

Leveraging computational systems for lifecycle management and enhancement of circular economy in fashion: A study on tracking, recycling, and reuse technologies

Yixin Zhou¹, Jiatong Zhao^{2,3}

¹The Chinese University of Hong Kong, Hong Kong SAR, China

²Queensland University of Technology, Brisbane, Australia

³wellington589125@gmail.com

Abstract. This paper investigates the role of computational systems in managing the lifecycle of fashion products to enhance circular economy practices. By integrating technologies such as IoT, blockchain, and AI, we explore how these systems can track, recycle, and reuse clothing items efficiently. The study highlights the advancements in smart recycling bins, the transparency provided by blockchain, and the optimization of recycling operations through AI. Additionally, the research delves into the impact of online second-hand marketplaces, clothing rental services, and upcycling initiatives, facilitated by computational systems, in promoting sustainable fashion practices. The findings underscore the potential of these technologies to significantly reduce environmental impact, extend garment lifecycles, and foster sustainable consumer behaviors. By leveraging these innovations, the fashion industry can transition towards a more sustainable and circular economy.

Keywords: Circular Economy, Fashion Lifecycle Management, Computational Systems, IoT.

1. Introduction

The fashion industry, known for its rapid production cycles and significant environmental footprint, faces increasing pressure to adopt sustainable practices. A promising solution lies in the concept of a circular economy, which emphasizes the reuse, recycling, and efficient management of resources throughout the lifecycle of products. This study explores how computational systems can facilitate these practices within the fashion sector, offering innovative solutions to long-standing sustainability challenges. Implementing IoT devices for real-time tracking and monitoring of garments can provide valuable data on their condition and usage patterns, enabling timely maintenance and extending their lifespan. Advanced data integration and analysis platforms can aggregate information from various sources, offering comprehensive insights that inform material selection, production techniques, and consumer behavior. These insights can drive more sustainable operations and reduce the environmental impact of fashion products. Furthermore, technologies such as smart recycling bins, powered by IoT and AI, can enhance the efficiency of garment sorting and recycling processes. Blockchain technology can ensure transparency and trust in recycling activities, while AI can optimize sorting and processing operations [1]. Additionally, consumer engagement platforms can educate and motivate individuals to participate in recycling and reuse programs, fostering a culture of sustainability. The development of

online second-hand marketplaces, clothing rental services, and upcycling initiatives further underscores the potential of computational systems to promote the reuse of fashion products. These platforms not only facilitate transactions and enhance user experiences but also provide valuable data on market trends and consumer preferences, encouraging brands to adopt more sustainable practices. By leveraging these technologies, the fashion industry can make significant strides towards a circular economy, reducing waste, conserving resources, and promoting more responsible consumption and production patterns.

2. Computational Systems in Fashion Lifecycle Management

2.1. Tracking and Monitoring

Implementing computational systems for tracking and monitoring fashion products throughout their lifecycle is a crucial step towards achieving a circular economy. IoT devices, embedded in clothing items, can provide real-time data on the location, condition, and usage patterns of these products. For example, sensors can detect wear and tear, usage frequency, and environmental conditions the garment is exposed to, such as humidity and temperature. This data can be transmitted to centralized systems for analysis, allowing stakeholders to monitor the lifecycle stages and identify opportunities for intervention. For instance, retailers can track the wear and tear of garments to offer timely maintenance services, such as repair or refurbishment options, while consumers can receive notifications for proper garment care tailored to their specific usage patterns [2]. By ensuring continuous monitoring, computational systems can significantly extend the lifespan of fashion products and reduce the frequency of replacements. This proactive approach not only reduces waste but also enhances customer satisfaction by maintaining the quality and longevity of their purchases.

2.2. Data Integration and Analysis

The integration and analysis of data collected from various sources are fundamental for effective lifecycle management. Advanced data analytics platforms can aggregate information from IoT devices, RFID tags, and consumer apps, providing a comprehensive view of each garment's lifecycle. This holistic perspective enables the identification of trends and patterns that can inform decision-making. For example, data analytics can reveal which types of fabrics are most durable or which manufacturing processes result in fewer defects, guiding brands towards more sustainable production choices. Additionally, predictive analytics can forecast future wear and tear, enabling companies to preemptively address potential issues [3]. By leveraging these insights, fashion brands can make informed choices about material selection, production techniques, and maintenance practices, ultimately leading to more sustainable operations and reduced environmental impact. Furthermore, this data can be shared with consumers to promote transparency and trust, showing them the environmental footprint of their clothing choices and encouraging more responsible consumption habits. Table 1 summarizes how data from IoT devices, RFID tags, and consumer apps can be integrated and analyzed to inform sustainable decision-making in fashion lifecycle management, enhancing material selection, production processes, and consumer transparency.

Table 1. Data Integration and Analysis for Sustainable Fashion Lifecycle Management

Data Source	Collected Data	Analytics Outcomes	Impact
IoT Devices	Real-time location, condition, usage patterns	Identify durable fabrics, monitor wear and tear	Inform material selection, enhance garment longevity
RFID Tags	Product identification, lifecycle tracking	Track manufacturing defects, optimize processes	Guide sustainable production, reduce defects
Consumer Apps	User behavior, preferences, feedback	Predict future wear, promote sustainable choices	Encourage responsible consumption, increase transparency

2.3. Consumer Engagement

Engaging consumers in the lifecycle management of fashion products is essential for fostering sustainable behaviors. Computational systems can facilitate this engagement through personalized apps and platforms that educate and encourage users to participate in recycling and reuse programs. For instance, apps can offer tips on garment care, suggest repair services, and provide information on local recycling centers. These platforms can provide users with information on how to care for their garments, where to donate or recycle them, and the environmental benefits of doing so. Additionally, gamification elements, such as rewards for sustainable actions like recycling or purchasing second-hand items, can motivate consumers to actively contribute to the circular economy. By making sustainability an integral part of the consumer experience, computational systems can drive widespread adoption of eco-friendly practices in the fashion industry. Moreover, social sharing features can enable users to showcase their sustainable actions, further spreading awareness and encouraging community participation in sustainability initiatives [4].

3. Technologies Promoting Fashion Recycling

3.1. IoT and Smart Recycling Bins

The integration of IoT technology with smart recycling bins represents a significant advancement in promoting fashion recycling. These bins, equipped with sensors and connectivity features, can identify and sort clothing items based on material composition and condition. For example, smart bins can use image recognition and RFID scanning to categorize fabrics, distinguishing between cotton, polyester, wool, and other materials. The data collected by these bins can be transmitted to recycling centers, enabling more efficient sorting and processing of garments. This technology not only improves the accuracy of recycling efforts but also reduces the labor and costs associated with manual sorting. Additionally, real-time data from these bins can inform municipalities about the volume and type of recyclables collected, allowing for better planning and resource allocation. By enhancing the efficiency of the recycling process, IoT-enabled smart bins can significantly increase the volume of clothing that is successfully recycled, contributing to the circular economy [5]. Furthermore, these systems can provide feedback to manufacturers and consumers about the recyclability of products, driving improvements in design and consumption patterns. Figure 1 illustrates the efficiency improvement in recycling different types of materials with IoT-enabled smart bins.

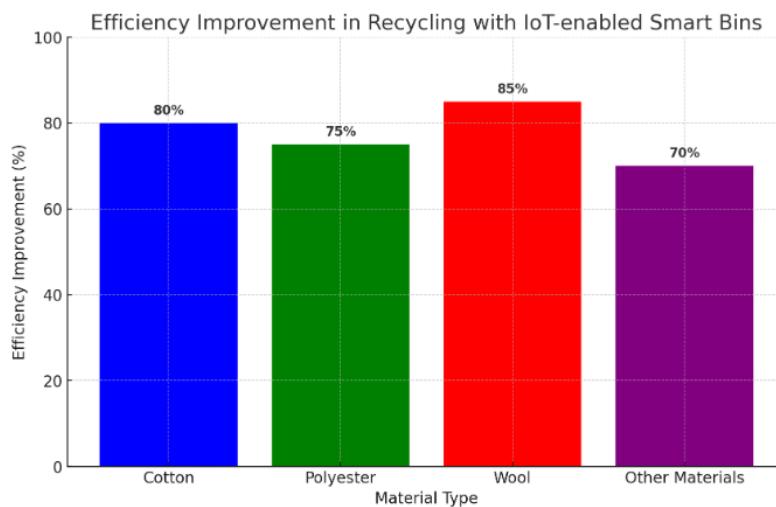


Figure 1. Efficiency Improvement in Recycling with IoT-enabled Smart Bins

3.2. Blockchain for Transparency and Trust

Blockchain technology offers a robust solution for ensuring transparency and trust in the recycling process. By creating an immutable ledger of transactions, blockchain can track the journey of each garment from donation to recycling to reuse. This transparency allows consumers to verify that their donated items are being recycled responsibly and not ending up in landfills. For example, each step of the recycling process can be recorded on the blockchain, including collection, sorting, processing, and distribution of recycled materials. Additionally, fashion brands can use blockchain to demonstrate their commitment to sustainability by providing verifiable records of their recycling efforts. This increased transparency can enhance consumer trust and encourage more people to participate in recycling programs, thereby supporting the circular economy. Blockchain can also facilitate the development of certification schemes for recycled materials, ensuring that consumers and businesses have access to reliable information about the origins and sustainability of products. By establishing a trusted system for tracking and verifying recycling activities, blockchain can play a crucial role in promoting responsible consumption and production practices in the fashion industry [6].

3.3. AI in Recycling Operations

Artificial Intelligence (AI) plays a pivotal role in optimizing recycling operations within the fashion industry. AI algorithms can analyze data from various sources to improve the efficiency of sorting and processing garments. For example, machine learning models can be trained to recognize different types of fabrics and their recycling requirements, enabling automated sorting systems to operate with greater accuracy. These models can process large volumes of data from sensors, cameras, and other sources to make real-time decisions about how to handle each item. AI can also predict the optimal recycling methods for different materials, minimizing waste and maximizing resource recovery. For instance, AI systems can recommend specific chemical or mechanical recycling processes based on the material composition and condition of garments [7]. By leveraging AI, recycling centers can enhance their operational efficiency, reduce costs, and increase the overall effectiveness of recycling programs. Furthermore, AI can provide insights into the environmental impact of recycling operations, helping to identify areas for improvement and drive the development of more sustainable practices.

4. Enhancing Reuse through Computational Systems

4.1. Second-Hand Marketplaces

The development of online second-hand marketplaces has been significantly boosted by computational systems, facilitating the reuse of fashion products. These platforms use algorithms to match buyers with sellers, optimizing the process of finding and purchasing pre-owned garments. Advanced search and recommendation features, powered by machine learning, help consumers discover items that match their preferences, promoting the reuse of clothing. For example, recommendation systems can analyze user behavior and preferences to suggest items that are likely to be of interest, increasing the likelihood of successful transactions. Additionally, these marketplaces often include features for verifying the authenticity and condition of items, ensuring a trustworthy shopping experience. This can involve user reviews, seller ratings, and even third-party verification services. By making it easier for consumers to buy and sell second-hand fashion, computational systems contribute to reducing waste and extending the lifecycle of garments [8]. Furthermore, these platforms can provide data on market trends and consumer preferences, informing brands about the demand for sustainable and second-hand products, and encouraging them to incorporate more sustainable practices into their business models. Table 2 outlines the key features of online second-hand marketplaces and their impact on promoting the reuse of fashion products [9].

Table 2. Features and Impact of Second-Hand Marketplaces in Fashion

Feature	Description	Impact
Algorithm Matching	Matches buyers with sellers to optimize the purchasing process.	Increases likelihood of successful transactions.
Advanced Search	Helps consumers discover items that match their preferences.	Promotes reuse of clothing by helping consumers find desired items.
Recommendation Systems	Suggests items based on user behavior and preferences.	Enhances user experience by suggesting relevant items.
Authenticity Verification	Ensures the authenticity of items through various verification methods.	Builds consumer trust in the marketplace.
Condition Verification	Verifies the condition of items for a trustworthy shopping experience.	Ensures quality and condition of pre-owned garments.
User Reviews	Provides reviews from previous buyers for informed decisions.	Informs potential buyers about item quality.
Seller Ratings	Rates sellers to build trust and ensure quality transactions.	Builds a reliable seller base and consumer trust.
Third-party Verification	Offers third-party verification services for additional trust.	Adds an extra layer of trust for buyers.

4.2. Clothing Rental Services

Clothing rental services represent another innovative approach to promoting reuse in the fashion industry. Computational systems play a crucial role in managing the logistics of rental operations, including inventory management, order processing, and delivery scheduling. These systems can track the usage and condition of rented garments, ensuring they are properly maintained and cleaned between rentals. For example, RFID tags can be used to monitor the number of times an item has been rented and its condition after each use, enabling timely maintenance and quality control. Additionally, rental platforms can use data analytics to understand consumer preferences and optimize their inventory accordingly. This can involve analyzing rental patterns to identify popular items and ensure sufficient stock levels, as well as predicting future demand based on trends and user behavior. By providing consumers with access to a wide range of garments without the need for ownership, clothing rental services reduce the demand for new products and support a circular economy [10]. Moreover, rental services can collaborate with designers and manufacturers to create garments specifically designed for durability and multiple uses, further enhancing the sustainability of the fashion industry.

4.3. Upcycling Initiatives

Upcycling, the process of transforming old garments into new products, is greatly enhanced by computational systems. Design software and digital fabrication tools enable designers to create upcycled products more efficiently and with greater precision. For example, CAD (Computer-Aided Design) software can assist in creating detailed designs that maximize the use of existing materials, while minimizing waste. These tools can help identify the best ways to deconstruct and repurpose old garments, minimizing waste and maximizing the value of materials. Additionally, platforms that connect designers with consumers interested in upcycled fashion can facilitate the distribution and sale of upcycled products. These platforms can provide designers with access to a broader market and offer consumers unique, sustainable fashion options. By supporting upcycling initiatives, computational systems contribute to the sustainable reuse of fashion products, reducing the environmental impact of the industry. Furthermore, upcycling can drive innovation in fashion design, encouraging the use of unconventional materials and techniques, and fostering a culture of creativity and sustainability.

5. Conclusion

In conclusion, the integration of computational systems in the fashion industry presents substantial opportunities for enhancing lifecycle management and promoting a circular economy. Technologies such as IoT, blockchain, and AI can significantly improve the tracking, recycling, and reuse of garments, leading to more sustainable practices. The study has demonstrated the potential benefits and challenges associated with these technologies, highlighting their role in reducing environmental impact and extending the lifecycle of fashion products. Moving forward, continuous innovation and collaboration among industry stakeholders will be crucial in achieving the goals of the circular economy and fostering a more sustainable fashion industry. By embracing these advancements, the fashion sector can contribute to a more sustainable future, reducing its ecological footprint and promoting responsible consumption and production practices.

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