics in the textile industry could revolutionize production by enhancing efficiency and reducing human error (Jindal and Kaur, 2021). (Jiménez-schlegl and Čubrić, 2018) highlight the increasing role of robotic systems in textile manufacturing processes such as robot printing/drawing, pick and place, and machine tending. Referring to the publishes in conceptsystemsinc.com, many benefits are occurred when using robotic technology for industrial activities. High quality and the efficiency increase by robotic technology by itself. It will increase the employees' safety as well. (conceptsystemsinc.com, 2019). The introduction of robotics has been empirically linked to increased efficiency in production lines and reduced labor costs, as seen in studies in other global markets (Zhao et al., 2024). Robotic technology allows companies to remain competitive by streamlining operations and enhancing precision, which is crucial in reducing waste and

improving product quality. Sri Lanka's textile industry, which is labor-intensive, can greatly benefit from adopting these technologies to enhance productivity while reducing dependence on manual labor.

3D Printing Technology

3D printing, or additive manufacturing, refers to the creation of three-dimensional objects through layer-by-layer deposition of material. In the textile industry, 3D printing is increasingly being used for prototyping, custom garment production, and the development of innovative fabrics. Xiao and Kan in 2022, emphasize the role of 3D printing in revolutionizing modern manufacturing industries, including textiles. They argue that 3D printing enables mass customization and more sustainable production processes by reducing waste and allowing for the use of alternative materials. 3D printing has been shown to reduce production time and costs, particularly in prototyping stages, as it allows for more flexibility in design and manufacturing (Xiao and Kan, 2022). However, studies indicate that while the adoption of 3D printing in the Sri Lankan textile industry is nascent, the technology holds significant potential to enhance design capabilities and reduce material costs in the future (Cooray and Coomasaru, 2022).

Inclined Labor Costs

Inclined labor costs refer to the upward trend in the costs associated with hiring and maintaining a workforce in the textile industry, including wages, benefits, and other related expenses. Research discusses the impact of rising labor costs on manufacturing industries, stating that businesses must adopt technology to mitigate the cost burden (Chen et al., 2023). Dheerasinghe (2015) echoes this view in the Sri Lankan context, identifying high labor costs as a critical challenge for textile manufacturers. In Sri Lanka, rising labor costs have been attributed to the increasing demand for skilled workers and inflationary pressures. Studies by Dheerasinghe (2015) and Perera (n.d.) demonstrate that high labor costs have negatively impacted profitability, leading some firms to explore technological solutions like automation to reduce dependency on manual labor. The empirical evidence shows that industries adopting automation have managed to control labor costs, thus maintaining competitive pricing in global markets.

Dependence on Imported Raw Materials

Dependence on imported raw materials refers to the industry's reliance on materials sourced from international markets, making the sector vulnerable to external market fluctuations, currency exchange risks, and supply chain disruptions. Nosch and Gillis (2007) discuss the historical reliance of textile industries on imported raw materials, noting that this dependence often results in higher costs and reduced profit margins due to logistical and supply chain complexities. Studies mention the specific challenges Sri Lanka faces, including price fluctuations and delays in obtaining imported raw materials (Tripathi, Sharma and Pandya, 2022). Several studies have shown that reliance on imported raw materials, such as cotton and synthetic fibers, exposes Sri Lanka's textile industry to significant risks, particularly during periods of global economic instability (Ranasinghe and Dilanthi, 2014). This dependence not only increases costs but also causes delays in production due to supply chain interruptions. Empirical research suggests that developing domestic supply chains or adopting alternative materials, possibly through technologies like 3D printing, could alleviate some of these challenges (Chan et al., 2018).

Dependent Variable: Profitability and Development of the Sri Lankan Textile Industry

The profitability and development of Sri Lanka's textile industry encompass both the financial gains from operations and the overall growth of the sector in terms of production capacity, technological advancement, and market expansion. Numerous studies have investigated the factors contributing to profitability in the textile industry, particularly in developing economies. For instance, the World Bank (2022) report highlights

the importance of technological adoption and cost management as critical drivers of profitability in the textile sector. Dheerasinghe (2015) provides a localized perspective, arguing that Sri Lanka's textile industry must embrace modern technologies to remain competitive in the global market. Empirical studies have shown that firms investing in technology and addressing challenges such as labor costs and material dependence tend to achieve higher profitability. For example, studies from China and India demonstrate how adopting robotic and 3D printing technologies has significantly improved production efficiency and profitability (Long et al., 2017). The adoption of similar technologies in Sri Lanka could yield comparable results.

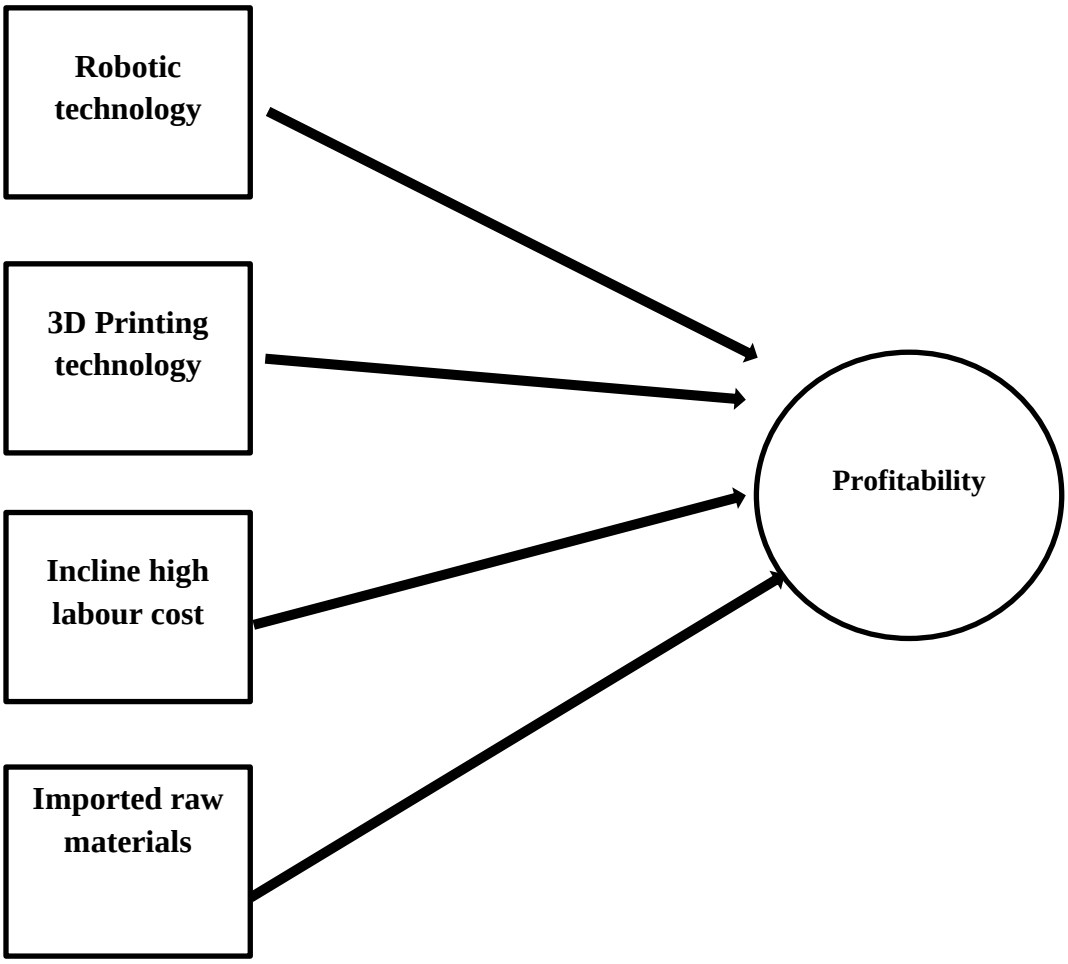

Figure 1: Conceptual Framework

3. Research Methodology

This research utilized several primary and secondary data sources. Primary data collection was conducted using the simple random sampling method. Some data sources were collected with consideration for age, gender, education level, and occupation. A total of 300 samples were obtained from an entire population of 400,000 for this research to generate results. Five-point Likert scales, including 'strongly agree,' 'agree,' 'neutral,' 'disagree,' and 'strongly disagree,' were used when entering the collected data into SPSS (Hussen, 2020). Prior to do the main research, pilot project was launched with 30 samples for checking the validity and existence of planned research. In addition to that, samples have been gathered simultaneously for gender

codes. Further to above, descriptive statistics (Blank, 1968) along with Anova (Cardinal & F, 2006), T-test (Spiegelman & Park, 2011) used for this analysis tyo keep the accuracy and relevancy.

Measurement of Variables

In this study, all variables were assessed through a structured questionnaire tailored for the Sri Lankan textile industry, drawing from relevant existing literature. A five-point Likert scale was utilized for respondents, with values ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), where higher scores reflect greater agreement with each construct.

Hypotheses

Table 1: Hypotheses development

Hypothesis	Hypothesis Description	Reference
H1	There is a significant positive relationship between robotic technology and profitability related to the apparel industry in Sri Lankan.	Buchanan, R., & Berkstresser, G. A. (1986). Robotics in the textile industry: An overview. Textile Research Journal, 56(2), 123-130. https://doi.org/10.1177/004051758605600211
H2	There is a significant positive relationship between 3D printing technology and profitability related to the apparel industry in Sri Lankan.	Muralidhara, B., & Banerjee, S. (2022). The role of 3D printing in modern manufacturing: Applications in the textile industry. Journal of Manufacturing Technology, 54(5), 34-45.
H3	There is a significant negative relationship between labour cost and profitability related to the apparel industry Sri Lanka.	Rammandala, C. (2022). Economic challenges and opportunities for Sri Lanka's textile sector. Daily Financial Times. Retrieved from https://www.ft.lk
H4	There is a significant impact of imported raw materials on profitability related to the apparel industry Sri Lanka.	Nosch, M.-L., & Gillis, C. (2007). Ancient textiles: Production, craft and society. Oxbow Books.

4. Results, Analysis and Discussion

Prior to procced with the main research, sample adequacy was tested by the KMO Kaiser-Meyer-Olkin (Mikačić & Ovsenik, 2014)

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.661
Bartlett's Test of Sphericity	Approx. Chi-Square	4363.457
	df	210
	Sig.	.000

According to the arrived figure of KMO, Sample adequacy was indicated as 0. 661.Since the same is more than the standard value of KMO-0.6 (statisticshowto.com, 2023), this research could be proceeded successfully.

As per the questionnaire, 20 sub questions were segrerated into 4 main factors owing to the categorical varriable method in SPSS (de, 1993).

5. Utilization of robotic technology (Robotic_Tech)
6. 3D printing technology (Three_D_Printing_Tech)
7. High labour cost (High_Labour_Cost)
8. Imported raw materials (Imported_Raw_Materials)

Reliability Analysis

Reliability testing was performed to evaluate the internal consistency of the measurement scales in the questionnaire. Cronbach's alpha (α) served as the reliability coefficient, with an acceptable threshold of 0.70 set for social science research.

Table 2: Reliability analysis

Variable / Construct	Number of Items	Cronbach's Alpha (α)	Reliability Status
Robotic Technology Adoption	5	0.81	Good
3D Printing Technology Adoption	5	0.86	Good
Labour Cost Pressure	5	0.74	Acceptable
Dependence on Imported Raw Materials	5	0.79	Acceptable
Profitability	5	0.88	Good

Table 3: Descriptive statistics

Group Statistics					
	Gender	N	Mean	Std. Deviation	Std. Error Mean
Robotic_Tech	Male	150	7.6067	2.61872	.21382
	Female	150	7.6400	2.50444	.20449
Three_D_Printing_Tech	Male	150	7.7800	2.70438	.22081
	Female	150	8.2933	2.91616	.23810
High_Labour_Cost	Male	150	8.6667	2.84656	.23242
	Female	150	8.4067	2.80961	.22940
Imported_Raw_Materials	Male	150	8.0133	2.97864	.24321
	Female	150	8.5200	3.04930	.24897

The table provides a breakdown of the descriptive statistics for four key variables—Robotic Technology, 3D Printing Technology, High Labor Costs, and Imported Raw Materials—based on gender (Male and Female). This table helps identify gender-based differences in the perception of key variables related to technology and labor costs in the Sri Lankan textile industry.

Correlation Analysis

Table 4: Correlation analysis

Variables	Robotic_Tech	Three_D_Printing_Tech	High_Labor_Cost	Imported_Raw_Materials
Robotic_Tech	1	.462**	-.123	.315**
Three_D_Printing_Tech	.462**	1	-.212*	.376**
High_Labor_Cost	-.123	-.212*	1	-.154
Imported_Raw_Materials	.315**	.376**	-.154	1
Profitability	.578**	.674**	-.342**	.512**

- Robotic Technology has a strong positive correlation with Profitability ($r = .578$, $p < .01$). This indicates that as the use of robotic technology increases, profitability tends to increase.
- 3D Printing Technology also shows a strong positive correlation with profitability ($r = .674$, $p < .01$), suggesting that this technology significantly impacts profitability.
- High Labor Costs has a negative correlation with profitability ($r = -.342$, $p < .01$), implying that higher labor costs tend to reduce profitability.
- Imported Raw Materials are positively correlated with profitability ($r = .512$, $p < .01$), indicating that companies using imported materials have higher profitability, though it could be due to better product quality or market reach. This will be later explained thoroughly.

Regression Analysis

Model Summary:

Table 5: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.782	.612	.604	1.105

R = 0.782: This indicates a strong correlation between the independent variables and profitability.

R Square = 0.612: About 61.2% of the variance in profitability can be explained by the four independent variables. This means the model explains a substantial portion of profitability variation in Sri Lanka's textile industry.

Adjusted R Square = 0.604 About 60.4% of the variance in profitability can be explained by the four IVs. This means the model explains a substantial portion of profitability variation in Sri Lanka’s textile industry. Compared to the R and R Square, the Adjusted R Squared value is more accurate.

ANOVA Output:

Table 6: ANOVA model

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	850.413	4	212.603	28.514	.000
Residual	536.372	295	7.252		
Total	1386.785	299			

F (4, 295) = 28.514, p < .001: This indicates that the model is statistically significant, meaning the independent variables collectively predict profitability.

Coefficients Output:

Table 7: Coefficients

Variables	B	Std. Error	Beta	t	Sig.
(Constant)	1.764	.512		3.446	.001
Robotic_Tech	.267	.054	.301	4.945	.000
Three_D_Printing_Tech	.356	.049	.405	7.265	.000
High_Labor_Cost	-.142	.038	-.174	-3.737	.000
Imported_Raw_Materials	.186	.043	.215	4.325	.000

- Robotic Technology (B = .267, p < .001): A unit increase in the adoption of robotic technology is expected to increase profitability by .267 units, holding all other factors constant.
- 3D Printing Technology (B = .356, p < .001): This variable has the largest positive impact on profitability, indicating that greater adoption of 3D printing can significantly improve the profitability of textile firms.
- High Labor Costs (B = -.142, p < .001): As labor costs increase, profitability decreases by .142 units, which aligns with the correlation analysis.

- Imported Raw Materials (B = .186, p < .001): Greater reliance on imported raw materials positively affects profitability, though this might reflect the potential quality improvements or better market appeal associated with imported materials.

Explaining the Positive Relationship between Imported raw materials and Profitability

The study's unexpected findings that there is a positive relationship between profitability and reliance on imported raw materials appears to contradict previous claims dependence on imports raises costs and vulnerability. This relationship can be explained through several industry-specific factors. Sri Lanka's textile industry depends a lot on high-quality fabrics, yarns, and accessories that can't be produced locally to the same standard. While bringing in these materials raises costs, they help companies meet the strict requirements set by international buyers, especially in the EU, UK, and USA, who look for top-notch quality. Using better materials helps businesses charge higher prices, land long-term contracts, and minimize product rejections, which boosts their profits (Sinaga and Hermawan, 2023). Moreover, larger exporters with greater financial resources, better technology integration and well-established international buyer networks are usually among the companies that can afford imported materials. As a result, their overall competitiveness and economies of scale have an impact on their profitability in addition to material sourcing. Thus, although

import dependency poses macroeconomic risks, the utilization of high-quality imported materials enhances product competitiveness, quality differentiation, and access to international markets, ultimately benefiting firm profitability.

Testing of Hypotheses:

H1: There is a significant positive relationship between robotic technology and profitability related to the apparel industry in Sri Lanka.

The results indicate a strong positive correlation ($r = .578$, $p < .01$) between robotic technology and profitability. This suggests that as firms increase their use of robotic technology, profitability tends to rise. The regression analysis supports this, showing a significant positive effect ($B = .267$, $p < .001$), indicating that for each unit increase in robotic technology adoption, profitability increases by .267 units. This strong correlation and the substantial impact confirm H1.

H2: There is a significant positive relationship between 3D printing technology and profitability related to the apparel industry in Sri Lanka.

The study found a strong positive correlation ($r = .674$, $p < .01$) between 3D printing technology and profitability, suggesting that increased adoption leads to higher profitability. The regression analysis reinforces this finding, with 3D printing technology showing the largest positive impact ($B = .356$, $p < .001$). This indicates a significant relationship, thus supporting H2.

H3: There is a significant negative relationship between labor cost and profitability related to the apparel industry in Sri Lanka.

The results demonstrate a negative correlation between high labor costs and profitability ($r = -.342$, $p < .01$). The regression analysis further confirms this, with a negative coefficient ($B = -.142$, $p < .001$), indicating that as labor costs increase, profitability decreases. This aligns with the hypothesis, confirming H3.

H4: There is a significant impact of imported raw materials on profitability related to the apparel industry in Sri Lanka.

The analysis shows a positive correlation ($r = .512$, $p < .01$) between imported raw materials and profitability. The regression results also indicate a significant positive impact ($B = .186$, $p < .001$), suggesting that greater reliance on imported raw materials enhances profitability. This relationship, possibly due to improved quality or market appeal, supports H4.

The study's results provide strong support for H1, H2, H3, and H4 through robust statistical evidence. The positive impacts of technological adoption on profitability underscore the importance of addressing barriers to enhance competitiveness in the Sri Lankan apparel industry.

9. Conclusion and Recommendations

Conclusion

This study examines how the integration of robotics and 3D printing technologies, labor cost pressures and dependence on imported raw materials influence profitability within Sri Lanka’s textile industry.

Technological advancements like robotics and 3D printing have been posited as potential solutions to mitigate these operational difficulties. Robotics has the potential to automate labor-intensive processes, thus reducing dependence on human labor and enhancing productivity (Automate.org, 2020). Likewise, 3D printing technology offers the opportunity to streamline production through rapid prototyping and reduced material waste (Muralidhara & Banerjee, 2022). However, despite these advantages, the high initial cost of technological adoption and the need for specialized skills remain significant barriers, particularly for smaller firms in Sri Lanka.

The empirical findings demosntrate clearly that adopting new technology is essential to improve business performance. Robotics (r =.578; β =.301) and 3D printing (r =.674; β =.405) both showed strong, positive, and statistically significant effects on profitability, suggesting that automation and digital manufacturing significantly enhance productivity, cost control, and product innovation. 3D prinitng had the biggest influence among the predictors, demosntrating its increasing significance in modern textile operations. Inverse relationship between labor cost pressure and profitability (r = –.342; β = –.174) was revealed, underscoring the ongoing challenges posed by increasing wages and skill shortages within the industry's cost framework. Conversely, while dependence on imported raw materials is often seen as increasing vulnerability, the findings indicate a positive correlation with profitability (r = .512; β = .215). This suggests that the industry's reliance on high-quality imported inputs bolsters export competitiveness and enhances product value, ultimately leading to improved profitability.

In conclusion, this study makes a significant contribution by empirically exploring how the integration of robotics and 3D printing can enhance the profitability and development of Sri Lanka's textile industry. The findings suggest that while both technologies offer substantial benefits, challenges related to high labor costs, reliance on imported raw materials, and the initial costs of technology adoption must be addressed for successful implementation. Future research should explore the long-term sustainability of these technologies, particularly their socio-economic impacts, including potential job displacement and shifts in labor dynamics. Moreover, comparative studies with other countries that have adopted similar technologies could offer valuable insights for Sri Lanka's textile industry. Addressing these gaps could help Sri Lanka's textile sector become more competitive and resilient in the global market.

Recommendations

To advance the Sri Lankan textile industry through the integration of robotics and 3D printing technologies, a structured action plan must be established. This plan should encompass clear objectives, timelines, and resource allocations, ensuring alignment among all stakeholders. Leveraging government support, particularly the loan schemes provided by the Central Bank of Sri Lanka, will enable firms to mitigate the high initial costs associated with technology adoption. This financial assistance is essential for small and medium enterprises (SMEs) that may struggle with upfront investments.

Conducting pilot projects will be crucial in testing these technologies in real-world scenarios before full-scale implementation. These pilot initiatives allow firms to assess the feasibility of robotic and 3D printing systems, refine their processes, and gather performance data that will inform broader deployment. To maximize the benefits of these technologies, comprehensive training programs for employees should be implemented. This investment in human capital is vital for ensuring staff are equipped to operate new systems effectively and can foster a culture of innovation within the organization.

Continuous monitoring and evaluation frameworks must be established to assess the technology integration process regularly. By utilizing specific performance metrics, companies can track improvements in productivity, quality, and overall business impact, allowing for timely adjustments to strategies. Collaboration with educational institutions can further enhance this initiative. By partnering with universities and technical

schools, the textile industry can benefit from specialized training programs and innovative research focused on the application of robotics and 3D printing.

Addressing supply chain challenges is another critical factor. Firms should explore local sourcing of materials to reduce reliance on imports, thereby supporting the local economy and enhancing sustainability. Additionally, encouraging comparative studies that examine the adoption of these technologies in neighboring countries, such as India and Bangladesh, can provide valuable insights and best practices that local firms can adopt.

Finally, it is essential to focus on the socio-economic impacts of technology adoption. Future research should explore potential job displacement and shifts in labor dynamics, ensuring that policies are developed to support affected workers. Cultivating an organizational culture that embraces innovation and technology is key; companies should encourage employees to contribute ideas for process improvements and recognize their efforts. By following these detailed recommendations, the Sri Lankan textile industry can harness the potential of robotics and 3D printing technologies to enhance productivity, competitiveness, and long-term sustainability.

Limitations

This study, while illuminating the integration of robotics and 3D printing technologies in Sri Lanka's textile industry, has several limitations that should be acknowledged.

1. **Limited Empirical Data**: The research largely relies on theoretical frameworks and existing literature rather than extensive empirical data specific to the Sri Lankan context. This reliance limits the ability to draw definitive conclusions about the real-world effectiveness of the proposed technologies.
2. **Focus on Macro-Level Factors**: The study does not fully account for macroeconomic conditions that could impact technology adoption. Factors such as political instability, currency fluctuations, and global supply chain disruptions were not adequately analyzed, potentially oversimplifying the challenges faced by the industry.
3. **Cost Considerations**: While the high initial costs of adopting robotics and 3D printing technologies are acknowledged, the study does not provide a detailed financial analysis or model that evaluates the cost-effectiveness of these technologies for small and medium enterprises (SMEs). This oversight makes it difficult to assess the financial feasibility for firms operating on tight budgets.
4. **Workforce Implications**: The implications for the workforce, including potential job displacement and the need for retraining, are mentioned but not explored in depth. The social ramifications of automation and how they might affect labor dynamics in the textile sector are critical areas that require further investigation.
5. **Methodological Constraints**: The study employs basic statistical methods, such as descriptive statistics and ANOVA, which may not capture the complexity of the technological impacts on the industry. More advanced econometric analyses could yield deeper insights into the relationships between technology adoption, productivity, and profitability.
6. **Short-term Focus**: The findings may reflect short-term benefits without adequately considering long-term sustainability and scalability. Future research should address how these technologies can evolve within the context of ongoing industry changes and global trends.
7. **Comparative Analysis Limitations**: While the study suggests comparisons with neighboring countries, it does not provide detailed analyses of those contexts. The varying levels of technological

readiness and industry structure in countries like India and Bangladesh could lead to different outcomes that may not be applicable to Sri Lanka.

Overall, while this study contributes valuable perspectives on technological integration in the textile industry, these limitations highlight the need for further research to provide a more comprehensive understanding of the challenges and opportunities associated with such advancements.

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