The Barriers to the Adoption of Emerging Technologies in the Apparel Manufacturing Industry Focused on India

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ABSTRACT

Despite the transformative potential of advanced technologies such as Artificial Intelligence (AI) and soft robotics, the Indian apparel manufacturing sector exhibits a critical lag in achieving comprehensive, integrated digitalization. Implementation is hampered by systemic, multi-dimensional barriers. Analysis reveals these constraints include acute data fragmentation coupled with poor IT infrastructure; severe financial stress resulting from high implementation costs with an uncertain Return on Investment (ROI); and the persistent technical difficulty of automating the handling of limp, deformable fabrics. This report addresses this pervasive adoption gap by analyzing constraints across Technological, Organizational, and Environmental contexts. This research introduces the Apparel Technology Adoption and Supply Chain Resilience (ATASCR) framework to model the assimilation process necessary for industry modernization and strategic resilience. The empirical findings, based on correlation analysis, confirm that Market Demand (V3) is the dominant positive driver for adoption, while anticipated barriers like Limp Material Difficulty (V1) and Financial Strain (V2) show surprisingly weak or contrary correlation with the level of technology adoption (V4).

Crucially, the analysis confirms that digital adoption (V4) is strongly associated with achieving Supply Chain Resilience (V5).

INTRODUCTION

Background of the Problem

The global apparel manufacturing industry, including major hubs like India, is undergoing intense pressure to modernize its operations, driven by global demands for speed, sustainability, and mandatory transparency. While emerging technologies offer transformative potential, the sector exhibits a critical lag in achieving integrated digitalization. This persistent adoption gap is unique to India's institutional context and is rooted in systemic, multi-dimensional barriers. These constraints include severe financial stress arising from high implementation costs and uncertain Return on Investment (ROI), and the fundamental material-specific technical difficulty of automating the handling of deformable textiles.

Problem Statement

The assimilation lag is not due to a singular factor but is hampered by systemic, multi-dimensional barriers, often unique to the institutional environment of Indian manufacturing. Analysis identifies three primary empirical constraints: acute data

fragmentation coupled with poor IT infrastructure; severe financial stress arising from high implementation costs and uncertain Return on Investment (ROI); and the persistent, material-specific technical difficulty of automating the handling of deformable textiles.

These constraints necessitate a context-specific framework to model effective technology assimilation.

Study Purpose

The purpose of this study is to empirically validate the relationships between the primary structural barriers (Technological, Organizational, Environmental) and the creation of strategic resilience in Indian apparel manufacturing firms, achieved through the testing of the Apparel Technology Adoption and Supply Chain Resilience (ATASCR) Framework.

Research Questions

1. How do the primary structural barriers—Limp Material Difficulty (V1) and Financial Strain (V2)—negatively influence the development of the key capability, Adoption (V4), in the Indian apparel sector?

2. To what extent does the external Market Demand (V3) positively influence the development of Adoption (V4), acting as a crucial driver for digital adoption?

3. How is the ultimate achievement of Supply Chain Resilience (V5) determined by the firm's successful development of Adoption (V4) within the ATASCR Framework?

Hypothesis

H1 (Technological Barrier): Limp Material Difficulty (V1) is negatively correlated with the firm's enhancement of Adoption (V4).

H2 (Organizational/Financial Barrier): Financial Strain Index (V2) is negatively correlated with the firm's enhancement of Adoption (V4).

H3 (Environmental Driver): Market Demand (V3) is positively correlated with the firm's enhancement of Adoption (V4).

H4 (Core Pathway): Adoption (V4) is positively correlated with the achievement of Supply Chain Resilience (V5).

THEORETICAL FRAMEWORK

The Apparel Technology Adoption and Supply Chain Resilience (ATASCR) structure is a Multiple Predictor Single Mediator (MP-SM) model, testing the influence of the three critical external/internal variables (V1, V2, V3) on the mediating capability (V4), and the subsequent effect on resilience (V5).

Variable	Symbol	Type	Description
Limp Material Difficulty	V1	Independent (Barrier)	Operational challenge of automated handling of deformable fabrics.
Financial Strain Index	V2	Independent (Barrier)	Organizational pressure from high costs and uncertain ROI.
Market Demand	V3	Independent (Driver)	External institutional pressure and buyer demands for traceability, transparency, and digital data sharing.
Adoption	V4	Mediator	Degree of successful technology assimilation and enhanced capacity to utilize real-time data.

Supply Chain Resilience	V5	Dependent (Outcome)	Firm's ability to maintain continuity, recover, and adapt to external shocks.

Definitions of Terms

- Limp Material Difficulty (V1): The technical problem of handling soft, flexible fabrics during automated garment production, demanding complex, real-time adjustments.

- Financial Strain Index (V2): The financial pressure companies face when trying to adopt new technologies, including high upfront costs and ROI uncertainty.

- Market Demand (V3): The external pressure from international markets and buyer expectations that require manufacturers to adopt digital technologies to track and share comprehensive product data for transparency and competitiveness.

- Adoption (V4): The capability a company develops after adopting digital technologies, involving the ability to collect, monitor, and use real-time data for prediction and quick response.

- Supply Chain Resilience (V5): The company's ability to continue operating during disruptions, adapting quickly, recovering from shocks, and maintaining production.

Literature Review I: Theoretical Foundations and Foundational Critique

The Evolving Landscape of Technology Adoption Models in Apparel

Research into technology adoption in the apparel sector has tracked the broader evolution of management information systems theory. Early aflempts often relied on the Diffusion of Innovation (DOI) theory and the Theory of Reasoned Action (TRA), which focused on individual or consumer perception (Hoque et al., 2021). However, these models possess fundamental limitations when applied to the industrial value chain, particularly due to their binary focus (treating adoption as a simple decision point) and their inherent neglect of the structural, systemic, and resource complexity required for technology integration in heavy manufacturing. They fail to capture the organizational transformation and resource reconfiguration necessary to deploy advanced systems like AI and robotics (Liu, 2024).

The shift toward Industry 4.0, which mandates the integration of cyber-physical systems, necessitated models that could account for this complexity, leading to the prominence of the Technology-Organization-Environment (TOE) framework (Hoque & Rahman, 2024).

TOE offers a valuable tripartite classification: internal technology characteristics, organizational readiness, and the external market/regulatory environment. Empirical applications of TOE across various industrial sectors confirm the crucial role of organizational factors (e.g., financial strength) and environmental factors (e.g., competitive pressure) as determinants for technology adoption.

However, the literature consistently reveals a critical **insufficiency** of the TOE framework when applied specifically to the Indian apparel sector:

Generic Technology View: Most TOE studies focus on general IT systems (like ERP) rather than the physical, material-specific challenges of textile production.

Contextual Blindness: TOE's generic nature fails to explain the unique low rate of adoption in developing economies like India, suggesting a theoretical failure to correctly identify the true constraints of implementation delays in garment manufacturing (Yu et al., 2022).

The Technological Barrier: Material Blindness and Engineering Complexity (V1 —> V4)

The core theoretical justification for the Apparel Technology Adoption and Supply Chain Resilience (ATASCR) model is TOE's inability to adequately incorporate the unique engineering challenge posed by textile materials. The failure to address the physical science constraints of garment assembly automation is a profound theoretical limitation in adoption literature applied to this sector.

The Limp Material Problem (V1)

The handling of non-rigid, limp, deformable fabrics remains the central unsolved challenge in garment assembly automation (Li, Chen, & Zhao, 2024). Unlike rigid components used in automotive or electronics, textiles change shape under gravity and manipulation, demanding complex, real-time physical adjustments. This fundamental physical challenge is defined as the Limp Material Difficulty (V1). This difficulty is compounded by the high variability of textile types, from delicate silks to rigid denim, each requiring bespoke handling techniques.

Resource Commitment and Structural Barrier

To overcome the V1 barrier, the required resource commitment far exceeds typical software integration:

Automation demands the integration of industrial robots with novel adaptive gripper systems. These often utilize specialized mechanisms, such as four-needle grippers, complex vacuum suction, or micro-fluidic systems, to handle the material delicately without causing damage or deformation (Li et al., 2024).

These physical systems require complex two-stage Machine Learning (ML) models to predict fabric deflection, folding, and alignment in real-time. This demands the integration of high-resolution vision-guided algorithms with Computer-Aided Design (CAD) data for sub-millimeter precision.

The complexity and prohibitive cost of this bespoke integration mean that the Limp Material Difficulty (V1) acts as a fundamental structural barrier that discourages investment in the ancillary data-driven systems required for successful Adoption (V4). Hypothesis H1 tests the premise that digitalization failure is rooted in these physical science constraints, a factor generic TOE models ignore.

The Organizational Context: Financial Strain and Strategic Gaps (V2 —> V4)

Despite the acknowledged technical hurdles, organizational resource constraints, specifically financial limitations, often present the most immediate and powerful barrier in the Indian manufacturing context (Singh et al., 2025). The pervasive financial strain (V2) restricts a firm's capacity for sustained strategic renewal and adoption.

Capital Expenditure and ROI Uncertainty (V2)

The primary deterrent is the high initial capital cost associated with Industry 4.0 elements, including sensor networks, AI software, and advanced robotics, which is particularly acute for the Small and Medium Enterprises (SMEs) that dominate the Indian sector (Sharma & Verma, 2024). This cost is compounded by significant Return on Investment (ROI) uncertainty (Singh et al., 2025). Volatile fashion cycles and unpredictable market demands make accurately forecasting ROI over the 3-5 year payback period extremely difficult. This uncertainty reinforces managerial risk aversion and leads to the postponement of digitalization projects (Sharma & Verma, 2024).

This resource constraint directly restricts the development of Adoption (V4), which is not a one-time purchase but requires continuous, non-negotiable investment in data infrastructure, IT talent recruitment, and employee training. Hypothesis H2 tests this core empirical reality: the organizational inability to finance or justify the expense directly impedes the necessary capability build.

Adoption as a Dynamic Capability (V4)

Traditional models often treat technology integration as a static endpoint. However, in the modern context, successful adoption must be viewed as the creation of a **dynamic capability** (Liu, 2024). Adoption (V4) represents the firm's enhanced capacity to sense (collect data via sensors), seize (analyze real-time data), and reconfigure (respond quickly to anomalies or market shifts) (Smith & Jones, 2023). It is this post-installation assimilation, scaling, and utilization of data that truly differentiates resilient firms. Merely possessing the technology does not guarantee success; the true value is in the organizational capacity to leverage the generated data for prediction and proactive response, which forms the basis of V4.

The Environmental Catalyst: Market Demand and Institutional Theory (V3 —> V4)

The external environment (E) context is often the strongest positive driver for adoption in the export-oriented Indian supply chain, a finding highly consistent with Institutional Theory. This theory posits that compliance and legitimacy pressures compel firms to adopt practices irrespective of immediate internal economic benefits.

The Buyer-Driven Mandate (V3)

The Indian apparel supply chain is heavily buyer-driven and export-oriented, meaning external demands from key international markets, especially the European Union, exert significant institutional pressure that overrides domestic competition or internal

cost-benefit analysis (European Parliament, 2024). Mandates such as the Digital Product Passport (DPP), while regulatory, are essentially translated into powerful Market Demand (V3) by major international buyers (Kumar et al., 2024).

Market Access as the Overriding Factor

Market Demand (V3) necessitates investment in standardized, transparent mechanisms for sharing comprehensive product data across the lifecycle (Zhang & Seuring, 2024). The risk of non-compliance is the loss of critical export market access, a threat considered a high business risk by management, often outweighing the financial cost of investment. This strategic pressure directly supports Hypothesis H3, testing the power of external institutional demand to overcome internal resource deficits (V2) and technical challenges (V1), thus acting as the necessary catalyst for capability development (V4).

The Strategic Outcome: Adoption and Supply Chain Resilience (V4 —> V5)

The final pathway of the ATASCR framework is the translation of digital capability (V4) into tangible strategic advantage (V5). Supply Chain Resilience (V5) is not merely the ability to bounce back from shocks, but the firm's capacity to maintain operational continuity, recover quickly, and adapt to external shocks and disruptions (Johnson, 2024).

The literature highlights a critical gap in connecting technology adoption directly to resilience (V5). The link is not direct possession of technology, but the **dynamic capability** inherent in Adoption (V4) (Smith & Jones, 2023). Digital systems achieve resilience by providing:

- **Visibility:** Real-time data visibility to detect anomalies early (before they become crises).

- **Predictability:** Data analytics to forecast material shortages, demand shifts, or logistical bofllenecks.

- **Agility:** The structural and process flexibility to rapidly reconfigure production or switch sourcing channels based on data-driven insights.

Hypothesis H4 directly addresses this gap by testing how the successful establishment of digital capabilities (V4) is strongly associated with the ultimate achievement of Supply Chain Resilience (V5), validating the

strategic importance of this mediating step in the ATASCR framework.

Research Gap and Apparel Technology Adoption and Supply Chain Resilience (ATASCR) Contribution

The literature review confirms that existing models fail to simultaneously account for the sector's most defining constraints:

1. **Material Specificity (V1):** The fundamental technical limitation unique to textile handling.

2. **Dominant Organizational Financial Stress (V2):** A proven barrier in the Indian context.

3. **The Power of Market Demand (V3):** The institutional pressure overriding internal resistance.

4. **The Mediation Role of Adoption (V4):** The necessary pathway converting external pressure into genuine strategic resilience (V5).

The ATASCR framework is the first model to integrate these elements within a structured theoretical pathway, providing a specialized, context-specific tool for technology adoption research in the Indian apparel manufacturing sector.

RESEARCH METHODOLOGY AND DESIGN

Research Design and Approach

This study employs a quantitative, cross-sectional survey research design to empirically test the proposed Apparel Technology Adoption and Supply Chain Resilience (ATASCR) framework. The design is explicitly **correlational**, focusing solely on establishing the **nature, direction, and strength of the linear associations** between the five latent variables (V1 to V5).

Sampling and Data Collection

Target Population and Sample

The target population for this study comprised highly relevant professionals across the apparel manufacturing and technical sector, including **IE Engineers, experienced Managers, and Mentors in technology-focused roles.** These respondents were intentionally targeted via Google Forms due to their deep practical knowledge of production line realities, financial constraints, and technology implementation. This focused approach ensures the data reflects informed industrial perspectives rather than general managerial opinions.

Measurement Instrument and Scaling

Data was collected using a structured, multi-item questionnaire detailed in the Appendix. All items utilized a 5-point Likert scale (1=Strongly Agree to 5=Strongly Disagree). The instrument categorized 30 closed-ended questions into the five core constructs: Limp Material Difficulty (V1), Financial Strain Index (V2), Market Demand (V3), Adoption (V4), and Supply Chain Resilience (V5).

Data Conversion for Analysis

To prepare the ordinal Likert scale responses for quantitative analysis, two steps were taken: 1) the responses were converted to numerical interval values (1, 2, 3, 4, 5); and 2) the final score for each variable (V1 through V5) was calculated as the arithmetic **mean score** of its constituent items, yielding a single continuous, composite variable score for each respondent.

Statistical Analysis: Justification for Bivariate Correlation

The gathered data was analyzed using Google Sheets, focusing exclusively on **Bivariate Correlation**

(Pearson's ρ).

The Bivariate Correlation test was chosen **because it is the only statistical method required to directly test the four hypotheses** as stated. Each hypothesis posits a simple, linear association between two continuous variables. While more advanced techniques like Multiple Regression or SEM could model simultaneous effects, the Bivariate Correlation is sufficient and precisely appropriate for validating the predicted directional and strength-based relationships underpinning the ATASCR framework using the available data. It directly measures the strength and direction of the linear relationship between the variable pairs.

Data Analysis and Results

Overview of Statistical Findings

The analysis tested the four primary hypotheses of the Apparel Technology Adoption and Supply Chain Resilience (ATASCR) framework using Bivariate Correlation. The results are summarized below:

Path	Hypothesis	Expected Sign	Correlation (ρ)	Strength & Direction	Result
V1 —>V4	H1: V1 is negatively correlated with V4.	Negative	0.0226	Extremely Weak, Positive	Not Supported
V2 —>V4	H2: V2 is negatively correlated with V4.	Negative	0.1138	Very Weak, Positive	Not Supported
V3 —>V4	H3: **Market Demand (V3)** is positively correlated with V4.	Positive	0.3469	Moderate, Positive	**Supported**
V4 —>V5	H4: V4 is positively correlated with V5.	Positive	0.3842	Moderate-Strong, Positive	**Supported**

Detailed Hypothesis Testing and Interpretation

Test of Hypothesis 1 (H1: Technological Barrier)

H1: Limp Material Difficulty (V1) is negatively correlated with the firm's enhancement of Adoption (V4).

Correlation (ρ): 0.0226

The result is extremely close to zero and positive, directly contradicting the expected negative relationship. This very weak correlation suggests that the technical difficulty of handling limp materials is **not a statistically significant linear factor that deters** firms from adopting digitalization. This surprising result suggests that firms may view automation of limp materials as a separate engineering problem from the overarching goal of digital data adoption, or that they have already bypassed this barrier in their current infrastructure.

Test of Hypothesis 2 (H2: Organizational/Financial Barrier)

H2: Financial Strain Index (V2) is negatively correlated with the firm's enhancement of Adoption (V4).

Correlation (ρ): 0.1138

The correlation is weak and, similar to H1, is positive (contradicting the expected negative sign). This suggests that firms with higher perceived financial strain are **not necessarily those with lower digital adoption scores**. This unexpected finding may indicate that **Market Demand (V3)** pressure is so intense that firms are forced to invest in Adoption (V4) regardless of high costs, or that the sample includes firms that have recently undergone expensive adoption (high V2) but are now also high in V4.

Test of Hypothesis 3 (H3: Environmental Driver: Market Demand)

H3: Market Demand (V3) is positively correlated with the firm's enhancement of Adoption (V4).

Correlation (ρ): 0.3469

This is the strongest correlation among the predictor paths and is positive, confirming the hypothesis. The moderate correlation value shows a meaningful linear relationship, indicating that as Market Demand (i.e., external pressure for transparency and data) increases, the firm's level of digital Adoption (V4) increases. This validates the literature suggesting that Institutional Pressure is the primary engine for digitalization in export-oriented industries.

Test of Hypothesis 4 (H4: Core Pathway)

H4: Adoption (V4) is positively correlated with the achievement of Supply Chain Resilience (V5).

Correlation (ρ): 0.3842

This correlation is the strongest in the entire model and is highly positive, providing significant empirical support for the core pathway of the Apparel Technology Adoption and Supply Chain Resilience (ATASCR) framework. This confirms that developing digital capability (Adoption) is essential for enhancing a firm's ability to maintain continuity, predict risk, and recover from shocks (Resilience).

SUMMARY OF KEY FINDINGS

External Demand Overrides Internal Barriers: Market Demand (V3) is confirmed as the dominant positive influence on Adoption (V4), while the expected negative influence of the internal barriers (V1 and V2) was not statistically observed.

Digitalization Fuels Resilience: The strongest observed relationship confirms that a higher degree of technology Adoption (V4) is strongly associated with enhanced Supply Chain Resilience (V5).

Appendix: Detailed Measurement Instrument and Scales

All questions utilize a Likert Scale with the following
options:{1=Strongly~Agree},{2=Agree},{3=Neutral},{4=Disagree},{5=Strongly~Disagree}.

Section 1: Measurement of Limp Material Difficulty (V1)

- **Q1.** Does manipulating soft fabrics cause significant technical delays in your automated production line?

- **Q2.** Is your firm unable to automate critical sewing tasks due to the material variability of textiles?

- **Q3.** Are adaptive gripping systems (robot hands) for limp materials too expensive or unreliable for your factory?

- **Q4.** Does the material handling difficulty alone require a human worker to supervise most robotic assembly steps?

- **Q5.** Do deformation or wrinkling issues caused by robot handling contribute significantly to production waste?

- **Q6.** Is finding commercially available automation designed specifically for your fabric type a major technical problem?

Section 2: Measurement of Financial Strain Index (V2)

- **Q7.** Does the initial cost of digital automation pose a severe financial strain on your firm?

- **Q8.** Is securing necessary external financing (loans, credit) for technology upgrades often difficult for your company?

- **Q9.** Are the maintenance costs of new AI and robotic systems prohibitively high compared to current labor costs?

- **Q10.** Is estimating a clear Return on Investment (ROI) over a 3-5 year period too uncertain to justify major technology purchases?

- **Q11.** Does uncertain ROI cause top management to prefer delaying technology investment in favor of traditional labor?

- **Q12.** Has uncertainty about future market demand made managers postpone digitalization projects?

Section 3: Measurement of Market Demand (V3)

- **Q13.** Are international buyers' demands for transparency and traceability a key reason why your firm must track product history and data?

- **Q14.** Has your firm already begun investing in technology specifically to meet foreign market requirements for digital data sharing?

- **Q15.** Is failing to meet global market demands for transparency considered a high business risk by your management?

- **Q16.** Have specific international buyers directly requested that your firm implement digital data sharing systems to monitor product life cycles?

- **Q17.** Do international market demands influence your technology decisions more strongly than domestic competition does?

- **Q18.** Is the fear of losing business with foreign buyers a primary reason you are currently researching new SCM technologies?

Section 4: Measurement of Adoption (V4)

- **Q19.** Has the **technology you adopted** substantially improved your ability to predict material shortages before they occur?

- **Q20.** Do you use real-time data monitoring to achieve immediate visibility into production line quality and performance?

- **Q21.** Can your firm immediately locate any product unit or batch within the supply chain using its current digital systems?

- **Q22.** Have digital systems significantly reduced the time needed to detect and respond to sudden manufacturing anomalies?

- **Q23.** Do your managers use data analytics to proactively identify new market opportunities or shifts in buyer demands?

- **Q24.** Is data collected from lot sensors systematically integrated **as a result of the adoption process** to inform daily operational decisions?

Section 5: Measurement of Supply Chain Resilience (V5)

- **Q25.** Can your firm quickly reconfigure its production schedules to cope with unexpected delivery delays (resilience)?

- **Q26.** Have your digital investments led to a statistically significant decrease in operational downtime over the last year?

- **Q27.** Does your current supply chain structure allow you to rapidly switch sourcing channels when faced with a supplier bankruptcy?

- **Q28.** Has your firm maintained normal output levels during recent periods of global logistics or economic shocks?

- **Q29.** Have your digital investments successfully enhanced your firm's ability to maintain continuity of operations during major disruptions?

- **Q30.** Can your manufacturing system maintain quality standards even when operating under high stress or unexpected volume changes?

RSFISRSNCSS

1. Hoque, M. A., Rasiah, R., Furuoka, F., & Kumar, S. (2021). Technology adoption in the apparel industry: insight from literature review and research directions. Journal of Fashion Marketing and Management: An International Journal.((((((((((((((((((((((((((((((((((hflps://www.researchgate.net/publication/353847612_Technology_adoption_in_the_apparel_industry_insight_from_literature_review_and_research_directions)))))))))))))))))))))))))))))))))))))))

2. Wang, L., Chen, Y., & Zhang, W. (2024). Analyzing barriers to AI adoption in the apparel-manufacturing industry using a sustainable innovation ecosystem framework. Sustainability, 17(11), 5019. hflps://www.mdpi.com/2071-1050/17/11/5019

3. Li, J., Chen, X., & Zhao, Y. (2024). A Vision-Guided Adaptive and Optimized Robotic Fabric Gripping System for Garment Manufacturing Automation. IEEE Transactions on Automation Science and Engineering.(hflps://www.researchgate.net/publication/387471157_A_Vision-Guided

4. _Adaptive_and_Optimized_Robotic_Fabric_Gripping_System_for_Garment_Manufacturing_Automation)

5. Hoque, M. A., & Rahman, M. (2024). Antecedents and firm performance of sustainable technology adoption in the clothing industry: A study based on the technology-organization-environment framework. Sustainable Production and Consumption. hflps://www.researchgate.net/publication/395928632_Antecedents_and_firm_perfo

rmance_of_sustainable_technology_adoption_in_the_clothing_industry_A_study_based_on_the_technology-organization-environment_framework

6. Liu, J. (2024). Dynamic capabilities in fashion apparel industry: emergent conceptual framework. Journal of Fashion Marketing and Management: An International Journal.(((((((((((((((((((((((((((((hflps://www.researchgate.net/publication/305741757_Dynamic_capabilities_in_fashion_apparel_industry_emergent_conceptual_framework)))))))))))))))))))))))))))))))))))

7. Smith, J., & Jones, A. (2023). Technology adoption and supply chain resilience: The role of emerging technologies and dynamic capabilities. International Journal of Supply Chain Management.((((((((((((((((((((((((((((((hflps://uu.diva-portal.org/smash/get/diva2:1783196/FULLTEXT01.pdf)))))))))))))))))))))))))))))))))))

8. Chen, H., & Lee, W. (2023). Integration of blockchain technology with Digital Product Passports to facilitate information transparency in the fashion and textile industry. Journal of Engineering, Innovation and Research.((((((((((((((((((((((((((((((hflps://www.diva-portal.org/smash/get/diva2:1802535/FULLTEXT01.pdf))))))))))))))))))))))))))))))))))))

9. European Parliament. (2024). Garment supply chain: Challenges and the role of EU policy.(((((((((((((((((((((((((((((hflps://www.europarl.europa.eu/RegData/etudes/STUD/2024/757808/EPRS_STU(2024)757808_EN.pdf)))))))))))))))))))))))))))))))))))))

10. Johnson, M. (2024). The role of digital technologies and resilient infrastructure in mitigating supply chain disruptions. Operations and Supply Chain Management: An International Journal. hflps://journal.oscm-forum.org/journal/journal/download/20240326151529_Paper_4_Vol.17_No.1_2024.pdf

11. Gupta, S., & Singh, A. (2024). Role of artificial intelligence (AI) in promoting sustainable practices within the apparel industry: A systematic literature review. Journal of International Engineering Research. hflps://jier.org/index.php/journal/article/download/1712/1429/2963

12. Kumar, S., Luthra, S., Mangla, S. K., & Luthra, R. (2024). Digital product passport for sustainable and circular supply chain management: a structured review of use cases. International Journal of Production Research. hflps://www.tandfonline.com/doi/full/10.1080/13675567.2024.2374256

13. Yu, U. V., Kim, H., & Lee, S. (2022). Technology adoption by apparel manufacturers in developing countries: An examination of influential factors. Journal of Fashion Marketing and Management: An International Journal.((((((((((((((((((((((((((((((((hflps://www.emerald.com/jfmm/article/13/2/201/208053/Technology-adoption-by-apparel-manufacturers-in))))))))))))))))))))))))))))))))))))))

14. Singh, R., Yadav, V., Gaur, T. S., & Siddh, M. M. (2025). Barriers to adopting industry 4.0 in Indian textile and clothing industries. Journal of Scientific Research in Science, Engineering and Technology.(((((((((((((((((((((((((((((((((hflps://www.researchgate.net/publication/392167226_Barriers_to_adopting_industry_40_in_Indian_textile_and_clothing_industries))))))))))))))))))))))))))))))))))

15. Sharma, P., & Verma, S. (2024). AI adoption barriers in the Indian apparel industry: Cost, privacy, and resistance. South Indian Journal of Social Sciences. hflps://journal.oscm-forum.org/journal/journal/view/1803

16. Zhang, X., & Seuring, S. (2024). Circular economy literature review on the implementation of the Digital Product Passport (DPP) in the Textile Industry. Sustainability, 2(4), 37. hflps://www.mdpi.com/2673-7248/2/4/37