Designing a Data-Driven Circular Business Model for Old Clothes in the Digital Era: Insights from Youth-Led Recycling Clubs

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ABSTRACT

Fast fashion and textile waste have become urgent sustainability challenges that demand immediate solutions, yet digital technologies are creating new opportunities for the fashion industry to build data-driven circular business models. This study develops and demonstrates a data-driven circular business model for used clothing based on a case study of a youth-led clothing recycling club established in 2024. The paper builds upon operational research findings on low-carbon inventory management under carbon tax and carbon labeling policies, as well as optimization research on recycling bin placement based on user preferences and social network data, integrating analytical tools into a comprehensive business model framework that encompasses value creation, value delivery, and value capture. Empirical data from the club's operations—including donation volumes, digital engagement records, and estimated carbon emission reductions—combined with qualitative insights from participants, are used to map current and potential circular value flows. The analysis reveals that digital tools such as data-driven location planning, carbon emission dashboards, and personalized reminders enable the transformation of clothing recycling from ad-hoc, dispersed collection methods into an integrated circular model that coordinates interactions among donors, schools, charitable organizations, and secondhand resale platforms. The paper's contributions include: (1) proposing a conceptual framework for a data-driven circular business model specifically for the used clothing sector; (2) demonstrating how youth-led initiatives can serve as "living laboratories" for digital sustainability innovation; and (3) providing managerial and policy implications for scaling similar models to other communities and regions.

Keywords: Circular Business Model, Recycling, Data-Driven, Digital Era

1. Introduction

The global fashion and textile industry has become a quintessential example of the linear "take-make-dispose" production and consumption model. Fast fashion has driven rapid growth in clothing production while significantly shortening garment lifespans: global textile production nearly doubled between 2000 and 2015, yet the average usage duration of clothing decreased by more than one-third, generating approximately 92 million tons of textile waste annually, which could increase to 134 million tons by 2030 if current trends continue. Textile production and disposal intensify greenhouse gas emissions, freshwater consumption, chemical pollution, and microplastic proliferation, while also triggering labor and human rights issues within complex global value chains, all of which indicate that introducing more sustainable and circular approaches in clothing production, use, and end-of-life management has become an urgent imperative.

Against this backdrop, the circular economy (CE) and circular business models (CBMs) have gradually emerged as important analytical perspectives in the textile sector. Circular approaches keep products and materials in use within the system for as long as possible through strategies such as design for durability, repair, reuse, remanufacturing, and material recycling, achieving value closure by integrating "reduce-reuse-regenerate" principles across various value chain segments. Related frameworks categorize circular fashion business models into types including resale, rental, repair, and remanufacturing/upcycling, highlighting the

close interaction between business model innovation, technological innovation (such as fiber regeneration and design for disassembly), and social innovation (such as new forms of ownership and participation). Practical guidelines further translate these categories into actionable steps for enterprises, emphasizing key issues such as product design, logistics, consumer engagement, and financial viability.

Meanwhile, the fashion and textile industry is undergoing extensive digital transformation. Digital platforms centered on resale, exchange, and rental, combined with product tracking systems, traceability tools, and data analytics technologies, are reshaping clothing design, marketing, and distribution methods. Research indicates that digital tools such as mobile applications, online platforms, QR codes, and gamified interfaces can incentivize consumers to return old clothes, purchase secondhand items, and engage in garment repair; consumer-centric recommerce platforms are highly dependent on data about user behavior, product flows, and logistics performance to design viable services and operational solutions. From a broader perspective, digital technology is viewed as a critical "enabler" for circular business models, driving organizations toward data-driven sustainable management by tracking product and material flows, providing decision support, and visualizing environmental impacts.

However, existing literature predominantly focuses on large brands, established platforms, or technology suppliers, with limited attention to small-scale, youth-led initiatives. International organizations and educational sectors increasingly emphasize the important role of youth-led environmental projects in climate action and the circular economy, yet systematic research on how these projects create, deliver, and capture value at the business model level through data and digital tools remains lacking. Used clothing recycling projects led by students and youth volunteers are particularly representative: on one hand, they directly address community-level textile waste problems by organizing collection activities, setting up recycling bins, and connecting with charitable or secondhand channels; on the other hand, these projects naturally generate data streams during operations including donation volumes, item categories and quality, participation patterns, and digital interactions, which, if effectively recorded and analyzed, have the potential to support the design of more complex and circular business models. Existing operational research has developed low-carbon inventory decision models under carbon tax and carbon labeling systems, as well as recycling bin location optimization models based on user preferences and social network data, but these efforts mostly remain at the level of single optimization problems and are rarely embedded within comprehensive organizational and business models.

Therefore, it is necessary to explore: how do data and digital tools integrate into circular business model design within youth-led initiatives, and subsequently transform daily management practices? Research needs to shift from conceptual advocacy of "digital circularity" to practice-based analysis grounded in specific cases, demonstrating how data-driven decision-making shapes value creation, stakeholder relationships, and learning processes in real projects. Existing circular business model research indicates that technological tools and business models co-evolve with social innovation and organizational capabilities, and calls for attention to the capabilities and governance arrangements required for implementing circular models, yet empirical research that combines CBM frameworks, digital technologies, and youth-led organizational contexts remains scarce.

To address this gap, this paper designs and analyzes a data-driven circular business model for used clothing based on a youth-led clothing recycling club established in 2024 at New Canaan High School (NCHS) in Connecticut, USA. The research integrates the club's operational data, previous analytical findings on low-carbon inventory and recycling bin placement optimization, and qualitative interviews with participants and partners to construct a business model framework that explicitly embeds data flows and analytical modules into the circular value creation, delivery, and capture processes. Specifically, this paper's objectives include:
(1) Proposing a conceptual and visual framework for a data-driven circular business model tailored to clothing recycling, facilitating application and adaptation by youth-led and community-level initiatives;
(2) Demonstrating through the case study how digital data and simple analytical modules (such as collection

point planning, basic carbon accounting, and engagement analysis) can support operational and strategic decision-making;
(3) Summarizing the managerial and educational implications of scaling such projects in schools, universities, and communities, illustrating how youth-led projects can drive broader circular management transformation in the digital age.

The paper is structured as follows: Section 2 reviews relevant literature on circular business models in the textile and apparel sector, digital solutions for promoting consumer participation in circular fashion, and youth-led environmental initiatives; Section 3 introduces the case background and research methodology; Section 4 proposes the data-driven circular business model for used clothing and maps it to the empirical context of the recycling club; Section 5 discusses how digital tools reshape the project's management practices and stakeholder relationships, and distills theoretical and practical implications; Section 6 summarizes the main findings, research limitations, and future research directions.

2. Literature Review

2.1 Circular Business Models and Circular Economy in the Textile Sector

Due to massive resource consumption, high waste volumes, and accelerating fast fashion development, the textile and apparel industry has become a focal area in circular economy (CE) discussions. Over the past two decades, global clothing production has grown rapidly while the lifespan of individual garments has continuously shortened, with large quantities of clothing that still possess use value exiting the system as waste, yet less than 1% is actually recycled into new textiles. Against this backdrop, increasing research and policy advocacy calls for a shift from the linear "produce-use-dispose" model toward circular pathways, keeping clothing in the use system for as long as possible through durable design, extended use cycles, and closed-loop approaches such as reuse, repair, and recycling.

In the broader circular economy discussion, circular business models (CBMs) have gradually emerged as a crucial concept for achieving circularity at the enterprise and value chain levels. CBMs restructure value creation, delivery, and capture methods to circulate products and materials in closed loops rather than consuming them along linear chains. Practice-oriented research, exemplified by the Ellen MacArthur Foundation, categorizes circular business models in fashion into types including resale, rental, repair, and remanufacturing/upcycling, noting that if successfully scaled, these models could account for approximately one-fifth of the global fashion market by 2030 and generate substantial economic benefits. Academia has proposed more refined classification frameworks, such as Coscieme et al. (2022) distinguishing between models centered on "durability," rental/sharing models emphasizing "access rights," models focused on collection and resale, and models centered on material recycling, while emphasizing that business model innovation often needs to advance synergistically with technological innovation (such as fiber regeneration and design for disassembly) and social innovation (such as new forms of ownership and participation). Industry guidelines from organizations like WRAP translate these frameworks into operational steps for enterprises, particularly emphasizing key elements such as product design, reverse logistics, consumer participation, and financial viability.

Systematic reviews of circular practices in the textile industry further indicate that circular strategies and business models exhibit high diversity: different segments of the value chain can combine strategies such as "reduce-reuse-regenerate" to form various pathways ranging from extending product lifespans, implementing extended producer responsibility, and conducting take-back programs, to establishing resale and remanufacturing markets and developing various recycling technologies. Related research generally agrees that circular business models hold enormous potential for environmental improvement and new revenue sources, while simultaneously facing multiple challenges including insufficient consumer acceptance, uncertain cost structures, complex reverse logistics, unstable quality of secondary materials, and

unclear regulatory policies.

Within these circular business models, the collection, sorting, and redistribution of used clothing constitute the physical and organizational infrastructure supporting numerous models. Charitable organizations, nonprofits, and secondhand retail systems have long undertaken substantial clothing collection and reuse work, yet many countries still lack unified textile-specific collection systems. In recent years, brand-led take-back programs and proprietary secondhand channels have developed rapidly, making collection and sorting gradually become integral parts of certain fashion enterprises' business models. However, existing research still primarily focuses on brand-level circular business models (such as companies launching rental or resale services) or technology-centered recycling solutions, with relatively limited attention to community-level, school programs, or youth-led clothing practices. Some conceptual work has begun to advocate understanding circular fashion as an ecosystem composed of various business model "combinations," including both global digital platforms and local social enterprises and educational programs, emphasizing the need for more empirical research to understand how these different actors collaborate to create value, share data, and collectively drive the circular transformation of the textile system.

Overall, the aforementioned literature provides a rich foundation for thinking about circular business models in the textile sector, encompassing both frameworks for typical models such as resale, rental, repair, and recycling, as well as used clothing collection systems and their pivotal role in the circular business ecosystem. However, there remains a lack of specific cases and structured analysis regarding how small-scale, youth-led practices can design their own circular business models within this framework and embed data and digital tools within them, which provides an entry point for the case study and model design in subsequent sections.

2.2 Digital Transformation and Data-Driven Management for Sustainability

In research on circular economy and sustainable management, digital technology is increasingly viewed as a critical "enabling infrastructure." Tools such as the Internet of Things, cloud computing, big data analytics, and artificial intelligence enable enterprises to track product and material flows in real-time, construct more sophisticated decision support systems, and present environmental impacts intuitively to managers and consumers. Compared to traditional management approaches that rely on rough statistics and experiential judgment, data-driven digital management emphasizes monitoring, early warning, and iterative optimization based on continuous data flows, thereby providing technical support for the design and implementation of circular business models.

Digital technology plays a particularly prominent role in the textile and apparel value chain. On one hand, technologies such as blockchain, IoT tags, and digital product passports are used to enhance supply chain traceability, recording fiber sources, production processes, and lifespan information, thereby providing a basis for reuse and recycling. QR codes and RFID enable individual garments to carry machine-readable "digital identities" throughout circulation, facilitating more precise decision-making in sorting, resale, and recycling processes. On the other hand, various digital tools aimed at end consumers—including mobile applications, online secondhand and rental platforms, repair booking systems, and gamified interactive interfaces—are used to encourage users to return old clothes, purchase secondhand items, or participate in garment repair. Related research indicates that these tools can change users' perceptions of clothing value and use cycles through personalized recommendations, carbon footprint feedback, and point-based incentives, thereby supporting circular consumption practices.

Broader sustainable management literature emphasizes the importance of being "data-driven." An increasing number of organizations are systematically collecting and analyzing environmental and operational data to construct dashboards for indicators such as carbon emissions, energy use, and waste generation, transforming previously implicit environmental impacts into visible, comparable, and trackable management objects. These digital dashboards not only serve internal decision-making but are also used

for external disclosure and accountability, driving the "visibility" and "manageability" of environmental performance in daily management.

However, existing research on digitalization and sustainable management still primarily focuses on large enterprises, established platforms, and technology-intensive pilots, with limited attention to resource-constrained community-based or youth-led projects. In these small-scale contexts, digital tools are often just simple websites, forms, spreadsheets, or basic geographic information tools, yet they can still play crucial roles in activity design, resource allocation, and impact presentation. At the same time, many studies treat digital technology as external tools rather than examining how data practices are embedded within organizations' business models: for example, who is responsible for data collection and maintenance, how data feeds back into collection point layout, partner selection, and recycling pathway planning, and how these data are used to tell "circular stories" to participants.

Therefore, it is necessary to examine how digitalization and data practices integrate with various components of circular business models in more practice-oriented cases, particularly in "small but dynamic" contexts such as school projects, community organizations, and youth-led initiatives. The clothing recycling club that this paper focuses on represents a typical context for conducting data-driven management through simple digital tools (websites, forms, basic statistics), providing an observational window for understanding "small-scale digital circular practices."

2.3 Operations and Analytical Methods for Used Clothing Recycling

Used clothing collection and reuse relies on a complex reverse logistics system to collect garments from dispersed donors, and after sorting and quality assessment, allocate them to different destinations including local resale channels, export secondhand markets, material recycling, or final disposal. Related research typically decomposes the problem into several operational decisions: including location and capacity configuration of collection points and sorting facilities, collection route and frequency design, inventory and allocation strategies, and incentive mechanisms for residents. Existing work has optimized textile reverse logistics networks through mixed-integer programming, simulation, and heuristic algorithms, pointing out that under conditions of highly uncertain demand and highly heterogeneous quality, finding a balance between economic feasibility and environmental benefits is one of the core challenges in system design.

In warehousing and sorting operations, some research focuses on how to use data and algorithms to improve the operational efficiency of secondhand goods. For example, scholars have used machine learning to identify key attributes affecting secondhand product sales and storage decisions, optimizing warehouse layout and priority sequencing; other research discusses improving the sorting accuracy and processing capacity of mixed textile waste through automation and intelligent recognition technologies. Regarding inventory and allocation strategies, analytical models often treat reuse, remanufacturing, material recycling, and disposal as competing destinations, constructing inventory control and revenue distribution schemes under different carbon policies, price structures, and cooperation mechanisms, exploring how carbon taxes, carbon trading, or label premiums affect clothing flows and overall system performance.

Within this overall framework, your two previous research projects can be viewed as specific analytical modules for the used clothing system: the first is a low-carbon inventory and coordination decision model incorporating carbon tax and carbon labeling systems, analyzing how collection enterprises and downstream channels balance between profit and emission reduction under different policy and contractual arrangements; the second is a recycling bin placement optimization simulation based on user preferences and location-based social network data, constructing various recommendation strategies using large-scale donation records and evaluating their impact on collection volume and convenience. These works demonstrate that operations research and data analysis can effectively improve the environmental and

economic performance of used clothing recycling systems.

However, such research mostly assumes the existence of scaled collection enterprises, recycling factories, or municipal systems, treating organizational and business models as given backgrounds, rarely exploring how these analytical modules are embedded in the daily management of specific organizations, especially in resource-limited, flat-structured youth-led or community projects. For practice entities like school clothing recycling clubs, the more critical questions are: what data can be continuously recorded under limited conditions? How can simple and feasible analytical methods support collection point layout, partner selection, and donation pathway planning? How do these operational decisions connect with the project's environmental, social, and educational objectives? Examining youth-led clothing projects from the perspective of operations and analytical models, and integrating scattered analytical tools into a complete circular business model, is precisely the direction this paper seeks to advance.

2.4 Conceptual Gap

In summary, the three sections of literature review above collectively form the theoretical background of this research: circular business model research in the textile sector provides frameworks for models and their combinations such as resale, rental, repair, and recycling; research on digitalization and data-driven sustainable management reveals the potential of digital tools in tracking clothing flows, supporting decision-making, and presenting environmental impacts; research on used clothing recycling operations and analytical models demonstrates how to optimize network layout, inventory, and flows using operations research and simulation methods. However, these studies also expose several critical gaps.

First, existing circular business model work mostly takes brand enterprises, professional social enterprises, or large-scale systems as units of analysis, with small-scale, youth-led initiatives often viewed as peripheral practices, rarely systematically analyzed as "organizations with complete business models." Entities such as school clothing recycling clubs actually play multiple roles simultaneously as clothing collectors and redistributors, environmental educators, and community connection nodes, yet have not been adequately characterized within circular business model frameworks.

Second, research on digitalization and data-driven management emphasizes the "enabling" role of digital technology for circular economy and sustainable management, but typical cases mostly focus on large organizations with complete IT infrastructure, with insufficient attention to how school projects and community organizations with limited resources conduct digital practices using simple tools and limited data. Existing research also often views digital tools as external technologies, rarely exploring how data collection, analysis, and feedback are embedded within business model components, and how they influence value proposition design, stakeholder relationships, and organizational learning processes.

Third, used clothing recycling operations and analytical models extensively employ optimization and simulation methods to improve environmental and economic performance, but generally assume the existence of professionally operated entities with well-established organizational structures and clear responsibilities, treating organizational objectives and governance logic as given premises. Analytical modules (such as inventory models and location models) are typically conceived as "standalone decision tools" rather than embedded within specific projects' business models. This leaves us with insufficient understanding of the process by which "small-scale organizations absorb, simplify, and use these analytical approaches in practice."

Therefore, there is a need both theoretically and practically to conduct a "bridging" study: on one hand, integrating the three threads of circular business models, digital sustainable management, and used clothing recycling operational analysis to reconstruct the value creation, delivery, and capture logic of youth-led clothing projects from a business model perspective; on the other hand, exploring how to transform analytical modules such as low-carbon inventory decisions and recycling bin placement optimization into "lightweight data practices" usable by school clubs without adding excessive complexity. Through the case

of New Canaan High School's clothing recycling club, this paper attempts to build a "meso-level" connection between theoretical frameworks and practical contexts within this conceptual gap, providing an operational analytical template for understanding small-scale digital circular practices.

3. Research Methodology

3.1 Research Design

This research adopts a single-case, embedded case study design to explore how a youth-led clothing recycling initiative constructs a data-driven circular business model in the digital era. Specifically, the research focuses both on the value creation logic at the overall organizational level and on several sub-units such as operational processes, digital channels, and analytical modules, thus treating this case as an embedded design containing multiple analytical units within a single organizational context. This research follows the logic of theory induction and iterative construction from cases proposed by Eisenhardt, aiming not to test preset hypotheses but rather to gradually refine and expand the conceptual framework of circular business models and data-driven management through in-depth analysis of the New Canaan High School (NCHS) clothing recycling club. The research pursues "analytical generalization," generating transferable theoretical insights through this specific case rather than making statistical inferences about a larger population. This case is "revelatory" because the researcher gained access to the interior of a youth-led project, systematically obtaining its operational records, digital materials, and design decisions, while introducing analytical tools such as low-carbon inventory decisions and recycling bin placement optimization to support the project as it progressed. It is precisely this close integration of practical implementation and analytical modeling that makes this case an ideal subject for observing how data and simple analytical modules are embedded in circular business model design in small-scale contexts.

3.2 Case Background: NCHS Clothing Recycling Club

The case in this research is a student-led clothing recycling club at New Canaan High School (NCHS) in Connecticut, USA. The club was established in early 2024 with two core objectives: (1) to reduce textile waste in the local community by collecting used clothing and directing it into high-value reuse channels; and (2) to serve as a platform for learning and experimenting with data-driven sustainable management. During an intensive action period of approximately five months in the 2024-2025 school year, the club organized a series of collection activities, set up recycling bins on the NCHS campus and at the local YMCA, and mobilized classmates, parents, and friends to participate, collecting over 10,000 pieces of clothing in total. After simple sorting, the clothing was donated to an American Veterans Association, combining environmental objectives (waste and emission reduction) with social objectives (supporting veteran communities).

In terms of organizational structure, the club is managed daily by a student leadership team, supported by an on-campus faculty advisor and collaborative researchers from Beijing Jiaotong University's International Information Research Center. The two parties had previously conducted two operations research studies on clothing recycling systems: one on low-carbon inventory and coordination decision models under carbon tax and carbon labeling policies, and another on recycling bin placement optimization simulation based on user preferences and location-based social network data. This paper treats these existing findings as reusable analytical modules and parameter sources (such as carbon emission factors and potential collection volume ranges), reinterpreting and integrating them within a circular business model framework.

At the digital level, the club maintains a public website (www.nchsrecycle.org) to introduce the project mission and textile waste issues, announce recycling bin locations and collection activity information, showcase partners (such as YMCA and the Veterans Association), and update cumulative collection quantities and estimated environmental impact indicators. This website serves as the core digital channel for donors, students, and community members, transforming data originally scattered in operational records into public-facing impact narratives. Overall, this organizational form positions the club at the intersection

of various circular business model prototypes: it is simultaneously a clothing collection and redistribution model, can be viewed as a student-led community social enterprise, and also serves as an educational experimental ground focused on circular economy and data practices.

3.3 Data Collection

This research follows the principle of "multiple sources of evidence and cross-validation" in case studies, comprehensively utilizing quantitative operational data, digital materials, and qualitative interview materials. The data primarily includes four categories: First, the club's operational records, such as collection volumes at various stages (decomposed by time and location), clothing categories and rough quality classifications, and handover batches with partner organizations, used to characterize clothing flow volumes and structure while providing a foundation for carbon emission reduction estimates. Second, the club's website and related digital texts and visual content, including project mission statements, activity announcements, impact statistics and charts, used to analyze value propositions, communication strategies, and "how data is used to tell stories." Third, semi-structured interviews and informal conversations with student leaders, faculty advisors, and partner organization representatives, focusing on themes such as project origins, decision-making processes, data usage methods, and learning outcomes, helping to reconstruct the business model evolution process and key turning points. Fourth, model documentation and parameter settings from previous low-carbon inventory models and recycling bin placement optimization research, serving as technical inputs for analytical modules and emission factors.

In terms of analytical steps, first, a project timeline was constructed based on operational records and interview materials, forming a narrative thread of "spontaneous practice → introduction of analytical tools → data-driven adjustments." Second, using a modified circular business model canvas as a framework, case materials were coded to systematically map elements such as value propositions, stakeholders, channels, key activities, resources and partners, costs and value capture to the clothing recycling club, with particular attention to data flows and analytical nodes within them. Third, existing models such as carbon emission estimation and collection point planning were treated as "pluggable analytical modules," exploring how they could be embedded in simplified form into club decision-making under current data conditions, with typical scenario calculations (such as collection volumes and emission reductions under different collection point combinations) demonstrating their potential value. Finally, based on longitudinal comparisons (before and after stages) and horizontal comparisons (different business model elements), several themes were distilled regarding how data and digital tools change project management practices, stakeholder relationships, and organizational learning, providing a foundation for subsequent discussion and theoretical generalization.

3.4 Data Analysis and Integration of Analytical Modules

Data analysis was divided into three main steps.

First, by constructing a chronological narrative of the club's formation and activities during the 2024-2025 action period, an internal case narrative was formed. The research synthesized operational records and interview data to identify key stages (planning, mobilization, collection, sorting, donation, reflection) and related decisions (such as recycling bin placement locations, which partners to contact, and how to communicate project impact). This narrative analysis helps reveal the business model logic that was originally implicit in the initiative.

Second, the research applied a circular business model framework to structure and interpret the case. Building on existing circular business models in the textile sector (such as durability, access rights, resale/redistribution, and recycling models), this research adapted a business model canvas-like structure to highlight value propositions, stakeholder classifications, channels, key activities, key resources and partners, and revenue/cost structures, while adding an explicit "circular layer" to present the circular

pathways of collection, redistribution, and potential recycling. Case data was coded according to these categories while incorporating emerging themes (such as educational value, digital communication, and social impact).

Third, analytical modules from previous operational research were conceptually integrated into the business model. The low-carbon inventory model was used to estimate avoided carbon emissions based on the total volume of collected items, drawing on published emission factors per kilogram of textiles and assumptions about avoided production and disposal scenarios. The recycling bin placement optimization and simulation framework served as a conceptual lens for discussing how the club could make its collection point selection (such as NCHS, YMCA, and potential new locations) more data-driven, although fully implementing this model exceeded the club's current resource capacity.

In the analysis, these mathematical models were not reproduced line by line, but rather treated as "pluggable" analytical capabilities to support specific components within the business model:

- **Operations and Logistics**: Planning collection points and collection schedules, estimating capacity requirements, and predicting fluctuations in donation flows.
- **Impact Assessment**: Converting collection quantities into avoided carbon emissions and other environmental indicators.
- **Strategic Development**: Exploring hypothetical scenarios (such as adding new collection partners or introducing resale channels) and their impact on environmental and economic outcomes.

Therefore, the overall analytical strategy is to connect micro-level operational data and analytical tools with macro-level business model elements, thereby elucidating how a youth-led clothing recycling initiative functions as a data-driven circular business model in the digital age.

4. Constructing a Data-Driven Circular Business Model

4.1 Conceptual Framework and Design Methods

The design of the data-driven circular business model for clothing recycling in this research is built on two complementary foundations: (1) existing circular business model (CBM) frameworks in the textile and fashion sectors, and (2) the specific empirical characteristics of the NCHS recycling club and its existing analytical modules. As described in Section 2.1, CBM literature typically distinguishes key components such as value propositions, value creation and delivery, value capture, and circular value closure, while specialized frameworks in the textile sector emphasize model archetypes such as resale, repair, rental, and recycling. For the purposes of this research, these concepts are integrated into an adapted business model canvas that highlights the central role of circular flows and data within the model.

The proposed framework (Figure 1) organizes the business model into three interconnected layers:

1. Core Business Model Layer
    - Building on the traditional business model canvas, this research identifies elements applicable to the NCHS club, including value propositions, stakeholder segmentation, channels, key activities, key resources, key partners, and cost/revenue structures.
    - For the club, its value proposition integrates environmental value (reducing textile waste and carbon emissions), social value (supporting veterans and educating students), and learning value (developing youth capabilities in data and management).
2. Circular Value Flow Layer
    - On the outer layer of the core canvas is the presentation of the physical circular flow of

used clothing: from donors (students, families, YMCA users) to recycling bins, then to the club's sorting activities, subsequently entering reuse channels (American Veterans Association and potentially other charitable or resale partners), and in the longer term extending to pathways such as recycling or downcycling.

- This layer explicitly presents the collection and redistribution closed loop that forms the core of the circular business model.

3. Data and Analytics Layer
    - Overlaid on the previous layers is the data layer, which tracks how information is generated, stored, analyzed, and subsequently fed back into various decisions.
    - For the NCHS club, the data layer includes donation records (item quantities, locations, times), basic quality and category coding, digital engagement metrics (website visits, online post interactions), and derived indicators (such as emission reductions estimated based on textile emission factors).
    - The data layer also includes analytical modules developed in previous research—low-carbon inventory modeling and recycling bin placement simulation — which are conceptualized as pluggable tools to support specific types of decisions.

By combining these three layers, the framework positions data and analytics as core components of value creation, value delivery, and value capture in the circular business model, rather than as auxiliary tools added on top.

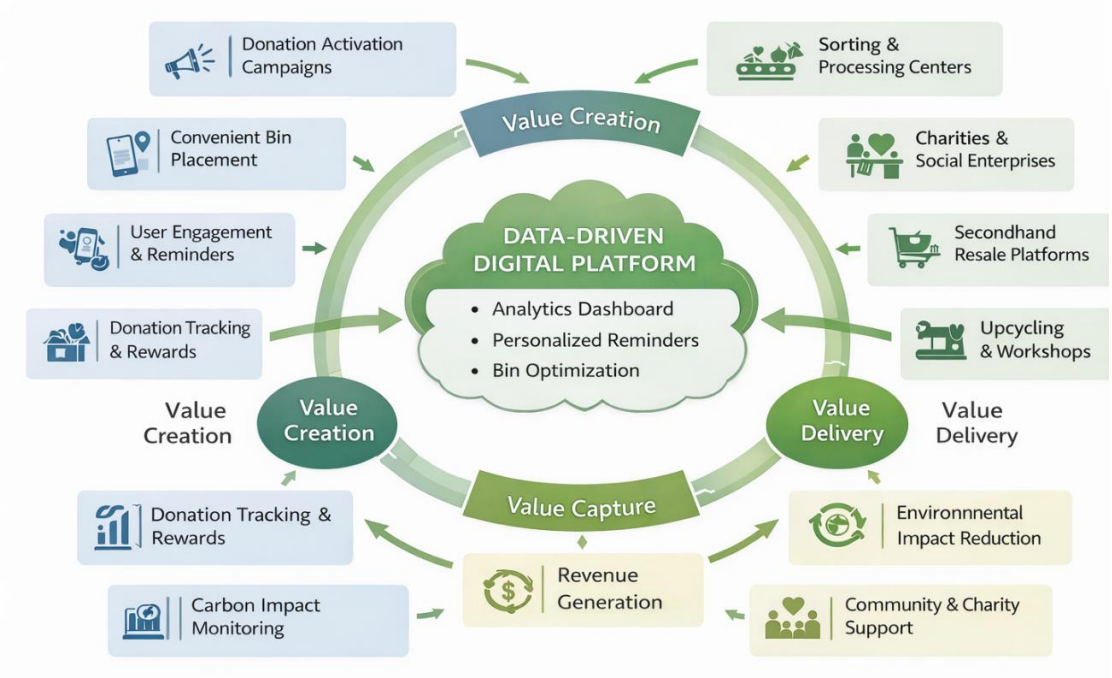

Figure 1. Data-Driven Circular Business Model Framework for Used Clothing Recycling

4.2 Circular Value Flows and Stakeholder Configuration

Based on the framework shown in Figure 1, we first map out the circular value flows and stakeholder structure of the NCHS recycling club (see Figure 2). The key participating entities and flows include:

- Donors (Families and Individuals)

  - Students, parents, teachers, and community members who donated used clothing during the five-month collection campaign period.
  - They interact with the club through offline drop-off points (recycling bins at NCHS and YMCA) as well as digital communication channels (school announcements, social media, and the club website).

- Collection and Sorting (NCHS Recycling Club)
  - The student-led club is responsible for coordinating recycling bin placement, organizing regular emptying and transportation, and conducting basic sorting work (such as categorization by type and condition).
  - Operational data is generated at this stage: including collection quantities (over 10,000 items in 5 months), approximate weight, and sorting results by category (such as wearable vs. non-wearable).
- Reuse Partners (American Veterans Association and Other Potential Partners)
  - After sorting, the clothing is donated to the American Veterans Association, which further distributes it to beneficiaries or incorporates it into its own resale/donation system.
  - In future expansions of the business model, more partners could be added (such as local secondhand stores and textile recycling enterprises) as alternative or supplementary destinations for different quality grades of used clothing.
- Educational and Community Stakeholders
  - NCHS administration and teachers, who view the club as an educational and civic engagement project and provide support.
  - The local YMCA, which supports the project by hosting recycling bins and extending outreach to its member community.
  - The research team from Beijing Jiaotong University, which provides analytical support for the project and jointly develops related models.
- Digital Audience
  - Members of the public who visit the club's website (www.nchsrecycle.org) and receive its online messages, who may be donors, supporters, or simply observers interested in the initiative's impact.

The circular model features multidimensional value flow characteristics: including physical flows of clothing, financial flows (such as potential small sponsorships or in-kind support), environmental value flows (such as avoided carbon emissions), and intangible value flows such as environmental awareness enhancement and student learning outcomes. Figure 2 depicts these flows as circular pathways, highlighting how used clothing flows from households to the club and then to reuse partners, while related data simultaneously cycles back through digital channels and analytical tools as feedback, thereby providing a basis for subsequent decision-making.

Figure 2. Circular Value Flows and Stakeholder Map of the NCHS Clothing Recycling Club

4.3 Embedding Analytical Modules into Operational Processes

A distinctive feature of this case is the ability to utilize two analytical modules developed in previous research and embed them into the club's circular business model as decision support tools:

1. Low-Carbon Inventory and Coordination Module
    - Based on the model by Gao et al. (2024), this module describes how used clothing collection organizations and their downstream partners (such as retailers and recyclers) optimize inventory decisions under carbon tax and carbon labeling systems, while considering carbon emissions generated during collection, storage, and transportation processes.
    - In the NCHS context, this module can be simplified to support the following aspects:
        - Estimating avoided carbon emissions by diverting over 10,000 pieces of clothing from landfill or incineration.
        - Exploring scenarios of directing portions of collected clothing into resale or recycling channels and evaluating the trade-offs between environmental benefits and potential revenues.
        - Designing coordination mechanisms (such as partnerships with secondhand stores or recyclers) to achieve equitable sharing of costs and revenues.
2. Collection Point Placement and Simulation Module
    - Based on simulation research by Gong et al. (2024), this module models and analyzes how different clothing recycling bin placement strategies affect collection volumes and accessibility under the influence of factors such as user preferences and social activity nodes (such as schools and gyms).
    - For the club that initially used only two main drop-off points (NCHS and YMCA), this module can:

- Evaluate the relative performance of existing collection points (such as daily/weekly average collection volumes).
- Simulate potential new collection locations (such as other schools, churches, community centers) and estimate the additional collection volumes they might generate.
- Support decisions about whether to expand or consolidate collection infrastructure in future campaigns.

Figure 3 illustrates the positioning of these modules within the circular business model. The inventory/low-carbon module primarily supports the downstream portion of the circular loop (post-collection distribution and impact measurement), while the recycling bin placement module supports the upstream portion (donor accessibility and collection planning). Both operate based on data generated during the club's operations and feed their outputs back into strategic and operational decisions.

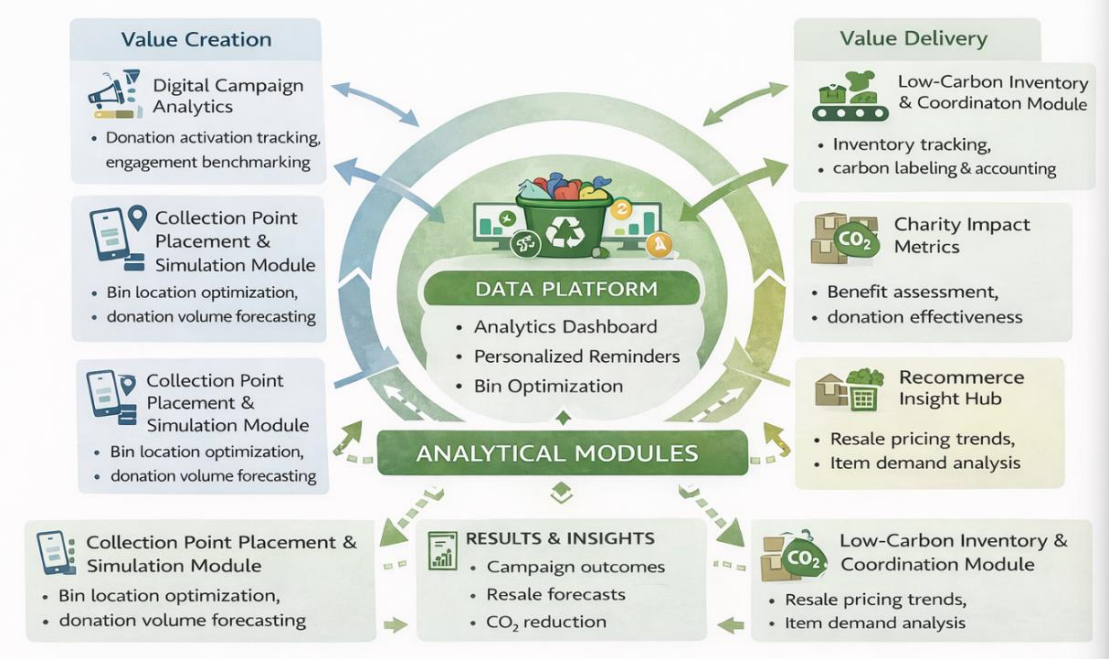

Figure 3. Integration of Analytical Modules within the Circular Business Model

In practice, due to resource and capability limitations, the actual application of these modules in the NCHS club is simplified and exploratory. The low-carbon model is primarily used to convert the total volume of collected clothing into approximate avoided carbon emissions (for example, applying textile emission factors per unit weight), with results disseminated on the website and in campus displays. The recycling bin placement logic is used qualitatively to justify why focus should be placed on high-traffic, socially active locations such as NCHS and YMCA, and to identify potential expansion candidate sites, even though complete optimization calculations based on local data have not yet been performed. Nevertheless, these applications still demonstrate how analytical thinking shapes the way youth-led initiatives understand their operational and strategic choices.

4.4 Digital Channels, Data Practices, and Feedback Mechanisms

The digital layer in the business model serves a dual function: it acts both as a channel for facilitating stakeholder engagement and as a key mechanism for capturing data and feeding it back into management decisions.

The NCHS recycling club's website (www.nchsrecycle.org) serves as the project's core digital hub,

functioning as a centralized platform. The website is used to communicate the club's mission (reducing textile waste, supporting veterans), provide information about recycling bins and related activities, showcase activity photos and stories, and publish key metrics such as "collected over 10,000 pieces of clothing in five months." The website also links to external resources about the environmental impact of clothing and provides basic educational content, thereby reinforcing the educational value proposition in the business model.

From a data-driven management perspective, the website and its related digital tools (such as school newsletters, social media posts, QR codes) can be used for the following:

- **Tracking Engagement**
    - Basic web analytics data (page views, unique visitors, traffic sources) can reveal which information or sections receive the most attention, as well as the temporal distribution of this attention.
    - Click rates on collection activity announcement posts can be correlated with actual peaks in donation volumes, thereby helping to optimize the timing and content of information releases.
- **Collecting Structured Feedback**
    - Brief online surveys embedded in the website, or linked through QR codes placed on recycling bins, can collect information about donors' motivations, perceived barriers, and suggestions for new locations or services.
- **Visualizing Project Impact**
    - Simple visualization dashboards (such as cumulative items collected, estimated weight of diverted textiles, estimated avoided CO2-equivalent emissions) can be presented on the website and in school displays, transforming operational data and low-carbon module outputs into clearly visible impact narratives.

Figure 4 presents a conceptualization of these digital feedback loops within the business model. Data generated from offline operational activities (collection, sorting, donation) is recorded in spreadsheets or simple databases; analytical modules transform this data into insights (such as hotspot areas, impact indicators, collection performance at different locations); subsequently, the website and other communication channels feed these insights back to donors, partners, and potential supporters. Over time, this process can form a virtuous cycle: better data → better decisions → greater impact → stronger engagement → more data.

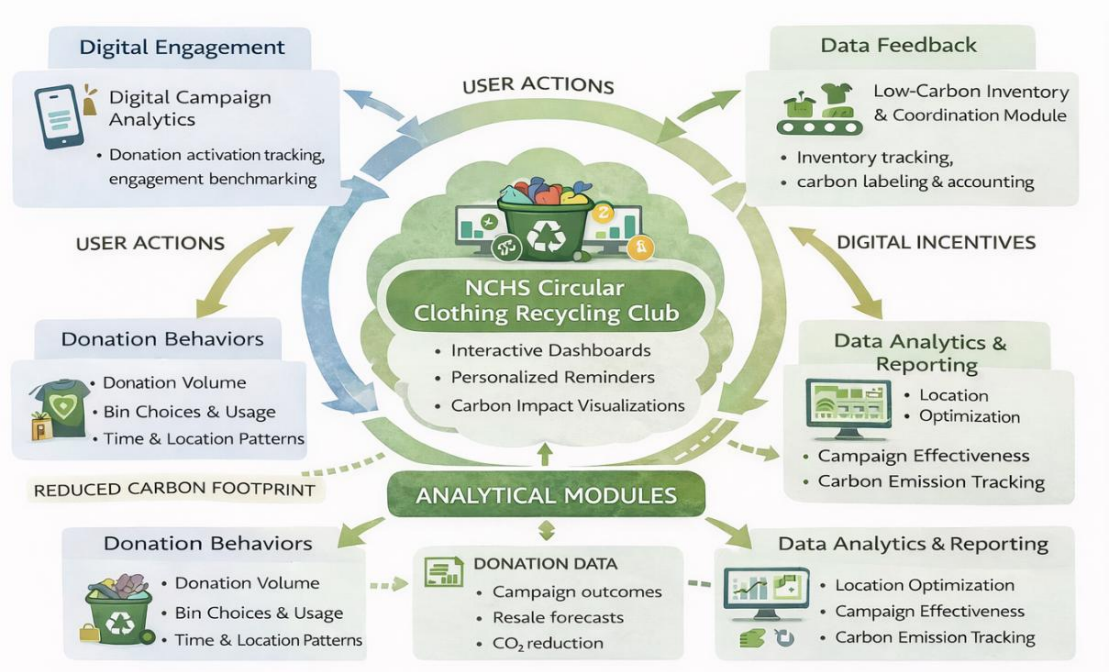

Figure 4. Digital Engagement and Data Feedback Loops in the NCHS Circular Business Model

5. Research Findings: How Digital Data Changes Management Approaches

This section presents the main empirical findings on how digital data and basic analytics are beginning to change the management approach of the NCHS clothing recycling club. The analysis is organized around four themes that emerged from the case: (1) data-enabled operational decision-making; (2) visualization of environmental and social impacts; (3) enhanced stakeholder engagement and behavior change; and (4) formation of organizational learning and capacity building. The final subsection discusses the tensions and limitations observed in this process.

5.1 Data-Enabled Operational Decision Making

The first research finding is that even with relatively simple digital data collection and analysis, the club's operational decisions have begun to shift from "intuition-based" to "data-informed." Before the launch of the 2024-2025 recycling campaign, recycling bin placement primarily relied on common sense judgment (such as "place them where there's high foot traffic"). After continuously recording collection volumes disaggregated by time and location, students discovered significant variations in output across different locations and time periods, such as donation peaks during school event weeks or certain YMCA program periods. Based on this, they adjusted bin emptying and pickup frequencies to avoid overflow, strengthened email and poster outreach during weeks when historical data indicated low donation volumes, and, following the "social activity nodes + accessibility" logic emphasized by the recycling bin placement optimization module, considered which locations with usage patterns similar to YMCA should be prioritized for new collection points. Although a complete location optimization model based on local data has not yet been run, the key concepts from the model have influenced how students read and interpret their own data as a kind of "mental framework."

Similar changes also appeared in inventory and batch arrangements. By tracking the accumulation of over 10,000 clothing items over five months and observing fluctuations in collection volumes over time, student leaders began to rethink how to utilize limited storage space and transfer capacity. After understanding how the low-carbon inventory model characterizes the "inventory level-carbon emissions-coordination cost" relationship, they realized that simply "piling clothes in one place for extended periods" could lead to

additional transportation trips and space waste, thus gradually shifting to smaller batches with higher frequency transfers to the Veterans Association. Overall, the case demonstrates that data and analytics don't need to be complex to be effective: consistently recording quantities, disaggregating information by location and time, and regularly reviewing trends is sufficient to shift decision-making from intuitive to evidence-based; meanwhile, the existence of analytical models provides students with a more professional vocabulary and structural framework when discussing "collection volume-capacity-tradeoff" issues.

5.2 Visualizing Environmental and Social Impact

The second important finding is that digital data and basic analytics played a central role in making the club's environmental and social impact visible to both internal and external stakeholders.

Using operational data on collection quantities and existing emission factors for textile production and disposal, supported by the low-carbon inventory model, the club was able to estimate the carbon emissions avoided by its activities. Rather than merely reporting "collected over 10,000 pieces of clothing," the club can now further communicate the following approximate quantitative data:

- The kilograms of textiles diverted from landfill or incineration disposal.
- The tons of CO_2-equivalent emissions avoided, based on per-kilogram factors.
- Where appropriate, converted into easily understandable equivalents from daily life (such as "equivalent to taking X cars off the road for a month").

These estimates were then transformed into digital impact narratives on the website and in campus displays. This type of quantitative expression serves multiple functions:

- At the internal level, it enables student leaders to more clearly recognize the scale of their achievements, thereby enhancing their motivation and lending greater legitimacy to their invested efforts.
- For partners such as YMCA and the Veterans Association, these quantitative results provide a concrete and compelling way to demonstrate the value of collaboration to their own stakeholders.
- For donors and the broader community, these quantitative results transform individual actions (such as donating a bag of clothes) into visible collective environmental benefits, thereby enhancing the sense of meaning and perceived importance of participation behaviors.

More importantly, this data also highlights the project's social impact: by tracking the quantity and types of clothing donated to the Veterans Association, the club can report the number of beneficiaries supported and the most needed item categories. This dual focus on environmental and social indicators helps maintain partner engagement and keeps the business model aligned with its multidimensional value proposition.

5.3 Enhanced Stakeholder Engagement and Behavior Change

Digital data has also changed how the club interacts with stakeholders and influenced their behaviors.

The website and related digital communication formats (such as school newsletters, social media posts, posters with QR codes) serve not only as information dissemination channels but also as data-driven feedback mechanisms. For example:

- When the club noticed temporary declines in donation volumes during certain weeks, it would strengthen digital reminders and experiment with different messaging approaches (such as emphasizing environmental benefits versus emphasizing support for veterans) to observe which approach generated more participation.
- Basic web analytics data (such as page views for specific website sections, traffic surges after announcements) helped identify which types of content most resonated with visitors. This

information further influenced the club's decisions about which stories to prominently feature (such as photos from sorting days, quotes from Veterans Association representatives, charts of cumulative donation volumes, etc.).

Although these practices are still in their early stages and primarily rely on manual operations, they demonstrate how data-driven digital experimentation can be integrated into the management practices of a youth-led project. Student leaders began discussing "what works" and "what doesn't work" based on measurable feedback (such as more visits, more donations), rather than relying solely on intuitive judgment.

Moreover, the public reporting of impact metrics also creates a sense of social accountability and positive peer pressure. When the club shares milestone achievements on its website and school channels (such as reaching cumulative totals of 5,000 or 10,000 items), students and families can clearly see the collective results brought about by their contributions. Interviewees indicated that these updates "make everything feel real and tangible" and motivate them to continue donating and promoting the project, thereby reinforcing a virtuous cycle of participation mechanisms.

5.4 Organizational Learning and Capacity Building

The fourth theme focuses on how data and digital tools trigger organizational learning and capacity building within the club. The process of designing a data-driven circular business model and attempting to embed analytical modules prompted student leaders to understand the project from a more systematic perspective, reconstructing it from a series of scattered activities into an interconnected system of material flows, information flows, and value flows. This process also enhanced students' basic data literacy: they learned to design simple collection templates, clean and aggregate records, read trends, and transform raw numbers into narrative content for donors and partners. Additionally, through interactions with the Beijing Jiaotong University team and through understanding and simplified use of inventory models and placement models, students were exposed to analytical and modeling thinking and began discussing future expansion using scenario analysis, such as "if collection volume increases by 50%, how many additional volunteers would be needed" and "what would adding a new school drop-off point mean for storage and transportation." Although these estimates remain relatively rough, they reflect an emerging data-driven mindset.

This learning was not one-way indoctrination but rather formed a "knowledge bridge" through collaboration with academic partners, translating complex operations research models into concepts and tools that the club could understand and partially apply. The case demonstrates that collaboration between universities and youth-led initiatives helps democratize analytical capabilities in small-scale circular projects: on one hand bringing more professional analytical perspectives and parameter support to the project, while on the other hand allowing students to experience how to support management decisions with data and models in real contexts. This practice-based capacity building has established an important cognitive and skill foundation for the club's future expansion of partners, attempts at resale channels, or design of more complex recycling pathways.

5.5 Tensions and Limitations

Despite the positive significance of the aforementioned developments, the case also reveals multiple tensions and limitations faced when using digital data to drive management transformation in youth-led circular initiatives. First is the constraint of resources and time. Student leaders need to allocate their energy between academics and extracurricular activities, forcing them to make trade-offs between "data granularity" and "process simplicity and feasibility." In practice, the club could only focus on a few key metrics (such as total collection volume, location, time periods), while more fine-grained information (such as detailed classification by category and quality, donor profiles, etc.) has not been systematically recorded and utilized.

Second, the deployment depth of analytical tools is limited. The low-carbon inventory model and recycling

bin placement model theoretically possess strong optimization capabilities, but are currently mainly used to provide macro-level insights and communication support (such as estimating emission reductions, guiding qualitative location judgments), rather than executing complete, data-intensive optimization. This is related both to the project's scale and short time series, and also reflects students' limitations in modeling skills and software tools, highlighting the gap between "advanced analytical methods" in the literature and actual adoption by grassroots initiatives.

Third, data governance and sustainability face uncertainty. Since the club is managed by rotating students, leadership changes can easily lead to data loss and unmaintained websites and spreadsheets. Currently, no formal data management and handover mechanisms have been established, and the data-driven circular business model still relies to some extent on a few key individuals. Finally, value capture being primarily in non-monetary forms also increases the complexity of business model analysis. The project does not directly monetize used clothing but relies on volunteer labor and in-kind support, which aligns with its educational and public service orientation but means that financial sustainability has not yet become a core issue, and whether to introduce revenue channels such as resale or sponsorship in the future remains to be explored.

Overall, the case demonstrates that digital data and basic analytics have begun to reshape the planning, communication, and learning approaches of the NCHS recycling club in small-scale contexts, while also reminding us that we must face resource constraints squarely, manage expectations for advanced analytical tools reasonably, and ensure the continuity of data practices through more robust institutional arrangements. These tensions and limitations provide important context for subsequent discussion about the significance of youth-led digital circular business models in broader management contexts.

6. Discussion

This section discusses the research findings in conjunction with relevant literature on circular business models, digital transformation, and used clothing recycling operations, and distills their theoretical, practical, and educational implications. Subsequently, this section also outlines possible directions for future research.

6.1 Theoretical Implications: Youth-Led Initiatives as Micro Circular Business Models

From a theoretical perspective, this research first demonstrates that youth-led projects like the NCHS clothing recycling club need not only be viewed as "public service activities" or "educational projects," but can be fully understood within a circular business model framework as a type of "micro circular business model." Existing circular business model research mostly focuses on brand enterprises, professional social enterprises, or large-scale systems, treating small-scale initiatives as peripheral supplements. The case analysis in this paper shows that youth-led entities also possess complete value structures: their value proposition simultaneously encompasses environmental emission reduction, social support, and educational experience; their value creation relies on specific collection and sorting activities, data recording and analytical work; their value delivery reaches donors, partners, and communities through channels such as offline recycling bins and online websites; their value capture is primarily in non-monetary forms such as environmental and social impact, student learning, and reputation enhancement.

This characterization helps expand the analytical boundaries of circular business models: on one hand, it reminds us that when discussing circular fashion ecosystems, we should include school projects, community organizations, and youth clubs in considerations of "portfolio business models," rather than focusing solely on brands and platforms; on the other hand, it also suggests that circular business models do not necessarily imply complex profit structures, and small-scale initiatives can equally operate under clear value logic.

Second, the case more closely connects operations research analysis with business model research. Previously, inventory models and location models were often viewed as independent decision tools, but this paper attempts to understand them as "analytical capability modules" within business models,

emphasizing how they support value propositions (such as quantification of environmental impact), influence key activities (collection point layout, batch arrangements), and reshape stakeholder relationships (how to explain project value to partners). This perspective helps advance circular business model research from static structural description toward attention to "business models with embedded analytical capabilities," providing a meso-level discussion starting point for future integration of business models and data analysis in multi-actor, multi-level circular practices.

6.2 Integrating Analytical Tools into Circular Business Models

The second theoretical implication involves the approach to integrating operational analytical tools into circular business model (CBM) design. Previous research on used clothing systems typically treats optimization and simulation models as standalone tools for solving specific decision problems—such as inventory control under carbon regulation scenarios or optimal recycling bin placement. In contrast, this research repositions such models as modular analytical components embedded within a broader business model framework.

In the NCHS case, the low-carbon inventory model and recycling bin placement simulation were not implemented as complete, large-scale optimization systems. Instead, they served the following functions:

- Conceptual scaffolding tools for shaping how student leaders think about flows, capacity, and various trade-off relationships.
- As estimation tools, transforming operational data into impact indicators (such as avoided carbon emissions) that feed back into value proposition articulation and external communication.
- As lenses for scenario analysis, used to explore possible future configurations (such as new collection points, alternative distribution channels).

This represents a more embedded analytical perspective, where models are viewed as components of the business model's "intelligence layer" rather than externally attached tools. This suggests that future circular business model research could conceptualize business models not only as static configurations of activities and relationships, but also as dynamic systems with built-in analytical capabilities that can continuously process data and adjust decisions. This perspective also aligns with broader discussions about data-driven and "smart" circular business models, where digital technology and analytical tools themselves are integral components of value creation and value capture.

6.3 Digital Transformation at the Micro Level: From Platforms to Projects

The third research finding refines the understanding in existing digital transformation and sustainability literature by shifting focus from large brands and commercial platforms to micro-level, youth-led projects. Extensive existing research emphasizes that advanced digital solutions — such as blockchain-based traceability systems, AI-driven recommendation systems, and sophisticated recommerce platforms—are important enablers of circular fashion. However, the NCHS case demonstrates that even very simple digital tools—such as a basic website, spreadsheets, and elementary analytical modules inspired by academic models—can substantially change management practices when embedded in daily operations.

In particular, this research emphasizes how small-scale digitalization can:

- Transform basic operational records into actionable insights (such as donation patterns at specific locations, peak donation periods).
- Support impact visualization, thereby enhancing the project's legitimacy, motivational effects, and relationships with partners.

- Enable the club to experiment with communication strategies at low cost and use simple web and engagement metrics to guide decisions.

This indicates that digital transformation for sustainability should not be understood solely as high-tech, capital-intensive projects; rather, it can be viewed as a spectrum of practices where even low-tech, light-data solutions can significantly impact how circular initiatives are managed. For theory, this finding calls for academia to pay more attention to the phenomenon of "everyday digitalization" in small organizations and community projects, and to explore how such practices can be scaled or connected with larger systems.

6.4 Managerial and Educational Implications

From a practical perspective, this case provides several insights for managers, educators, and supporting institutions hoping to advance circular initiatives in the digital age. For community organizers and project practitioners, a "minimalist" digital and data toolkit—such as a basic website, simple data spreadsheets, and a few key metrics (items collected, locations, estimated emission reductions, etc.)—is already sufficient to support meaningful operational optimization and impact presentation. Explicitly viewing such actions as a circular business model, rather than just one-off activities, helps clarify objectives, stakeholders, and value flows, making projects easier for partners, funders, and community members to understand and support. Meanwhile, establishing collaborative relationships with universities or technical experts can enable the absorption and simplification of analytical tools like operations research models without "adding excessive complexity," making them applicable to small-scale, resource-limited contexts.

For schools and universities, the NCHS case demonstrates how to develop a clothing recycling club into a project-based "living laboratory" at the intersection of sustainability, data science, and management. Students experience the entire process of designing and operating circular initiatives, collecting and analyzing data, and communicating project impact to different audiences through digital channels, which highly aligns with the educational philosophy advocated in education research and policy of "developing digital literacy and sustainability literacy through real projects." Schools and universities can systematically support such projects by providing basic digital infrastructure (such as simple data platforms), providing mentor support, and formally recognizing student investment through course credits, awards, and other means.

For policymakers and supporting organizations, this research indicates that youth-led recycling clubs can serve as valuable complements to local textile circular strategies. Although their processing volume is limited, they can mobilize groups that are otherwise difficult to reach directly (such as students and families) to participate in behavior change, generate localized data and insights that can inform larger-scale textile policies and infrastructure development, and explore innovative combinations of environmental, social, and educational value. Supporting such "micro circular initiatives" through small grants, providing access to data tools or platforms, and building collaboration channels with charitable organizations and recycling enterprises could become a low-cost but impactful component of local textile circularity and waste reduction programs.

6.5 Future Research Directions

This research also opens up multiple directions for further exploration:

1. Comparative Studies of Youth-Led Circular Initiatives
    - Analyzing multiple clubs or community projects from different regions and institutional contexts could reveal patterns in their business model design, digital practices, and outcomes, and identify contextual factors that promote or hinder data-driven circular management.
2. Longitudinal Studies of Digital and Analytical Capability Development

- Tracking the same initiative over multiple years would enable researchers to examine how data practices evolve over time, how leadership transitions affect project continuity, and how more advanced analytical tools (such as route optimization, demand forecasting) might be gradually adopted.

3. Integration with Behavioral Experiments
    - Future research could embed controlled experiments within club activities (such as different digital information presentation formats, gamification elements) to rigorously test how specific digital interventions affect donor behavior and engagement.
4. Exploring Revenue-Generating Expansion Directions
    - As youth-led initiatives gradually mature, some may consider adding elements such as resale or upcycling to generate revenue for social or educational projects. Future research could explore how data-driven tools support the design of such hybrid models and how they balance financial sustainability with social and environmental objectives.
5. Data Governance and Ethics in Small-Scale Digital Sustainability Projects
    - Finally, it is necessary to examine issues related to data ownership, privacy, and ethical use in community-level circular initiatives, especially when involving minors and vulnerable groups.

7. Conclusion

This paper uses the New Canaan High School (NCHS) clothing recycling club as a case study to explore how digital data and basic analytics can be embedded into used clothing recycling practices in youth-led contexts, constructing a data-driven circular business model. Based on literature on circular business models in the textile sector, digital sustainable management, and operational analysis of used clothing recycling, the research treats the club as a "living laboratory" for circular innovation in the digital age. By comprehensively utilizing multiple data sources including operational records, website and communication materials, interview data, and existing low-carbon inventory and recycling bin placement optimization models, the study constructs a three-layer framework consisting of a core business model layer, circular value flow layer, and data and analytics layer, to characterize how this youth organization creates value across environmental, social, and educational dimensions.

The research yielded four main findings: First, data-enabled operational decision-making—continuously recording and disaggregating donation volumes by location and time enabled decisions about collection point selection, emptying frequency, and batch arrangements to gradually shift from experiential judgment to evidence-based adjustments, with operations research models providing structured language at the conceptual level for students to understand "collection volume-capacity-tradeoff" relationships. Second, visualizing environmental and social impact—by converting cumulative collection volumes into estimated emission reductions and beneficiary group information, and presenting these on the website and in school communications, the project's environmental and social value became more concrete and perceptible. Third, enhanced stakeholder engagement—data-driven impact feedback and online communication mechanisms not only increased identification among donors and partners but also strengthened the project's presence in the school and community. Fourth, organizational learning and capacity building—through the process of constructing the business model and using analytical tools, student leaders grew in systems thinking and data literacy, while collaboration with the university team provided them with a knowledge bridge for "translating" complex models into usable concepts.

At the same time, this research also reveals several limitations and tensions: data collection and analysis depth are constrained by time and capabilities, with analytical tool applications mostly remaining at simplified and conceptual levels; periodic student turnover poses challenges for data continuity and knowledge transmission; the single case has strong contextual specificity, with conclusions being more inspirational than statistically generalizable. Nevertheless, the research theoretically incorporates small-scale youth-led initiatives into the discussion of circular business models and digital management, and attempts to embed analytical modules such as low-carbon inventory and location optimization into business model frameworks; practically, it demonstrates that even relying on simple websites, spreadsheets, and basic statistics, small-scale circular projects can organize material flows, data flows, and learning flows in a data-driven manner. Future research could, based on multi-case and longitudinal studies, compare data practices across different school and community projects, explore feasible applications of more advanced analytical tools in such contexts, and further discuss how to alleviate resource and capability constraints through institutional arrangements, thereby promoting more "small but vibrant" data-driven circular initiatives to take root in different communities.

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