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A Systematic Review of Artificial Intelligence in Transforming the Apparel Industry to a Circular Economy: Current Practices and Future Approaches

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Abstract

The study presents a systematic review that focuses on the involvement of artificial intelligence in revolutionising the clothing sector into a circular economy, where the majority of industries' transition has benefited from environmental and economic benefits. The study included the PRISMA framework that was used to analyse 10 recent studies from 2021 to 2025 to find AI-driven applications, benefits and barriers to identify the contribution. Results from the survey indicated that AI enhances circular economy involvement through smart textile sorting, predictive design, waste management, and sustainable supply chain management. However, the results also identified prevalent issues such as minimal data availability, high implementation cost with uncertainty and scalability issues. Thus, the study also identified the gaps associated with the post-implementation stage (such as material reuse rate, consumer behavior modeling, closed-loop logistics) as well, while recommending it under areas for future research.

Keywords

Circular Economy, Artificial Intelligence, Apparel Industry, Transformation, Sustainability

1. Introduction

Among the concerns of environmentalists and local economy, the apparel industry has been under significant scrutiny to make changes in its practices to control the environmental cost of business through circular economy principles [1] [2].

Commonly, circular economy practices are associated with a longer product lifecycle, along with controlled environmental cost. Artificial intelligence (AI) has been pivotal in the shift, where it provides insightful decision-making regarding supply chain and areas to improve in pursuit of adhering to circular economy principles [3] [4]. Despite being increasingly discussed, AI's involvement in restructuring the apparel industry to a circular economy is highly disjointed and requires significant attention [5] [6]. Therefore, this research provides a systematic review to summarise the context of existing literature while promoting the idea of the circular economy in the apparel industry. Moreover, the research summarises the gaps in existing studies to ensure effective utilisation of future studies in implementation as well.

2. Methodology

2.1 Research Objectives

The primary aim of the research is to examine the role of AI in assisting the transformation of the apparel industry to circular economy principles, with the following objectives:

- To critically search and classify available literature on the uses of artificial intelligence (AI) that can assist the apparel industry in upholding the principles of the circular economy.
- To critically assess the reported results, advantages, and drawbacks of AI efforts in circular practices in various points of the apparel value chain (design, production, distribution, use, and recycling).
- To compile the salient issues, research gaps, and future directions based on the literature, and to suggest future methods of transforming the apparel industry to a circular economy using AI.

2.2. Systematic Review Approach

This paper is presented as a systematic literature review (SLR) so as to perform an unambiguous, reproducible and detailed synthesis of the current state of the research literature on the issue of the role of artificial intelligence (AI) in facilitating the realisation of the circular economy (CE) in the apparel industry. The review has been conducted following Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA), which makes reference to the four most important steps, namely identification, screening, eligibility and inclusion. It is a formal approach which enables the collection, analysis and synthesis of peer-reviewed articles and other relevant grey literature to minimise the possibility of bias and maximise the likelihood of credibility. Giri *et al.* (2019) [7] also determined that the results of the literature should be connected in a systematic manner towards ecologically valid results. Thus, the studies were selected using a standardised inclusion and exclusion criterion that was strictly followed in the completion of the research, where the primary inclusion criteria required the studies to include AI, applications and the apparel industry. From the understanding of Anderson *et al.* (2020) [8], the research followed the requirements where the studies were systematically extracted, analysed and synthesised to find common themes to maintain ecological validity without the involvement of possible bias.

2.3. Inclusion and Exclusion Criteria

Table 1 shows the inclusion and exclusion criteria followed for the completion of this research:

Table 1. Inclusion and exclusion criteria of the research.

Type	Description	Rationale
Inclusion	Studies published between 2021 and 2025	Captures recent developments and ensures relevance to current AI and CE practices
Inclusion	Peer-reviewed journal articles, conference papers, and credible industry reports	Ensures academic reliability and inclusion of practical insights from industry
Inclusion	Studies focusing on AI applications (e.g., machine learning, computer vision, predictive analytics) in circular apparel or fashion systems	Directly aligns with the research aim of exploring AI's role in circular transformation
Inclusion	Research addressing CE principles such as recycling, waste minimisation, design for longevity, and resource efficiency	Ensures relevance to circular economy objectives
Exclusion	Studies unrelated to the apparel/fashion industry	Maintains focus on the target sector
Exclusion	Publications without a clear reference to AI or CE concepts	Ensures thematic consistency with research objectives
Exclusion	Non-English publications	Avoids translation bias and ensures accurate interpretation
Exclusion	Editorials, commentaries, theses, or non-peer-reviewed sources	Excludes materials lacking methodological rigour or empirical grounding
Exclusion	Duplicate or incomplete studies	Prevents redundancy and ensures data integrity

2.4. Search Strategy

Search strategy prioritised to identify studies on the integration of AI in the development and implementation of the circular economy for the apparel industry. For this purpose, several databases were explored, including Scopus, Web of Science, ScienceDirect, IEEE Xplore and Google Scholar, to cover the domains of this research extensively. The search terms comprised a mixture of keywords and Boolean operators (AND, OR) to incorporate differences in terms used around AI, CE and the apparel industry. The initial search on all the aforementioned databases was restricted to titles to ensure that the research readily incorporated the topic of discussion. Furthermore, Table 2 showcases the usage of titles and keywords used to standardise the data extraction process:

Table 2. Keywords and titles used for the data extraction process.

Database	Search Keywords/String Example	Purpose
Scopus	("Artificial Intelligence" OR "Machine Learning" OR "Deep Learning") AND ("Circular Economy" OR "Sustainable Fashion" OR "Circular Apparel")	To retrieve peer-reviewed literature on AI and CE in fashion and apparel.
Web of Science	("AI applications" AND "circular textile industry" OR "sustainable apparel")	To identify interdisciplinary studies with technological and sustainability perspectives.
ScienceDirect	("Artificial intelligence in apparel" AND "circular economy transformation")	To access high-quality journal articles in sustainability and technology.
IEEE Xplore	("AI" AND "textile manufacturing" AND "resource efficiency")	To locate technical and engineering-focused research on AI-enabled CE processes.
Google Scholar	("AI in circular fashion" OR "digital transformation in apparel recycling")	To include grey literature and emerging research not indexed in traditional databases.

2.5. Selection Process

The PRISMA (Preferred Reporting Items to Systematic Reviews and Meta-Analyses) framework was used to select the articles so that the transparency, consistency, and replicability of the results can be achieved. It was done in a number of consecutive steps, which included identification, screening, eligibility assessment, and inclusion. The first step was to eliminate duplicates and then perform title and abstract screening to eliminate irrelevant research. Predefined inclusion and exclusion criteria were then utilised to determine the full-text articles. PRISMA criteria were followed for the research under the guidelines of Chintalapati and Pandey (2022) [9], where the researcher also used a similar approach to identify the contribution of AI in marketing. The discrepancies between the reviewers were remedied by discussions so as to give objectivity and minimise selection bias.

The results of the study were filtered to come up with a final list of studies that would be used to conduct the synthesis. The steps are well elaborated as Table 3:

Table 3. PRISMA criteria to conduct this study.

Stage	Description	Outcome
Identification	Retrieval of articles from databases using predefined search strings.	All potential records collected.
Screening	Removal of duplicates and review of titles and abstracts to assess relevance.	Irrelevant and duplicate papers excluded.
Eligibility	Full-text assessment of remaining studies based on inclusion/exclusion criteria.	Only studies addressing AI and CE in apparel were retained.
Inclusion	Final selection of articles meeting all quality and relevance requirements.	Studies included in the systematic synthesis.

2.6. Data Collection Process

All the selected studies were searched to gather data systematically with the help of a standardised extraction form to prevent any inconsistency and incorrectness. The main points were the authors, year of publication, purpose of the research, applied methods of AI, the areas of focus of the circular economy, methodology, core findings, and challenges. The extraction of the data was done by the various reviewers to reduce bias and increase reliability. Any differences were deliberated and removed by consensus. The data gathered were tabulated and synthesised in terms of their themes in a bid to establish patterns, emerging trends, and research gaps around the application of AI in circular apparel systems. PRISMA diagram is used for this systematic review process which is shown in Figure 1.

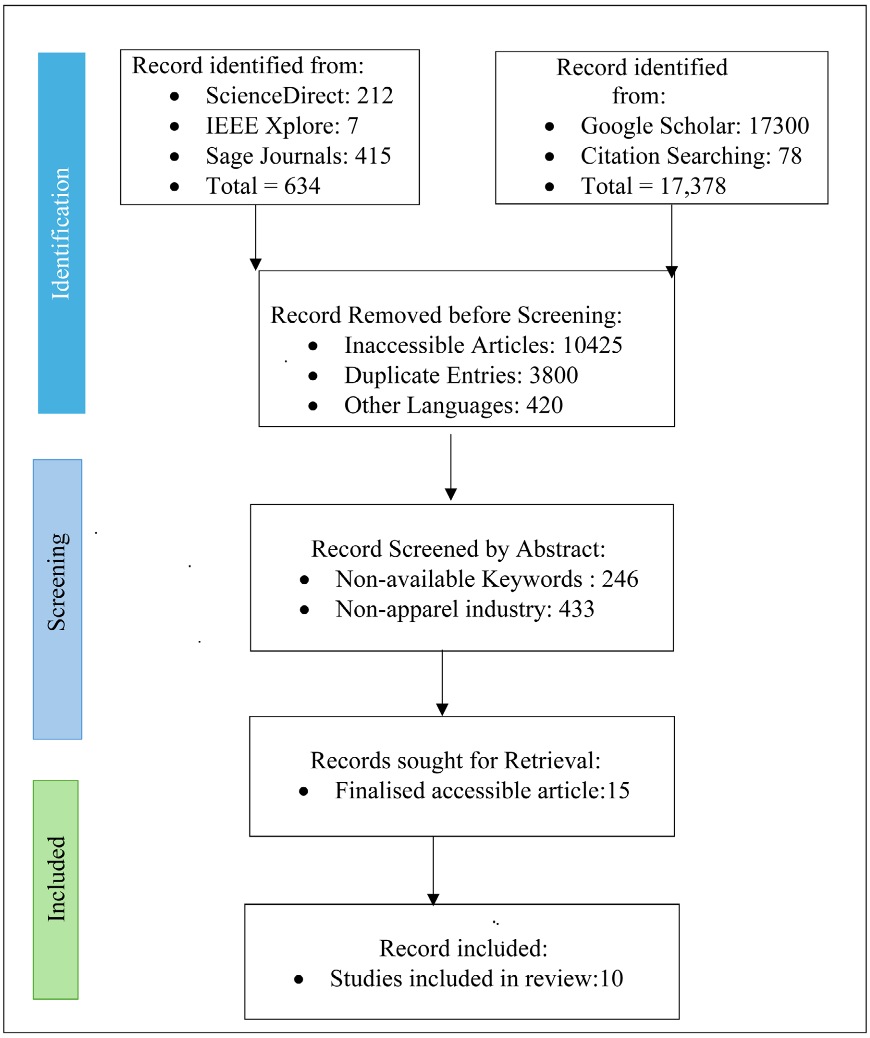

Figure 1. PRISMA diagram for SLR (Author, 2025).

2.7. Information Extraction

Information extraction was to be focused on systematically extracting relevant information from each of the selected studies for use in a systematic synthesis. Information extracted included the study context, research design, type of AI technology, application area in the apparel value chain, and the contributions of this type of technology towards the aims of the circular economy, including reduction of waste, optimising resources, and product longevity. A codebook was also developed to categorise the information into thematic categories. Secondly, the extracted data was also critically appraised in order to achieve ecological validity and validity in the extraction of information free from bias. The data collected formed the basis for comparison and the identification of the key trends, challenges and opportunities in the future.

3. Theoretical Background

This systematic review can be linked to the technological innovation systems (TIS) framework that focuses on the importance of emerging technologies in facilitating systemic sustainability transitions. AI is a technological and socio-technical facilitator which affects design, production, and consumption activities throughout the apparel value chain. According to Rahaman and Khan (2024) [10], along with findings from Oladapo *et al.* (2024) [11], AI combined with a circular business model can facilitate the development of green merchandising and responsible production. Thus, further studies must consider the incorporation of integrative frameworks of AI, digital traceability, and CE strategies that would promote a complete circle of an intelligent apparel ecosystem.

While technological innovation is central, the social and ethical dimensions of AI integration into circular apparel systems deserve equal attention [12]. The reviewed studies rarely address the human implications of automation, such as workforce reskilling, digital literacy, and potential job displacement. As AI-driven processes increasingly replace manual operations in textile sorting and manufacturing, industry stakeholders must ensure inclusive transitions that empower, rather than marginalise, workers. Ethical concerns related to data governance, transparency, and algorithmic bias also remain underexplored. For example, AI-based decision systems for sustainable sourcing or consumer profiling could unintentionally reinforce inequalities if data inputs are skewed or incomplete [13]. Therefore, responsible AI governance frameworks, combining environmental, social, and ethical accountability, are essential to ensure that AI deployment supports not only environmental circularity but also social sustainability within the global apparel sector [14].

The transition of the apparel industry to the CE is a paradigm change of the conventional linear take-make-dispose linear approach to the system towards resource efficiency, durability and regeneration. The circular model encourages recycling design, closed supply chains, and less waste production [15] [16]. In this respect, Artificial Intelligence (AI) has become one of the most relevant technological supports in the form of data-driven knowledge and automation possibilities, which are the basis of sustainable production and consumption cycles [17] [18].

Machine learning, computer vision, deep learning, and predictive analytics are examples of AI technologies used to make decisions at various levels of the apparel value chain (design and production), as well as in recycling and resale [19] [20]. As an example, material recognition systems and automated waste sorting pipelines that are powered by AI can be used to accurately classify textile fibres and thus increase the efficiency of recycling [21] [22]. In addition, pattern recognition and zero-shot learning methods have enhanced the quality of the textile and accuracy of waste segregation [3] [23].

AI can also assist in smart manufacturing and predictive maintenance to improve resource consumption and production waste [24]. At the same time, green merchandising and demand forecasting through the use of data analytics and AI-supported retail systems can be used to match production with sustainable consumption [10] [25]. Together, the innovations of AI support a digitally empowered circular apparel system, in which automation and intelligence will help optimise and make every life-cycle step more efficient and sustainable.

4. Results

Ten major studies that were published in 2021-25 were included in the systematic review and covered peer-reviewed journals, conference proceedings, and open-access preprints. The findings indicate the increasing number of interdisciplinary studies that relate AI applications to principles of a circular economy in the sphere of apparel and textiles. The following is the summary Table 4 for the incorporated articles:

Table 4. Summary of selected articles for the review.

Author(s) & Year	Focus Area/ Purpose	AI Technique/ Approach	Circular Economy (CE) Dimension	Key Findings	Limitations/ Research Gaps
Damayanti *et al.* (2021) [15]	Review of textile recycling technologies.	Not AI-specific; material analysis and polymer recovery.	Recycling and waste reduction.	Identified potential routes for chemical and mechanical recycling of textiles.	Lacks integration of AI-enabled optimisation for recycling processes.
Faghih *et al.* (2025) [21]	AI-enabled textile waste sorting for circular fashion.	Machine Learning (ML), Computer Vision.	Recycling and resource recovery.	Demonstrated improved sorting accuracy and automation efficiency.	Limited scalability and lack of large, standardised datasets.
Karmali & Valilai (2025) [3]	Pattern recognition in textile recycling.	Deep Learning (DL), Pattern Recognition.	Recycling and material recovery.	AI effectively classifies fibre types and textile blends.	Focused on lab-level applications; lacks industrial implementation.
Mohammadi & Kalhor (2021) [19]	Review of AI applications in fashion and apparel.	Various AI tools: ML, NLP, Image Processing.	Production and design optimisation.	AI enhances design creativity, demand forecasting, and trend analysis.	Not specifically circular; lacks focus on end-of-life applications.
Nisa *et al.* (2025) [20]	AI in sustainable fashion and CE transformation.	Data analytics, ML frameworks.	Design, manufacturing, and recycling.	AI accelerates sustainable transitions by optimising material use.	Need for a holistic CE model integrating social and environmental dimensions.

Continued

Rahaman & Khan (2024) [10]	Circular merchandising and sustainable supply chains.	Predictive AI and data-driven systems.	Supply chain and consumer engagement.	AI promotes green merchandising and sustainable consumption.	Theoretical model; lacks empirical validation.
Ramos *et al.* (2023) [17]	AI and sustainability in fashion (2010-2022).	Text mining, bibliometric analysis.	Cross-stage CE impacts.	Identified AI's contribution to energy savings, smart manufacturing, and waste reduction.	Limited discussion on closed-loop product systems.
Spyridis & Argyriou (2025) [23]	Textile analysis for recycling automation.	Transfer Learning, Zero-Shot Models.	Recycling automation.	Advanced models outperform traditional classifiers in identifying textiles.	Early-stage research; lacks industrial deployment data.
Spyridis *et al.* (2024) [22]	AI-enabled industrial sorting for textile recycling.	Machine Vision, Robotics, Automation.	Industrial recycling and reprocessing.	Demonstrated real-time sorting and material classification accuracy.	High cost and complexity hinder adoption in SMEs.
Weimer *et al.* (2025) [26]	AI system for enhanced textile recycling and reuse.	AI-integrated mechanical systems.	Reuse and recycling.	Showed potential of hybrid AI-engineering systems for CE.	Limited pilot testing; requires large-scale validation.

4.1. AI Applications in Circular Apparel Systems

In the analysed literature, AI applications were divided into three broad areas:

1) Recycling and Waste Management: Faghih *et al.* (2025) [21], Spyridis *et al.* (2024) [22], and Weimer *et al.* (2025) [26] have discussed the application of AI-based computer vision and robotics to sort textile waste, identify fibres, and perform automated recycling. These methods enhance the rate of material recovery and minimise the rate of sorting errors, which makes it possible to have closed-loop recycling systems.

2) Product Design and Development: Mohammadi and Kalhor (2021) [19] and Nisa *et al.* (2025) [20] research work proved that AI-based design tools and digital twins are effective in optimising the selection of materials, the generation of patterns, and the prediction of their lifecycle, with sustainability principles being introduced into the design phase.

3) Supply Chain and Retail Optimisation: Rahaman and Khan (2024) [10] and Ramos *et al.* (2023) [17] highlighted the use of AI in predictive analytics, demand forecasting, and sustainable merchandising, which can assist in the balancing of inventory, avoiding overproduction, and traceability.

4.2. Key Themes Identified

- Increased Efficiency: AI algorithms are much more efficient in terms of the accuracy of sorting, the speed of processing, and quality control, and help minimise the costs and loss of materials.
- Sustainability Impact: The use of AI helps reduce carbon emissions, enhance the circularity of materials, and conserve resources.
- Data Integration Issues: Data availability is still low, no standardisation and the cost of implementation is still huge [3].
- Emerging Trends: More exploration of zero-shot learning, transfer learning and textile recycling through autonomous AI systems points to full automation and smart CE networks.
- Social and Ethical Dimensions: The circular apparel industry's implementation of AI presents various ethical challenges, on all sides of issues of data privacy, transparency, and accountability, along with social issues such as job insecurity, workforce disembodiment, and digital inequality.

4.3. Overall Insights

The review confirms that although the use of AI in circular apparel systems remains a fledgling area, it will make a significant contribution to sustainable change. Recycling and production are the current applications, but the modelling of consumer behaviour, reuse network, and closed-loop logistics has not been studied extensively. Further evolution of AI-centred data sharing systems and inter-sector cooperation will speed up the transition of the apparel industry into the circular economy.

The selected studies in this research were centralised and dominant, with the finding that AI serves as a significant enabler of advancing CE principles in modernised market conditions. Furthermore, it optimises the value creation of the textile industry's supply chain through constructive and unbiased data analysis, predictive analytics and practical recommendations such as route planning. Meanwhile, the systematic literature also highlights that AI's capacity to enhance design intelligence, production efficiency, waste management, and recycling automation are the four critical factors that give considerable advantage for AI.

For the design and production stage, Nisa *et al.* (2025) [20] and Mohammadi & Kalhor (2021) [19] were pivotal in emphasising AI-driven analytics, predictive algorithms, and generative design tools to ensure that the designs were readily acceptable with increased product lifecycle as well. Furthermore, AI trends supported designers considerably with the advantage in design philosophy, selection of fabric, customer demand, fashion trends and several other dimensions that they have to consider.

Rahaman and Khan's (2024) [10] and Ramos *et al.*'s (2023) [17] studies were significantly important in demonstrating the importance of the role of AI in supply chain management, with particular emphasis towards demand forecasting, inventory optimisation, and green merchandising. From the findings of preceding studies, it was revealed that they minimise overproduction, improve resource utilisation, and foster circular business models such as resale and rental.

Recycling and other end-of-life product cycles have been a major concern for businesses in implementing CE principles. Faghih *et al.* (2025) [21], Karmali and Valilai (2025) [3], and Spyridis *et al.* (2024, 2025) [22] [23] present evidence of AI's ability to automate textile waste sorting using AI vision, deep learning, and robotics to improve decision-making and precision for completion of the supply chain. Such technologies drastically improve accuracy in fibre recognition and contamination detection, which are the key challenges in the manufacturing process. Furthermore, Weimer *et al.* (2025) [26] highlight how integrated AI-enabled mechanical systems can facilitate automated reuse and material recovery.

However, most studies remain in early or pilot phases, with scalability, interoperability, and data standardisation identified as recurring challenges. The review reveals that while AI has laid the technological foundation for circular transformation, system-wide integration across design, production, consumption, and recycling stages remains underdeveloped. Achieving a fully circular apparel ecosystem will require collaboration between AI innovation, policy frameworks, and industry adoption to close material loops effectively.

5. Discussion

The results of this systematic review also show that artificial intelligence (AI) is a key driver in introducing the apparel industry into a circular economy (CE). The inclusion of AI in the recycling of textiles, the creation of its products, and the supply chain shows that it can help seamlessly integrate material loops to improve sustainability performance. Research like Faghih *et al.* (2025) [21] and Spyridis *et al.* (2024) [22] demonstrates that AI-driven automation, especially in the sorting of waste and fibre recognition, improves the accuracy and efficiency, which eliminates one of the biggest issues of textile recycling, namely the heterogeneous material composition. On the same note, AI-based design tools that were identified by Nisa *et al.* (2025) [20] and Mohammadi and Kalhor (2021) [19] enable designers to reduce the number of materials used, design products that consume less energy throughout their lives, and forecast product lifespans, which directly uphold CE principles of reuse and longevity.

Nevertheless, although it could be a transformer, the implementation of AI in circular apparel systems is not even as identified by Fraga-Lamas *et al.* (2021) [27] as well. There are still gaps in research in the field of consumer-oriented and post-consumption stages, in which AI has the potential to support new business opportunities, including an anticipatory resale, a rental platform, or a network of automated repair. There is also a shortage of standardised data, and the interoperability of digital systems is low, as well as the high costs of implementing it [3] [28]. Moreover, there are numerous AI solutions in pilot or lab phase, which suggests that AI has to be done on a wider industrial scale and aligned with the policy.

Moreover, the scalability and integration of AI into industrial and policy ecosystems remain key barriers to achieving a truly circular apparel economy [29]. Current implementations are fragmented, with most innovations developed in isolation by technology start-ups or research institutions rather than embedded across global supply chains. To move from pilot initiatives to full-scale adoption, collaboration between academia, policymakers, and apparel manufacturers is necessary. Governments and industry bodies could incentivise the adoption of AI-enabled circular practices through funding schemes, digital infrastructure investments, and harmonised data standards. Simultaneously, cross-sector platforms should be established to facilitate data sharing, traceability, and benchmarking of circular performance. Integrating AI with blockchain and Internet of Things (IoT) technologies can further enhance transparency and accountability across supply networks. Ultimately, the long-term success of AI in transforming the apparel industry toward a circular economy depends on systemic coordination, where technology, policy, and social innovation operate in synergy to create an equitable and regenerative industrial future [30].

6. Conclusions

6.1. Summarised Findings

It is a systematic review done on the intersection of artificial intelligence (AI) and circular economy (CE) in the context of the apparel industry, which summarised the results of ten recent articles published between 2021 and 2025. These findings validate the notion that AI technologies (machine learning, computer vision, and predictive analytics) are revolutionising the most relevant processes in the apparel design, manufacturing, and recycling processes. The applications of AI in textile sorting, textile pattern recognition and intelligent planning of production have already demonstrated positive results in terms of resource utilisation and waste management, as well as optimisation of the circular supply chain. All these innovations demonstrate the potential of AI to make the apparel industry a regenerative, sustainable, and data-driven system.

6.2. Implications for Research

Future research should not restrict itself to production and recycling and should also incorporate consumer behaviour modelling, reuse of products after consumption and reverse logistics. The combination of AI and digital twins, blockchain traceability and a life-cycle assessment model can improve the knowledge of the system-wide circular effects. The longitudinal studies are also needed to make a comparison between the applicability of AI in practice and the socio-environmental benefits of applying AI. Interdisciplinary research integrating fashion design, computer science, behavioural studies, and environmental management will be very important for examining the interaction of AI with consumer behaviour, design aesthetics, and ethical decision-making in circular business models. This integration would elucidate the impact of AI-driven personalization, sustainable design automation and, predictive demand modelling on consumer engagement and brand accountability. Furthermore, in the apparel sector, researchers must examine the ethical and governance aspects of AI implementation. This research may examine frameworks for data ethics, responsible AI utilisation and inclusivity algorithmic transparency which ensure that AI-driven circular transformations don't keep inequality or exploitation of supply chains within worldwide fashion in future.

6.3. Implications for Practitioners

The results demonstrate how AI can refine decision-making, automate material classification, and boost supply chains transparency for practitioners. AI also bolsters visibility and auditability all the way through the production stages by utilizing AI-driven tracking, data analytics, blockchain integration. AI-driven tools such as predictive analytics, computer vision, and automated quality control can play a crucial role in reducing textile wastage and optimizing materials usages. Practitioners can implement AI-driven categorisation systems to sort and repurpose post-consumer textiles, thereby forward-moving zero-waste production models and refining material recirculation. Moreover, designers and product developers can leverage AI-driven predictive design and digital prototyping to simulate product lifecycles, choose sustainable supplies and assess recyclability.

However, practitioners are also required to address implementation barriers, the high cost of systems absence of data standardisation, and limited interoperability between different software platforms for artificial intelligence. It is essential collaboration with technology providers, policymakers, and research institutions is crucial for developing shared data infrastructures and guarantee that everyone has equal access to advanced artificial intelligence solutions. In inference, it is important to integrate ethical and social factors into implementation plans for examples of these factors include the promotion of inclusive governance of artificial intelligence, workforce adaptation, data privacy. It is essential to promote AI literacy to ensure that the transformation of AI advances social welfare, workforce retraining, and fair digital practices while also promoting equitable growth across industries. AI-driven analytics can help companies to make correct predictions about demand, reduce overproduction, and promote sustainable design and retail concepts.

6.4. Limitations and Future Directions

This review has been restricted to the English language, and it might not reflect the regional inventions in the non-English literature. The next systematic review must expand its search scope and encompass empirical case studies that legitimise the use of AI in the quickening of the circular transition process in various apparel ecosystems.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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