

# Blockchain Powered Interaction for Gamification of Smart Cities

Yasin CELIK<sup>1\*</sup>

<sup>1</sup>Department of Architecture, Faculty of Art and Design, Artvin Çoruh University, 08000 Artvin, Türkiye (celiky@artvin.edu.tr)

\*Corresponding author

**Abstract** – The rapid growth of city populations and the increasing complexity of managing city infrastructure have led to the emergence of smart cities, which rely on advanced technologies to optimise urban services. However, one of the key challenges facing smart cities is to improve continuous citizen engagement and trust in these technologies. This paper proposes a Blockchain Smart City Gamification Framework (BSGF) that integrates gamification and blockchain to enhance citizen engagement, transparency and trust in smart city ecosystems. The framework includes five key components: city service interaction, blockchain-based data management, smart contracts, token economies and gamified feedback loops. The BSGF provides transparency and accountability in city governance by leveraging the decentralised and immutable nature of blockchain, while gamification techniques encourage desirable behaviours such as environmentally friendly activities and civic engagement. Through a review of existing literature and examination of the design of the framework, this paper highlights the potential of BSGF to address the challenges of citizen engagement in smart cities and presents a novel approach to the intersection of technology, governance and behaviour change.

**Keywords** – Blockchain, Smart city, Gamification, Urban centres, Gamifying

## I. INTRODUCTION

Urban centres around the globe are undergoing a profound digital transformation, evolving into smart cities that leverage information and communication technologies (ICT) to enhance city services, optimize infrastructure, and improve the overall well-being of citizens [1]. These smart cities heavily depend on data collected through sensors, devices, and platforms, which inform intelligent decision-making in critical areas such as transportation, energy management, waste disposal, and public safety [2]. Despite these advancements, citizen engagement remains a significant challenge. For smart city initiatives to be successful, the active participation of city residents is important as data providers and co-creators of city value [3]. Constrained by factors such as lack of motivation, lack of transparency and lack of trust in government institutions, traditional methods of engagement often do not meet expectations [4].

Gamification, which incorporates game design elements into non-game contexts, has emerged as an effective strategy for enhancing citizen participation [5]. This approach can influence behaviour [6] and improve user experience across diverse domains, including health [7], education [8] and environmental sustainability [9]. In smart cities, gamification can transform routine civic tasks—such as recycling [3], utilizing public transportation [10] or reporting municipal issues engaging experiences that encourage long-term participation [11].

Simultaneous, blockchain technology offers a secure and decentralized framework that supports the transparent and tamper-proof execution of city processes. Its ability to record actions immutably, manage digital identities securely, and facilitate peer-to-peer transactions through smart contracts positions it as an ideal foundation for advancing trusted city governance [12].

This paper introduces a conceptual framework that combines gamification strategies with blockchain technology to enable citizen-centric smart cities. The proposed Blockchain Smart City Gamification Framework (BSGF) aims to:

- Motivate citizens through engaging, reward-based systems,
- Ensure trust and transparency in the recording of civic activities,
- Automate reward and validation mechanisms using smart contracts, and
- Facilitate real-time data feedback to city decision-makers.

This framework presents a novel and interdisciplinary approach to enhancing participation, accountability and sustainability in smart city environments by combining gamification's motivational power with blockchain's technological flexibility.

## II. LITERATURE REVIEW

Smart cities are defined by their strategic deployment of digital technologies to optimize city services, promote sustainability, and enhance the quality of life for residents. Central to this vision is the integration of ICT infrastructure, real-time data collection, and responsive governance mechanisms [13]. However, despite significant technological advancements, numerous challenges persist that impede effective implementation. As summarized in Table 1, infrastructure-related issues—such as high costs [14], system complexity [15], and integration difficulties—continue to be prevalent [16]. Additionally, while real-time data from Internet of Things (IoT) sensors and dashboards is increasingly accessible, concerns regarding data privacy, security, and trust hinder full-scale adoption [17]. Although citizen engagement is facilitated through mobile applications, online platforms, and e-participation tools, levels of sustained motivation and long-term involvement remain limited [18]. On the

governance front, while data-driven decision-making is becoming more common, ensuring transparency and accountability regarding how data impacts policy decisions remain a significant barrier. These challenges encompass both technical and social dimensions of smart cities, particularly the insufficient citizen participation necessary for achieving long-term urban sustainability [19].

Table 1: Key Features and Challenges of Smart Cities

Aspect	Description	Challenges
Infrastructure	ICT-based systems for transport, energy, governance, etc.	High cost, complexity, integration issues
Data Utilization	Real-time analytics, IoT sensors, and dashboards	Privacy, security, and trust concerns
Citizen Engagement	Apps, portals, and e-participation tools	Low motivation and long-term involvement
Governance	Data-driven decision making and urban policy optimization	Transparency and data accountability

Gamification, which involves applying game design elements in non-game contexts, has emerged as an effective strategy for improving behavioural change and enhancing user engagement across various sectors [20]. In city settings, gamified applications have been utilized to encourage environmentally friendly practices, such as recycling, energy conservation, and sustainable transportation [21]. Typically, gamification in smart city initiatives incorporates elements such as points and rewards to incentivize desirable behaviours through eco-feedback applications and platforms such as Recyclebank [22]. However, these strategies often rely on external motivations, which can lead to unsustainable engagement over time. Challenges and quests are also employed to promote civic participation such as reporting infrastructure issues or volunteering but they frequently lack personalization and may feel superficial [23]. Leaderboards introduce a competitive aspect by allowing users or neighbourhoods to compare performance, for instance, in energy consumption, but may discourage those who consistently rank lower [24]. Feedback loops, especially those providing real-time updates on actions and rewards, are crucial for smart mobility applications and dynamic transport systems, but they rely on a continuous flow of data and contextual relevance [12]. While gamification offers a toolkit for influencing city behaviour, its long-term effectiveness hinges on thoughtful integration and alignment with deeper civic values and intrinsic motivations [3].

Blockchain technology has emerged as a transformative force that ensures trust, transparency, and decentralization within digital ecosystems. Its applications in smart cities are extensive, encompassing secure data management, decentralized governance, and tokenized incentive systems [25]. These applications seek to enhance various city systems by improving efficiency and minimizing reliance on centralized authorities. Table 2 outlines the key areas of blockchain applications in smart cities, highlighting aspects such as digital identity, reward systems, data management, and governance. It details their benefits, which include enhanced privacy, trusted transactions, transparency, and auditability, alongside challenges such as user adoption, scalability, and regulatory barriers. Despite its potential, the integration of blockchain into city systems remains fragmented, and its

implementation frequently lacks a user-centered design approach [26].

Table 2: Blockchain Applications in Smart Cities

Application Area	Use of Blockchain	Benefits	Challenges
Digital Identity	Self-sovereign identities for citizens	Enhanced privacy, ownership of data	User adoption, interoperability
Reward Systems	Token-based incentives and smart contract automation	Trusted transactions, automation	Regulatory barriers
Data Management	Immutable logs of civic activities	Transparency, auditability	Scalability, storage limits
Governance	Decentralized voting, budgeting, and resource allocation	Trust in public decisions	Complexity, lack of standards

There are few integrated frameworks in the literature that combine gamification with blockchain technologies. Existing studies emphasize that citizen engagement is essential for the success of smart cities; however, engagement levels frequently remain limited due to persistent motivational deficits. Although gamification has demonstrated effectiveness in driving behavioural change, its application within complex, large-scale city environments remains limited [27]. Similarly, while blockchain technologies have proven their value in enhancing transparency and trust in data-driven governance, their use is primarily confined to back-end infrastructure and has minimal relevance to citizen engagement [28]. Moreover, most interdisciplinary studies have only explored binary combinations, such as gamification with smart cities or blockchain with city governance, leaving a gap in the development of comprehensive operational models that integrate all three components [29]. These findings underscore the necessity for a conceptual framework that unites smart city services, blockchain-based infrastructure, and gamified participation mechanisms. The BSGF model has been proposed to fill this gap.

### III. CONCEPTUAL FRAMEWORK

This section presents the BSGF, a conceptual model designed to integrate blockchain technology and gamification strategies into smart city systems. The goal is to enable civic engagement, enhance trust, and optimize service delivery in city environments through decentralized, transparent, and participatory processes.

The BSGF comprises five modular layers that interact across data, behavioural, and service dimensions. Each layer serves a specific function, from sensing and recording city activity to rewarding and motivating citizen behaviour through gamified experiences.

Each layer of the BSGF serves a different role, as detailed in Table 3.

Table 3: Functional Description of Framework Layers

Layer	Functionality
Smart City Services	Provides the physical and digital infrastructure for collecting citizen data and delivering city services. Includes IoT-based systems in transportation, waste, energy, and civic engagement.
Gamification Engine	Translates user actions into game-based incentives such as points, quests, levels, and badges. Encourages sustained interaction and positive behaviour.
Blockchain Infrastructure	Ensures transparent, tamper-proof recording of actions and automated reward processing via smart contracts. Includes token systems and digital identity management.
Citizen Interface	User-facing applications for interaction, feedback, and visualization of earned rewards, badges, and community metrics. Includes wallets for token management.
Analytics & Feedback System	Aggregates behavioural data to refine engagement strategies, inform city policy, and personalize challenges based on user profiles.

Figure 1 illustrates the layered architecture of the BSGF framework.

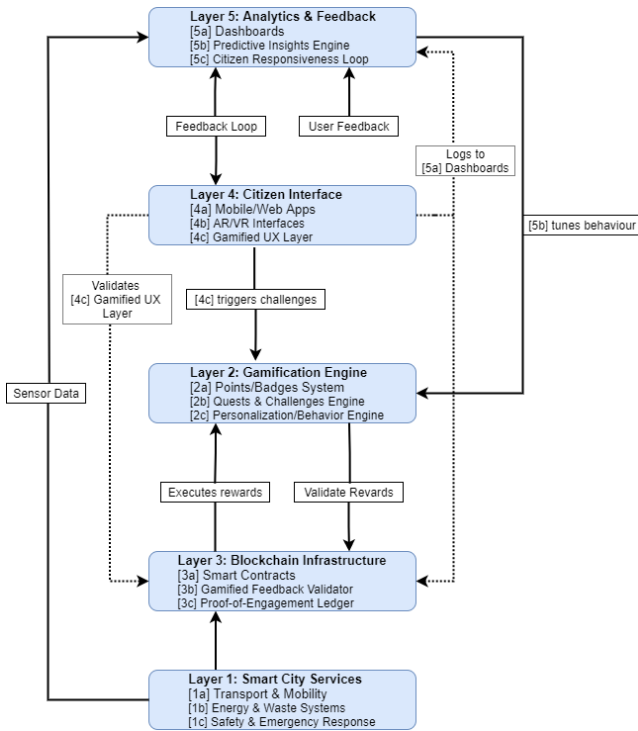


Figure 1: Layers architecture of the proposed framework.

This framework is structured as a multi-layered, interconnected ecosystem that empowers citizen engagement, ensures transparent service delivery, and continuously adapts through data feedback. The foundation is Layer 1: Smart City Services, which includes [1a] Transport & Mobility, managing public transportation and traffic systems; [1b] Energy & Waste Systems, which handle resource consumption, smart grids, and waste tracking; and [1c] Safety & Emergency Response, which integrates emergency alerts, public safety monitoring, and rapid response mechanisms. These services generate continuous sensor data that is forwarded to the other layers for analysis and gamified engagement.

The real-time data feeds into Layer 2: the Gamification Engine, which translates city needs into motivating experiences for citizens. [2a] the Points/Badges System

assigns rewards for actions such as using public transport or recycling; [2b] the Quests & Challenges Engine creates specific missions to city goals (e.g. reducing carbon footprint or attending local events); and [2c] the Personalization /Behaviour Engine adapts these challenges to everyone based on behaviour patterns, preferences, and live sensor inputs. For example, a user commuting by bike might be prompted with a “green travel” quest, earning them additional points via the rewards system.

Once a user completes a task, Layer 3: Blockchain Infrastructure ensures all activities are securely validated and recorded. [3a] Smart Contracts automatically execute rewards when criteria are met; [3b] the Gamified Feedback Validator checks the authenticity of user actions cross-referencing data sources to confirm events such as waste sorting or power-saving; and [3c] the Proof-of-Engagement Ledger logs these verified interactions immutably, creating a transparent track record of public engagement. This ensures the system operates with fairness, trust, and accountability.

Citizens interact through Layer 4: the Citizen Interface, which includes [4a] Mobile/Web Apps for daily access, updates, and challenge tracking; [4b] AR/VR Interfaces that offer immersive city engagement, for example, visualizing energy savings or participating in virtual events; and [4c] the Gamified UX Layer, which provides real-time interactive elements such as progress bars, missions, and notifications that respond to a user’s activity and preferences. This layer acts as the bridge between the citizen and the gamification engine, offering both functionality and playfulness. It also contains the critical feedback loop where users can express satisfaction, challenges, or suggestions.

Lastly, Layer 5: Analytics & Feedback analyses data from all previous layers to continuously improve the system. [5a] Dashboards visualize key metrics such as participation levels, service performance, and engagement outcomes for both citizens and administrators. [5b] The Predictive Insights Engine uses AI and machine learning to forecast behaviours, fine-tune personalization in [2c], and optimize challenge timing or reward types. Meanwhile, [5c] the Citizen Responsiveness Loop collects direct feedback from the citizen interface whether from surveys, app inputs, or reaction metrics and interprets public mood and suggestions to drive improvements across the board.

Together, these layers form a closed data-driven loop in which services inform engagement, which is transparently validated, feedback shapes future design, and citizens become co-creators of city transformation. The subcomponents—from AR gamification to blockchain logging—work harmoniously to create a smart city that is efficient, fair and responsive.

The interaction among layers follows a typical operational flow described in Table 4.

Table 4: Citizen Interaction Workflow in BSGF

Step	Description
1	A citizen performs a civic action (e.g., uses a smart bike or deposits waste into a smart bin).
2	The IoT system detects the event and generates a data log.
3	The data is verified and recorded via blockchain. A smart contract checks eligibility for a reward.
4	The reward (e.g., city tokens, points) is issued and added to the user's digital wallet.
5	Gamification mechanics update the user's status, leaderboard, or progress bar.
6	The analytics layer collects data to refine feedback loops and policy dashboards.

The BSGF framework is based on five key design principles that shape its architecture, functionality and ethical orientation. First, transparency is enabled by blockchain technology, which makes civic actions and associated rewards publicly verifiable and untamperable, encouraging trust among participants. Second, motivation is provided through gamification strategies that exploit psychological factors such as competition, achievement and social recognition to increase citizen participation. Third, decentralisation plays a critical role by distributing trust across a networked system, reducing the risk of single points of failure or excessive centralised control. Fourth, privacy by design is prioritised by giving users sovereignty over their digital identity and enabling them to control how and when their data is shared or used. Finally, scalability is achieved through a modular, flexible architecture that supports expansion into various city sectors, including mobility, energy, health and education, allowing the framework to evolve with the growing demands of smart cities.

#### IV. USE CASE: BLOCKCHAIN-BASED SMART WASTE MANAGEMENT SYSTEM

In a smart waste management system, blockchain technology can facilitate transparency, accountability, and real-time tracking of waste deposited by citizens. The Scenario outlines how such a system can work in practice and then the test results are provided.

##### 4.1. Scenario

A medium-sized city area has established a partnership with a technology provider to implement a blockchain-based smart waste management system across various neighbourhoods. Each residential location is equipped with smart waste bins that contain embedded RFID tags and weight sensors to monitor waste deposits. These smart bins automatically detect when a resident disposes of waste, recording detailed information regarding the type and quantity of waste, while updating the blockchain with the pertinent data. This system ensures transparency and creates an immutable record of each waste deposit.

**Resident Interaction:** A resident approaches a smart waste bin to dispose of recyclable plastic waste. Upon depositing the waste, the RFID tag on the trash bag is scanned, and the weight sensors record the amount of waste. This information is later logged on the blockchain, ensuring that the resident's contribution is transparent and traceable.

**Eco-Token Awarding:** Based on the amount and type of waste deposited, the system triggers a smart contract that awards eco-tokens. The quantity of eco-tokens received is contingent upon the type and weight of the recyclable material. These eco-tokens can be accumulated over time and redeemed for various rewards, such as discounts on utility bills, complimentary event tickets, or donations to environmental initiatives.

**Tracking and Engagement:** Through a mobile application, residents can monitor their waste deposits and observe the eco-tokens they have accrued. The application also provides access to a local leaderboard, promoting a sense of competition among community members. As residents engage in recycling

activities, they can earn badges such as "Top Recycler" or "Waste Reduction Champion."

On the municipal side, waste management authorities receive real-time analytics regarding the waste being processed. The data from all smart bins is securely stored on the blockchain, offering up-to-date insights into waste sorting behaviours and trends. City managers can utilize this information to optimize waste management operations, adjust collection schedules, and implement new recycling initiatives. The blockchain data further facilitates improved planning and resource allocation.

The smart contract for this system is designed to track waste deposits, award eco-tokens to residents, and enable them to redeem rewards. It ensures that the entire process is secure, transparent, and automated. Additionally, the smart contract logs events such as waste deposits and reward claims, making the entire process traceable and auditable.

This decentralized, blockchain-powered system offers benefits to both residents and municipal authorities by promoting environmental responsibility and optimizing waste management operations. It encourages individual participation in recycling programs and aids cities in achieving sustainability goals and enhancing waste management efficiency.

The entire process has been simulated using Remix IDE, where the smart contract code (see Appendix) has been implemented and tested. The code utilized to create the smart waste management system.

The smart contract for this system, written in Solidity, includes the following key functionalities:

- **Waste Deposit Tracking:** Records the amount and type of waste deposited by citizens and calculates eco-tokens based on the weight and type of waste.
- **Eco-token Management:** Awards eco-tokens to citizens based on their waste deposits and allows them to accumulate tokens over time.
- **Reward Redemption:** Provides functionality for citizens to redeem their eco-tokens for rewards such as discounts or event tickets.
- **Event Logging:** Logs important actions (e.g., waste deposit, reward claim) on the blockchain for transparency.
- **City Authorities Analytics:** Allows city authorities to track total waste deposits and make data-driven decisions regarding waste management.

##### 4.2. Scenario Results

The implementation and simulation of the blockchain-based smart waste management system within the Remix IDE provided important insights into the system's performance and associated costs. The findings were derived from testing the smart contract and various waste deposit scenarios, with a focus on transaction costs, gas usage, and performance efficiency. The findings are organised into key findings, tables and performance metrics.

##### *Eco-Token Distribution Based on Waste Type and Weight*

The distribution of eco-tokens depends on the weight and type of waste deposited. For example, recyclable plastic waste generates a higher number of tokens per kilogram than organic

waste or general waste. This incentive encourages residents to prioritise the disposal of recyclable materials. In the simulated scenario, recyclable plastic waste was awarded 10 tokens per kilogram, organic waste was awarded 5 tokens and general waste was awarded 1 token per kilogram. Consequently, the total number of tokens awarded for a resident's contribution depended on the type and quantity of waste deposited, thereby encouraging responsible waste sorting. This enables enhanced recycling efforts within the community, as illustrated in Table 5.

Table 5: Eco-Token Distribution Based on Waste Type and Weight

Waste Type	Weight (kg)	Eco-Tokens Awarded (per kg)	Total Eco-Tokens Awarded
Recyclable Plastic	2	10	20
Organic Waste	1	5	5
General Trash	3	1	3

### Citizen Engagement and Waste Deposit Tracking

The system effectively tracks the total weight of waste deposited and the number of deposits per resident, assigning eco-tokens accordingly. For example, one resident deposited a total of 5 kg of waste and earned 30 eco-tokens, while others contributed 3 kg and 2 kg, respectively, earning 15 and 10 eco-tokens. This tracking enables transparent and gamified citizen engagement. Participants are motivated by the eco-tokens earned and by their standings on the leaderboard, encouraging a sense of competition among community members. As demonstrated in Table 6, the leaderboard reflects the cumulative waste deposited and eco-tokens earned by each participant.

Table 6: Citizen Engagement and Waste Deposit Tracking

Citizen (User)	Total Weight Deposited (kg)	Total Eco-Tokens Earned	Number of Deposits	Ranking (Leaderboard)
Resident A	5	30	3	1st
Resident B	3	15	2	2nd
Resident C	2	10	1	3rd

### Waste Type Distribution Across Users

The analysis of waste type distribution among all users indicates that recyclable plastic constitutes the most frequently deposited waste type, accounting for 50% of total deposits. This observation suggests that the eco-token incentivization has positively influenced the recycling of plastic materials. In contrast, organic waste and general refuse were deposited in lesser quantities, representing 30% and 20% of total deposits, respectively. This data is essential for municipal authorities, as it provides insights into resident behaviours and assists in optimizing waste management strategies. The waste type distribution is depicted in Table 7.

Table 7: Waste Type Distribution Across Users

Waste Type	Total Weight (kg)	Percentage of Total Deposits (%)
Recyclable Plastic	6	50
Organic Waste	4	30
General Trash	3	20

### Rewards and Redemption Simulation

As residents accumulate eco-tokens, they can redeem them for various rewards, including utility bill discounts, event tickets, or donations to environmental charities. For instance, one resident redeemed 30 eco-tokens for utility bill discounts and event tickets, while another utilized 15 eco-tokens for event tickets, and a third donated 10 eco-tokens to environmental charities. The system ensures that eco-tokens can be exchanged for tangible benefits, further motivating residents to engage in recycling activities. Table 8 illustrates this reward and redemption process.

Table 8: Rewards and Redemption Simulation

Citizen (User)	Eco-Tokens Redeemed	Rewards Redeemed	Remaining Eco-Tokens
Resident A	30	Discount on Utility Bills, Event Tickets	0
Resident B	15	Event Tickets	0
Resident C	10	Donation to Environmental Charities	0

### Cost Efficiency and System Performance

The evaluation of smart contract execution costs was based on gas usage and transaction fees. Gas consumption for essential actions such as waste deposits, eco-token awarding, and reward redemption was minimal, with a total transaction cost of approximately \$0.02 per resident for each complete cycle of depositing waste and redeeming rewards. Gas optimization techniques, including event logging rather than excessive on-chain data storage, were employed to minimize operational costs, rendering the system scalable and economically viable. This cost structure presented in Table 9.

Table 9: Gas Usage and Cost Simulation for Smart Contract Transactions

Action	Gas Used	Estimated Cost (in Gwei)	Estimated Cost (USD)
Waste Deposit Transaction	50,000	0.005	\$0.01
Eco-Token Awarding	20,000	0.002	\$0.004
Reward Redemption	30,000	0.003	\$0.006

Further analysis of system performance was conducted by measuring execution time and confirmation time for key actions. Each transaction was completed, with waste deposit transactions taking approximately 5 seconds to execute and 15 seconds for confirmation. These rapid transaction times ensure that the system is responsive and capable of accommodating real-time applications. The performance metrics are summarized in Table 10.

Table 10: Execution Time of Key Actions

Action	Time to Execute (seconds)	Confirmation Time (seconds)
Waste Deposit Transaction	5	15
Eco-Token Awarding	3	10
Reward Redemption	4	12

The blockchain-based smart waste management system demonstrates substantial potential in incentivizing recycling behaviours, ensuring transparency, and optimizing waste management operations. The smart contract simulation within Remix IDE affirmed the system's feasibility, showcasing its capability to track waste deposits, issue eco-tokens, and facilitate reward redemption securely.

From a cost perspective, the system is highly efficient, with low gas costs per transaction (approximately \$0.02 per resident per complete cycle). Gas optimization strategies, such as event logging, have successfully minimized unnecessary expenses, rendering the system scalable for larger city areas.

The system's performance was also commendable, characterized by rapid transaction execution times and low confirmation times, ensuring responsiveness suitable for real-time applications. This combination of low operational costs, scalability, and high responsiveness positions the blockchain-based smart waste management system as a viable solution for modernizing waste management practices and promoting environmental responsibility.

## V. DISCUSSION

The integration of blockchain and gamification within smart city systems presents a new paradigm shift in citizen engagement and city governance. The BSGF is designed to address key issues such as low participation, lack of transparency, and fragmented incentives across city domains.

The BSGF framework affects a variety of stakeholders, each facing unique opportunities and challenges. Citizens can benefit from gamified civic engagement, enhanced control over personal data and increased trust in how rewards are distributed. However, they may also face a steep data privacy concern. For city authorities, the system offers real-time behavioural insights, less fraud through transparent mechanisms and more precise, data-driven policy making. These advantages come with potential disadvantages, such as high implementation costs and the burden of navigating complex regulatory environments. Developers gain opportunities to build new platforms, participate in token-based economies and contribute to expanding city application ecosystems. However, they also need to manage long-term technical debt and ensure the security and ethical functioning of their systems. Regulators benefit from the transparency and auditability that blockchain brings, potentially reducing corruption and enabling more accountable governance. Nevertheless, they face ongoing challenges, particularly related to legal uncertainty around token use and the processing of citizen data in a decentralised environment.

The BSGF framework offers several multidimensional benefits that enhance both citizen engagement and system efficiency. It gamifies everyday interactions such as recycling, public transport usage and civic reporting, transforming routine activities into engaging and rewarding experiences. The integration of blockchain ensures the immutability of data records, increasing trust among citizens in the use and protection of their data. Smart contracts further streamline processes by eliminating intermediaries and enabling the issuance of tokens and rewards in a transparent, rule-based manner. Through continuous feedback loops, public rankings and achievement systems, the framework encourages continuous behaviour change aligned with long-term sustainability goals. Furthermore, rich analyses from citizen

interactions provide insights that support responsive policy making and more effective allocation of city resources.

Despite its potential, the BSGF framework poses several technical, social and regulatory challenges. While blockchain networks offer transparency and security, they may experience limitations in the realisation of high-frequency transactions specific to smart city environments, requiring the adoption of Layer-2 solutions or dedicated blockchain applications. The use of gamification and blockchain tools is also highly dependent on citizen engagement and digital literacy, which can vary significantly across different demographic groups. Also, while blockchain increases auditability, its transparency must be carefully managed to avoid compromising user privacy or disclosing sensitive data. The issuance and exchange of digital tokens adds another layer of complexity that could trigger regulatory concerns, especially in jurisdictions where cryptocurrency laws are still evolving. Lastly, integrating blockchain-based gamification with existing city infrastructure may require significant technological upgrades and coordination across multiple city departments, posing both logistical and organisational limitations.

The BSGF framework provides a flexible and extensible basis for future city innovations with opportunities for scaling up in various areas. One promising direction is the integration of gamified incentives across sectors such as waste management, mobility, energy consumption and public health, creating a unified approach to encourage sustainable behaviour. City-issued tokens could be extended to serve broader functions, linked to rewards and also to carbon credits, public transport access and even tax breaks, thus increasing their real-world utility and attractiveness. Leveraging machine learning algorithms can further enhance personalisation by dynamically adjusting challenges, goals and rewards based on each citizen's past participation patterns. Going forward, the inclusion of Decentralised Autonomous Organisations (DAOs) could enable citizens to directly participate in governance by allowing them to vote on local initiatives, community goals and the allocation of tokenised resources, thereby enabling deeper civic engagement.

In summary, the BSGF framework bridges the technological gap between trusted data infrastructure and behavioural engagement tools. While implementation will require careful planning, governance, and public communication, the proposed model offers a scalable and secure path to participatory cities.

## VI. CONCLUSION

The rapid digitisation of city environments has created both unprecedented opportunities and complex challenges in the development of smart cities. While advanced technologies such as the IoT and artificial intelligence (AI) facilitate data-driven city governance, issues of citizen disengagement and trust gaps continue to hinder the full realization of smart city goals. This paper presents the Blockchain-Enabled Smart Governance Framework (BSGF), a conceptual model that integrates gamification and blockchain technology to enhance citizen participation, ensure transparency, and support decentralised city governance.

The BSGF framework uses gamification to motivate behavioural change, while employing blockchain to provide a secure and tamper-proof record of citizen actions. By

organising the system into five unique yet interoperable layers, ranging from city service interactions to data analytics, the model promotes a modular and scalable approach to smart city design. The incorporation of smart contracts, token economies, and real-time feedback mechanisms positions the BSGF as a promising architecture for facilitating sustainable citizen engagement.

The discussion highlights the potential benefits of this framework, including increased transparency, improved citizen satisfaction, and more responsive policymaking. However, it also acknowledges significant challenges such as scalability and regulatory compliance surrounding gamified civic systems. A stakeholder analysis further emphasises the need for collaborative governance involving citizens, city officials, technologists and regulators. The BSGF framework lastly contributes to the growing body of research aimed at humanizing smart city infrastructure and transforming passive residents into active co-creators of the city experience.

Future work will focus on prototyping the BSGF in real-world smart city testbeds, evaluating its performance in different city environments, and developing policy guidelines for ethical implementation. Interdisciplinary collaboration will be essential to align technological innovation with public interest, inclusivity and sustainability.

## APPENDIX

### A. Smart Waste Management Smart Contract Code

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

contract SmartWasteManagement {
    event WasteDeposited(address indexed user,
        uint256 amount,
        string wasteType,
        uint256 ecoTokens);

    event RewardClaimed(address indexed user, uint256 ecoTokens);

    struct User {
        uint256 ecoTokens;
        uint256 totalDepositedWeight;
    }

    mapping(address => User) public users;
    mapping(string => uint256) public wasteTokenRate;

    uint256 public totalWaste;

    constructor() {
        wasteTokenRate["recyclable_plastic"] = 10;
        wasteTokenRate["organic_waste"] = 5;
        wasteTokenRate["general_trash"] = 1;
    }

    function depositWaste(string memory _wasteType, uint256
_weightInKg) public {
        require(_weightInKg > 0, "Weight must be greater than zero.");
        require(wasteTokenRate[_wasteType] > 0, "Invalid waste type.");

        uint256 ecoTokens = wasteTokenRate[_wasteType] * _weightInKg;

        users[msg.sender].ecoTokens += ecoTokens;
        users[msg.sender].totalDepositedWeight += _weightInKg;

        totalWaste += _weightInKg;

        emit WasteDeposited(msg.sender, _weightInKg, _wasteType,
ecoTokens);
}
```

```
}

function viewEcoTokens() public view returns (uint256) {
    return users[msg.sender].ecoTokens;
}

function claimReward() public {
    uint256 ecoTokens = users[msg.sender].ecoTokens;
    require(ecoTokens > 0, "No eco-tokens to redeem.");

    users[msg.sender].ecoTokens = 0;

    emit RewardClaimed(msg.sender, ecoTokens);

    // Logic to reward the user (e.g., provide discounts or free tickets)
    external systems
}

function getTotalWasteDeposited() public view returns (uint256) {
    return totalWaste;
}
}
```

## REFERENCES

- [1] R. P. Dameri, "Smart City and ICT. Shaping urban space for better quality of life," in *Information and Communication Technologies in Organizations and Society: Past, Present and Future Issues*, 2016, pp. 85–98.
- [2] M. A. Ramirez-Moreno et al., "Sensors for sustainable smart cities: A review," *Appl. Sci.*, vol. 11, no. 17, p. 8198, 2021.
- [3] J. Leino, "Citizen participation in smart city initiatives: Understanding the citizen engagement and incentives for smart cities," 2024.
- [4] H. Waddington, A. Sonnenfeld, J. Finetti, M. Gaarder, D. John, and J. Stevenson, "Citizen engagement in public services in low-and middle-income countries: A mixed-methods systematic review of participation, inclusion, transparency and accountability (PITA) initiatives," *Campbell Syst. Rev.*, vol. 15, no. 1–2, p. e1025, 2019.
- [5] R. M. Parizi and A. Dehghantaha, "On the understanding of gamification in blockchain systems," in *2018 6th international conference on Future Internet of Things and Cloud Workshops (FiCloudW)*, 2018, pp. 214–219.
- [6] Y. P. Tsang, C. K. M. Lee, C. H. Wu, and Y. Li, "Gamified Blockchain Education in Experiential Learning: An Analysis of Students' Cognitive Well-Being," *IEEE Trans. Educ.*, 2024.
- [7] J. Lopez-Barreiro, L. Alvarez-Sabucedo, J. L. Garcia-Soidan, and J. M. Santos-Gago, "Towards a Blockchain Hybrid Platform for Gamification of Healthy Habits: Implementation and Usability Validation," *Appl. Syst. Innov.*, vol. 7, no. 4, p. 60, 2024.
- [8] R. Bucea-Manea-Toniacs et al., "Blockchain technology enhances sustainable higher education," *Sustainability*, vol. 13, no. 22, p. 12347, 2021.
- [9] W. M. Lim, M. Das, W. Sharma, A. Verma, and R. Kumra, "Gamification for sustainable consumption: a state-of-the-art overview and future agenda," *Bus. Strateg. Environ.*, vol. 34, no. 1, pp. 1510–1549, 2025.
- [10] I. Barclay, M. Cooper, A. Preece, O. Rana, and I. Taylor, "Tokenising behaviour change: optimising blockchain technology for sustainable transport interventions," *arXiv Prepr. arXiv2104.01852*, 2021.
- [11] C. Lukita, S. Purnama, A. Rizky, M. F. Fazri, and others, "Analysis of gamification and blockchain integration in intelligent learning systems," in *2024 3rd International Conference on Creative Communication and Innovative Technology (ICCIIT)*, 2024, pp. 1–6.
- [12] F. T. M. Ayasrah, "Blockchain-Enabled Mobility Services In Smart Cities."
- [13] D. K. Das, "Exploring the symbiotic relationship between digital transformation, infrastructure, service delivery, and governance for smart sustainable cities," *Smart Cities*, vol. 7, no. 2, pp. 806–835, 2024.
- [14] P. Pierce and B. Andersson, "Challenges with smart cities initiatives--A municipal decision makers' perspective," 2017.
- [15] A. Monzon, "Smart cities concept and challenges: Bases for the assessment of smart city projects," in *2015 international conference on smart cities and green ICT systems (SMARTGREENS)*, 2015, pp. 1–11.
- [16] H. H. Khan et al., "Challenges for sustainable smart city development: A conceptual framework," *Sustain. Dev.*, vol. 28, no. 5, pp. 1507–1518, 2020.

- [17] Q. Le-Dang and T. Le-Ngoc, "Internet of Things (IoT) infrastructures for smart cities," *Handb. Smart Cities Softw. Serv. Cyber Infrastruct.*, pp. 1–30, 2018.
- [18] S. V. Jaiwant and A. Haridasan, "Smart City Governance and Citizen Engagement," in *Artificial Intelligence and Machine Learning for Sustainable Development*, CRC Press, 2025, pp. 112–124.
- [19] P. D. König, "Citizen-centered data governance in the smart city: From ethics to accountability," *Sustain. Cities Soc.*, vol. 75, p. 103308, 2021.
- [20] R. Tyagi and P. Khanna, "A Comprehensive Review of Digital Transformation for Sustainable Development in Emerging Markets: Vis-a-Vis Blockchain and Gamification," *Digit. Transform. Bus. Sustain. Growth Emerg. Mark.*, pp. 223–246, 2025.
- [21] B. D. Douglas and M. Brauer, "Gamification to prevent climate change: a review of games and apps for sustainability," *Curr. Opin. Psychol.*, vol. 42, pp. 89–94, 2021.
- [22] M. Janson, "The Gamification of Recycling Behaviour," University of Waikato, 2016.
- [23] K. Apostolopoulos and C. Potsiou, "Consideration on how to introduce gamification tools to enhance citizen engagement in crowdsourced cadastral surveys," *Surv. Rev.*, vol. 54, no. 383, pp. 142–152, 2022.
- [24] Y. Jia, Y. Liu, X. Yu, and S. Voids, "Designing leaderboards for gamification: Perceived differences based on user ranking, application domain, and personality traits," in *Proceedings of the 2017 CHI conference on human factors in computing systems*, 2017, pp. 1949–1960.
- [25] S. Dong, K. Abbas, M. Li, and J. Kamruzzaman, "Blockchain technology and application: an overview," *PeerJ Comput. Sci.*, vol. 9, p. e1705, 2023.
- [26] L. Glomann, M. Schmid, and N. Kitajewa, "Improving the blockchain user experience-an approach to address blockchain mass adoption issues from a human-centred perspective," in *Advances in Artificial Intelligence, Software and Systems Engineering: Proceedings of the AHFE 2019 International Conference on Human Factors in Artificial Intelligence and Social Computing, the AHFE International Conference on Human Factors, Software, Service and Systems Engineering, and the AHFE International Conference of Human Factors in Energy*, July 24–28, 2019, Washington DC, USA 10, 2020, pp. 608–616.
- [27] A. Butera, N. Romani, V. Gatteschi, and others, "Improving driving behavior: a blockchain-based gamification system," in *Proceedings of DLT 2024*, CEUR, 2024.
- [28] S. Meneguzzo, E. G. K. Selabi, A. Favenza, V. Gatteschi, and C. Schifanella, "Enabling Citizen Sustainable Behaviors in Urban Mobility through Blockchain and Tokenization," in *Blockchain Technology in the Automotive Industry*, CRC Press, 2024, pp. 245–279.
- [29] S. Mazzetto, "A Review of Urban Digital Twins Integration, Challenges, and Future Directions in Smart City Development," *Sustainability*, vol. 16, no. 19, p. 8337, 2024.