Blockchain Technology for Certifying Waste Management within the digital transformation for industry and SME

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ABSTRACT

The need for recycling and a circular economy has grown significantly in recent years, accompanied by challenges such as greenwashing and fraudulent recycling practices. Blockchain technology is a new emerging technology that aims to facilitate information sharing, enable comprehensive government oversight, and establish effective incentive mechanisms. This paper explores digital transformation within blockchain frameworks to revolutionize waste management certification processes. Through the description of a real-world scenario, involving the recycling of food containers, in our case study pizza boxes within a pizzeria, this study highlights the tangible benefits, and challenges encountered from integrating blockchain technology into waste management processes. This case study demonstrates the potential for technology-driven solutions to address environmental challenges while fostering community engagement and incentivizing sustainable practices with the digital transformation of SMEs.

CCS CONCEPTS

• **Information systems** → *Information storage systems*; • **Computing methodologies**; • **Software and its engineering** → **Software organization and properties**; • **Applied computing** → *Law, social and behavioral sciences*;

KEYWORDS

Blockchain, Waste Management, Token, Notarization, Digital Transformation

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1 INTRODUCTION

The need for recycling and a circular economy has significantly increased in recent years. Despite sincere efforts in this direction, negative phenomena have emerged that exploit the demand for genuine recycling, leading to scams and frauds within this sector. One well-known example is greenwashing, where goods or items are falsely claimed to be produced through virtuous processes and behaviors, while in reality, they do not adhere to the rules and laws established for achieving a true circular economy and waste recycling. Blockchain technology can play a crucial role in addressing some of the aforementioned problems by certifying processes and artifacts in a tamper-proof manner. Additionally, it can incentivize virtuous behaviors through the creation of reward systems, wherein individuals and companies are rewarded for their responsible recycling practices. In this short paper, we present a study aimed at integrating and leveraging different technologies within a small company to improve digitalization. Our focus is on a real-world scenario involving the recycling of paper boxes in a company that produces and sells pizzas. Blockchain technology enables the certification of the quantity of waste management of paper boxes and aims to encourage virtuous behaviors among customers and the company itself through the "tokenization" of recycled paper. Additionally, the solution involves the use of IoT sensors and robotic arms to automate the process of cutting pizza boxes, separating clean parts from dirty ones using AI capable of distinguishing between them after specific training. The IoT sensors also automate the recording of operations on the blockchain and the issuance of tokens associated with the recycling of clean box parts. We specifically focus on the blockchain technology aspect, as well as the use of IoT sensors and tokenization and token management. We assume that robotic arms guided by AI will be able to recognize different boxes parts after specific training and effectively separate recyclable parts from non-recyclable ones. Through this case study, we highlight the tangible benefits associated with the integration of blockchain technology into waste management processes. The main contributions of this work can be summarized as follows: introducing the application of blockchain to address challenges in waste management, particularly focusing on recycling practices within the pizzeria industry; implementing tokenization to incentivize proper waste disposal behaviors, both for customers and companies; integrating IoT devices, such as smart scales, to automate

waste tracking and token generation processes; utilizing smart contracts deployed on the blockchain to automate token management, including issuance, distribution, and redemption, while ensuring compliance with predefined rules and conditions. Moreover, the significance of this work lies in its potential for generalization and extension to other use cases across various contexts. While the case study focuses on a pizzeria context, the proposed model can be generalized and extended to various other industries and use cases within the broader context of digital transformation. By promoting community engagement and collaboration in waste management initiatives, the system contributes to fostering sustainable practices and environmental stewardship.

The paper is organized as follows: Section 2 explores existing research and projects in waste management and blockchain technology. Next, Section 3 delves into the concept of tokenization and its application in incentivizing proper waste disposal. Subsequently, in Section 4, we provide a detailed examination of the blockchain-enabled waste management system implemented in the pizzeria, showcasing its functionalities and benefits. Finally, Section 5 summarizes key findings, discusses the implications of the system, and suggests avenues for future research and application.

2 RELATED WORK

The circular economy aims to eliminate waste and promote resource continual use, emphasizing waste reduction, product longevity, and natural system regeneration. The use of blockchain technology for the circular economy is a key concept in the intersection of digitalization and sustainability. Blockchain technology may assist in overcoming barriers to adopting the circular economy concept. Bokhel in this article [4] delves into the burgeoning field of blockchain for the circular economy and examines current trends in both research and practical applications. Employing a systematic literature review, this article constructs and conducts a research-practice gap analysis, revealing patterns of interest and potential avenues for research and practical implementation, while also highlighting areas of ambiguity that warrant attention in both domains. In the work of Castiglione et al.[5], a blockchain framework is proposed to enhance monitoring and decrease costs, allowing complete waste traceability and rewarding conscientious citizens. In their work França et al. [7] outlines the implementation of Ethereum Blockchain digital architecture for solid waste management in a small town in the state of Sao Paulo, Brazil. The blockchain-based system provides financial oversight for garbage collection in the municipality, aiming to enhance public health, socio environmental education, and promote financial and social inclusion of volunteers through the use of social currency. The proposed program, involving volunteer citizens, business owners, and public agents, substitutes printed cards named Green Coins with social cryptocurrency and security support via the Ethereum Blockchain.

Government waste management initiatives often fail due to public unawareness of the immediate consequences of improper waste disposal. Akter [2] introduces a blockchain-based smart waste management system for developing countries like Bangladesh. The system features smart dustbins with lids that open automatically when individuals approach, and it offers incentives based on the quantity of waste contributed by each person.

The work of Jiang et al. [8] offers awareness into emerging blockchain applications within waste management and it also shows the ways in which Blockchain has been utilized in the waste management industry and the related challenges and opportunities of the combination of this technology with IoT, artificial intelligence (AI), and life cycle assessment (LCA) to advocate for the application of blockchain technology. Akram et al. in their work [1] explore blockchain's role in solid waste management, proposing an architecture integrating IoT devices with blockchain for real-time rewards. The paper discusses blockchain's features and compares previous studies, detailing the proposed architecture. Lin et al. in [9], suggest a blockchain integration to address illegal dumping and low recycling rates. A conceptual model outlines functional requirements, demonstrates low costs and latency, and suggests benefits like information sharing and incentive mechanisms. Wankmüller et al. in [10] introduce blockchain tokenization for plastic bottle supply chains, studying its impact on recycling incentives. Findings highlight token-based incentives' effectiveness, especially for social causes. RecycleGO [6] offers a blockchain-based application for tokenized reward systems, encouraging responsible recycling with tangible rewards. For a compehensive state of the art about the use of blockchain technology in the context of waste management we refer to Baralla et al. [3], here the authors explored ongoing projects and the literature's state of the art, along with potential barriers.

3 TOKENIZATION

Tokenization, a process of representing real-world assets or rights as digital tokens on a blockchain network, has emerged as a powerful tool in various domains. In our context of waste management, tokenization offers a means to digitize and track assets such as recyclable materials or waste collection credits. These tokens, stored and managed on a blockchain network, serve as immutable records of ownership, value, or access to specific assets or services.

Each token possesses unique cryptographic properties, including a digital signature, metadata, and ownership information, ensuring their authenticity and integrity. Through blockchain technology, these tokens are recorded on a decentralized ledger, accessible and verifiable by network participants. This decentralized nature eliminates the need for intermediaries, facilitating secure and transparent peer-to-peer transactions with minimal friction.

Smart contracts, self-executing code stored on the blockchain, play a crucial role in automating various aspects of tokenized assets. They govern processes such as token issuance, distribution, and compliance with predefined rules or conditions. In the waste management domain, smart contracts can streamline operations related to waste tracking, incentivization, and reward distribution.

4 CASE STUDY: BLOCKCHAIN-ENABLED WASTE MANAGEMENT SYSTEM FOR A PIZZERIA

In this case study, we explore the implementation of a blockchain-based waste management system in SMEs, more specifically in the context of a pizzeria. The system aims to encourage correct waste disposal by focusing on the recycling of pizza boxes, also providing

a transparent and certified traceability mechanism. The pizza industry generates a significant amount of waste, particularly in the form of pizza boxes. Traditional waste management methods often lack transparency and accountability, leading to inefficiencies and environmental concerns. By leveraging blockchain technology, the pizzeria can establish a secure and verifiable system for monitoring and encouraging waste.

We use blockchain to identify the different actors involved. On the one hand there are the customers, individuals who purchase and consume pizza both on site and at home where the pizza can be delivered. Each customer is identified by a unique blockchain address, a unique string that can also be represented by a QR code. On the other side there is the company, the "pizzeria", also identified by a unique blockchain address.

When customers consume pizza on site, used paper pizza containers are collected directly from the pizzeria and processed by robotic arm devices, which separate the recyclable parts from the non-recyclable ones. The recyclable parts are weighed by a smart scale, which interacts with a processor (such as an ESP32 device or a Raspberry Pi) to send a transaction corresponding to a specific smart contract in the blockchain. This process triggers the creation of a first type of token, with the smart contract "minting" a token associated with the pizzeria's blockchain address, which reflects the weight of the recycled paper. When customers consume pizza at home, they are encouraged to return the paper packaging to the pizzeria. In this case, the customer's responsible behavior is rewarded and the paper pizza bag is processed by robotic arms to separate the recyclable parts from the non-recyclable ones. The recyclable parts are weighed by an intelligent scale, which automatically activates the creation of a second type of token belonging to the specific customer who returned the recyclable paper. This process is facilitated by the smart contract, which "mints" a second type of token associated with the customer's specific blockchain address, linked to the customer's QR code.

The waste management system therefore consists of two levels of incentives, managed through a combination of smart scales, IoT devices and blockchain technology:

(1) **Customer incentives:** Customers are encouraged to return used pizza boxes to the pizzeria for recycling. The tokens assigned to them, called "second level" tokens, can be exchanged with each other or be redeemed for prizes offered by the pizzeria, such as free pizzas or drinks.
(2) **Pizzeria incentives:** The pizzeria earns "first level" tokens for each delivery of pizza boxes to the waste management agency or municipality. Also in this case, an intelligent device installed in the pizzeria calculates the weight of the recyclable waste delivered and consequently generates tokens. These tokens are the exclusive property of the pizzeria and serve as a form of currency to obtain benefits from the waste management agency or municipality. In exchange for the tokens, the waste management authority or municipality offers discounts on the annual waste tax, thus incentivizing good waste disposal practices by businesses.

The token reward dynamics are illustrated in the UML sequence diagram shown in Figure 1.

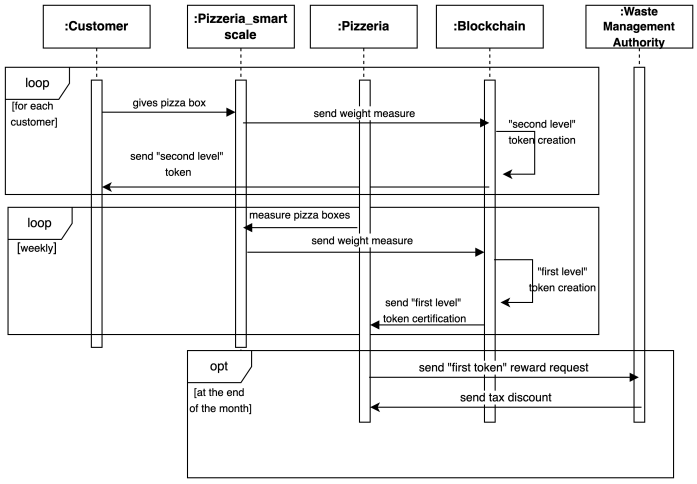

Figure 1: The creation of reward Token for customers and Pizzeria.

The entire system is built on a blockchain platform, ensuring transparency, immutability, and security of transactions. Each token transaction, whether initiated by customers or the pizzeria, is recorded as a blockchain transaction, providing a transparent audit trail of waste management activities. Smart contracts are employed to automate token generation, distribution, and redemption processes, reducing the need for manual intervention and ensuring the execution of predefined rules and conditions. All operations are permanently tracked on the blockchain and can be transparently verified, ensuring a tamper-proof record of recycled waste. Moreover, the smart contract can facilitate token exchange between customers, enabling, for example, members of the same family to pool their tokens to qualify for a pizza discount or a free drink on their next order. Simultaneously, the pizzeria can demonstrate its commitment to recycling to municipal authorities and be rewarded based on the number of first-kind tokens earned, such as through a waste-tax reduction.

Figure 2 displays the Solidity code of the smart contract. This contract enables the creation of a custom token ("WasteManagementToken") with functionalities such as token minting, token transfer between addresses, and approval of token transfers. Additionally, it incorporates events to emit transfer and approval events for enhanced transparency.

5 CONCLUSIONS AND FUTURE WORK

In the realm of digital transformation, this paper presents a blockchain-enabled waste management system tailored for pizza box disposal. Leveraging blockchain technology ensures transparency and accountability in waste management practices, thereby fostering trust among stakeholders. The incentive mechanisms embedded within the system incentivize active participation from both customers and the pizzeria, promoting proper waste disposal and recycling efforts, and ultimately contributing to a cleaner environment. Through earning tokens for waste disposal, the pizzeria can mitigate waste management costs by availing discounts on waste taxes, leading

```
pragma solidity >=0.6.12 <0.9.0;

contract WasteManagementToken {
    string public name;
    string public symbol;
    uint8 public decimals;
    uint256 public totalSupply;

    mapping(address => uint256) public balanceOf;
    mapping(address => mapping(address => uint256)) public allowance;

    event Transfer(address indexed from, address indexed to, uint256 value);
    event Approval(address indexed owner, address indexed spender, uint256 value);

    constructor() {
        name = "WasteManagementToken";
        symbol = "WMT";
        decimals = 18;
        totalSupply = 0; // Initially, no tokens are minted
    }

    function mint(address account, uint256 amount) external {
        require(msg.sender == address(this), "Only the contract owner can mint tokens");
        require(amount > 0, "Amount must be greater than zero");

        totalSupply += amount;
        balanceOf[account] += amount;
        emit Transfer(address(0), account, amount);
    }

    function transfer(address to, uint256 value) external returns (bool) {
        require(to != address(0), "Transfer to the zero address");
        require(value <= balanceOf[msg.sender], "Insufficient balance");

        balanceOf[msg.sender] -= value;
        balanceOf[to] += value;
        emit Transfer(msg.sender, to, value);
        return true;
    }

    function approve(address spender, uint256 value) external returns (bool) {
        allowance[msg.sender][spender] = value;
        emit Approval(msg.sender, spender, value);
        return true;
    }
}
```

Figure 2: Solidity smart contract to manage the tokens.

to significant cost savings. Additionally, the token-based reward system fosters community engagement and collaboration in waste management initiatives, thus strengthening the bond between the pizzeria and its customers.

The implementation of such a system in the pizzeria exemplifies the potential for technology-driven solutions to tackle environmental challenges while encouraging community engagement and incentivizing sustainable practices within the digital transformation of SMEs. By harnessing blockchain technology, the pizzeria can bolster transparency, accountability, and efficiency in waste management, thus contributing to a more sustainable future. However, despite the potential benefits, tokenization in waste management faces various challenges and considerations. It is imperative to conduct further analysis and improve regulatory compliance with respect to the proper management and disposal of waste. Additionally, exploring the necessity for interoperability standards will facilitate the seamless exchange of tokens between different waste management platforms or ecosystems.

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