Concept Paper

Smart Food Waste Management Platform for Sustainable University Cafeterias Using Blockchain Technology

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Smart Food Waste Management Platform for Sustainable University Cafeterias Using Blockchain Technology

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Abstract

The global food waste crisis poses significant environmental and economic challenges, particularly within institutional settings such as university campuses. At NSBM Green University, South Asia's first green university, traditional food waste management systems are hampered by opacity and unverifiable data, impeding effective reduction strategies. This paper proposes a blockchain-based Smart Campus Waste Management Platform to revolutionize food waste tracking in campus canteens. Utilizing blockchain's immutability, smart contracts, and integrated authentication, the system ensures secure, tamper-proof data management. It captures real-time waste data through authenticated manual inputs, processes it via a secure gateway, and records it on an Ethereum ledger, enabling precise sustainability reporting and data-driven interventions. The study details the system's architecture, implementation with Ethereum and Solidity, and alignment with NSBM's sustainability goals. Key benefits include enhanced accountability, optimized waste reduction, and reinforced green leadership, with future enhancements such as AI integration, scalability, and incentive mechanisms addressing potential challenges.

Keywords: blockchain; food waste management; transparency; sustainability; smart campus; smart contracts; authentication; waste reduction; AI integration

1. Introduction

Food waste represents a critical global challenge, contributing to environmental degradation through landfill overflow, greenhouse gas emissions, and substantial economic losses across the supply chain [1]. University campuses, with their extensive canteen networks and diverse food services, are significant contributors to this issue. At NSBM Green University, South Asia's pioneering green university and a Gold Award recipient for Best Government Institution Contributing to the Environment, the absence of transparent and reliable waste data impedes effective management and sustainability progress. Conventional methods, such as manual or fragmented data collection, often yield inaccuracies, obscuring waste patterns and limiting accountability.

Blockchain technology, characterized by its decentralized, immutable ledger and cryptographic security, emerges as a transformative solution to enhance data integrity in waste management [2]. This paper introduces a blockchain-enabled Smart Campus Waste Management Platform tailored for NSBM's canteens, addressing the challenge of opaque waste tracking through authenticated data inputs and verifiable records. The platform supports targeted waste reduction, aligns with NSBM's environmental mission, and establishes a model for smart campus initiatives. This study explores the system's design, implementation strategy, and potential impact, offering a novel application of blockchain technology to advance institutional sustainability.

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2. Literature Review

The integration of advanced technologies like blockchain, AI, and IoT is revolutionizing supply chain management, environmental sustainability, and smart campus initiatives by enhancing transparency, efficiency, and traceability. Queiroz et al. [3] provide a comprehensive analysis of blockchain's role in food supply chain traceability, highlighting its ability to mitigate deception, counterfeit products, and data inconsistencies through immutable, auditable records that build stakeholder trust. Their systematic review underscores blockchain's reliability. Similarly, Feng et al. [4] explore blockchain's application in agri-food traceability, emphasizing its management of transparent transaction records and digital assets. They discuss development methods, benefits like enhanced visibility, and challenges such as scalability and integration costs, offering valuable insights for resource-intensive systems.In smart campus environments, AI and IoT technologies significantly improve operational efficiency. Al-Sharafi et al. [5] demonstrate how AI-driven models, including machine learning and reinforcement learning, optimize green energy and waste management in universities. Predictive analytics enhances resource allocation, such as energy and waste management in campus kitchens, promoting sustainability. However, the application of blockchain for food waste management in university canteens, particularly at institutions like NSBM Green University, remains underexplored. Existing research primarily focuses on industrial or commercial supply chains, leaving a gap in localized institutional contexts.This study addresses this gap by proposing a blockchain-enabled Smart Campus Waste Management Platform tailored to NSBM's specific environmental and operational needs. Drawing on traceability and immutability principles from Queiroz et al. [3] and Feng et al. [4], and incorporating AI insights from Al-Sharafi et al. [5], the platform ensures reliable, authenticated data handling. This innovative, context-specific solution enhances data integrity, supports sustainability goals, and sets a new standard for smart campus innovations, contributing to technology-driven environmental management.

3. System Architecture

The Smart Campus Waste Management Platform is structured with interconnected layers to securely capture, record, and disseminate food waste data, beginning with the Data Input Layer where authenticated canteen staff use digital interfaces or integrated point-of-sale (POS) systems to input weight and category details (e.g., pre-consumer kitchen waste or post-consumer plate scrapings) using unique identifiers like QR codes. The Gateway/Server Layer then processes this raw data, applying validation before submission to the Blockchain Layer, which utilizes an Ethereum testnet to record waste events as immutable transactions, ensuring data integrity. The Smart Contract Layer deploys self-executing contracts to validate data, enforce rules, and automate recording, while the Application Layer provides a secure web/mobile dashboard for authenticated users—staff, administrators, and auditors—to access real-time metrics, trends, and reports. Data flow initiates with waste generation, where authenticated staff measure and input data (weight, type, timestamp) into the interface, which the gateway preprocesses, and smart contracts validate and record as transactions on the blockchain ledger. Key components include a blockchain ledger storing immutable records with unique IDs, timestamps, weights, waste types, and canteen identifiers to prevent tampering; smart contracts automating validation (e.g., positive weight checks) and calculating aggregated metrics; manual data entry interfaces designed as secure digital forms to minimize errors; unique identifiers like QR codes or RFID tags linking physical waste to digital records for traceability; and stakeholders comprising staff, administrators, sustainability officers, and auditors. The blockchain's tamper-proof nature ensures trustworthy data, which is essential for accurate sustainability reporting.

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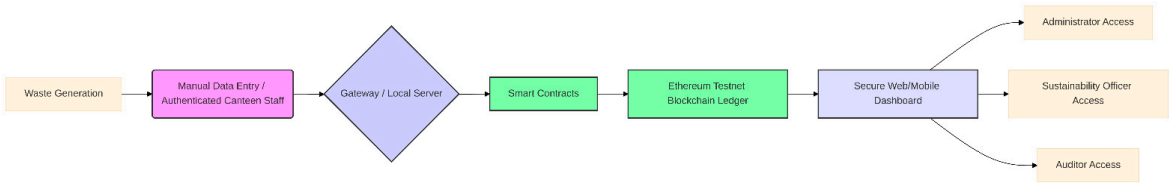

Figure 1. High-Level System Architecture for Blockchain-Enabled Food Waste Management.

4. Methodology

The methodology details the development of the Smart Campus Waste Management Platform to enhance transparency in food waste management at NSBM Green University's canteens, integrating authenticated manual data collection with blockchain technology. Authenticated staff measure waste weight using scales and input data, including weight, type, and timestamp, via a secure interface, categorizing it as pre- or post-consumer waste. Role-based authentication, utilizing username/password with multi-factor authentication, restricts data entry to authorized staff while providing tiered access for administrators and auditors. A local gateway validates and secures the data prior to transmission to the blockchain, which is implemented using an Ethereum testnet with Solidity smart contracts to enforce data integrity, validate inputs, and automate rules such as positive weight validation. The methodology includes deploying a secure web/mobile dashboard for real-time access by authenticated users, with smart contracts authenticating transactions and ensuring tamper-proof records through unique identifiers. This approach adopts a proof-of-concept strategy, simulating authenticated data on a local blockchain to assess feasibility, while laying the groundwork for scalability and future feature integration.

5. Idea and Conceptualization

The Smart Campus Waste Management Platform is a hybrid solution featuring a centralized data ecosystem that collects, processes, and stores authenticated waste data through a secure gateway and blockchain. It offers multi-platform accessibility via a secure website (e.g., waste.nsbm.ac.lk) for administrators and auditors, alongside a mobile app for staff and students to engage in sustainability initiatives. Designed with a scalable architecture tailored for NSBM, it supports expansion through IoT sensors or cloud hosting. Additional features include AI integration for predictive waste forecasting, an incentive module with smart contract-based rewards like tokens, and composting linkage for facility integration. The deployment model is initially localized for NSBM, with potential evolution into a Software-as-a-Service (SaaS) model and open-source sharing to encourage broader adoption.

6. Results and Discussion

Simulations on the Ethereum testnet validate the system's capability to record authenticated waste data immutably, with an example of 5 kg of edible leftovers from Canteen A recorded on November 13, 2025 [4]. The platform offers notable benefits, including enhanced transparency for sustainability reporting, a projected 10-15% reduction in waste through data-driven interventions, and its role as an educational tool. However, challenges such as manual entry errors and scalability limitations are identified. These are mitigated by proposed future enhancements, including AI and IoT integration [5], while privacy concerns are addressed through robust authentication mechanisms [3]. The results underscore the system's potential to support NSBM's sustainability goals, with ongoing refinements to ensure long-term efficacy.

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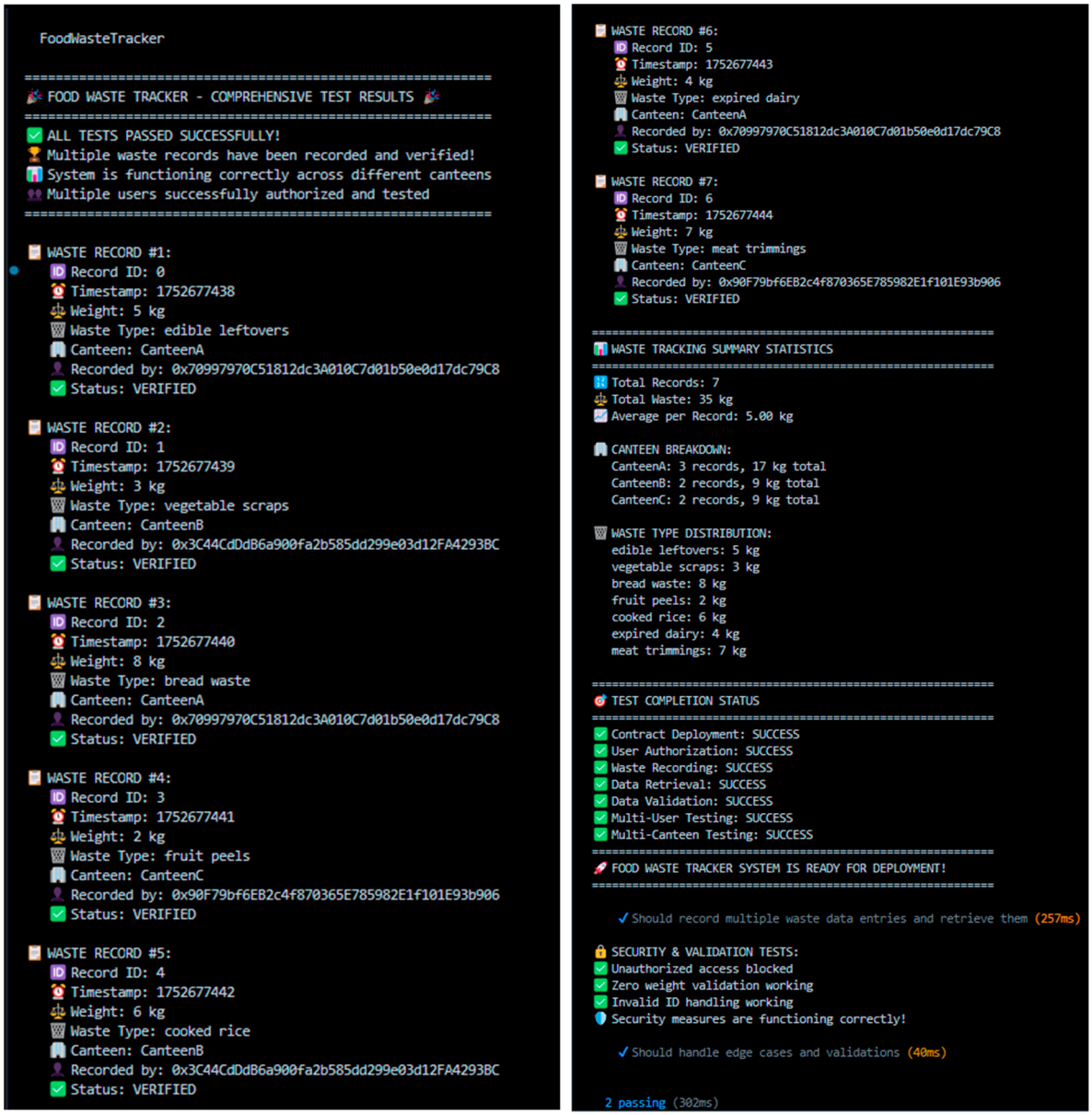

Figure 2. Terminal Output of Food Waste Tracker Test Execution.

7. Future Directions and Recommendations

The proof-of-concept Smart Campus Waste Management Platform at NSBM Green University holds transformative potential for food waste management, necessitating future enhancements to maximize impact and align with sustainability goals. Integrating artificial intelligence (AI) can enhance predictive capabilities by analyzing historical waste data, menu plans, and footfall patterns to forecast trends, enabling proactive portion size or menu adjustments with machine learning modules in the blockchain layer using authenticated data [5]. Deploying Internet of Things (IoT) sensors, such as smart bins with weight sensors and RFID tags, will automate waste measurement, reduce errors, and scale across canteens with real-time data transmission [4]. An incentive module using smart contracts could award tokens or discounts to staff and students, with a late 2025 pilot and user feedback adjustments [3]. Linking to composting or waste-to-energy systems via smart contracts, supported by APIs, will optimize resources and cut landfill use [4]. A cloud-based architecture with Polygon and a Software-as-a-Service (SaaS) model, plus open-source code, will handle expansion [2]. Enhanced security with biometrics or Ethereum wallets and staff training are crucial [3]. Post-deployment, an evaluation framework tracking waste reduction, adoption, and

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accuracy, informed by feedback, will ensure long-term environmental goals, reinforcing NSBM's green leadership globally.

8. Conclusion

The blockchain-enabled Smart Campus Waste Management Platform at NSBM Green University addresses food waste challenges by leveraging blockchain's immutability and smart contracts for transparent, tamper-proof data tracking in canteens. It promotes accountability, supports NSBM's sustainability goals, and projects a 10-15% waste reduction through data-driven strategies. Despite challenges like manual entry errors, future enhancements, including AI for predictive forecasting, IoT for automation, and incentive systems, promise greater impact. This innovative platform sets a benchmark for smart campus solutions, contributing to global sustainability efforts. As NSBM leads in green innovation, this system inspires broader adoption, fostering a sustainable future for universities.

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