FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Driving Motivation: A Digital Incentive System for Citizen Engagement in Urban Sustainability

Tiago Nunes Moreira Branquinho

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Mestrado em Engenharia Informática e Computação

Supervisor: Prof. Nuno Feixa Rodrigues

Second Supervisor: Prof. António Coelho

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Approved in oral examination by the committee:

President: Prof. Gil Manuel Magalhães de Andrade Gonçalves

Referee: Prof. Mary Barreto

Referee: Prof. António Fernando Vasconcelos Cunha Castro Coelho

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Resumo

De acordo com a ONU, a população urbana global deverá aumentar em cerca de 2,5 mil milhões de pessoas até 2050, o que resultará em 68% da população mundial a viver em áreas urbanas em meados do século [11]. À medida que as cidades crescem e as pressões ambientais aumentam, a participação dos cidadãos em esforços de sustentabilidade, como a comunicação de resíduos, tornou-se cada vez mais vital. No entanto, motivar e manter o envolvimento em plataformas de *crowdsensing* continua a ser um desafio fundamental. Este trabalho investiga como um sistema de incentivos digitais pode fomentar a participação, combinando gamificação, tokens de utilidade emitidos numa *blockchain* Hyperledger Fabric e um assistente digital alimentado por um modelo de linguagem em grande escala (LLM).

Baseada em teorias motivacionais estabelecidas, como a Teoria da Autodeterminação [37], a Teoria Cognitiva Social [5] e a Teoria do Fluxo [9], a plataforma proposta integra recompensas tangíveis e intangíveis, incluindo um sistema de emblemas, classificações em tabelas de líderes e uma loja baseada em tokens. Uma inovação central deste trabalho é a inclusão de um assistente educacional projetado para aumentar o impacto percecionado, fornecer feedback motivacional e oferecer informações ambientais por meio de interações diretas. O assistente envolve proativamente os utilizadores com base no seu comportamento, complementando os mecanismos de recompensa mais tradicionais.

Para avaliar a eficácia do sistema, foi realizado um estudo experimental de 17 dias com dois grupos de utilizadores divididos numa plataforma de *crowdsensing* destinada a coletar relatórios de resíduos: um grupo de controlo que utilizava as funcionalidades de incentivo tradicionais e um grupo experimental com acesso adicional ao assistente. O envolvimento foi avaliado através de dados comportamentais, tais como submissões e utilização de funcionalidades, e feedback motivacional recolhido através de inquéritos. Os resultados indicam que o assistente contribuiu para uma participação mais sustentada, perceções mais fortes de competência e importância da tarefa em questão, e níveis mais elevados de motivação intrínseca. Além disso, os recursos tradicionais de gamificação, particularmente tabelas de classificação e emblemas, permaneceram bastante eficazes e foram encarados de forma mais positiva quando combinados com as mensagens do assistente.

Embora limitações como uma amostra pequena e estruturas de recompensa simplificadas devam ser consideradas, os resultados sugerem que a combinação de sistemas gamificados com apoio inteligente e motivacional pode enriquecer a experiência do utilizador e aprofundar o envolvimento cívico. Apresentando estratégias personalizadas e significativas para os participantes que vão além da funcionalidade para proporcionar experiências envolventes, este trabalho delineia um caminho promissor para a conceção de estratégias de incentivo em plataformas de *crowdsensing* focadas na sustentabilidade apelando tanto à consciência ambiental como pessoal dos utilizadores, combinando motivação com educação.

Abstract

According to the UN, the global urban population is projected to increase by around 2.5 billion people by 2050, which will result in 68% of the world's population living in urban areas by mid-century [11]. As cities grow and environmental pressures mount, citizen participation in sustainability efforts, such as waste reporting, has become increasingly vital. Yet, motivating and sustaining engagement in crowdsensing platforms remains a key challenge. This work investigates how a digital incentive system can foster participation by combining gamification, utility tokens issued on a Hyperledger Fabric blockchain, and a digital assistant powered by a large language model (LLM).

Grounded in established motivational theories, such as the Self-Determination Theory [37], Social Cognitive Theory [5], and Flow Theory [9], the proposed platform integrates both tangible and intangible rewards, including a badge system, leaderboard rankings, and a token-based store. A central innovation of this work is the inclusion of an educational assistant designed to increase perceived impact, provide motivational feedback, and deliver environmental insights through direct interactions. The assistant proactively engages users based on their behavior, complementing the more traditional reward mechanisms.

To evaluate the system's effectiveness, a 17-day experimental study was conducted with two user groups divided on a crowdsensing platform aimed at retrieving waste reports: a control group using the more traditional incentive features and an experimental group with additional access to the assistant. Engagement was assessed through behavioral data, such as submissions and feature usage, and motivational feedback collected via surveys. Results indicate that the assistant contributed to more sustained participation, stronger perceptions of competence and task significance, and higher levels of intrinsic motivation. Additionally, traditional gamification features, particularly leaderboards and badges, remained quite effective and were more positively perceived when paired with assistant feedback.

While limitations such as a small sample size and simplified reward structures must be considered, the findings suggest that combining gamified systems with intelligent motivational support can enrich user experience and deepen civic engagement. By presenting strategies that go beyond functionality to deliver experiences that are engaging, personalized, and meaningful to participants, this work outlines a promising path for designing incentive strategies in sustainability-focused crowdsensing platforms appealing to both users' environmental and personal conscience by combining motivation with education.

Keywords: digital incentives, gamification, sustainability, blockchain, intrinsic motivation

UN Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) provide a global framework to achieve a better and more sustainable future for all. It includes 17 goals to address the world's most pressing challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice.

This Master's dissertation, titled "Driving Motivation: A Digital Incentive System for Citizen Engagement in Urban Sustainability", contributes directly to several of these goals. By developing an innovative digital platform that leverages gamification, blockchain, and a digital assistant, this work provides a practical engineering solution to educate and foster citizen participation in urban waste management, a key aspect of creating sustainable and resilient cities. The following analysis details the alignment of this project with the specific targets of SDGs and outlines metrics to measure its impact.

The specific SDGs addressed by this work are listed bellow, along with their respective targets and contributions:

SDG 4 Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

SDG 9 Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

SDG 11 Make cities and human settlements inclusive, safe, resilient and sustainable

SDG 12 Ensure sustainable consumption and production patterns

SDG 13 Take urgent action to combat climate change and its impacts

SGD	Target	Contribution	Performance Indicators and Metrics
4	7	The educational assistant ensures that learners acquire the knowledge and skills needed to promote sustainable development through facts, curiosities, and real-time feedback educating toward sustainable lifestyles.	Number of educational messages sent to users; High ratings for the assistant's clarity (Fig. 7.11); Measured increase in user intrinsic motivation (Fig. 7.18) and feature recognition (Fig. 7.14)
9	1	The project involves the design and implementation of a novel and resilient digital ICT infrastructure combining blockchain, LLMs, and mobile tech for urban sustainability.	Successful deployment of the system's architecture (Figs. 4.1 and 4.2); System reliability measured by uptime and successful transaction rates.
	c	The mobile application provides citizens with a means to participate in civic processes through modern ICT.	High usability scores from user surveys (Fig. 7.11); Geographical reach of submissions (Fig. 7.4); High NPS indicating platform value (Fig. 7.16).
11	6	Apart from promoting sustainable behaviors, the platform directly enables citizen reporting of waste, contributing to improve municipal waste management and reduce the adverse environmental impact of cities.	Number of waste reports submitted (215 in the study); Geographic distribution of reports (Fig. 7.4); Future reduction in waste collection time.
	a	The system creates a digital infrastructure that strengthens the link between citizens and municipal services, fostering collaborative urban planning and management.	User engagement rates; NPS indicating user willingness to engage with the platform (Fig. 7.16).
12	5	The platform incentivizes the identification and reporting of waste, which promotes recycling, reuse, and the reduction of waste generation. It educates users to adhere to sustainable practices.	Future volume of waste diverted from landfills based on platform reports.
	8	The integrated assistant provides users with educational content on sustainability and responsible consumption, directly promoting awareness for sustainable lifestyles.	Number of educational messages delivered by the assistant; User interaction metrics with the assistant (Fig. 7.9).
13	3	The platform's assistant directly improves user education and awareness on climate change mitigation by providing facts and contextual feedback on the environmental impact of effective waste management.	Number of educational messages sent by the assistant related to climate change; User interaction rates with the assistant (Fig. 7.9).

Agradecimentos

I would like to express my deepest gratitude to my supervisor, Professor Nuno Rodrigues, for the time, dedication, and invaluable guidance throughout this journey. Your insights and feedback were truly essential to shaping this work. I am also very thankful to André Torneiro for his much-appreciated technical support and guidance during this time.

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Tiago Branquinho

"Hope is a good thing,
maybe the best of things,
and no good thing ever dies."

Andy Dufresne - The Shawshank Redemption

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Abreviaturas e Símbolos

AI	Artificial Intelligence
API	Application Programming Interface
CA	Certificate Authority
CLI	Command Line Interface
FCM	Firebase Cloud Messaging
GPS	Global Positioning System
gRPC	Google Remote Procedure Call
HTTP	Hypertext Transfer Protocol
ICT	Information and Communications Technology
IMI	Intrinsic Motivation Inventory
JSON	JavaScript Object Notation
LLM	Large Language Model
MSP	Membership Service Provider
NPS	Net Promoter Score
PDF	Portable Document Format
PEM	Privacy Enhanced Mail
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
REST	Representational State Transfer
RPC	Remote Procedure Call
SDK	Software Development Kit
SDGs	United Nations Sustainable Development Goals
SQL	Structured Query Language
TLS	Transport Layer Security
UI	User Interface
UN	United Nations

Chapter 1

Introduction

1.1 Context

According to the UN, the global urban population is projected to increase by around 2.5 billion people by 2050, which will result in 68% of the world's population living in urban areas by mid-century [11]. This rapid urbanization intensifies critical environmental challenges, including escalating waste generation, increased pollution levels, and unsustainable resource consumption. Improving the sustainability and livability of cities as they steeply increase in size is an enormous challenge for future generations and one that can only be overcome by the collective, informed, and oriented action of citizens.

In today's digitally connected world, Knowledge Management Systems and Multi-Sided Platforms play a crucial role in easing exchange and access to knowledge. The idea behind using collective power and intelligence is really powerful when it comes to getting citizens involved in environmental initiatives. Crowdsourcing and crowdsensing hold promising value to engage large groups of citizens. However, despite their valuable advantages, the success of these platforms is heavily dependent on active user participation. Fortunately, advances in blockchain technology and the incorporation of gamification techniques offer encouraging solutions. By integrating digital incentives and game-like elements, platforms can enhance user engagement. These methods, apart from being used to encourage information sharing and overall participation, may also serve to influence users' behavior. In that sense, when applied to urban platforms, these tools can encourage environmentally friendly actions aligned with the goals of smart cities.

1.2 Motivation

As the urban population is set to increase dramatically in the upcoming decades, sustainable urban development is a growing global priority. The success of future cities will depend on their ability to engage citizens in collaborative environmental monitoring efforts, such as waste, pollution, and resource consumption tracking.

Although traditional incentive methods, often relying on voluntary initiatives or limited public campaigns, have struggled to maintain active participation in related community-driven efforts [30], studies indicate that blockchain-based digital incentives and gamification techniques, such as points, leaderboards and badges, show potential in promoting such behaviors [4, 43] by rewarding users with a feel of value or achievement for their contributions. Therefore, the motivation for this research derives from the need to understand how these digital tools can be effectively applied in real-world urban contexts, potentially driving both citizen awareness and sustainability.

1.3 Problem

Studies reveal that monetary incentives can boost the number of user contributions but often reduce their quality due to a *crowding-out effect*, while reputation-based incentives may have the opposite effect, fostering high-quality contributions but with slower initial engagement [4]. In fact, financial rewards act as extrinsic motivators that persuade users to sacrifice meaningful data contributions over maximizing personal earnings. In addition, non-fixed digital tokens, if not managed carefully, face the issue of speculative behavior, where users prioritize token accumulation over meaningful engagement with the platform, which can inhibit its usage after initial adoption [10]. Gamification can be an exciting way to engage users, but it needs to be crafted mindfully. The goal is to enhance the user experience, not to create a tense environment, encourage shallow participation, or lead to poor-quality submissions.

One of the biggest challenges is creating incentive systems that intrinsically motivate users to get involved, both in the short and long-term scenarios, without sacrificing the quality of the data shared. On the other hand, these must be balanced to ensure they do not encourage unwanted behaviors like excessive competition, superficial engagement, or even divert users from the platform's purpose.

Current platforms tend to rely on fixed uniform incentive structures. This constitutes a problem since such approaches do not take into consideration that user motivations and behaviors can change over time. For example, factors such as experience level or evolving psychological needs can strongly influence what drives participation. Without mechanisms to adapt to these dynamics, many systems struggle to sustain engagement or align incentives with meaningful platform goals. Addressing this gap calls for more responsive user-centered strategies that go beyond static gamification or purely extrinsic rewards.

1.4 Research Questions

Given the challenges described in the previous section, the following questions can be formulated:

- **Q1:** How can participation be incentivized in crowdsensing platforms?
- **Q2:** What user behaviors and perceptions are associated with sustained contributions in crowdsensing platforms?

1.5 Hypotheses

The following hypotheses were formulated to test the impact of specific motivational mechanisms:

- **H1:** Higher perceived motivation is associated with increased engagement and sustained participation over time.
- **H2:** Platform feedback mechanisms reduce drop-off and enhance contribution rates.
- **H3:** Emphasizing the individual impact and importance of contributions increases users' sense of task significance.

1.6 Document Structure

The remainder of this dissertation is structured to guide the reader from theoretical foundations to practical implementation and empirical evaluation. Following these introdutory insights, Chapter 2 establishes the background, reviewing key motivational theories and the state-of-the-art in gamification and incentive systems. Chapter 3 then details the methodology used to conduct the literature review that informs this work.

Afterwards, the focus shifts from theory to practice, with Chapter 4 presenting the high-level conceptual architecture of the proposed system, and Chapter 5 describing its practical implementation, detailing the backend and frontend development. Chapter 6 outlines the experimental protocol used to evaluate the platform, including the study design and data collection methods. The results of this experiment are then presented and discussed in Chapter 7, which analyzes both behavioral data and user perceptions. Finally, Chapter 8 offers concluding remarks by summarizing the key findings, outlining the contributions and limitations of the work, proposing directions for future research, and reflecting on the project's alignment with global sustainability goals.

Chapter 2

Background

This chapter contains a comprehensive overview of the state-of-the-art in incentive techniques and gamification strategies applied in general information-sharing (Section 2.2) and crowdsensing or crowdsourcing scenarios (Section 2.3). Section 2.1 introduces theories of profound importance to the subject under study.

2.1 Theoretical Background

Understanding the concept and fuels of motivation is crucial to drive engagement in digital platforms, as the success of these relies on how their goals and incentive techniques align with users' beliefs. In that way, findings from theories such as the Self-Determination Theory [37], Social Cognitive Theory [5], and Flow Theory [9] are of deep importance for exploring how gamification and incentives can foster meaningful participation.

2.1.1 Self-Determination Theory

Self-Determination Theory [37] is a psychological framework that, focusing on individuals' tendencies and psychological needs, categorizes motivation from non-existent to intrinsic, including its extrinsic form in between, as illustrated in Figure 2.1. Extrinsic motivation refers to behaviors induced by external factors with separable outcomes, such as monetary or reputational tokens. Although it is driven by external causes, extrinsic motivation can sometimes induce intrinsic motivation, which involves engaging in activities for inherent joy or satisfaction.

According to Ryan & Deci [37], "autonomy", "competence", and "relatedness" are essential psychological needs that, when satisfied, enhance intrinsic motivation. In the context of gamified environments, competence and relatedness can be supported through leaderboards and badges, including collaborative challenges. On the other hand, considering personal values and preferences, allowing users to choose tasks or incentive mechanisms can also promote their autonomy.

This theory is particularly relevant to platforms that aim for long-term user engagement rather than short-term participation spikes. Developers can trigger internalization mechanisms that make participation self-sustaining by designing systems that respect the mentioned users' psychological

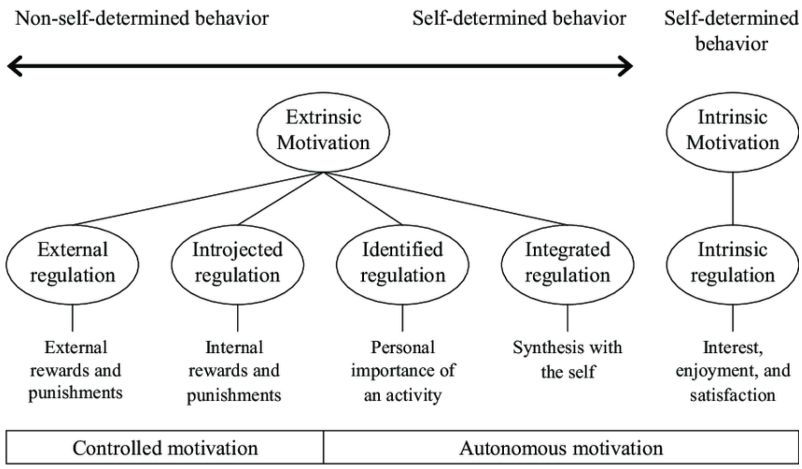


Figure 2.1: Motivation types highlighted by Ryan & Deci [37]

needs. In such settings, extrinsic tools are perceived less as ends and more as motivators toward more autonomous forms of motivation. This is especially important in platforms where lasting impact depends on repeated engagement over time rather than isolated interactions.

2.1.2 Social Cognitive Theory

These ideas are complemented by the study of how "personal cognition", "environmental factors", and "observed behaviors" interact to influence human behavior, which is also of great importance to better understand it, according to Bandura [5]. The accomplishment-sharing nature of some gamification elements, such as leaderboards and badges, promotes both outcome expectations and self-efficacy, which can be defined by one's confidence in the ability to complete a certain task. These cognitive factors are crucial in determining participation in crowdsourcing tasks. In the context of crowdsourcing, self-efficacy can be enhanced through segmented tasks with clear instructions and real-time feedback. Bandura [5] highlights observational learning as a key principle in his work, which refers to the influence of visible examples in one's perception of a task: users are more likely to participate when visualizing others successfully engaging and benefiting from the platform.

The idea of reciprocal determinism is central to the Social Cognitive Theory [5], as it highlights how well-designed platforms can create a cycle of engagement that benefits the users involved. When participants see others succeeding, it boosts their own motivation to contribute, which in turn keeps a lively and responsive environment. In fact, users can also become sources of motivation for each other.

This feedback loop is particularly important in incentive systems that aim to engage users by encouraging friendly comparisons that help to drive more participation. Additionally, it is worth noting that one's self-efficacy is not fixed, as it can change over time based on own experiences. Offering opportunities for early success or low-barrier contributions is crucial in establishing initial confidence and setting the stage for a more meaningful involvement.

2.1.3 Flow Theory

Apart from the foundational and social aspects of motivation, user participation can also be related to concepts such as immersion and engagement. Flow Theory [9] describes that task difficulty, when appropriate, can induce immersion and focus, resulting in a *flow* state. This is the result of an optimal challenge that interacts with the actor over time, preventing boredom and frustration. That state can also be characterized by "clear goals", "immediate feedback", and a "sense of control". Csikszentmihalyi's [9] findings highlight the need for immediate feedback and for a balance considering task difficulty: while very hard challenges induce disengagement, simple ones cause loss of interest from participants.

Furthermore, Csikszentmihalyi [9] emphasizes that flow is characterized by a combination of action and awareness, where individuals become so involved in the activity that nothing else seems to matter. During flow, the experience is so intrinsically rewarding that people engage in the task not for external outcomes but for the sheer enjoyment of doing it. Another central condition for achieving flow is a sense of personal control over the situation and the outcome. Even when the task is challenging, if individuals feel capable of influencing their progress, the likelihood of entering flow increases. These cognitive shifts reflect a high level of absorption and signal that attention is fully directed toward the task.

2.2 Information and Knowledge Sharing

Knowledge sharing is a fundamental process that not only enables information exchange but also promotes teamwork and problem-solving in digital ecosystems. By leveraging the collective expertise of participants, platforms can foster innovation by creating spaces where contributors can freely share insights. Because these offer structured frameworks for organizing, retrieving, and updating information, digital platforms have become essential in facilitating this exchange.

The ability to share knowledge enhances decision-making processes and supports continuous learning across diverse contexts. While the benefits of knowledge sharing are clear, challenges remain in ensuring the reliability, accessibility, and meaningful use of shared information. Understanding how those sharing behaviors evolve under the presence of token incentives and gamification elements is critical to designing effective platforms.

2.2.1 Token Incentives

Although monetary tokens have a positive impact on the quantity of information shared, these often reduce its quality [4] due to a crowding-out effect, as explained in the Self-Determination Theory [37]. This phenomenon occurs when external rewards diminish intrinsic drivers of motivation, leading individuals to focus on rewards rather than on the task itself. Participants may prioritize maximizing rewards with minimal effort over contributing high-quality outputs, which can harm creativity in knowledge-sharing contexts, as Ballandies *et al.* [4] further observed a significant drop in both quality and quantity of shared data when monetary incentives ceased in an experimental group. This decline contrasted with the groups that received reputational tokens, where engagement levels remained stable. That study also supports the *internalization effect* proposed in the Self-Determination Theory [37], where well-structured extrinsic rewards can transition into intrinsic motivation aligned with personal values and psychological needs. Ballandies *et al.* [4] verified results similar to other studies, illustrated in Figure 2.2.

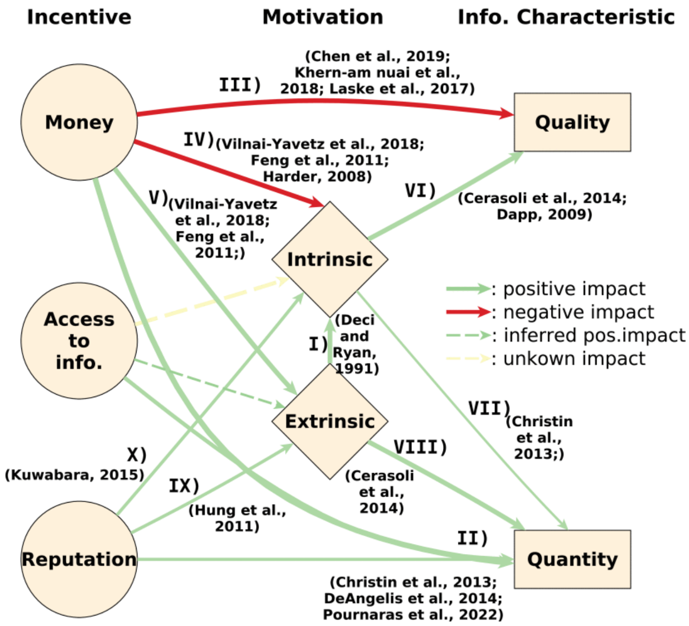


Figure 2.2: Influence of tokens on information sharing [4]

Adding further complexity to this debate, the crowding-out effect resulting from the interaction between extrinsic rewards and intrinsic motivation seems to be less universal than traditionally posited. Hendijani *et al.* [16] conducted a laboratory experiment with 187 university students, where participants solved logic-based tasks that either aligned or misaligned with their self-reported expertise. The study measured changes in both overall motivation and task performance by manipulating both task expertise fit and the presence or absence of performance-contingent monetary rewards. Their findings suggest that performance-contingent rewards do not always undermine intrinsic motivation. When aligned with user values and expertise, even monetary rewards seem to complement rather than conflict with intrinsic drivers, fostering higher engagement and performance.

Similarly, Garaus *et al.* [12] further challenged the inevitability of the crowding-out effect, defending that minor monetary rewards can trigger a *crowding-in* effect in "moderate task complexity and autonomy-supportive" scenarios. Through a 2x2x2 factorial experiment involving 238 participants, the study combined the presence and absence of small completion-contingent monetary rewards with low and moderate task complexity and controlling and autonomy-supportive feedback. The results revealed that intrinsic motivation was significantly enhanced in the condition with moderately complex tasks, autonomy-supportive instructions, and small monetary rewards.

Participants asked to contribute with creative sustainability ideas reported higher interest and engagement when guided by a small reward combined with encouraging and autonomy-focused prompts. This configuration led to a crowding-in effect, where rewards complemented intrinsic motivation rather than suppressing it. On the other hand, the opposite crowding-out effect was perceived in groups with simplified tasks and controlling language. In this way, the study suggested that, by designing rewards perceived as "supportive" rather than "controlling", the question that remains is "when", rather than "how", monetary rewards cause a crowding-out effect.

The usage of utility tokens presents a compelling incentive mechanism to gather early engagement. Drasch *et al.* [10] developed a theoretical model showing how tradable fixed-supply tokens can help address the "chicken-and-egg" problem faced by early-stage platforms, where potential users hesitate to join precisely due to a lack of existing activity. By offering tokens that are expected to gain value as the platform grows, systems can attract early adopters. However, the model also reveals a long-term risk, as users may be incentivized to hold rather than use tokens once these acquire speculative value, leading to reduced participation and threatening platform sustainability. This two-faced incentive structure underscores the importance of careful token design to balance short-term growth with long-term engagement, particularly by monitoring shifts in perceived token value and their effects on user behavior.

2.2.2 Gamification

Gamification involves using game-like elements, such as leaderboards, points, badges, and other progress-tracking tools in non-game contexts to boost overall user enjoyment and retention. By making tasks more interactive and fulfilling, gamification has proven effective in diverse fields, like education [2, 35], business [23, 42, 45], healthcare [46], and smart city development [19, 36, 52, 53]. Swacha [45] highlighted how gamification can address the lack of intrinsic motivation among employees, a critical barrier to knowledge sharing within organizations. The proposed model includes a point and badge system serving as status symbols to reward specific activities, paired with leaderboards to promote competition and peer-allocated knowledge credits to foster social recognition. Leveraging gamification's potential to foster collaboration and sustained engagement, the proposed model is focused on enterprise scenarios where these principles can be extrapolated into broader contexts. Similarly, Viberg *et al.* [48] concluded that gamified environments facilitate ideation in organizations, fostering employee-driven innovation. Apart from an overwhelming preference for gamified options, participants felt more engaged due to competition and progress-showing mechanics secured by points, leaderboards, and progress indicators, which align with the immersion state described in the Flow Theory [9].

Gamification can also be implemented to boost engagement in older platforms. Sutoyo *et al.* [44] addressed low engagement levels in an educational knowledge repository by adding elements such as leaderboards, points, and medals, which significantly increased user interaction. Despite general satisfaction with the gamified system and high levels of engagement, some downsides regarding competition between users also arose. Almujally *et al.* [2] also perceived that the status level feature in the developed platform for educational purposes could potentially raise some problems, shifting participants' focus from collaboration to outperforming others. Features like leaderboards and other public comparison mechanisms, if not carefully designed, can compromise the quality of shared data and undermine the collaborative nature of such systems. Almujally and Joy's [2] Teaching Practices Management System also addressed the importance of immediate feedback and social recognition in driving user engagement. Participants recognized feedback from peers as a key driver to motivate knowledge sharing. According to the authors, "knowledge contributors placed more weight on social recognition than on any possible financial rewards".

Peer and immediate feedback mechanisms hold great potential to sustain engagement in gamified systems, aligning closely with principles from the discussed theories. Regarding the discussion held in the Self-Determination Theory [37], immediate feedback satisfies the psychological need for competence, as users gain a clear understanding of how their contributions are impactful. Social recognition also fulfills the need for relatedness, fostering a sense of connection among participants as it is tied to peer feedback and other accomplishment-sharing elements. From a Social Cognitive Theory [5] perspective, feedback serves as a reinforcement tool, enhancing both self-efficacy and outcome expectations. Those techniques are also relatable to Flow Theory [9], as clear and immediate feedback contributes to the immersion state categorized as the flow state.

Cai *et al.* [7], after conducting a survey on Q&A platforms, highlighted competence and relatedness as key principles driving knowledge-sharing behavior, as illustrated in Figure 2.3. Their findings revealed that customizable or progress-tracking features (immersion-related) and leaderboards and badges (achievement-related) significantly enhanced users' sense of competence and relatedness, while social-oriented features, including collaboration tools, primarily fostered relatedness and autonomy.

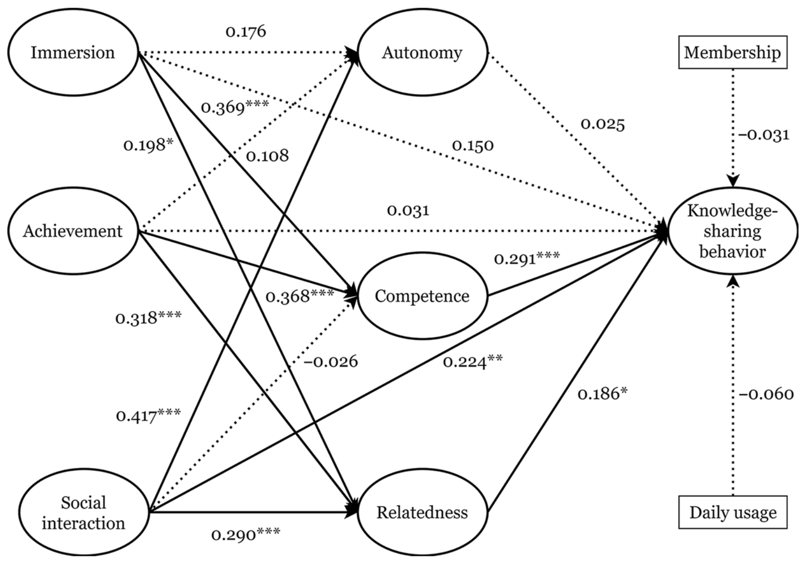


Figure 2.3: Correlations perceived by Cai *et al.* [7]

The work of Ma *et al.* [26] further explored this dynamic through a survey of 290 participants grounded in the Stimulus-Organism-Response (S-O-R) model. Their research provided empirical support for the idea that satisfying the psychological needs of autonomy, competence, and relatedness is crucial, demonstrating that a user's internal psychological state, defined as self-determination (the organism), serves as the key "mediation role" between gamification features (the stimulus) and user behavior (the response).

2.3 Crowdsourcing

Crowdsourcing and crowdsensing have gained popularity as a way to leverage the combined knowledge and efforts of individuals in order to address social challenges. This approach, relying on contributions from diverse participants, is particularly relevant in the context of urban sustainability, where collective data sharing and participation are vital. Figure 2.4 identifies the general components of mobile crowdsourcing applications. Digital platforms, enhanced by gamification and incentives, are reshaping the ways citizens participate in such initiatives.

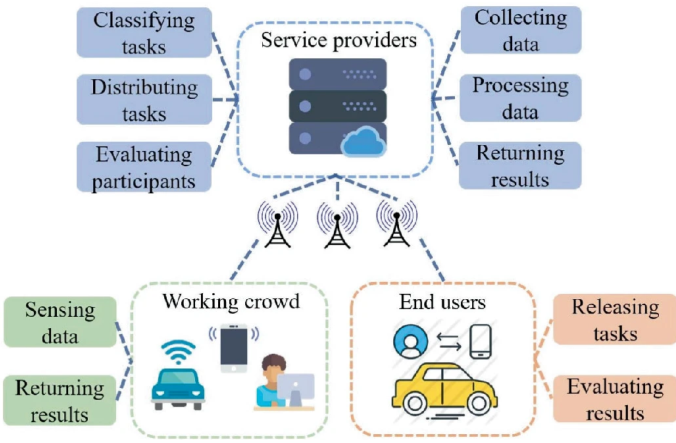


Figure 2.4: Components of crowdsourcing platforms [33]

Crowdsourcing and crowdsensing platforms succeed by understanding the motivational drivers of their contributors. Alhammah *et al.* [1] investigated these in the context of citizen reporting applications. Their findings highlighted output quality and self-concern as significant motivators, particularly when users directly benefited from those platform outcomes. Interestingly, social responsibility, considered a common motivator in other contexts, was not a significant factor, suggesting that users prioritize personal benefits over societal gains when engaging with commercial reporting systems. Similarly, monetary rewards had no impact, reinforcing the idea that intrinsic factors like self-interest and a sense of justice outweigh financial incentives in this context.

Complementing these insights, Scholtz and Mloza-Banda [39] demonstrated the effectiveness of intrinsic motivators like environmental responsibility in driving participation in water resource monitoring projects. Their work also highlighted the most frequent demotivational factors (Table 2.1), such as participants' belief that their data contributions might go unused and insufficient time.

Demotivational Factor	**Frequency**	**%**
Data not being used	68	56.7%
Insufficient time	55	45.8%
Power gap between volunteer and coordinators	43	35.8%
Unappealing recording process	26	21.7%
Lack of confidence	12	10.0%
Not willing to collect for management purposes	9	7.5%
I do not own a smartphone	6	5.0%
Volunteer physically unable	3	2.5%
Other	13	10.4%

Table 2.1: Demotivational factors for volunteer participation [39]

2.3.1 Design of Incentive Tokens

Monetary incentives have been a basis for crowdsourcing strategies, particularly in labor-intensive or data-collection tasks [25, 51]. Their effectiveness depends on the careful structuring of payment schemes in order to align user and platform goals. In the field of sustainability, Bracciali *et al.* [6] work highlights the role of autonomy in fostering citizen participation within frameworks for managing urban resources. The study emphasizes the importance of democratic participation in driving collective action by enabling citizens to propose and vote on water conservation policies. This aligns with the proposed psychological needs in the Self-Determination Theory [37], which underscores the role of autonomy in enhancing intrinsic motivation. In this case, the use of blockchain technology with smart contracts not only ensures transparency and fairness but also empowers individuals to act both independently and collaboratively, bridging personal and communal responsibility.

According to Jaimes *et al.* [18], every incentive scheme must be designed according to some metrics: economic feasibility, data quality, fairness, area coverage, and participant retention. Due to challenges in maintaining a balance between recruitment costs and data quality, which are often raised, several strategies in different areas of crowdsourcing are being studied. Fixed-price incentive schemes tend to maximize reward fairness and participant trust. However, in crowdsourcing or crowdsensing scenarios where data gathering locations are unrestrained or task time is considered, dynamic incentive strategies are very popular.

Building on this, Liu *et al.* [24] demonstrated that adaptive incentive mechanisms allow to meet task-specific requirements in an air quality measuring context without compromising efficiency or fairness. The proposed sensing framework dynamically allocates rewards to chosen participants based on the geographical importance of data and the quality of submissions, which ensures that more relevant contributions are incentivized while less relevant contributions are still compensated fairly.

Due to the reliance on distributed participants for localized sensing tasks, participant recruiting is a research focus on spatial crowdsourcing and crowdsensing scenarios based on episodic tasks, such as last-mile delivery or vehicular crowdsensing contexts, where reverse auctions are a common solution for selecting workers. Wang *et al.* [50] proposed a model that employs a recurrent reverse auction mechanism, dynamically prioritizing participants based on their contributions' geometric coverage-to-cost ratio. This ensures efficient resource allocation, minimizes redundancy, and maximizes area coverage. Additionally, virtual participation credits and a rejoin mechanism were introduced to enhance participant retention and inclusivity, making the framework particularly robust for dynamic large-scale sensing tasks.

Participant reputation also represents a good metric for determining worker selection and contribution payment. Han *et al.* [14] introduced a quality-aware posted pricing mechanism based on Bayesian optimization techniques to improve recruiting cost-efficiency while ensuring high-quality data collection in mobile crowdsensing. This approach aims to select appropriate candidates based on their historical contribution data. Han *et al.* [14] also highlighted the bi-criteria approximation methods used to address the trade-off between price and quality. The proposed mechanism incorporates iterative pricing adjustments, allowing the posted pricing to adapt dynamically based on the outcome quality and the desired price. Alternatively, Sanjaya *et al.* [27] proposed a model grounded in Stackelberg game theory, which prioritizes credible contributors based on reputation levels while maintaining opportunities for new users by granting them maximum reputation. The model effectively addresses trust, inclusivity, and priority issues under limited budget scenarios.

Wang *et al.* [49] proposed a blockchain-based crowdsensing system with distributed storage. Their model integrates task allocation through a multi-attribute reverse auction based on user reputation, bid price, data reliability, and sensing location. The system addresses scalability issues and fosters higher participation rates, especially in large-scale applications like smart cities, by using smart contracts to automate reputation updates and screening malicious contributions based on KNN filtering on data similarities. Reputation and quality-based rewards in crowdsensing scenarios were further explored by Zhang *et al.* [54]. Their work consisted of a hybrid blockchain-based system that leverages the Shapley value to allocate payments based on overall data quality. The proposed reward scheme contains a parameter `h` to adjust the influence of workers' past contributions on the allocated payment, as plotted in Figure 2.5.

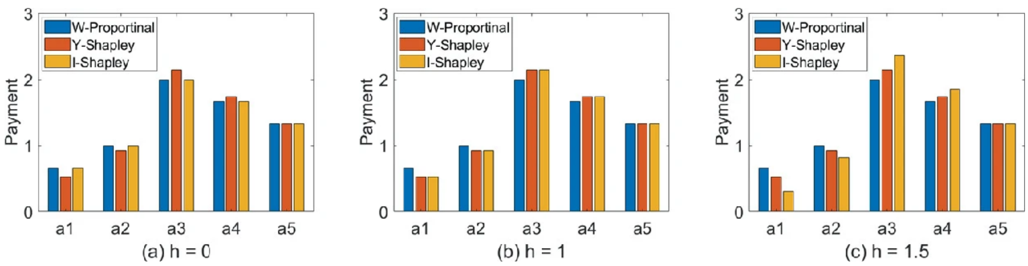


Figure 2.5: Payment considering contribution quality for different `h` [54]

Cheng *et al.* [8] proposed an innovative framework to address unreliable data by leveraging social psychology principles, such as the *witness effect*. The Inspector Sense Model (ISM) enables participants to act as both contributors and inspectors, enhancing data reliability since users know their contributions will be reviewed by others. The study also introduced the Inverse Inspector Sense Model (I-ISM) for converting ambiguous or private data into solvable formats by trying to reconstruct the collection context based on historical data. Cheng *et al.* [8] join contributors and inspectors in all pay auctions, where only the best quality data is selected, considering the budget constraints.

Another challenge in crowdsourcing and crowdsensing practices is related to workers' privacy. The problem relies on data exposure, for example, in the form of location annotations, being central to the development of fair and transparent incentive schemes. Zhang *et al.* [54] work adds an additional layer of security using Sybil-resistant mechanisms while handling sensitive data on a private blockchain to prevent manipulation, ensuring the integrity of crowdsourced data and workers' privacy. Platforms performing data analysis on private networks allow workers to benefit from blockchain's security while enriching contributions with more sensitive data.

Last-mile delivery services have gained popularity, particularly in urban centers, where flexible and cost-efficient logistics demand coincides with environmental and traffic congestion concerns. Mohamed and Ndiaye [28] highlighted the role of dynamic routing and task assignment models to balance efficiency and environmental impact through linear programming formulations. The model proposes the usage of parcel lockers considering constraints such as availability time, drivers' capacity, and consumer delivery time windows. Similarly, Ghaderi *et al.* [13] proposed the use of parcel lockers as intermediary exchange points, minimizing detour distances and enhancing delivery success rates in collaborative crowdshipping networks. Kim *et al.* [22] extended this understanding by integrating floating population data into last-mile delivery pricing strategies, optimizing task allocation based on demand density. Huang *et al.* [17] explored how "push", "pull", and "mooring" factors influence crowd worker participation. Trust and monetary rewards emerged as critical motivators, emphasizing the importance of fair compensation and transparency in ensuring worker engagement.

Phuttharak and Loke [34] expanded the scope of monetary incentives by incorporating social factors into their design. Apart from fixed-price payments and voluntary contributions, some groups were restricted to receiving money through different referral strategies. This dual-incentive layered model contributes to broaden area coverage by integrating community benefits and a sense of shared responsibility. The low-price referral strategy achieved the most area coverage, followed by high-price referral and fixed-price incentives (Table 2.2). Although fixed price was found to be the most cost-efficient mechanism for high-quality data, referral strategies may be used to promote platform longevity.

Monetary rewards are a key driver for participation in online crowdsourcing platforms, positively impacting frequency, duration, and breadth, as verified by Shi *et al.* [40]. The study also highlighted the positive influence of intrinsic and extrinsic motivators in crowdsourcing participation, such as perceived self-efficacy and outcome expectations, which align the with Social Cog-

Incentive Method	**Participants**	**Tasks Submitted**	**Total Expenses**	**Correctness**	**Photo Description**
Fixed-price	10	132	875	125	130
Low-price referral	52	175	1260	164	171
High-price referral	45	146	1059	137	142
Non-payment	7	47	–	38	35

Table 2.2: Phuttharak and Loke [34] results

nitive Theory [5]. Social recognition, perceived as "gain face", and overall enjoyment were also considered significant key drivers. These findings, detailed in Figure 2.6, align with the growing emphasis on gamification as a strategy to enhance intrinsic motivation in crowdsourcing contexts, as it provides users with mechanisms to build reputation, achievement, and social connection.

	Hypothesis	**Result**
H1	Perceived self-efficacy is positively related to solver participation in OCPs	Partially supported
H2	Personal outcome expectation is positively related to solver participation in OCPs.	Partially supported
H3a	Monetary reward is positively related to solver participation in OCPs.	Supported
H3b	Monetary rewards are positively related to solvers' self-efficacy in OCPs.	Supported
H3c	Monetary rewards are positively related to solvers' outcome expectations in OCPs.	Supported
H4a	Gain face is positively related to solver participation in OCPs.	Partially supported
H4b	Gain face is positively related to solvers' self-efficacy in OCPs.	Supported
H4c	Gain face is positively related to solvers' outcome expectation in OCPs.	Supported
H5a	Enjoyment is positively related to solver participation in OCPs.	Partially supported
H5b	Enjoyment is positively related to solvers' self-efficacy in OCPs.	Supported
H5c	Enjoyment is positively related to solvers' outcome expectation in OCPs.	Supported
H6a	Social affiliation is positively related to solver participation in OCPs.	Partially supported
H6b	Social affiliation is positively related to solvers' self-efficacy in OCPs.	Not supported
H6c	Social affiliation is positively related to solvers' outcome expectation in OCPs.	Not supported

Figure 2.6: Shi *et al.* [40] findings

2.3.2 Gamification Mechanisms

Gamification has also been applied to address challenges in crowdsourcing and crowdsensing scenarios, aiming to enhance user engagement and data quality. Ananta *et al.* [3] developed a platform to incentivize collaborative waste collection and reporting through a gamified points-based reward system. Supriyanto *et al.* [43] explored the role of competitive gamification in enhancing ecotourism publicity in Indonesia. The implemented leaderboard, allied to users' feelings of social recognition, boosted social media posts by 400%. Kim *et al.* [21] investigated the use of a gamified app to acquire landscape design and spatial planning knowledge. GPS reliability for data collection was evaluated at 70%, and 70% of survey respondents classified the gamified platform as "enjoyable". However, some participants had privacy concerns with the invasive login mechanism.

Tinati *et al.* [46] provided a comprehensive analysis of the motivational dynamics in gamified citizen science platforms through a survey of 1500 players. Their findings highlighted altruism, derived from contributing to a meaningful goal, as the primary source of motivation. Challenges and entertainment brought by gamification features also served as significant motivators, however, collaborative elements were underutilized. The dominant motivation of altruism aligns closely with the constructs of competence and relatedness from the Self-Determination Theory [37], emphasizing the importance of fulfilling those psychological needs to sustain participation. Hantke *et al.* [15] explored motivational dynamics in gamified annotation-based tasks, highlighting the importance of participants perceiving the value of their contributions. While altruism wasn't mentioned, the study noted that users frequently requested clear feedback on how their contributions were utilized, suggesting an intrinsic desire to ensure their efforts made a meaningful impact.

Ommer *et al.* [31] proposed a gamification-based app with the aim of bridging the "knowledge-action gap" in the mitigation of climate change by motivating users through the "avoided footprint" metric. "Challenge Yeti" aligns with the Self-Determination Theory [37] by fostering competence through immediate feedback, relatedness via collaborative community challenges, and autonomy through user-driven behavior decisions, such as choosing challenges based on their capabilities and preferences. It also integrates principles of the Social Cognitive Theory [5], leveraging social recognition, self-efficacy, environmental influences, and modeled behaviors to promote sustainable actions. Additionally, as outlined in the Flow Theory [9], the app's mascot, combined with real-time feedback and progressively challenging tasks, facilitates the attainment of a flow state, ensuring sustained engagement and immersion.

Score, ranking, and achievement mechanisms are among the most common in gamification practices. However, leaderboards, while effective for fostering competition and engagement, often disadvantage new users who may find it difficult to compete with more experienced participants. This disparity can discourage continued participation, particularly in systems where visibility or recognition is tied to leaderboard rankings. In the context of collecting city data, Ortiz and Tang [32] proposed a timed competition system to address low retention among new users. By dividing the city into zones with individual leaderboards, users competed to become "owners" of specific areas. This *mapathon* feature led to a 171% increase in data contributions compared to the standard gamified approach, as plotted in Figure 2.7. However, the study also highlighted challenges, such as balancing competition intensity and ensuring data quality, as the validations were deprioritized during the competitive phase.

Data quality is a persistent challenge within crowdsourcing contexts, often stemming from intentional misuse aimed at exploiting system benefits. Kapenekakis and Chorianopoulos [20] approached this issue by incorporating penalties for malicious contributions evaluated with peer reviews in the proposed gamification system for documenting pedestrian cartography. As such, negative ratings resulted in point deductions with the aim of reducing the frequency of low-quality

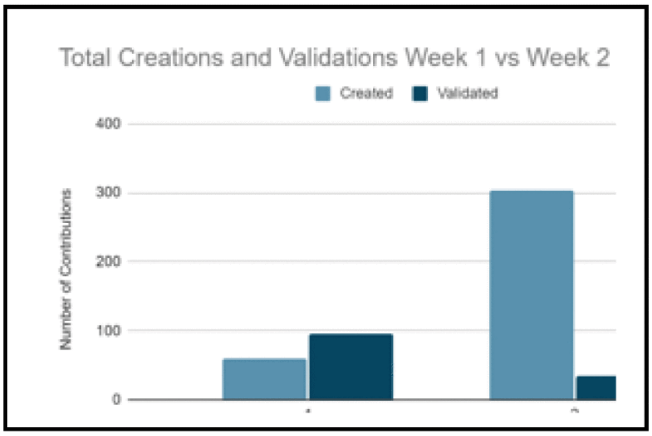


Figure 2.7: Ortiz and Tang [32] results

uploads. Kapenekakis and Chorianopoulos [20] also verified instances where users tried to manipulate peer reviews to boost their own scores, which suggests that penalties alone may not be sufficient to prevent system misuse.

Kampyli *et al.* [19] further addressed this issue in parking ecosystems by introducing a dynamic incentive system. Their approach required users to spend points to access parking data, with partial refunds provided for inaccurate reports. This mechanism not only discouraged untruthful reporting with penalties but also balanced user engagement with data reliability, showcasing a novel method to maintain system integrity by ensuring that only truthful and well-intentioned users could continue to benefit from the platform. L'Heureux *et al.* [23] addressed data quality challenges in IoT environments through a gamification framework designed for sensor data labeling further used for machine learning. To ensure data quality, the framework discarded false gaming events, where users logged actions without performing them, by cross-referencing gaming data with sensor outputs. Additionally, a clustering mechanism eliminated noise from erroneous labels, producing reliable datasets for machine learning applications. By integrating points, leaderboards, and task feedback, users reported increased awareness of energy consumption, aligning their behavior with the system's sustainability goals.

Studies comparing gamification with alternative incentive schemes provide valuable insights into its effectiveness in crowdsourcing scenarios. Salomoni *et al.* [38] found that gamification yielded data contributions comparable to monetary rewards in urban accessibility mapping (Table 2.3), emphasizing that well-designed gamified systems could achieve high participation without tangible rewards. Although the tested reward approach achieved slightly higher engagement, "Geo-Zombie" secured a much higher spatial breadth of contributions across participants.

Complementing these findings, Spicher *et al.* [41] compared gamification, citizen science, and paid microtasks for medical image segmentation. While gamification produced data quality close to citizen science, moved by altruism and intrinsic motivation, and outperformed paid microtasks, it stood out for its cost-effectiveness and ability to maintain user engagement over time. These comparisons underscore the potential of gamification as a flexible tool that, when aligned with

Apps	Number of Reports	Number of Users	Reports per User (Average)	Reports per User (Standard Deviation)
BASIC	95	48	1.97	1.28
REWARD	311	47	6.60	3.56
GAMIFIED	286	48	5.95	16.60

Table 2.3: Comparison of apps for urban accessibility mapping [38]

task requirements and user preferences, can effectively balance engagement, cost, and data quality effectively.

2.4 Summary

Designing effective crowdsourcing and crowdsensing systems requires a broad understanding of the concept of motivation, as highlighted by theories such as the Self-Determination Theory [37], Social Cognitive Theory [5], and Flow Theory [9]. These frameworks reveal that intrinsic motivators such as autonomy, competence, and relatedness can drive meaningful participation when supported through gamified elements such as leaderboards, badges, and collaborative challenges. At the same time, if aligned with user values and preferences, extrinsic motivators, including monetary rewards and tangible incentives, can complement intrinsic drivers.

Non-monetary incentives should not be seen as less important when compared to monetary rewards. While monetary incentives can certainly encourage participation, particularly in data-intensive tasks, non-monetary incentives that promote social recognition and self-efficacy can lead to a more sustained engagement by addressing the concept of intrinsic motivation. It is also crucial to recognize the relationship between intrinsic and extrinsic motivators, which highlights the need for an approach that takes into consideration the different backgrounds and profiles of potential workers. On the other hand, real-time feedback, clear task goals, and immediate rewards contribute to the immersive flow state that enhances user retention. Meanwhile, privacy concerns, equitable reward distribution, and mitigating the adverse effects of over-competitiveness remain critical challenges. Addressing these requires transparent policies and secure systems that balance engagement, fairness, and trust while maximizing data quality.

Ultimately, the success of crowdsourcing and crowdsensing platforms is correlated to their ability to integrate diverse motivational strategies to meet both user needs and platform goals. By recognizing the strengths of non-monetary incentives and leveraging gamification alongside monetary rewards, platforms can create participatory ecosystems that are both impactful and sustainable, as the one proposed by Neofotistos *et al.* [29] to address waste collection. These approaches not only enhance user engagement but also align with broader societal challenges such as sustainability and resource management, making crowdsourcing a powerful tool for collective action.

Despite the progress made, several gaps remain in the current literature and practice. Many studies focus on short-term engagement, leaving the long-term sustainability and reliability of incentive strategies underexplored. Prolonged studies are necessary to evaluate how gamification elements and rewards affect user retention and motivation over time. Furthermore, current systems often rely on static mechanisms that do not adapt to evolving user preferences and participation patterns in real-world scenarios. Modern approaches often face significant limitations in their ability to address powerful sources of participation, like individual preferences and values. Instead, contributions are frequently regulated by generalized external incentive mechanisms that fail to resonate with intrinsic motivators, such as participants' sense of purpose or desire to make or to be aware of the impact made.

To move forward, incentive schemes must become more adaptive and personalized. In this way, strategies that address individual beliefs, provide educational feedback, and highlight contribution relevance can be employed to create stronger engagement. These gaps highlight the need to blend psychological theories with emerging technologies to create dynamic platforms. By integrating adaptive incentive mechanisms, educational insights, and real-time feedback, such systems can evolve into drivers for collective awareness and sustainable behaviors rather than just tools for data collection.

Chapter 3

Literature Review

A scoping review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Extension for Scoping Reviews, PRISMA-ScR [47], which provides guidelines to synthesize existing research rigorously. By applying PRISMA-ScR, this review ensures a comprehensive understanding of the current knowledge on digital incentives, gamification, and their application in sustainable urban development.

3.1 Research Domain

Platforms enabling active user participation are essential drivers of information flow and knowledge sharing. Such platforms have become essencial to harness the collective power of users to gain insights into societal matters through crowdsourcing and crowdsensing initiatives. However, sustaining user engagement poses significant challenges, particularly when it comes to motivating citizen contributions toward sustainable initiatives. Low retention rates and fluctuating engagement highlight the need to analyze digital incentives to promote sharing practices.

This scoping review seeks to explore how different forms of digital incentives influence engagement in participatory platforms, particularly within the context of sustainability and urban sensing. To guide the review, two central research questions were formulated:

- **Q1:** How can participation be incentivized in crowdsensing platforms?
- **Q2:** What user behaviors and perceptions are associated with sustained contributions in crowdsensing platforms?

To address these questions, this review explores the impact, limitations, and applications of digital tokens and gamification strategies as mechanisms to encourage meaningful user contributions. Figure 3.1 describes the steps conducted according to the PRISMA-ScR concept. These will be further explained in the following sections.

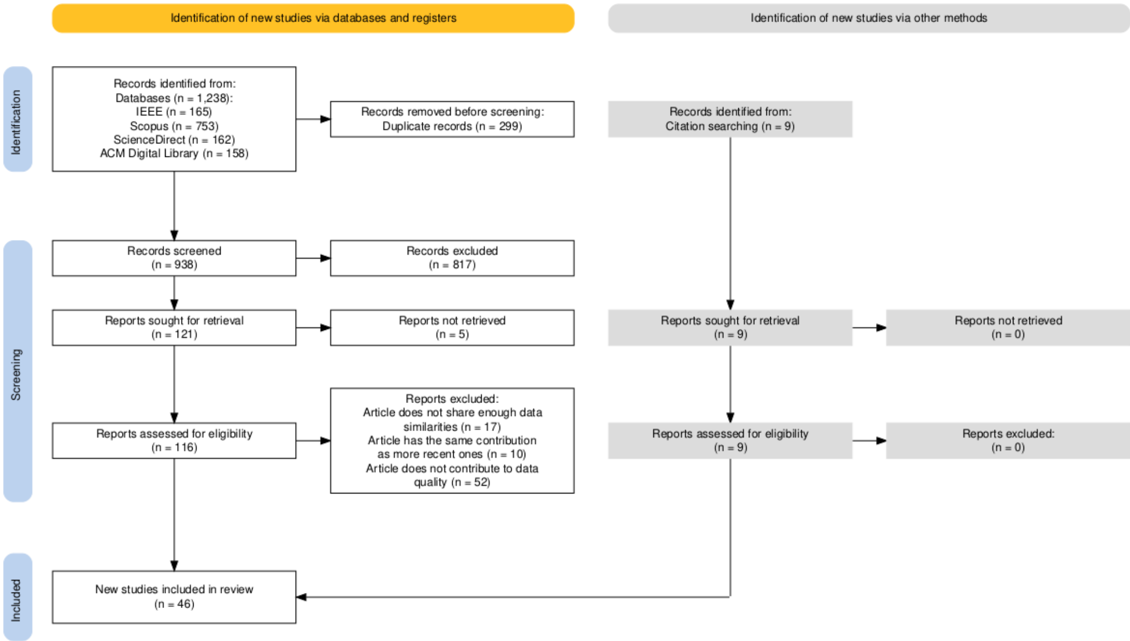


Figure 3.1: PRISMA flowchart

3.2 Identification phase

Information was retrieved from four digital databases: ACM Digital Library, Science Direct, Scopus, and IEEE Xplore. Table 3.1 documents the initial search queries formulated to address the topic discussed in the previous section. These were further refined to enhance the data retrieved.

SQ1	(digital OR blockchain) AND (tokens OR incentives OR rewards) AND ("information sharing" OR "knowledge sharing" OR engagement)
SQ2	(tokens OR incentives OR rewards) AND (crowdsourcing and crowdsensing) AND (city or urban)
SQ3	gamification AND ("information sharing" OR "knowledge sharing")
SQ4	gamification AND (crowdsourcing OR crowdsensing)

Table 3.1: Initial search queries

The proposed search queries aim to cover the various ends of the existing literature. While *SQ1* explores studies on digital incentives and their roles in information sharing and engagement, *SQ2* focuses on these strategies applied to urban development and sustainability contexts. *SQ3* and *SQ4* follow a similar approach, as they refer to gamification strategies applied in information sharing and crowdsensing or crowdsourcing scenarios, respectively.

3.2.1 Refinement Process

A refinement process was undertaken based on the number and quality of articles retrieved from each search string. Query 1 was improved with the `NEAR` operator, as it was found to be too general, fetching articles that were not relevant to the study. On the other hand, search strings 2, 3, and 4 proved to be precise, so the `NEAR` operator was not necessary.

Finally, in order to ensure a more inclusive search, all the queries were enhanced with the `*` wildcard to capture variations of key terms. For instance, the usage of `incentiv*` captures terms such as *incentive*, *incentives*, and *incentivizing*, while `shar*` corresponds to terms such as *share*, *shared*, and *sharing*.

After the tuning strategies defined above, the final versions of the search queries are documented in Table 3.2.

SQ1	(digital OR blockchain) NEAR/4 (tokens OR incentiv* OR rewards) AND ("information shar*" OR "knowledge shar*" OR engagement)
SQ2	(tokens OR incentiv* OR rewards) AND (crowdsourcing OR crowdsensing) AND (cit* OR urban)
SQ3	gamification AND ("information shar*" OR "knowledge shar*")
SQ4	gamification AND (crowdsourcing OR crowdsensing)

Table 3.2: Search queries for the scoping literature review

As shown in Table 3.3, these final queries retrieved a total of 1238 articles from the four mentioned databases. ACM Digital Library and Science Direct do not support proximity operators, and the latter does not allow wildcards either. The procedure followed consisted of leveraging all query enhancement techniques allowed in each database.

	SQ1	SQ2	SQ3	SQ4	**Total**
IEEE	11	73	11	70	165
Scopus	125	219	79	330	753
Science Direct (no `NEAR` or `*`)	119	15	6	22	162
ACM Digital (no `NEAR`)	83	21	0	54	158
Total	338	328	96	476	**1238**

Table 3.3: Search strings results

3.2.2 Search Criteria

The search based on the defined queries was conducted on titles, abstracts, and keywords of research articles, books, conference papers, and short papers. Only articles accepted after 2015 (inclusive) were considered relevant since a 10-year difference encompasses significant mentality and behavior changes among study participants. Exceptions to these rules consist of theories [5, 9, 37] regarding individuals' motivation and engagement.

3.3 Screening Phase

A filtering process was conducted to filter the papers retrieved. Table 3.4 presents the inclusion and exclusion criteria that this phase relied on.

No.	Criteria
1	Results fetched from the search queries
2	Publication date after 2015 (inclusive)
3	Paper is not a duplicate
4	Paper was not retracted
5	Paper isn't a work-in-progress
6	Paper wrote in English
7	Paper not related to intelligent agents or robotics
8	Paper not related to supply chain security
9	Paper not related to specific conditioned minorities

Table 3.4: Inclusion and exclusion criteria

3.4 Elegibility Phase

After the steps defined above, 117 papers were considered appropriate for a full-text assessment. The search for those PDFs fetched 112 files, of which eight were searched manually. The content of those 112 papers was analyzed in order to determine which would be considered relevant to this study.

After applying inclusion and exclusion criteria followed by a methodical analysis of the papers' full content, 46 were selected. These are described in Tables 3.5, 3.6, 3.7 and 3.8, sorted by date in ascending order. The number of papers retrieved from different years is plotted in Figure 3.2.

Reference	Research Purpose	Approach/Domain
[53]	Present a WiFi advisory crowdsensing platform sustained by gamification incentives.	Gamification in crowdsensing platforms.
[38]	Compare monetary and gamification-based incentives results in an urban accessibility platform.	Comparison of incentives in crowdsourcing.
[45]	Investigate and propose specific gamification rules to support knowledge transfer between employees.	Gamification applied in enterprises.
[16]	Measure effects of intrinsic motivation and external rewards (pieced and fixed) on overall motivation and performance.	Study on higher education institutions.
[24]	Propose an adaptive monetary incentive based on the contribution's geographical importance.	Adaptive incentives in crowdsensing.
[20]	Propose a gamification framework with penalties to discourage bad submissions in pedestrian routing.	Gamification in crowdsourcing.
[46]	Investigate the motivational dynamics in gamified citizen science.	Survey on citizen science.
[42]	Investigate how conceptualized gamification affordances contribute to hedonic value, quality, and quantity of shared knowledge.	Theoretical model validation on an enterprise collaboration system.
[23]	Promote sensor labeling through gamification, and data quality via cross-referencing and clustering algorithms.	Gamification on crowdsourcing.

Table 3.5: Relevant studies description

Reference	Research Purpose	Approach/Domain
[28]	Propose optimum assignment and routing for drivers in e-commerce delivery to minimize paid reward.	Task optimization on delivery crowdsourcing platforms.
[15]	Investigate gamification's role in annotation-based tasks in citizen science.	Survey about a gamification mechanism.
[14]	Propose an iterative pricing algorithm considering users' historical data and desired quality and price.	Dynamic pricing algorithm.
[43]	Investigate gamification influence on eco-tourism content creation.	Gamification applied in crowdsourcing.
[35]	Investigate gamification influence on student learning behavior by comparing a gamified with a non-gamified experience.	Gamification applied in educational institutions.
[39]	Propose a framework for motivational and demotivational factors in crowdsensing.	Survey regarding motivational factors in crowdsensing.
[44]	Analyze gamification's impact on the sharing of knowledge in an academic environment.	Gamification applied in higher education institutions.
[6]	Promote water-related sustainability practices using policies, smart contracts, and data gathering in smart cities.	Usage of incentives to promote collaborative sustainability practices.
[17]	Discover motivational factors influencing participation in last-mile delivery.	Survey on last-mile delivery workers.
[21]	Investigate the influence of gamification in spatial planning and the quality of location annotations.	Gamification applied in crowdsourcing.
[34]	Compare fixed-price to referral incentive strategies in city zones annotation.	Comparison of incentives in crowdsourcing.
[48]	Propose gamification strategies in workplaces, compared with non-gamified approaches.	Gamification applied in enterprises.
[50]	Present a recurrent reverse auction based on coverage-to-cost ratio, with a rejoin mechanism.	Incentive model on vehicular crowdsensing.

Table 3.6: Relevant studies description

Reference	Research Purpose	Approach/Domain
[2]	Propose and evaluate a gamified teaching practices management system to promote knowledge sharing among instructors.	Gamification applied in higher education institutions.
[10]	Conceptually measure non-fixed digital token effects on user participation and retention on pre- and post-launch scenarios of multi-sided platforms.	Usage of utility tokens on MSPs.
[1]	Discover the motivational factors impacting participation in citizen reporting applications.	Survey on citizen reporting applications.
[19]	Introduce a dynamic point incentive in parking systems to incentivize truthfulness and platform longevity.	Gamification in crowdsourcing.
[25]	Propose a cryptocurrency to reward users for participating in sustainable collaborative processes.	Usage of cryptocurrency to promote sustainability.
[4]	Study the influence of monetary and reputational tokens on the quality and quantity of information shared.	Usage of digital tokens on questionnaires.
[27]	Propose an incentive model based on Stackelberg game theory, prioritizing contributions from users with high reputation.	Incentive model on citizen reporting applications.
[36]	Showcase and evaluate a gamified smart parking solution.	Gamification applied in crowdsourcing.
[52]	Showcase an app to report waste heat, integrating gamification and tokens.	Crowdsourcing platform to promote sustainability.
[26]	Investigate the relationship between gamification and knowledge-sharing behavior.	Survey on gamification traits.
[13]	Propose intermediary exchange points to optimize crowdshipping networks.	Routing model for last-mile delivery.
[29]	Propose a theoretical approach to a mobile application to reward users for waste collection, raising awareness for circular bioeconomy.	Theoretical crowdsourcing platform.
[49]	Propose a crowdsensing platform with a multi-attribute reverse auction to select workers.	Crowdsensing platform.

Table 3.7: Relevant studies description

Reference	Research Purpose	Approach/Domain
[3]	Showcase a crowdsourcing platform to incentivize waste collection via gamification.	Gamification on crowdsourcing.
[8]	Propose a framework to address unreliable data in mobile crowdsensing using social psychology principles.	Incentive model on crowdsensing.
[12]	Analyze the effects of task complexity, autonomy, and monetary rewards on intrinsic motivation.	Factors influencing intrinsic motivation.
[40]	Investigate the influence of motivation in crowdsourcing participation through cognitive processes.	Study on survey contributions.
[41]	Compare drivers for medical image segmentation, including paid microtasks, gamification, and citizen science.	Crowdsourcing drivers comparison.
[54]	Propose a secure hybrid blockchain with dynamic incentive payments based on a truth-discovery algorithm.	Crowdsourcing system.
[7]	Investigate whether features related to gamification correlate with psychological intrinsic motivation needs.	Q&A in a significant global content community.
[32]	Showcase a gamification model containing timed competition in crowdsourcing activities.	Gamification applied in crowdsourcing.
[51]	Showcase a crowdsensing platform for wetland monitoring, with smart contracts deciding the incentives.	Crowdsensing platform.
[22]	Propose a pricing strategy involving demand density in last-mile delivery systems.	Pricing model on last-mile delivery.
[31]	Showcase a gamification app to mitigate climate change based on psychological foundations.	Crowdsourcing platform.

Table 3.8: Relevant studies description

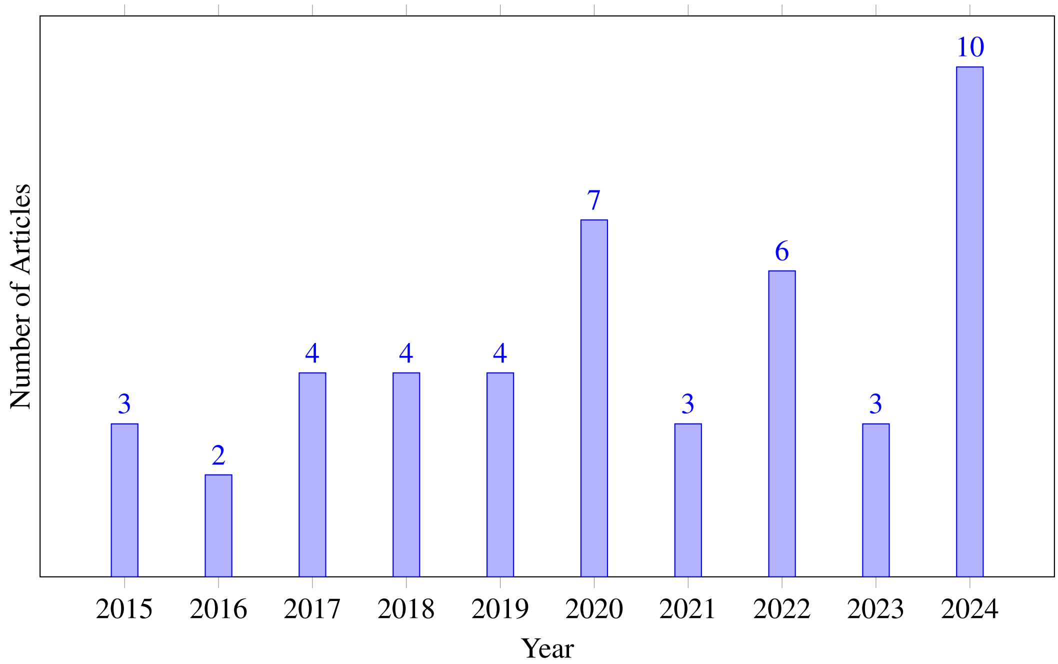


Figure 3.2: Number of articles fetched per year

3.5 Results

Related work in the area of sustainability indicates a growing tendency toward the usage of distributed ledger technologies alongside digital incentives in crowdsourcing and crowdsensing practices, considering their security, transparency, and traceability benefits [6, 12, 25, 52].

Gamification continues to emerge across various fields as a versatile tool, notably in organizational environments to enhance employee motivation and performance [18, 42], as well as in educational institutions to improve engagement and learning outcomes [2]. These implementations are now increasingly adapted to crowdsourcing and crowdsensing platforms, where gamified elements are also very popular [3, 19, 20, 23, 31, 36, 43, 51–53].

Behavioral and motivational theories were also considered to deepen the understanding of user engagement mechanisms. These delve deeper into psychological factors that foster intrinsic motivation [37], how observational learning is crucial to behavior adoption [5], and how an immersive flow state can be categorized [9] regarding participant engagement. Based on those findings, some recent studies focus on fostering intrinsic motivation through psychological and cognitive approaches [7, 26, 40], which can be pivotal in maintaining high-quality long-term contributions.

Recent applications of crowdsourcing and crowdsensing span a wide range of domains, encompassing sustainability [3, 6, 25, 29, 31, 51, 52] and smart-city development initiatives [6, 19–21, 32, 36, 39, 53]. The growing emphasis on those platforms is also joined by surveys aiming to explore workers' motivational factors [1, 17, 39, 40, 46].

Overall, the retrieved articles support the notion that digital incentives and gamification have the potential to encourage sustainable behavior changes and engagement in urban data-sharing platforms. These insights enable a better understanding of the research questions posed.

3.6 Beyond PRISMA

The PRISMA-ScR methodology was followed during the entire process. However, some additional sources were incorporated to strengthen the conceptual foundation and enhance the relevance of the findings. These supplementary studies were selected because they directly addressed the research questions or contributed critical perspectives that were underrepresented in the initial structured search.

First, several articles offering illustrative crowdsourcing and gamification case studies, such as those by Supriyanto *et al.* [43], Bracciali *et al.* [6], Neofotistos *et al.* [29], and Warrier *et al.* [51], were included to provide concrete examples of how digital incentive mechanisms are implemented in practice. These helped interpret trends and bridge gaps between theoretical models and real-world applications.

High-quality experimental studies were added, including Hendijani *et al.* [16], Garaus *et al.* [12], and Shi *et al.* [40]. These are particularly relevant for addressing the concept of motivation regarding the nuanced interaction between extrinsic and intrinsic drivers, offering empirical insights into crowding-out and crowding-in effects that directly contribute to the incentive design challenges explored in this thesis.

Finally, the study by Drasch *et al.* [10] extended the scope of token-based systems beyond static exchange models by theorizing how fixed-supply utility tokens can act as a two-faced incentive across different stages of a platform's lifecycle. This allowed for a broader and more flexible understanding of token design possibilities and respective outcomes, which is an increasingly relevant consideration for future incentive systems. Together, these additions were made to complement the scoping review with high-relevance contributions that addressed theoretical blind spots or introduced innovative incentive concepts not captured in the original search.

3.7 Summary

This chapter presents a structured review of the literature exploring the intersection of knowledge sharing, gamification, and digital incentives in the context of crowdsourcing and crowdsensing platforms. The review enables the identification of trends and challenges associated with fostering user engagement, ensuring data quality, and supporting collaborative behaviors in these systems. Key themes include the adoption of gamification and tokenized rewards to enhance participation and align individual motivations with platform objectives, and foundational theories provide insights into how these mechanisms interact with intrinsic and extrinsic motivators to sustain engagement.

This scoping review offers a comprehensive basis for the previous chapter. Following the PRISMA-ScR [47], it lays the groundwork for understanding the state-of-the-art and the theoretical foundations driving advancements in user engagement and data-sharing platforms. Overall, the literature underscores the interplay between digital incentives, gamification, and user engagement, providing insights into designing effective platforms that balance motivation, fairness, and data reliability in diverse contexts.

Chapter 4

System Architecture

This chapter covers the software architecture designed to implement the crowdsensing platform's digital incentive system aimed at motivating user participation. Rather than detailing how the system was implemented, this chapter focuses on its high-level design, mainly the roles and strategic selection of each technological component, the rationale behind corresponding architectural choices, and the structure of their interactions. Specific implementation details are reserved for Chapter 5.

The proposed system architecture forms a modular backend capable of delivering personalized and trustworthy incentive mechanisms by strategically combining blockchain technology, a flexible NoSQL database, and a locally hosted LLM assistant with external services. Ensuring user privacy, enabling decentralized elements where appropriate, fostering component modularity for maintainability, and designing for system extensibility to accommodate future enhancements are the key architectural drivers. Section 4.3 describes each subsystem in terms of its responsibilities and architectural purpose.

4.1 Architectural Approach and Design Goals

Incentive mechanisms are the driving force behind participation in crowdsourcing and crowdsensing platforms, playing a crucial role in ensuring their success. While monetary incentives such as utility tokens can encourage contributions effectively, non-monetary incentives hold equal, if not greater, importance. The state-of-the-art conducted in Chapter 2 emphasizes that non-monetary incentive techniques must not be overshadowed when compared to others integrating tangible rewards. Gamification strategies providing users with a sense of achievement through leaderboards and badges have proven to be particularly effective in fostering engagement.

In contrast to past considerations, the reviewed literature also unveiled the advantages of a moderated tangible reward system when complemented by non-monetary motivators [12, 16]. Nevertheless, modern approaches often face significant limitations in their ability to address individual preferences and values, which are a powerful yet untapped source of user participation. Workers' contributions are frequently regulated by generalized incentive mechanisms that fail to resonate with intrinsic motivators. Users' sense of purpose or their desire to make or be aware of the impact made by their actions are usually left unaddressed.

These limitations underline the necessity for more adaptive and user-centered features in incentive schemes. To address these challenges, the proposed architecture integrates established gamification elements, namely leaderboards and badges, and utility tokens, exchangeable for items, with a novel digital assistant. The mentioned element is a crucial architectural differentiator that aims to close the gap between platform actions and intrinsic motivational drivers. By enabling a significant level of personalization and direct feedback, which are often absent in existing systems, the ultimate objective is to create a system that cultivates a deeper and more intrinsically driven engagement with urban sustainability rather than simply incentivizing participation.

4.2 Incentive Scheme

The proposed solution combines tangible rewards, such as utility tokens, with intangible rewards, such as badges. Drawing from the knowledge gathered in the literature review, the scheme combines different types of incentives that resonate with different motivational drivers.

4.2.1 Tangible Rewards

Tangible rewards are implemented through a utility token system intended to reinforce submission quality. These tokens function as a virtual currency only valid inside the platform and are securely stored by a private blockchain network. Tokens are conceptually redeemable through a built-in marketplace, which offers a set of predefined items, simulating a real-world store. However, for the purpose of this project, even though the marketplace is functional, the listed items are fictitious and serve primarily as a prototype to demonstrate a working backend token management system, as well as future platform functionalities that would enable a direct correlation between the quality of submissions and the rewards received by users.

Crucially, the tokens are non-tradable to avoid speculative behaviors, preserving their functional role as engagement incentives rather than investment assets. This decision directly addresses concerns raised in prior research regarding token speculation, which can undermine meaningful participation and long-term platform viability [10].

Token issuance is also simplified. Initially, it was planned to be directly tied to submission quality, which would be evaluated using external image classification algorithms capable of detecting waste type and severity. However, their implementation was not possible, and due to that work being outside the scope of this dissertation, each submission was granted a random number of tokens, between 10 and 55. This simplification still allows users to conceptualize the idea of a functional store while getting a feeling of reward for their contributions. In contrast, a complete development would involve the integration of an external AI service for waste classification, allowing the adoption of token rewards based on the type, severity, and ecological impact of the reported waste, thereby strengthening the link between contribution quality and the correspondent tangible reward.

The overall design centered on non-tradable tokens, a moderate task complexity, and thematically aligned marketplace items was intended to mitigate the potential crowding-out effect. The literature suggests that extrinsic incentives may support rather than hinder intrinsic motivation when rewards are perceived as supportive and congruent with users' values and the nature of the task [12, 16]. By reinforcing token value through meaningful and supportive feedback and situating them within an autonomy-supportive and environmentally focused context, the platform aims to foster a crowding-in effect, where external rewards enhance rather than diminish user motivation.

4.2.2 Intangible Rewards

The platform incorporates badges given when users reach predefined milestones, such as a specific number of submissions or maintaining an active submission streak. The badge system is designed to encourage long-term engagement as a form of recognition for consistent and meaningful contributions. It also enables the platform to adapt to various user types by recognizing different levels of submission effort, ranging from casual contributors to highly active participants. In this way, the system promotes consistent user participation, as each badge can evolve across bronze, silver, and gold tiers, reflecting the user's continued effort over time. This adaptability ensures that all users feel valued and motivated, regardless of their level of engagement and commitment to the platform.

The badge system was designed with inclusivity in mind. While some badges promote quantity, others focus on data quality. On the other hand, others target specific behaviors, such as submission time or tokens spent in the store. This variety allows this incentive type to reward different dimensions of participation while also promoting the usage of different application features, such as the store and the visualization of the leaderboard. The different badges implemented are detailed in Table 4.1. Their descriptions contain the values of the three corresponding tiers available: bronze, silver, and gold, as mentioned above. Gold badges count as three units for the `Eco Legend` badge since users need to possess bronze and silver variants in order to obtain the best tier badge. That logic also applies to silver badges, which are counted as two.

The thresholds for badge progression were calibrated considering the duration of the trial, further described in Chapter 6. The tiers were designed to promote not only sustainable long-term engagement but also early participation through the bronze level. Although some badges are intrinsically more challenging to achieve than others, bronze ones are generally obtainable with only one to two submissions per day. In contrast, silver levels are more challenging, being obtained with three to four submissions per day. Gold achievements are set as ambiguous targets for the most dedicated participants, as they require more effort in the use of the application. This balance offers accessibility with incremental accomplishments for casual users while preserving a sense of challenge and prestige for more committed participants.

Name	Description
Eco Addict	Reach (10 / 25 / 50) total submissions.
Streak Keeper	Submit reports for (3 / 5 / 10) consecutive days.
Early Bird	Submit (3 / 8 / 15) reports in the morning.
Night Owl	Submit (3 / 8 / 15) reports at night.
Top Photographer	Submit (5 / 15 / 30) high-quality reports.
Clean City Champion	Reach the top (15 / 10 / 5) positions in the leaderboard.
Eco Legend	Earn (6 / 12 / 20) badges.
Token Recycler	Spend (500 / 900 / 2000) tokens in the store.
Eco Tycoon	Earn (500 / 900 / 2000) tokens.

Table 4.1: Badge definitions and tier thresholds

4.2.3 Perceived Value

While the technical implementation of the incentive scheme is an important matter, its effectiveness relies on how users perceive its rewards and feedback mechanisms. The system is designed not only to reward participation but also to promote deeper values, such as recognition, self-efficacy, environmental awareness, and a sense of contribution to a collective goal.

The digital assistant enhances the perceived value of each user submission by generating dynamic and personalized feedback that acknowledges and reinforces their contribution. This design directly addresses findings from prior research [15], which highlighted that users have an intrinsic desire for clear feedback to understand the value and impact of their contributions. The assistant operates in two distinct modes: **reactively**, by responding to direct user input in the chat interface, and **proactively**, by autonomously delivering motivational and supportive educational messages based on system triggers and scheduled tasks. In its proactive mode, the assistant performs three main behaviors:

- **Post-submission feedback:** After every image submission, the backend triggers a personalized congratulatory message, coupled with encouragement to maintain participation and facts reinforcing the environmental value of the action.
- **Inactivity reminders:** Every day at 3:00 PM, the backend executes a streak check task that scans for users who have been inactive for more than 48 hours. Eligible users receive a motivational reminder encouraging them to resume activity and restore their submission streak or start one by making their first contribution, considering their history.
- **Daily ecological facts:** Twice a day, at 10:00 AM and 6:00 PM, the backend generates and delivers sustainability-related facts or curiosities to all users. This scheduled outreach is designed to increase environmental awareness even in the absence of user interaction.

The assistant was thought to reach participants with less environmental awareness or interest. Instead of merely answering user questions, which would assume those would be made in the first place, the dual-mode operation ensures the assistant is both responsive and autonomous in the task of keeping the users motivated and, most importantly, educated about environmental concerns. The integration of this component is intended to promote intrinsic motivation and self-efficacy by providing meaningful feedback rather than just numerical scores. In this way, it aims to increase the perceived ecological value of user contributions, obtained with immediate and meaningful feedback.

Different forms of the feeling of recognition are also explored by the existing leaderboards. As this feeling has been shown to be impactful in gamified systems [2, 40], the platform leverages social comparison to support motivation through the point and badge leaderboards, which rank users based on their cumulative token and badge earnings, respectively. While the token leaderboard highlights the tangible dimension of rewards by emphasizing the direct results of both the quality and quantity of users' contributions, the badge leaderboard relates to sustained engagement by showcasing diverse achievements also obtained through the consistent usage of the platform features. This ranking system fosters friendly competition between users, and even though it does not constitute a reward in itself, it provides an important layer of social recognition: users are not only contributing privately but also positioning themselves in a community formed by the sense of union that the mentioned rankings also provide.

To mitigate the risks commonly associated with overly competitive gamification, such as excessive pressure, reduced collaboration, or decreased intrinsic motivation [2, 44], the platform also emphasizes private recognition through the assistant's individualized feedback. While public leaderboards provide a social layer of recognition and relatedness, private messages triggered after submissions ensure that users receive non-comparative supportive reinforcement. The offer of both public and private forms of acknowledgment responds to concerns raised in the literature about the negative impact of over-competitiveness, particularly when users shift focus from personal contribution to outperforming others [2]. The platform seeks to balance the benefits of social comparison with the need to maintain an inclusive environment, considering the risk of disengagement among less competitive or newer users.

The immediate feedback from the assistant, allied to clear progress indicators represented by the badge and leaderboard systems, aims to support a state of flow [9], where users are continuously engaged through a balance between challenge and skill. These incentive design choices are also grounded in the Self-Determination Theory [37], supporting autonomy through voluntary participation, competence through assistant feedback and badge progression, and relatedness via the social comparison enabled by leaderboards. The scheme also mirrors principles from the Social Cognitive Theory [5], reinforcing self-efficacy through personalized encouragement and enabling observational learning through public recognition. Together, these foundations ensure that the platform's incentive system draws from established psychological principles to support meaningful long-term engagement.

Together, the elements described constitute a diverse motivational strategy. Combined with the shop, utility tokens simulate economic value through tangible rewards, while badges simulate a sense of achievement through the reach of several milestones. The assistant fosters intrinsic motivation by delivering educational and motivational feedback, and lastly, the leaderboards provide both relatedness and recognition through public comparison. This combination is designed to appeal to a diverse user base with varying motivators so that individual goals align with the platform's goals.

4.3 Conceptual System Components

The platform architecture is organized into conceptually distinct modules, each designed to help fulfill the core system goals, particularly increasing user engagement in urban sustainability, supporting transparent and tamper-proof reward mechanisms, and delivering personalized feedback to foster intrinsic motivation. This section outlines the conceptual structure of the system, explains the rationale behind each module, and clarifies how these elements interact to support the platform's objectives. All design decisions were guided by the motivational foundations discussed and the limitations of prior systems reviewed in Chapter 2.

Figure 4.1 provides a complementary logical perspective, focusing on the logical modules' interaction flow. This diagram abstracts implementation details to clearly illustrate the coordinated modular flow of data and control across services, all orchestrated by the coordination layer.

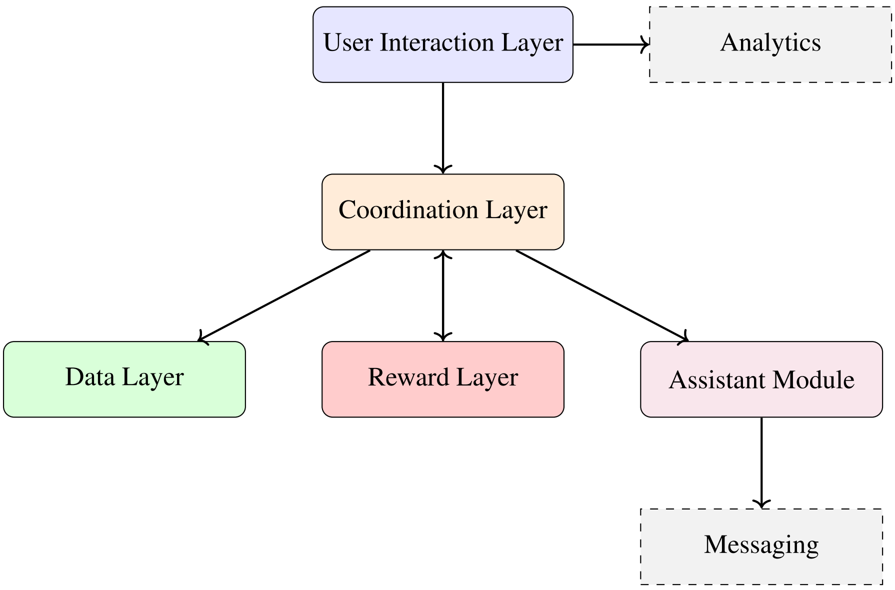


Figure 4.1: High-level system architecture

4.3.1 Reward Management Layer

A central architectural requirement of the platform is to ensure that all issued rewards are secure, auditable, and resistant to manipulation. To fulfill this requirement, the reward management layer consists of a tamper-proof ledger responsible for tracking token issuance, transactions, and marketplace exchanges. This layer functions independently of the user interface and storage modules, enforcing strict validation rules for any operation that affects the user's tangible incentives.

The platform adopts a permissioned blockchain to address privacy and governance concerns present in public or centralized systems. The choice of a private ledger enables access policies ensuring that only authorized entities can perform critical actions such as token issuance or store inventory modification. The mentioned structure supports a multi-party control that prevents unilateral updates and reinforces the platform's trustworthiness.

The conceptual separation of this layer allows the system to enforce specific governance rules while ensuring that user-facing features remain decoupled from validation logic. Such modularity also ensures extensibility, as new types of rewards or validation procedures can be introduced without disrupting the core user experience. This layer plays a vital role in the platform's architecture as, beyond its technical advantages, it supports key psychological drivers such as fairness, competence, and external regulation.

4.3.2 State and Data Management Layer

A separate database layer was incorporated into the system architecture to complement the blockchain component primarily used to store sensitive or trust-critical operations. Relying on the distributed ledger as the sole source of data would introduce significant performance bottlenecks, particularly given the high volume of read operations required for user-facing features and the presence of non-sensitive data that would not benefit from blockchain-level immutability.

To avoid overloading the reward ledger with high-frequency unsensitive operations, the platform architecture includes a dedicated flexible data storage layer optimized for responsiveness. This component manages evolving user data such as submission records, progression indicators, and assistant interaction logs. Rather than enforcing rigid data models, it supports a semi-structured design which validates key fields for consistency while auxiliary ones remain flexible. Conceptually, this enables an efficient storage while reducing the need for complex data normalization. The result is a scalable and adaptable storage system capable of supporting data integrity as new platform features evolve, such as user interaction patterns and motivational strategies.

The storage layer plays a critical role in supporting the assistant's contextual awareness by recording user state and interaction data. By maintaining persistent records of past conversations and user actions, the system enables the assistant module to generate coherent and personalized messages supporting dynamic feedback, which enhances perceived autonomy, competence, and relevance.

From a motivational perspective, this layer enables features like visual progress tracking, historical feedback referencing, and observational learning achieved by comparison. These capabilities contribute to competence, autonomy, and goal clarity, and are aligned with research that emphasizes the role of feedback in maintaining sustainable behavior change (Flow Theory [9]), with the psychological drivers of intrinsic motivation (Self-Determination Theory [37]), and lastly with the role of observational learning and behavioral outcomes in shaping human behavior (Social-Cognitive Theory [5]).

4.3.3 Motivational Assistant Module

The motivational assistant is a defining system component that consists of a dedicated module designed to deliver contextual and personalized messages that educate users with the aim of reinforcing positive behaviors. Unlike traditional chatbots or static help systems, the assistant takes the initiative, as it celebrates user milestones and highlights the environmental significance of their actions.

This proactive behavior distinguishes the assistant from conventional chatbots, which typically operate in a reactive or query-based mode. By taking the initiative to engage users at key moments, such as after a submission or upon prolonged inactivity, the assistant contributes directly to sustained engagement and perceived guidance.

The assistant is fully decoupled from the user interface and coordination logic, enabling future model updates or behavioral logic enhancements without disrupting the broader system. This separation reflects a decision oriented toward modularity, extensibility, and long-term adaptability. The component is designed to operate within the system's boundaries to prioritize data privacy, avoiding the reliance on third-party APIs. In this way, all operations are conducted within a trusted and controlled environment that mitigates privacy concerns associated with external services.

A core architectural feature of the assistant module is its ability to maintain contextual memory while adjusting its outputs based on the user's system events and submission patterns. By adapting its outputs to recent submissions and behavioral patterns, this conceptual design enables the platform to fulfill deeper psychological needs, notably relatedness, task significance, and autonomy, as described in Self-Determination Theory [37] and Social Cognitive Theory [5].

4.3.4 Coordination Layer

The coordination layer acts as the central hub between the mobile frontend and all the platform's core backend services, including the reward system, the data management module, and the digital assistant. The module is responsible for handling incoming client requests, routing them to the appropriate internal modules, and managing authentication and authorization within the blockchain.

This layer handles key functions such as validating user interactions, managing identity and access logic for the reward system, and synchronizing user-facing features with backend changes. A critical role of this component is its event-driven behavior to coordinate updates across modules, as it reacts to system events, such as new submissions, user inactivity, or goal completions. For instance, it may trigger an assistant intervention or initiate a reward update in response to these events, enabling a seamless and contextually responsive user experience.

The coordination layer follows a service-oriented layout that prioritizes modularability to provide a scalable and extensible foundation for the integration of future features while maintaining a logical separation between system concerns. Its separation from both the interface components and backend modules facilitates the integration of new features without disrupting existing workflows. This component ensures the system remains maintainable by aligning with the architectural principles of extensibility and decoupling.

4.3.5 User Interaction Layer

The user interaction layer provides the primary access point through which participants engage with the platform's incentive mechanisms. Conceptually, this module is designed to present gamified features, track user progression, and deliver motivational feedback in a visually coherent and psychologically engaging way. This layer is responsible for capturing submissions and displaying progress and real-time feedback delivered by the assistant module.

The interface presents several distinct components designed around core motivational principles. A central dashboard view acts as a hub for incentive-related features, including visualizations of token balances, leaderboard rankings, and badge progression. For instance, visual representations of progress through badges or rankings foster a sense of competence and goal clarity [9, 37], while the leaderboard encourages relatedness, social comparison, and observational learning [5, 37]. The interface also integrates real-time assistant feedback, with context-sensitive messages presented both through local notifications and within a dedicated chat interface.

The interaction layer operates as a stateless client relying on the coordination layer to route user actions and synchronize backend-driven updates. This separation of concerns ensures maintainability, as it allows interface updates to be independent of the backend logic. The user interaction layer acts as an interface that drives behavioral reinforcement by integrating motivational principles into both layout and function. It connects the platform's psychological objectives with its technical infrastructure, converting system logic into meaningful user experiences.

4.3.6 External Services

The platform integrates external services for analytics tracking and messaging delivery to support additional system goals such as behavioral analytics and timely user re-engagement. These services are conceptually decoupled from the platform's core and communicate through lightweight interfaces to monitor feature usage and deliver the assistant's proactive messages.

Asynchronous messaging capabilities allow the system to sustain user engagement and perceived continuity by delivering the generated motivational prompts while the app is closed. Meanwhile, behavioral analytics services collect engagement metrics related to interactions with incentive features. Apart from allowing the assessment of the impact of the various motivational strategies, these insights can also inform the platform's future iterations.

These external modules are loosely coupled with the rest of the system and communicate through well-defined interfaces. This design choice preserves modularity, as a future substitution of these services would not interfere with core functionalities. These external services enable the platform to extend its functionality without compromising its autonomy or complicating its architecture.

4.3.7 Incentive Logic Flow

While Figure 4.1 presents the high-level overall architecture and its connections, in order to synthesize the roles of each component and demonstrate how the platform coordinates its motivational logic, Figure 4.2 follows the same color scheme to present a data flow diagram centered on the report submission process. This view highlights the logical sequence of backend actions, from verifying submissions and issuing rewards to updating progression records and generating feedback through the assistant module. It encapsulates how the conceptual architectural modules collaborate to implement the incentive model described earlier, with privacy-preserving, modular, and personalized interactions at its core.

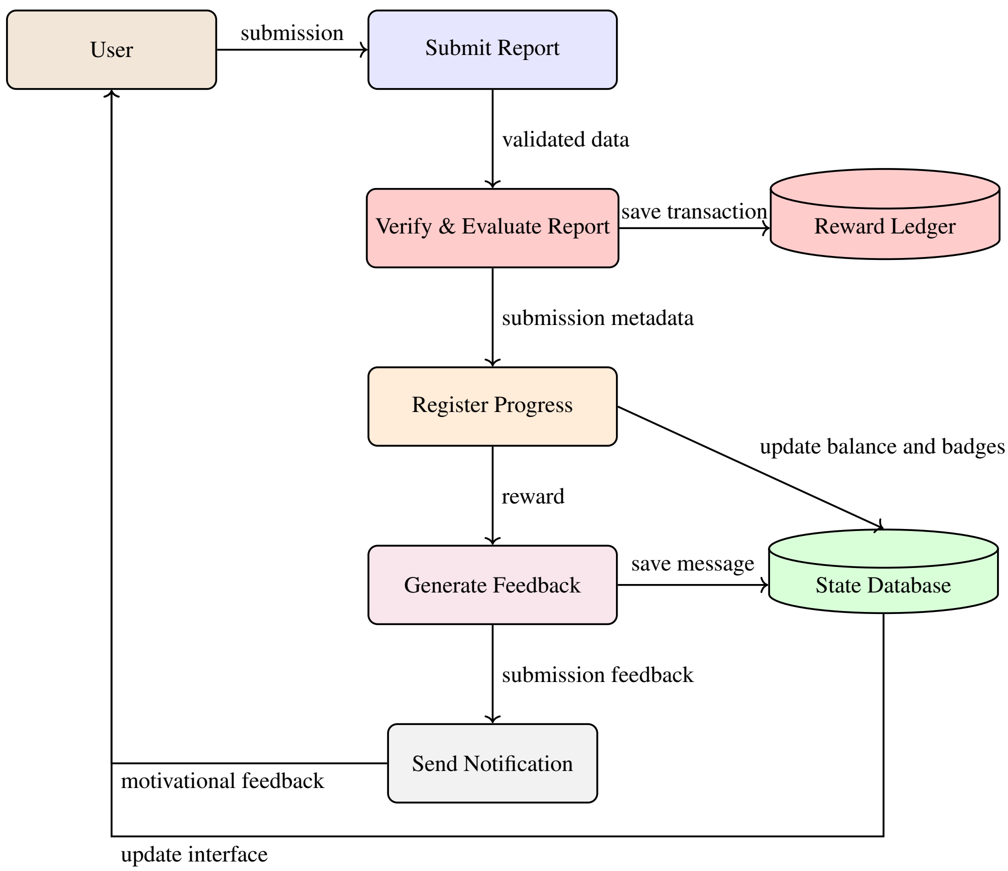


Figure 4.2: Data flow diagram for submission logic

This flow also illustrates the architectural decision to decouple tamper-proof reward validation from flexible state tracking by maintaining two complementary data stores: the blockchain ledger and a general-purpose database. Although these serve distinct purposes, the diagram also illustrates how they are synchronized during reward processing, ensuring that core reward records benefit from immutable and auditable storage while user-facing features like badge progression and leaderboard updates remain responsive and lightweight.

4.4 Architectural Qualities

The architecture was designed to ensure long-term viability and alignment with the platform's motivational goals. This section outlines the core qualities that guided the system's structural design.

Modularity is a defining trait of the system achieved through the separation of concerns into conceptually distinct services, such as the reward management, data storage, coordination, user interface, and assistant layers. These modules communicate through well-defined interfaces, allowing for an independent development and easier evolution over time. New features can be introduced with minimal disruption, enabling the system to grow in functionality.

Extensibility and **maintainability** are also supported by the decoupled nature of components. New incentive mechanisms paired with different data sources or feedback logic can be integrated without disruptive changes to the core structure. For instance, the digital assistant or reward engine can be updated without impacting user interaction or data storage modules. On the other hand, this structure supports easier monitoring, debugging, and feature extension, contributing to sustainable long-term development through the separation of concerns.

This partitioned architecture further supports **reliability** and **availability** through a division between stateless and stateful responsibilities. Stateless layers, such as coordination and feedback logic, are conceptually replicable across deployments. Meanwhile, stateful components like the reward ledger and data storage are designed to isolate potential faults by being loosely coupled with user-facing features. This separation minimizes cascading failures and ensures that critical operations, such as reward tracking, can remain operational even if auxiliary services experience disruptions.

Access control policies to sensitive operations ensure **security and privacy** by preventing unnecessary data exposure. The reward management layer operates under a permissioned governance model, ensuring that only authorized actors can issue tokens or query the ledger. Additionally, the assistant is isolated from third-party inference, as it operates within the system's internal boundaries, which ensures that content generated and the respective behavioral data are processed locally. Together, these choices reflect a trustworthy design guided by privacy that aligns with user expectations.

The architectural qualities mentioned ensure that the platform is not only technically viable but also aligned with its mission of supporting personalized, trustworthy, and motivating user experiences in urban sustainability. By decoupling responsibilities across modules, the system is conceptually **prepared to scale** on a functional and operational level. Accordingly, new components can be introduced with minimal friction, and existing services can evolve or replicate to accommodate broader participation. Overall, the architecture supports sustainable platform growth while remaining focused on the core goals of motivation, personalization, transparency, and trust.

4.5 Summary

This chapter presented the conceptual architecture of a crowdsensing platform's incentive scheme designed to promote citizen participation through a diverse motivational strategy. The system is coordinated through a central API and structured around modular components, namely a permissioned blockchain, a flexible NoSQL database, a self-hosted digital assistant, and external messaging and analytics services. Each was selected to fulfill a well-defined role in supporting motivation and adaptability.

The architecture emphasizes the separation of concerns to ensure extensibility and maintainability, enabling the platform to accommodate future user needs and technical requirements. Privacy and transparency are also addressed through a permissioned reward system and local assistant design, while functional decoupling supports availability and minimizes cascading failures. Moreover, the architecture is conceptually designed for scalability, allowing components to grow independently and new features to be introduced with minimal friction.

Each module was selected to fulfill a specific architectural role: the reward management layer ensures transparency and immutability for reward-related activities; the data management layer supports scalable access to dynamic user-facing data; the assistant enables personalization through contextual memory; and the external services integration extends platform capabilities without increasing internal complexity. These architectural choices respond directly to the motivational limitations identified in Chapter 2, particularly the lack of personalization, the rigidity of static incentive models, and the need for trustworthy infrastructure in citizen-driven platforms.

Together, these elements form a cohesive and reproducible architecture that supports the platform's motivational objectives of promoting urban sustainability while remaining adaptable to future enhancements. Technical implementation details and component-specific logic are addressed in Chapter 5.

Chapter 5

Implementation

This chapter details the practical realization of the software architecture presented in Chapter 4. It describes how the architectural components and design principles were translated into a functional system. The subsequent sections elaborate on the configuration and development of the backend services, the detailed component communication flows, and finally, the integration of these features into the frontend mobile application. The aim is to provide a clear account of how the architectural blueprint was brought to life to create the proposed crowdsourcing platform.

5.1 Backend Implementation

The backend system, designed according to the architecture presented in Chapter 4, was implemented using several key technologies. Figure 5.1 presents a high-level infrastructure-centric view of the core system components and their planned containerized development. The backend services are orchestrated using Docker Compose, ensuring a scalable and consistent deployment across development and production environments. The API serves as the central orchestration hub connecting the mobile frontend to the three primary service layers: the Hyperledger blockchain network, the MongoDB database, and the Ollama LLM-powered assistant. The Traefik reverse proxy is positioned to manage external request routing and expose the API to mobile clients. Each major backend module is designed to run in an isolated container, promoting modularity and independent management by communicating over a shared internal network.

The following subsections detail the specific implementation of each core backend component.

5.1.1 Blockchain Configuration

The platform relies on Hyperledger Fabric to deliver a secure and auditable foundation for its utility token incentive mechanisms. Unlike public blockchains, Hyperledger Fabric's permissioned model ensures that only authorized participants can access and validate transactions, thereby protecting sensitive user data while maintaining transparency in reward allocation. This technology

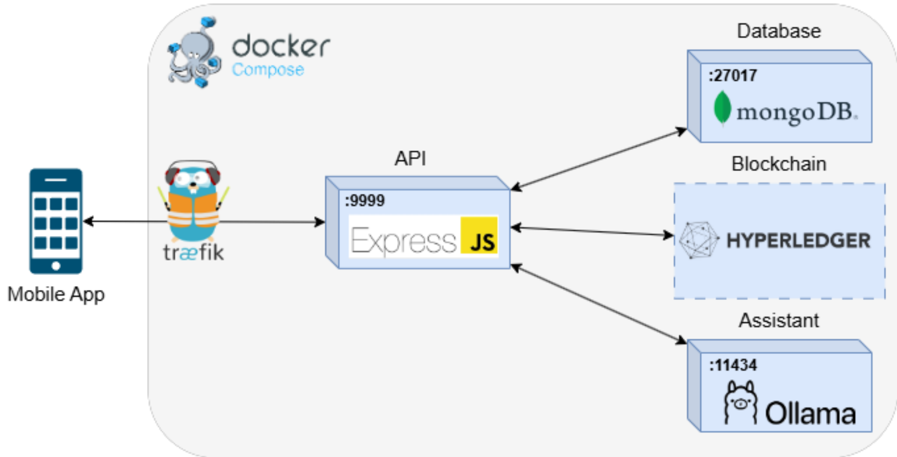


Figure 5.1: General infrastructure and deployment of backend services

was selected for its enterprise-level features vital for the platform's trust and governance framework, including support for private channels with customizable endorsement policies and modular consensus mechanisms.

The blockchain backend was implemented using Hyperledger Fabric v2.0, a stable and well-documented release that marked the transition to the new *chaincode* lifecycle. Although more recent versions introduce refinements and newer features, such as the `channel participation API`, version 2.0 was selected to align with community support and full compatibility with the standard CLI-based channel creation flow. It offers the stability, tool maturing, and community documentation needed to construct a multi-organization environment. The following sections detail the setup of the blockchain environment, the deployment of smart contracts, the integration with backend services, and the automation scripts developed to streamline system initialization.

5.1.1.1 Network Setup

To enhance fault tolerance and network resilience, the design incorporates multiple peer nodes per organization, further supported by a multi-node orderer cluster utilizing a crash fault-tolerant consensus mechanism to ensure high availability and improved load distribution. This organizational separation enables strict access control while aligning with the platform's trust model, where users submit data but cannot manipulate assets or reward systems managed by administrators.

To achieve the desired privacy control and access segregation, the channel comprises a two-organization structure managed by distinct Certificate Authorities. This structure separates regular platform users from administrative entities responsible for token and marketplace operations. While `Org1` represents regular platform users, `Org2` is designated for administrative entities responsible for managing token issuance and marketplace item control. Each organization includes two peer nodes to ensure fault tolerance and network resilience.

These guarantees are further reinforced by a three-node ordering service using the Raft consensus mechanism. Raft is a crash fault-tolerant protocol, meaning it ensures safe block ordering and liveness as long as the majority of nodes remain online and correct. In the three-node configuration implemented, the system can tolerate the failure of one node without halting transaction processing, therefore ensuring availability.

An endorsement policy framework is configured such that transactions require approval from a defined set of peers, which is a key technical element. This enforces a minimum trust threshold across organizational boundaries and prevents the unilateral execution of critical functions by any single party, such as token or stock updates. The organizational separation mirrors the platform's trust model: users interact with the system but are not granted authority over incentive mechanisms or store assets, while administrators define critical reward- and purchase-related logic. A channel-level endorsement policy enforces that transactions must be approved by multiple organizations, thus preventing the unilateral execution of sensitive actions.

5.1.1.2 Smart Contracts and State Access

The smart contract, called chaincode in Hyperledger terminology, encapsulates the business logic for all interactions with the blockchain, including data querying, manipulation, or user registration. All chaincode functions are invoked through peer nodes, with all transactions validated according to the network's endorsement policy and consensus mechanism before being committed to the ledger. The chaincode serves as the trusted execution layer, encapsulating all logic related to data integrity and reward issuance, ensuring that off-chain manipulation cannot affect on-chain records.

Each peer node is paired with a CouchDB state database instance for efficient querying of the ledger state. Although CouchDB introduces additional resource overhead compared to the LevelDB alternative, CouchDB's additional resource consumption may be considered negligible, considering that the blockchain only handles sensitive data. The choice was supported by its capability to accommodate rich JSON queries and relational-like access to ledger state data. This capability enables the platform to use flexible JSON queries to retrieve token balances, transaction histories, and inventory information in an efficient way, without requiring complex client logic.

All transactions, anchored to the blockchain and committed as an immutable block, provide transparency and ensure that tamper-proof records are saved on the ledger state. Despite write operations to the ledger occurring through validated and signed transactions, read access is facilitated through the peer's state database, allowing backend services to query user states and marketplace availability without reprocessing the transaction log.

5.1.1.3 Channel Bootstrapping and Peer Communication

The blockchain channel, named `mychannel`, was set up using the system channel approach. The configuration artifacts were generated with the `configtxgen` tool based on values declared in `configtx.yaml`, and cryptographic materials for the peers and CAs were created using the `cryptogen` tool and a tailored `crypto-config.yaml`. After generating the genesis block and the channel transaction, all peers joined the channel, and anchor peers were updated to enable inter-peer gossip communication. This setup adheres to Fabric's standard deployment conventions for version 2.0 and forms the basis of the single-channel topology used throughout the platform.

To support peer-to-peer communication across organizational boundaries, each organization designates an anchor peer, defined during channel configuration. Anchor peers are the gateway nodes advertised to other organizations, acting as discovery points that allow efficient gossip-based data propagation between otherwise isolated peers. Although all peers maintain a full copy of the ledger, anchor peers ensure that each organization can synchronize state updates, ensuring consistent channel data without direct connections. Figure 5.2 provides a container-level view of the deployed blockchain infrastructure, including peer, orderer, CA, and state database containers.

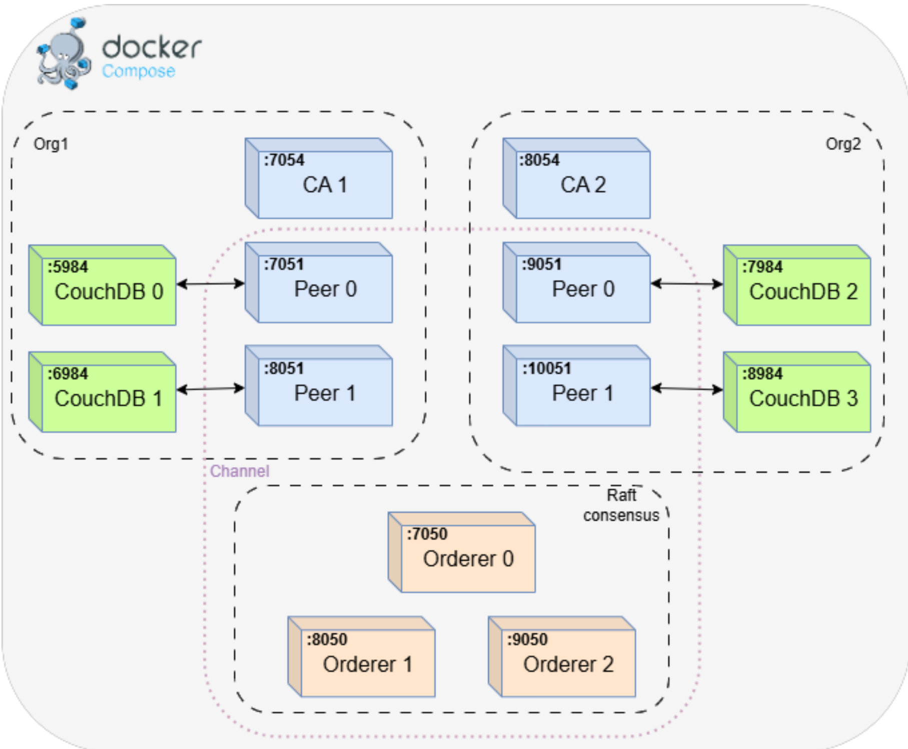


Figure 5.2: General Hyperledger Fabric deployment topology

5.1.1.4 User-Facing Organization Layout

To offer a deeper look at how the blockchain network is interfaced in practice, Figure 5.3 provides a focused view of the components belonging to the user-facing organization (`Org1`), the only one accessible to end-users, in which arrows represent functional relationships between components, such as data flows, state access, and authority registration links. The diagram encompasses its CA, peer containers, and the associated chaincode runtime environments.

Each of the two peer nodes in `Org1` runs an independent instance of the smart contract logic, as required by Hyperledger's lifecycle. These chaincode containers are shown alongside their hosting peers and handle the corresponding functions. Upon invocation from the API, the chaincode executes deterministically, producing the same output across both peers. The arrow connecting the two peers represents the internal gossip protocol used to synchronize the ledger state and maintain consistency across the organization. This mechanism ensures that even if only one peer is directly involved in the endorsement process, the others are kept updated.

The diagram also shows port mappings, which reflect internal network bindings in the Docker Compose setup. The CA operates on port 7054 and is responsible for issuing the digital identities, X.509 certificates, used by the Fabric SDK to authenticate and authorize client interactions. This authority also issues the *MSP* credentials required to authorize all network participants within the organization, including clients and peers.

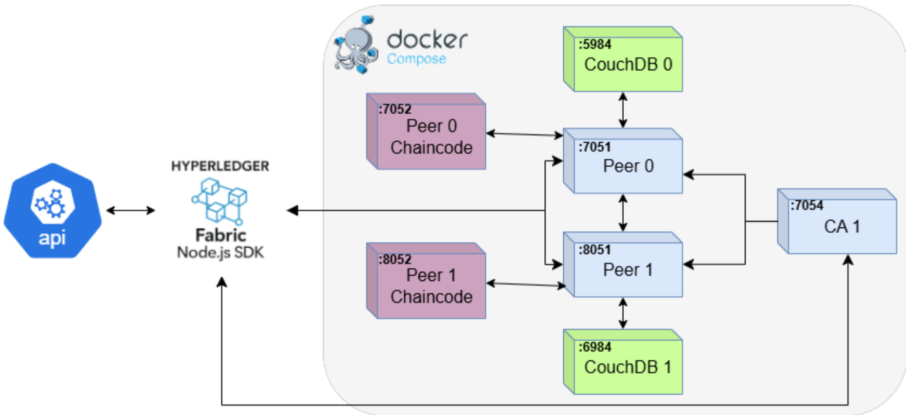


Figure 5.3: User organization layout and interaction with the API via Hyperledger Fabric SDK

5.1.1.5 Chaincode Deployment and API Integration

The chaincode was implemented in TypeScript and packaged using the Fabric v2.x *chaincode lifecycle*, which requires chaincode approval from each participating organization before committing it to the channel. This lifecycle decouples installation from definition, providing fine-grained control over endorsement policies and versioning. After being installed on the peers, the chaincode was approved by both `Org1` and `Org2`, satisfying the endorsement policy `AND('Org1MSP.peer', 'Org2MSP.peer')`, which mandates cross-organizational validation for all transactions. This policy ensures that critical operations, such as token issuance, cannot be executed unilaterally by any single party, preserving trust between actors.

Users interact with the ledger through a secure interface exposed by the backend API. When a user registers on the platform, the API communicates with `Org1` 's CA to generate an X.509 identity certificate, which is then stored in a secure local wallet managed by the Fabric Node.js SDK. This wallet maps user identifiers to their cryptographic credentials and serves as the primary authentication mechanism for transaction submissions. The corresponding directory was configured as a volume in the respective API container in order to ensure persistent storage of user credentials across container restarts.

Whenever a request requires interaction with the blockchain, such as recording a new submission or processing a purchase, the API retrieves the appropriate credentials from the wallet and uses them to construct, sign, and submit proposals to the network. Once proposals are endorsed and committed, chaincode events are emitted and captured by the backend's event listener, which serves as the connecting layer between blockchain actions and off-chain logic like badge updates or assistant responses.

5.1.1.6 Deployment Automation and Connection Profiles

A series of automation scripts were developed to minimize setup complexity and ensure a repeatable deployment of the blockchain environment. These scripts handle the entire lifecycle of the network, from downloading Fabric binaries to starting the API and assistant services. The main entry point, `init.sh`, orchestrates all other scripts and provides a linear workflow that eliminates manual steps. It invokes artifact generation tools, launches all Docker containers, executes channel creation procedures, and deploys the chaincode to all four peers. This includes compilation and packaging of the TypeScript chaincode, approval from both organizations, and the final commit to the ledger, followed by an initial ledger population via `initLedger`, which adds the store items.

Channel creation and peer participation are handled by `create-channel.sh`, which ensures that all peers join the channel and that anchor peers are correctly configured to support gossip communication across organizational boundaries. The `deploy-chaincode.sh` script is responsible for chaincode installation, approval, and invocation, and is structured to support future extensions like private data collections and customizable endorsement policies. Configuration files and cryptographic materials are automatically generated by `create-artifacts.sh`, which uses `cryptogen` and `configtxgen` to produce the genesis block, channel transactions, and anchor updates.

For backend communication, a custom Node.js utility (`generate-connection.js`) dynamically generates the connection profile consumed by the API. This script assembles a valid `connection.json` by reading TLS certificates and endpoint configurations from the generated crypto material, assigning per-component gRPC URLs, and embedding the required PEM-encoded CA certificates. The resulting profile includes default settings such as a 300-second peer endorser timeout and hostname overrides, which are critical to establish secure TLS connections in Docker-based deployments. This connection profile is directly loaded by the Fabric Node.js SDK, which uses it to discover peers, resolve endorsement policies, and route transaction proposals through the correct TLS-protected channels. By automating this generation, the system ensures that all client interactions remain valid even after certificate regeneration or network reinitialization. In this way, the system preserves the reliability of transaction submission and event listening mechanisms as long as the ledger data is appropriately preserved in the respective docker volumes.

As a result, any regeneration of the cryptographic assets or reinitialization of the network can be absorbed seamlessly by re-running this script pipeline. This fully automated setup proved crucial not only for local testing and development but also for ensuring deployment reproducibility and minimizing human error in configuring cross-organizational interactions within the Fabric network.

5.1.2 Database Schema

To implement the off-chain data storage layer as specified in Chapter 4, a MongoDB instance was deployed as a Docker container. Communication between the API and MongoDB is handled using the `MongoClient` library for Node.js, which facilitates schema definition and data manipulation.

The MongoDB instance is responsible for storing several key entities, including user profiles, assistant message logs, submission metadata, badge definitions, store items, and purchase histories. In the case of data present in the blockchain, the database is only updated after the corresponding transactions are validated and committed to the ledger. This pattern ensures consistency between the blockchain's authoritative state and the application's data model. Considering off-chain records, such as user progression values or assistant dialogues, MongoDB provides the necessary low-latency access, supporting a simplified logic that would be inefficient to implement on the blockchain.

Its document-oriented structure aligns naturally with the platform's evolving data structure, especially for handling nested or variable structures such as user state arrays or assistant conversation logs. Such structures would otherwise demand complex joins or multiple normalized tables in relational systems but can instead be stored and queried efficiently as embedded documents in MongoDB. This design not only reduces retrieval complexity but also makes the system more adaptable and scalable as user interactions and data complexity grow.

An initial design incorporating JSON schema validation enforces data consistency within MongoDB without limiting future data models by imposing rigid constraints on the system's data evolution. While core data fields are mandatory, other document fields are optional, allowing a balance between structural integrity and adaptability across evolving application features. Listing 5.1 illustrates a sample document from the `users` collection. It reflects dynamic reward tracking fields, including currency, badge progress, and FCM tokens used to deliver assistant messages. Optional fields not enforced in the schema include the mentioned `FCMToken`, as well as the `last_submission` and `badges` fields, which are populated after user registration. The `language` option, relative to the user preferences, also influences the chatbot responses, and finally, the `group` field is used to split users into groups, later explained in Chapter 6.

```
{
 _id: ObjectId('680ca077a6b1398e37568ed0'),
 username: 'Pedro',
 balance: 1277,
 tokensEarned: 1277,
 badges: [
 { badgeId: 'Eco Addict', level: 'silver', progress: 45 },
 { badgeId: 'Streak Keeper', level: 'none', progress: 1 },
 { badgeId: 'Early Bird', level: 'bronze', progress: 3 },
 { badgeId: 'Night Owl', level: 'none', progress: 0 },
 { badgeId: 'Top Photographer', level: 'bronze', progress: 10 },
 { badgeId: 'Clean City Champion', level: 'gold', progress: 1 },
 { badgeId: 'Eco Legend', level: 'bronze', progress: 10 },
```

```
{ badgeId: 'Token Recycler', level: 'none', progress: 0 },
{ badgeId: 'Eco Tycoon', level: 'silver', progress: 1277 }
],
badgesEarned: 10,
last_submission: '2025-05-02T18:19:14.000Z',
FCMToken: 'dL19JfK5QFyEiqKzepG4zI:APA91bFriiIZEz5s01eHwViVVZ0mfNiIhyRb1NbxD4eP29
    TkDYil0VzKqYbI6Ro0GYRBk9xktSSZzWSwDh3oe4SCJo72j-Sr7HimlOYYqMpzpCRp6jz4A6U',
group: 'experimental',
language: 'pt'
}
```

Listing 5.1: User Collection Schema

Figure 5.4 presents a visual overview of the collections and their associated document fields, considering the corresponding schemas enforced. Although MongoDB does not enforce foreign keys, fields like `badgeId`, `username`, and `itemId` act as logical links between connections. While not enforcing strict relational links, the structure highlights the central role of the `users` collection and its connections to submissions, purchases, assistant conversations, and badge tracking.

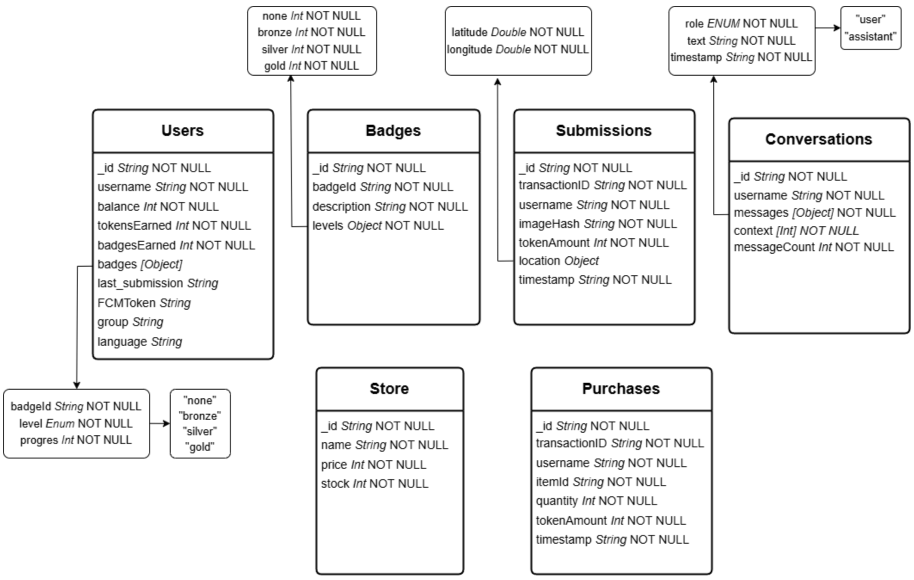


Figure 5.4: MongoDB collections and document field overview

Users' badges are also structured, as each item in the `badges` array must have an `id` reference to be associated with the badge definition in the `badges` collection, a `level` that represents the tier of the corresponding badge (`none`, `bronze`, `silver`, or `gold`), and lastly the `progress` field so that progression of badge tiers can be computed.

To support leaderboard ranking and a quick retrieval of top performers, descending indexes on the `tokensEarned` and `badgesEarned` fields were created. This optimization, executed during the backend setup, enabled efficient sorting of user rankings. Overall, the database layer serves as a platform pillar enabling fast access to user-related information. This hybrid approach ensures the system remains scalable and trustworthy, with sensitive data validated in the ledger being seamlessly accessed in the NoSQL database.

5.1.3 LLM Deployment

To prioritize transparency, data privacy, and local control, the assistant is deployed using Ollama, a self-hosted open-source LLM framework. This choice obviates the need for third-party APIs and ensures that all LLM operations are conducted within a trusted, locally controlled environment, mitigating privacy concerns associated with external services.

To tailor the assistant's responses to the project domain, a custom `Modelfile` was created for the downloaded model with 9 billion parameters. This configuration file enables fine-tuning the model with a restrictive prompt scope, ensuring the assistant focuses solely on sustainability, recycling, and pollution topics. The assistant's configuration also includes the `temperature` parameter set to 1 in order to generate more creative and engaging messages without leaving the topic.

The assistant leverages the *Gemma 2* model, a lightweight yet performant model chosen for its favorable balance between computational efficiency and linguistic understanding capabilities. *Gemma 2* was preferred over its successor, *Gemma 3*, since the outputs of the most recent model were found to be less consistent, especially in the constrained educational domain. Although modern advances in edge computing have enabled the execution of lightweight LLMs directly on mobile devices, this option was deliberately avoided. The primary limitations include restricted memory, limited processing power, and mainly the lack of contextual integration capabilities, which would prevent the assistant from maintaining continuity across interactions. Running an LLM on a mobile device would have introduced fragmentation in its ability to access historical user data. In contrast, backend hosting ensures access to the necessary contextual data from MongoDB and provides a more reliable and coherent user experience, apart from preserving system performance.

5.1.4 API Logic

The API was implemented using Express and serves as the central integration layer across all backend services, including the blockchain network, MongoDB database, and the self-hosted LLM assistant. Designed with a modular service structure, it exposes a set of *RESTful-style* endpoints to facilitate operations like user registration, image submissions, badge tracking, and marketplace transactions. Its lightweight nature and ease of route definition made Express particularly well-suited for quickly connecting diverse backend functionalities while preserving maintainability and extensibility.

5.1.4.1 Fabric Integration and Identity Management

The component's interface with the Hyperledger Fabric network is a critical submodule designed to manage user identities for blockchain interaction, submit transactions for endorsement, and process blockchain events. Its event-driven capability enables real-time synchronization between on-chain records, such as token issuance, and off-chain application data stored in MongoDB. The API also manages updates to user rewards and triggers assistant interactions in response to system events, ensuring a seamless and responsive flow of information and feedback across the platform.

The API communicates with the Hyperledger Fabric network via the official `Fabric Node.js SDK`, which handles user identity registration and enrollment via `Org1` 's CA, enabling secure transaction submission. This connection, represented in Figure 5.3, is made between the API and peers from both organizations using the mentioned SDK in order to invoke smart contract functions as well as to listen for blockchain events. This connection is made by registering users in the component's wallet with the generated `Org1` 's certificates, retrieved from the corresponding CA.

User identities and their credentials are managed locally within a dedicated file-based wallet, configured through the `Fabric SDK`. This wallet acts as a secure store for X.509 certificates and private keys issued by the CA of `Org1`, and it serves as the core authentication layer for all blockchain interactions. When a new user registers on the platform, the API enrolls them with the CA and proceeds to retrieve and store their digital credentials in the wallet under a unique label derived from the username. This identity is then used to sign transactions, ensuring that all operations on the blockchain are correctly attributed to the initiating user and comply with the chaincode's access control rules. The wallet structure also enables session persistence across API restarts and provides a foundational trust mechanism for scalable client management in multi-user environments.

5.1.4.2 Transaction Events and Off-Chain Processing

Once consensus is reached and a transaction is committed to the ledger, the API's event listener, initialized through the same `Fabric SDK`, detects this event and triggers post-transaction logic such as off-chain database updates or assistant interaction logic. In parallel, the API manages the badge system logic entirely off-chain. After every user submission, the backend updates the corresponding badges, checking them against predefined criteria to compute progress and award levels, namely bronze, silver, and gold.

5.1.4.3 Assistant Communication and Background Tasks

Communication with the assistant container is done over HTTP using Ollama's inference API, which follows an *RPC-style* pattern for text generation. This microservice architecture separates language model inference from the main application logic while maintaining a conversation state through the MongoDB-stored context. Upon blockchain transaction confirmation, the system generates personalized motivational feedback by sending the user's submission data and conversation history to the Ollama service, with responses stored for notification delivery.

Scheduled assistant tasks, such as reminder prompts or environmental fact delivery, are orchestrated using `node-cron`. These background tasks run at configurable intervals, with reminding prompts checking for user-specific triggers, such as inactivity periods over one day. When a relevant condition is met, a message is generated and sent through the assistant, as in any other reactive response.

5.1.5 Firebase Analytics and Messaging Setup

The work encompasses the setup of Firebase functionalities, as the application uses two key services: `Firebase Cloud Messaging` and `Firebase Analytics`. Push notification delivery is handled through `FCM`, which was adopted to enable users to receive notifications whenever the application is in the background, foreground, or even terminated. These are initiated through scheduled backend jobs that generate the specified assistant messages. On the other hand, `Firebase Analytics` tracks interaction metrics in the form of events, such as items purchased or submissions made. Additionally, the time spent in each incentive-related section is also fetched. These events were crucial to capture engagement insights, further detailed in Chapter 6.

Push notifications are delivered through `FCM`. Each mobile device generates a unique `FCMToken` upon installing the application, which serves as its identifier for push delivery. This token is generated on the frontend and sent to the backend, where it is stored in the database and associated with the corresponding user. Upon generating a message, the backend invokes the `Firebase Admin SDK` to send the push notification to the appropriate client device using the respective token stored. This setup ensures real-time message delivery, even if the application is running in the background or has been terminated. By combining assistant output with Firebase's push infrastructure, the platform ensures that assistant messages, whether educational, motivational, or reminder-based, consistently reach users in a timely and reliable manner.

5.1.6 Image Submission Workflow

When a user submits an image through the mobile application, as described by Figure 5.5, the frontend sends an HTTP request to the API container. Upon receiving an image submission request, the API authenticates the user's credentials against the stored identities in the wallet. Once authenticated, the API establishes a secure connection with the blockchain network using `Fabric SDK` in combination with the related normal users' CA.

After selecting an appropriate peer to invoke the chaincode functions, the API constructs a transaction proposal containing the required submission metadata, which is further endorsed according to the policy defined. After the required peer nodes have validated the proposal, each prepares its internal state to accommodate the new block about to be committed. Once that step is completed, the transaction is forwarded to the orderer cluster, which achieves consensus using the Raft protocol. Upon reaching consensus, the transaction is committed to the distributed ledger as an immutable record, which triggers a configurable blockchain event.

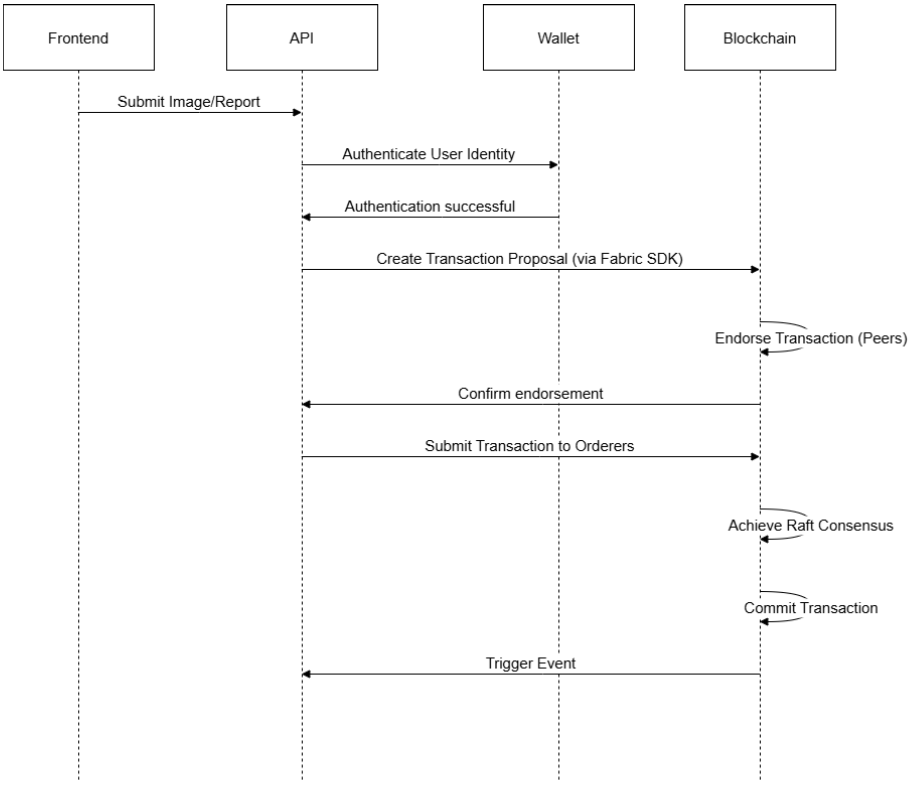


Figure 5.5: Image submission - Part I

In parallel, the API continuously listens to blockchain event notifications, allowing it to react promptly to successful transaction commitments. After detecting such events, the API proceeds to update the MongoDB container accordingly, as visible in Figure 5.6. The container also manages the logic for generating personalized assistant messages, which involves combining the conversation context retrieved from the database with the eventual payload originating from the ledger to communicate with the assistant so an adequate personalized message can be generated. Once it is, the API communicates with the database controllers to update both the conversation context and its messages, further establishing a connection to the Firebase API to send a push notification containing the assistant's message.

5.2 Frontend Development and Integration

This work was developed on top of an existing waste-reporting mobile application, which initially lacked any incentive mechanisms. The development focused on extending the frontend and developing a backend to support the new features introduced in this solution, including gamification elements, blockchain-based utility token management, and the integration of a digital assistant for motivational and educational feedback.

The frontend application was implemented using the `Flutter SDK`, enabling cross-platform deployment with a unified codebase. The frontend communicates with the backend API using the `http` package, which is responsible for making requests to submit images, retrieve user state,

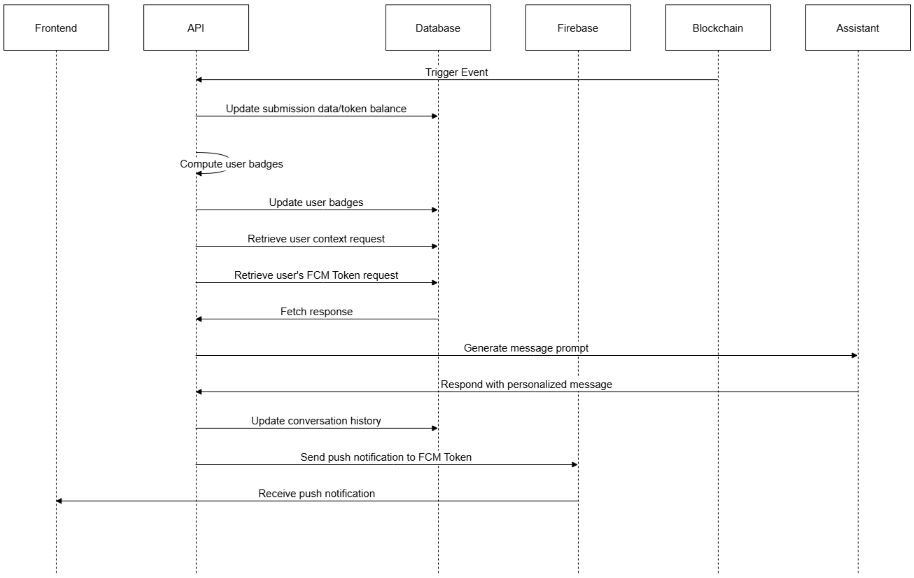


Figure 5.6: Image submission - Part II

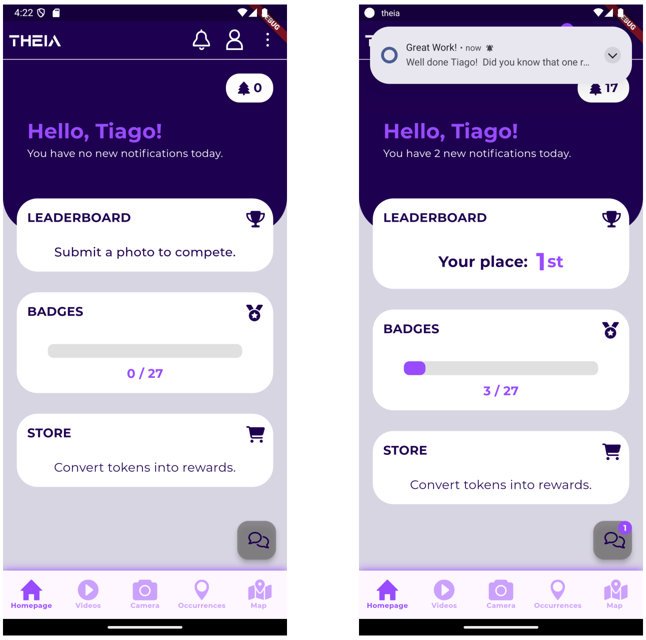
perform purchases, and fetch assistant messages. The application's internal state is managed using the `provider` package that ensures consistent UI updates across components when backend data changes.

Analytics, configured through the Firebase Console, were integrated using the `firebase_analytics` plugin and linked to the application using the corresponding Google services files. User interaction events, such as image submissions, store purchases, leaderboard visits, and badge screen usage, were recorded as custom events. Time spent in key incentive-related sections was captured using a custom `RouteObserver`, which logged entry and exit times for each screen and aggregated this data under dedicated analytics events. These interactions were later analyzed to assess user engagement in order to support the evaluation process described in Chapter 6.

Several new interfaces were implemented on the frontend to ensure the incentive mechanics had a positive influence on the user experience. The frontend logic was adapted to display real-time feedback reflecting changes triggered by the backend services, ensuring users immediately saw the outcomes of their contributions. Although these mechanisms are explained in previous sections, it is important to highlight that the application layer plays a crucial role in delivering motivational cues in an engaging and accessible way.

5.2.1 Incentive Dashboard

Figure 5.7 represents the homepage, which acts as a central incentive dashboard, greeting users with shortcuts to all the incentive-related features of the platform. On this page, apart from their balance, users can also visualize their current leaderboard ranking and the number of badges they possess. Initially, users who have not made any submissions are presented with a basic layout represented in Figure 5.7a. Doing so triggers a homepage update (Figure 5.7b) to reflect the corresponding user balance, ranking, and the number of acquired badges. At the top of the page, there is a local notification containing the assistant's message to congratulate and motivate the user. The push notification can be seen on the top of the screen, as the application has sent a notification to the smartphone's operating system.



(a) User without submissions (b) After the first submission

Figure 5.7: Homepage at different moments

The homepage also contains an elevated button, highlighted in Figure 5.8a, with a conversation icon that provides access to the assistant chat interface. The number of unread messages is also shown in the respective icon.

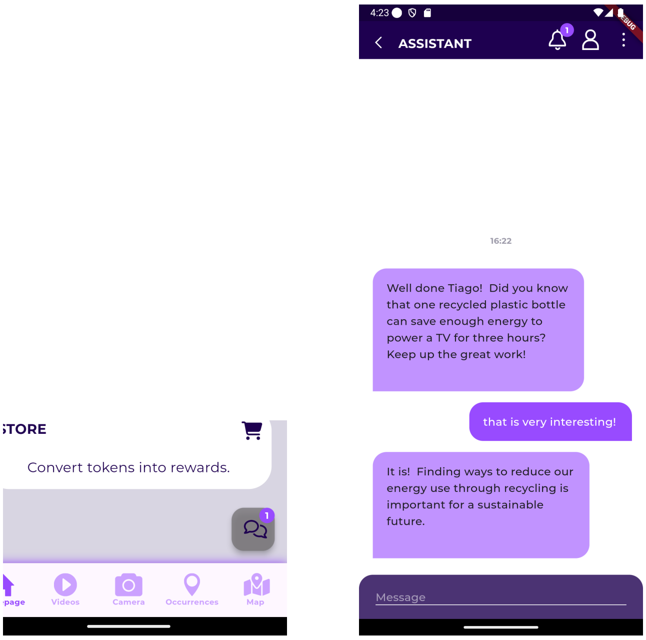
5.2.2 Assistant Interface

As a result of the submission made to trigger the previous homepage state change, the assistant has sent a motivational message to the user, which is displayed in the notification. Figure 5.8b shows a conversation held after the assistant's proactive message was received. Messages are typed in a text box at the bottom of the page, which opens a virtual keyboard.

5.2.3 Token Store

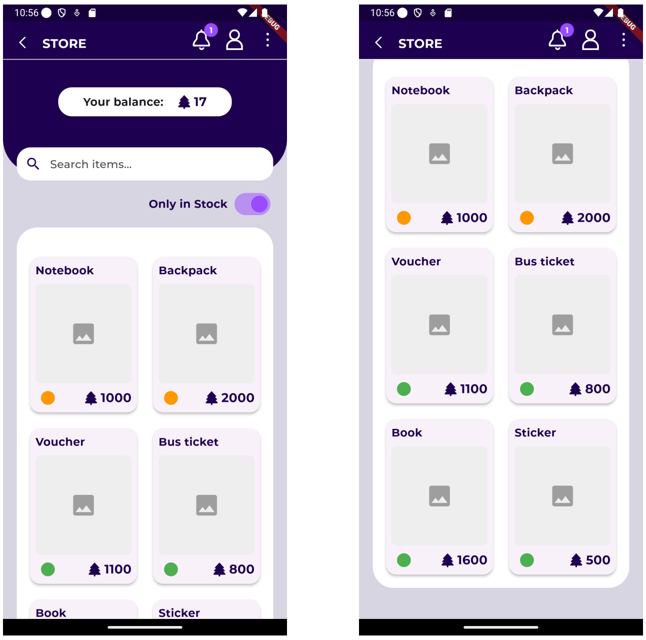
Following a submission, users receive a token reward. That currency can be spent on the integrated store, which is accessible through the homepage. Figure 5.9a shows the marketplace page, which includes a token balance display and various filters to ease item search. Filters include a full-text search and a toggle for hiding out-of-stock items, which is turned on by default. The list of available products is detailed in Figure 5.9b.

Apart from the item preview shown above, clicking on a store item opens a detailed view. In this view, users can read descriptions, scroll through different product images in a carousel,



(a) Assistant's icon (b) Interacting with the assistant

Figure 5.8: Assistant integration

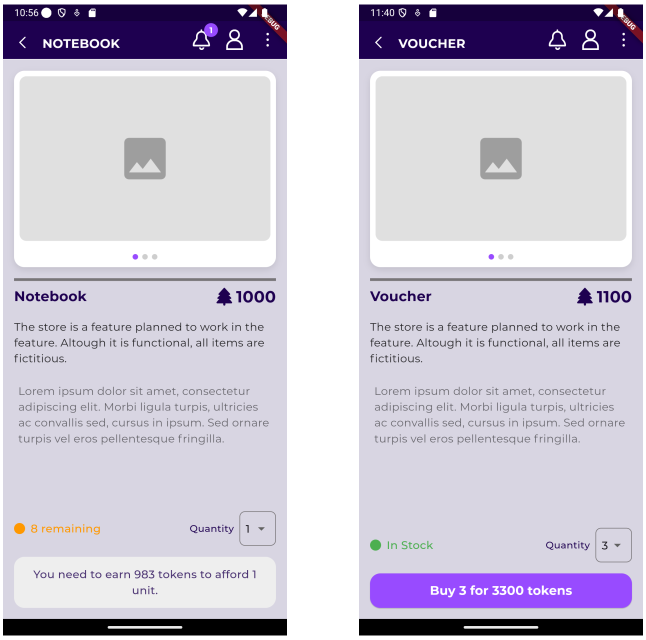


(a) Store page (b) Item previews

Figure 5.9: Store integration

and select the desired purchase quantity. Additionally, stock level indicators are visually encoded using the color red for out-of-stock items, yellow for limited stock, interpreted as less than ten units remaining, and green for items with high availability. The same logic is consistently applied to the circles in product previews displayed on the store page.

Users can purchase up to five units of an item at a time by utilizing the quantity dropdown selector. Depending on the user's balance and the quantity selected, the message displayed at the bottom of the page changes. If the user does not have the required currency, the amount needed is displayed, as shown by Figure 5.10a. Otherwise, the message is replaced by a button that allows the item to be purchased (Figure 5.10b).

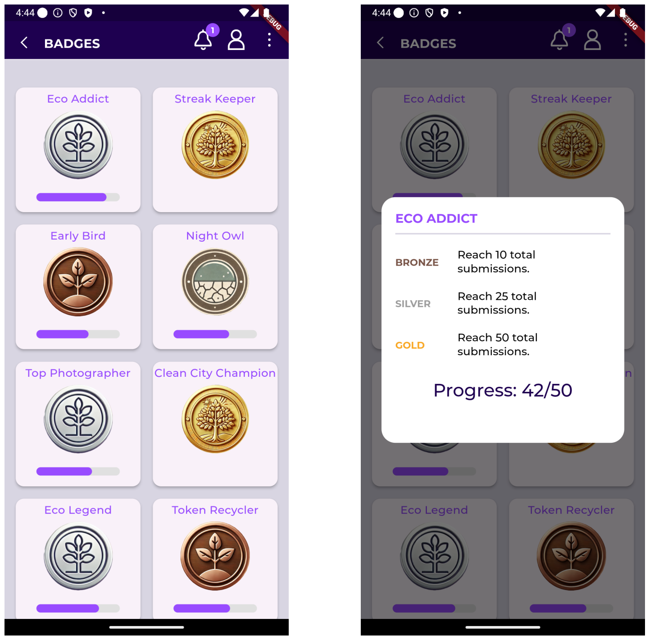


(a) Insufficient funds (b) Sufficient funds

Figure 5.10: Item details

5.2.4 Badge Visualization and Progression

The badges page, shown in Figure 5.11a, is another key view of the designed incentive scheme, as it offers a comprehensive view of the user's badge progression. Similarly to the progress bar displayed on the homepage (Figure 5.7) regarding the total number of badges acquired, each card includes one. The described component represents the progress toward the next level of the corresponding badge, showing how close the user is to unlocking it. Badge medal design was AI-generated to reflect the theme of sustainability: as levels increase from none to gold, the associated tree graphic visually grows. Clicking on a badge card opens a detailed view, represented in Figure 5.11b, where users can see the full badge descriptions, as presented in Table 4.1, as well as the current progress metrics. The screen captures presented in Figure 5.11 were obtained with randomized data to showcase different badge progressions and their respective medal designs.



(a) Badge cards (b) Badge detail

Figure 5.11: Badge integration

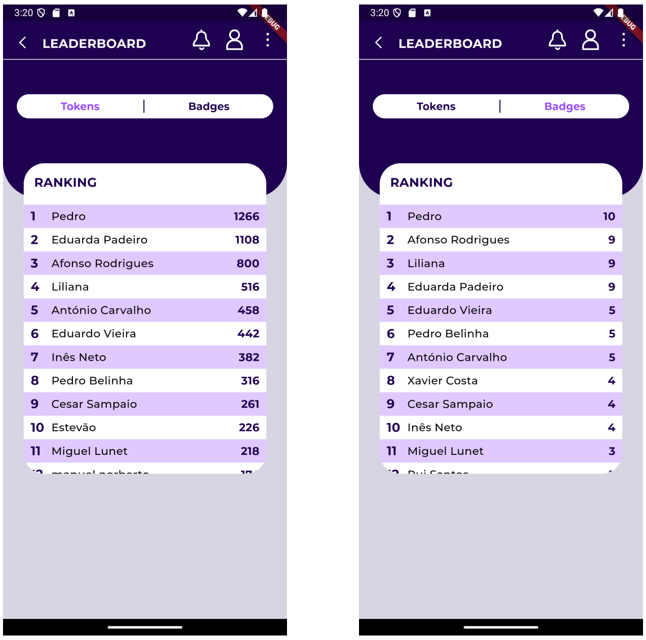
5.2.5 Leaderboard Page

The leaderboard interface provides users with information about their performance relative to the community. Accessible directly from the homepage, the leaderboard page offers a clear and intuitive way to visualize rankings based on two distinct criteria: accumulated tokens and total badges earned. Users can switch between these two ranking modes using a selector at the top of the page. The mentioned token and badge leaderboards are respectively displayed in Figures 5.12a and 5.12b.

Both leaderboard views present users' current rank, profile identifiers, and relevant performance metrics, allowing them to quickly assess their position relative to peers. By providing immediate social comparison and recognition, the leaderboard aims to enhance motivation, encouraging users not only to participate actively but also to engage with multiple facets of the platform to improve their rankings. The dual-leaderboard integration allows users to select and focus on the type of achievement most meaningful to them, whether that is sustained reporting activity or broader platform engagement through badge accomplishments.

5.3 Summary

This chapter has detailed the practical implementation of the crowdsensing platform's incentive scheme, translating the architectural concept from Chapter 4 into a working system. The backend implementation detailed the setup and configuration of the Hyperledger Fabric network, the MongoDB database schema, the deployment and fine-tuning of the *Gemma 2* model via Ollama



(a) Token leaderboard (b) Badge leaderboard

Figure 5.12: Leaderboard page

for the LLM assistant, and the development of the central API using Express. Furthermore, the chapter described the integration of Firebase services for notifications and analytics, along with the specific inter-component communication flows for core operations.

The system's Docker-based deployment model and automation scripts ensured reproducibility and minimized human configuration errors, supporting maintainability and extensibility. Other key architectural qualities described in Chapter 4, such as modularity, privacy-by-design, and availability, were concretely enforced through the separation of the assistant, blockchain, and database services into independently managed containers, as well as through the use of internal communication networks, secure identity management, and blockchain peer replication.

Finally, the chapter outlined the frontend integration using Flutter, with interfaces built to showcase and reinforce the motivational design logic through real-time feedback, progress tracking, and gamified dashboards. Together, these implementation efforts demonstrate not only a functional platform ready for evaluation but also the realization of a system whose concrete structure supports the conceptual goals of transparency, adaptability, and personalized motivation in sustainable urban engagement.

Chapter 6

Experimental Protocol

The present chapter outlines the empirical methodology adopted to evaluate the effectiveness of the proposed incentive system in fostering participation within a sustainability-focused crowdsensing platform. This investigation is driven by the research questions introduced in Section 1.4, which frame the evaluation from an incentive design and user behavior perspective:

- **Q1:** How can participation be incentivized in crowdsensing platforms?
- **Q2:** What user behaviors and perceptions are associated with sustained contributions in crowdsensing platforms?

The study integrates both behavioral tracking and motivational assessment tools to provide empirical answers to these questions. Building upon the gaps identified in the state-of-the-art (Section 2.4), highlighting the limitations of static incentives and the need for more adaptive, personalized, and intrinsically motivating strategies, this experiment was designed to test the following specific hypotheses detailed in Section 1.5:

- **H1:** Higher perceived motivation is associated with increased engagement and sustained participation over time.
- **H2:** Platform feedback mechanisms reduce drop-off and enhance contribution rates.
- **H3:** Emphasizing the individual impact and importance of contributions increases users' sense of task significance.

In addition to detailing the study design and recruitment process, the chapter also includes details on participant demographics, monitoring tools, data collection procedures, and an outline of the procedures adopted for data collection and preparation. The survey instruments used to assess participant demographics, user experience, and motivation are also addressed in detail. The chosen methodology ensures transparency and replicability, providing a robust framework to fulfill the research objectives outlined.

6.1 Research Context and Design

As previously mentioned, the study was conducted within the context of an existing mobile crowd-sensing platform designed for waste reporting, where users contribute by submitting photos and videos of waste tagged with GPS data. The platform integrates all core components of the developed incentive scheme, including the store, the leaderboards mechanism, the badge system, and the LLM-powered digital assistant to enhance user engagement.

The research design adopts an experimental framework incorporating A/B testing to directly investigate **H2** and **H3** by evaluating the impact of the platform's digital assistant. This approach involved dividing participants into two groups: a control group, which interacted with the platform without the digital assistant, and an experimental group, which had full access to all platform components. This condition included the assistant serving as a "platform feedback mechanism" (**H2**) while "emphasizing individual impact and importance of contributions" (**H3**).

This testing framework was chosen to isolate the impact of the assistant on user behavior and perceptions while still evaluating the influence of more traditional incentive methods. The comparison between both groups is central to testing **H2** and **H3**, as it isolates the effect of the assistant as both a feedback mechanism and a source of personalized motivational messaging. Additionally, because both groups interacted with the same gamified and tokenized incentives, the broader dataset enables a robust exploration of **Q1**, offering insights into which mechanisms most effectively drive participation.

The evaluation process lasted 17 days, during which quantitative data, such as behavioral and subjective metrics, were collected. This approach enabled the analysis of not only how users interacted with the platform but also how the value of the integrated features was perceived. Subjective metrics gathered also included perceptions among four feeling subscales related to intrinsic motivation and overall user experience. These insights, further explained in Subsection 6.3.2, address both **H1** by quantifying perceived motivation and **Q2** by linking psychological dimensions to actual user behavior.

On the other hand, the core behavioral metrics included in the analysis encompass the number of submissions and purchases made, as well as the number of interactions with the assistant. These were also complemented by page navigation data gathered with the integrated `Firebase Analytics` service, further detailed in Subsection 6.3.1, strengthening the study's ability to reveal how perceptions and behaviors interact in sustaining contributions on the platform.

The evaluation took place with real users in controlled groups, ensuring the collection of authentic interactions and feedback. The study's environment matches the platform's operational conditions, enabling an accurate assessment of key components such as token issuance workflows, badge allocation mechanisms, and chatbot functionalities. By employing controlled groups, the research ensures that the findings have real-world applicability while maintaining a structured evaluation framework.

6.2 Population and Demographics

The target population consists of volunteers who are likely to engage with the waste reporting platform, particularly those interested in environmental sustainability. Participants are real users chosen without specific requirements on prior crowdsensing platform usage. The inclusion criteria consist of participants with Android smartphones capable of internet access and willing to engage with the platform during the testing period. The study aims to generate insights that are generalizable to broader populations by selecting a diverse volunteer group.

To broaden participation, initial outreach efforts included contacting a local environmental organization and the Eco Club of a local high school. While collaboration with the former was ultimately not possible, one participant was successfully recruited through the school-based environmental group.

A power analysis was conducted to determine the minimum required sample size for statistical validity. Given the gap found in the literature regarding the lack of interplay with participants' intrinsic motivation, a medium effect size (Cohen's $d = 0.5$) was assumed. Based on this effect size, with a significance level (α) of 0.05 and a desired statistical power of 80%, the analysis revealed that a minimum of 64 participants per group, 128 in total, would be necessary to detect meaningful differences between conditions reliably. Despite these calculations, only **28 participants were recruited** due to resource, time, and availability constraints. The final sample was distributed equally across the control and experimental conditions.

Upon onboarding, participants were asked to complete an anonymous pre-testing survey to gather basic demographic and background information. The survey, shown in Appendix A, gathered information on age, gender, self-assessed technological proficiency, and frequency of smartphone usage. Not only did these insights help to characterize the participant pool, but they also provided a general understanding of participant behavior, thus helping to assess whether background variables may have influenced the user experiences, engagement, or performance patterns.

The following figures present the distribution of the **26 survey responses** obtained. As shown in Figure 6.1, approximately 70% of the participants identified as male, with the remaining 30% identifying as female. According to Figure 6.2, the majority of the volunteers are between 18 and 24 years old.

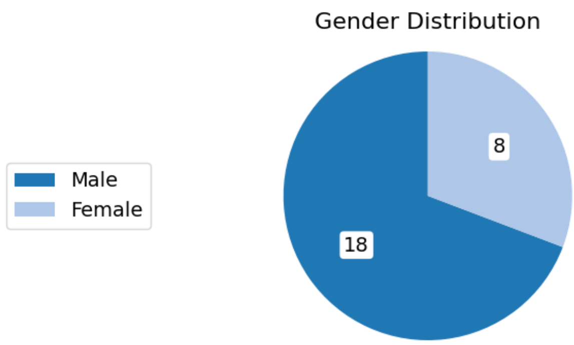


Figure 6.1: Gender distribution of participants

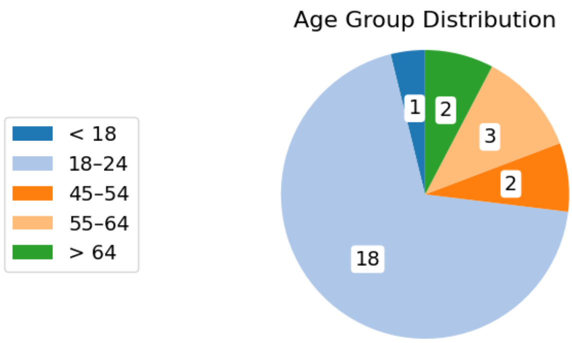


Figure 6.2: Age range of participants

Figure 6.3 presents the distribution of participants' self-reported technological proficiency. The majority has a moderate to high proficiency, indicating a generally confident and tech-savvy user base. The respective answers vary on a five-point ordinal scale, with the following levels:

- **Very Low**: I have difficulties with most technologies.
- **Low**: I can use basic applications or technologies.
- **Moderate**: I feel comfortable using smartphones and applications.
- **High**: I learn new technologies easily.
- **Very High**: I am very skilled and often help others with technology-related issues.

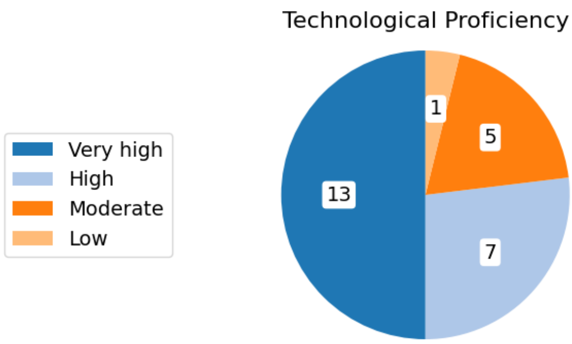


Figure 6.3: Technological proficiency self-assessment

The previous result is consistent with the reported smartphone usage patterns, illustrated in Figure 6.4. According to the expectations, most participants reported using their mobile devices too frequently, suggesting a strong familiarity with mobile-based applications and interaction patterns. Nevertheless, the presence of less confident users highlights a healthy range of technological familiarity within the sample, which proves valuable when assessing the platform's accessibility and findings' generalizability.

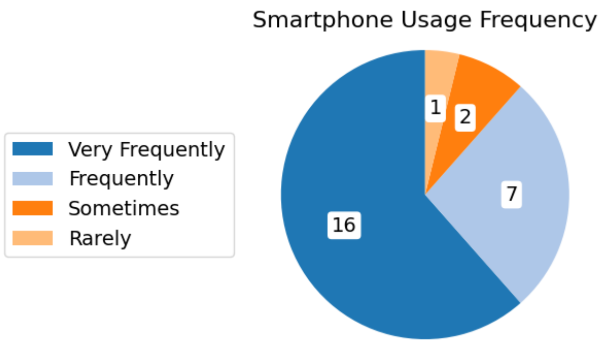


Figure 6.4: Reported smartphone usage frequency

6.3 Data Collection and Monitoring

Data collection focuses on capturing user interactions with the platform's core features, including the number of submissions of waste reports, token issuance and redemption rates, and assistant interactions. Surveys were administrated at the end of the testing phase to collect quantitative feedback regarding user experiences, including overall engagement with the platform. These multiple data sources provide a comprehensive view of user behavior and system performance, ensuring the study's objectives are appropriately addressed. The platform was instrumented to collect both system-logged behavioral data and user-reported experiential data.

6.3.1 Behavioral Data

The following behavioral metrics were collected throughout the experimental period:

- **Submissions:** Every photo or video submission, including metadata such as timestamps.
- **Assistant Interactions:** Number of messages sent to the assistant (experimental group only).
- **Marketplace Activity:** Number of fictitious store items purchased.
- **Page Activity:** Time spent on key pages per day, recorded via `Firebase Analytics`. These include the camera, homepage, chatbot, badges, and leaderboard page.

These metrics were segmented by group, considering the control and experimental ones, and linked to user identifiers, allowing for a comparative analysis.

6.3.2 Survey Instruments

Participants completed a post-experiment survey in addition to behavioral data to report their overall experience and component-specific perceptions, covering aspects such as perceived usefulness, ease of use, motivation, engagement, and satisfaction. To capture user feedback across the different incentive components, the questionnaire began with a series of Likert scale sections, one for each major feature: badges, marketplace, leaderboard, and the assistant.

Each section employed a consistent set of statements, slightly tailored to reflect the specific component being evaluated. For instance, in the case of the badge system, participants responded to the following prompts using a five-point Likert scale ranging from 1 ("Strongly Disagree") to 5 ("Strongly Agree").

- Badges motivated me to submit more reports.
- Badges were easy to understand.
- Badges made the platform more engaging.
- Badges helped me feel recognized.
- Badges gave me a sense of accomplishment.

Following the component-specific sections, the survey incorporated a broader instrument based on the Intrinsic Motivation Inventory, a well-established and validated tool developed within the framework of Self-Determination Theory [37]. The IMI is widely used in psychology and human-computer interaction studies to assess participants' internal feelings related to task completion. For this evaluation, a subset of 22 questions was selected from the official IMI questionnaire. The set of items chosen consists of a more specific questionnaire regarding task evaluation, in this case, with the referenced task defined as the act of submitting photos or videos of waste. The feelings targeted by the described section include:

- **Interest/Enjoyment:** Considered the self-report measure most directly linked to intrinsic motivation.
- **Perceived Competence:** Linked to confidence and task mastery.
- **Perceived Choice:** Measuring to what extent participants felt autonomous and self-directed in their decision to engage with the task.
- **Pressure/Tension:** Offering insights into the participants' emotional states, revealing possible psychological burdens.

Participants responded to these items on a seven-point Likert scale, ranging from "Not at all true" to "Very true", as indicated in the IMI template. The structure and validity of the followed methodology have been supported across numerous empirical studies, making it a credible and reliable measure for evaluating motivation in interactive systems and educational interventions. Additionally, it also provides a scoring system, which maps a numerical value to each feeling enumerated based on survey answers.

As the dimension of *Interest/Enjoyment* is most directly associated with intrinsic motivation and, therefore, most relevant to hypothesis **H1**, particular attention was given to the survey items corresponding to this construct. These items, drawn from the IMI, are listed below and used to compute each participant's aggregate intrinsic motivation score. Items marked with *(R)* are reverse-coded, meaning their Likert scale responses will be inverted during analysis to ensure alignment with the construct's directionality.

1. While I was working on the task I was thinking about how much I enjoyed it.
2. I found the task very interesting.
3. Doing the task was fun.
4. I enjoyed doing the task very much.
5. I thought the task was very boring. **(R)**
6. I thought the task was very interesting.
7. I would describe the task as very enjoyable.

Lastly, the survey concluded with a Net Promoter Score item, which asked if participants would likely recommend this platform to friends or colleagues. Participants rated their response on a scale from 0 to 10, with zero meaning "Not at all likely" and ten corresponding to "Extremely likely." The NPS is a standard industry metric used to measure overall satisfaction and user loyalty. Although it holds a more general value compared to the other survey sections, it still represents a powerful summary indicator of the platform's perceived value and potential for user-driven diffusion.

An open-ended feedback box followed the NPS question, inviting participants to share any suggestions or criticisms regarding the platform. These qualitative insights complement the quantitative findings and help guide future improvements. Although the primary evaluation process remained purely quantitative, these comments may be helpful to further improve the user experience on the mobile crowdsensing platform. The whole platform evaluation questionnaire is available in Appendix B.

6.4 Analytical Overview

While the detailed results and interpretations are presented in Chapter 7, this section outlines the general analytical method adopted to evaluate the effectiveness of the proposed incentive system. Apart from general optional feedback, all collected data were quantitative in nature and subjected to structured analysis to detect significant differences between the control and experimental groups, particularly regarding user engagement and intrinsic motivation.

The study's independent variable is the presence of the digital assistant, which was only accessible to the experimental group. Dependent variables include behavioral engagement metrics, such as the number of image submissions, purchases, and time spent on each platform page, as well as subjective measures of motivation and satisfaction derived from the post-experiment survey instruments described above.

Submission counts and purchase activity were compared across the two groups to assess behavioral differences. Additionally, engagement duration, measured through daily time spent in the described key incentive sections of the app, was also analyzed. Group comparisons were conducted using descriptive statistics and independent samples t-tests, selected to compare continuous variables such as time spent on a page or IMI scores between the two independent groups.

For the motivational analysis, IMI survey results were grouped into their corresponding psychological dimensions, namely interest and enjoyment, perceived competence, perceived choice, and pressure and tension, with composite scores computed per participant. Although comparisons were made across all mentioned dimensions, the analysis was focused on the feelings of interest and enjoyment, which form the subscale most related to the intrinsic motivation topic. These results served as input for a post-hoc power analysis conducted using the observed standard deviations to assess the statistical power achieved in testing whether the integrated assistant helped to boost users' intrinsic motivation.

Finally, the NPS is independently interpreted as a general indicator of platform satisfaction and perceived value. By combining this metric with behavioral data and validated psychometric scores, the analysis aims to provide a statistically grounded understanding of how different incentive mechanisms shape user participation, with a focus on validating the assumption that the assistant intrinsically motivates users.

6.5 Ethical Considerations and Limitations

The study follows ethical research standards designed to ensure data integrity while protecting participant rights, as all were clearly informed about the study's objectives, the procedures involved, and their right to withdraw at any time without penalty. Informed consent was also obtained from all participants prior to data collection, which is anonymized to prevent any form of personal identification.

Before starting the research, some constraints were expected, mostly related to the diverse environment it tries to capture. The complexity of real-world conditions may not be completely captured by the controlled groups, which restricts the generalizability of the results. Secondly, given time, resource, and technological limitations, as the platform was only accessible for Android smartphones, the number of participants recruited fell short of the power analysis threshold. The degree of technological expertise and past knowledge of crowdsensing platforms could also cause noise in the observed engagement patterns.

The duration of the testing period, limited to two weeks, also constrained the ability to observe long-term engagement and possible motivational shifts. While short-term changes were detected, specific effects inherited from the incentive scheme may require more time to manifest fully. At last, that impact may have been influenced by the lack of real tangible rewards in line with the dependence on random token assignment. Acknowledging these constraints guarantees openness in the interpretation of the results and establishes a foundation for future research to address these challenges.

Several mitigation strategies were incorporated to address the identified limitations and enhance the reliability of the findings. The study recruited a diverse participant pool to address the limitation of not fully replicating real-world conditions. On the other hand, a short tutorial containing a platform walkthrough was provided at the beginning of the testing period to mitigate possible differences in technological proficiencies and prior experiences with crowdsensing platforms, familiarizing participants with the platform's functionality and ensuring that they had a basic understanding of how to interact with it. The tutorial covered the core functionalities, including how to submit reports, navigate the incentive dashboard, and interact with the assistant. These measures aimed to minimize the impact of external variables and technological barriers, enhancing the study's ability to produce meaningful insights.

6.6 Summary

This chapter presented the experimental setup designed to evaluate the proposed incentive system. It outlined the platform context, participant recruiting, demographics, data collection instruments, and the analytical framework used.

Each hypothesis is directly linked to the evaluation strategy. **H1**, concerning the correlation between perceived motivation and engagement, is explored through correlations between users' self-reported motivation, captured through the IMI survey, and behavioral metrics such as submission counts and feature engagement. On the other hand, **H2** and **H3** are investigated using an A/B design that isolates the influence of the assistant as the independent variable. The mentioned component serves a dual role, aligned with **H2** as a feedback mechanism and with **H3** as a motivator emphasizing personal impact.

Gamification components and token-based rewards were available to both groups, allowing the experiment to generalize insights about incentive effectiveness relative to **Q1**. Simultaneously, the study also addressed **Q2**, as the IMI survey's motivational dimensions enabled the investigation of feelings tied to sustained engagement and internal satisfaction over time.

The combination of behavioral and psychological dimensions not only reveals how users interacted with the platform but also how they perceived the various features, offering a great interpretation of the system's impact and fully covering the research questions and hypotheses posed. While the research questions are framed in general terms, the scope of this investigation is grounded in the evaluation of a single crowdsensing platform. As such, the results should be interpreted in the context of this specific implementation and cannot claim universal validity across all crowdsensing environments. However, the study was carefully designed to strengthen the plausibility of broader insights.

The evaluation follows a replicable and well-documented procedure that combines behavioral analytics with psychological feedback to provide converging evidence that helps to connect platform-specific results to more general motivational principles. Accordingly, while the findings are context-bound, they contribute meaningfully to the understanding of incentive design and user motivation in crowdsensing platforms.

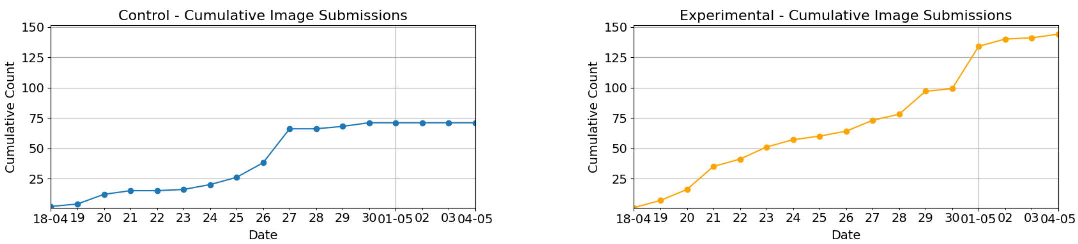
Chapter 7

Results and Discussion

This chapter presents the results of the 17-day experimental evaluation of the waste-reporting platform described. Participants were divided into two groups: a control group, which engaged with the standard incentive mechanisms, and an experimental group, which also had access to a motivational assistant powered by LLMs. The following sections analyze usage patterns, user interactions, and motivational outcomes gathered through behavioral metrics and responses to the post-testing survey applied.

7.1 Behavioral Data

The analysis begins with the number of submissions made, which is a core metric directly evaluating the platform's primary objective. During the evaluation period, the platform successfully fulfilled its purpose of gathering waste data, accumulating a total of **215 contributions**, among which 202 photos and 13 videos. Figure 7.1 compares cumulative submission trends between the control and experimental groups.

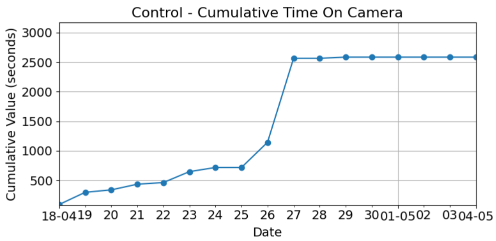


(a) Control group (b) Experimental group

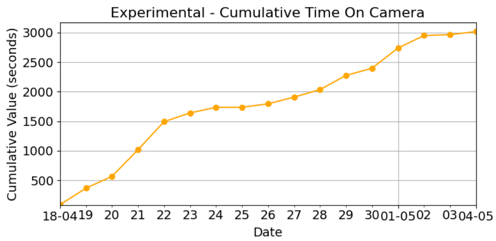
Figure 7.1: Cumulative submissions

Both groups demonstrated consistent reports in the early days, with the experimental group ultimately surpassing the control group in total submissions. While the control group's activity tapered off midway through the trial, the experimental group demonstrated a steady pace and even exhibited a noticeable increase around May 1 (Figure 7.1b), a national holiday. The recorded patterns suggest better long-term retention and sustained motivation than the control group throughout the period. Specifically, the **control group contributed with 71 uploads**, while the **experimental group submitted 144 reports**. These numbers consist of an average of 4.18 and 8.47 per day, with 5.46 and 11.08 per participant, respectively.

To complement the submission data, the following metric analyzed is the time spent using the camera functionality, which directly reflects how often users interacted with the core reporting feature. According to Figure 7.2, the experimental group accumulated more time on the camera overall, clocking at around 50 minutes, with an average of approximately 3.85 minutes per user. This behavior suggests not only a more frequent usage but a potentially greater linkage to the act of reporting. On the other hand, the control group revealed a pattern of early enthusiasm followed by a significant decline after an engagement peak, as previously detected in the submission analysis.



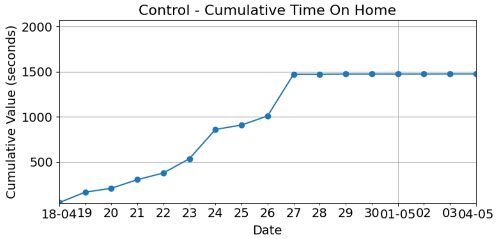
(a) Control group



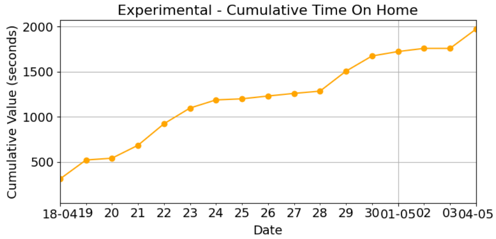
(b) Experimental group

Figure 7.2: Time spent on the camera functionality, in seconds

Submission and camera usage metrics establish a clear contrast between groups in terms of engagement and, especially, commitment to the platform. Time spent on the homepage was also analyzed to provide additional context on general engagement. The page served as the entry point for all other features, thus reflecting the overall user presence on the platform. As shown in Figure 7.3, both groups accumulated a substantial amount of time on the homepage, with the experimental users eventually surpassing the others due to a more linear and consistent engagement pattern.



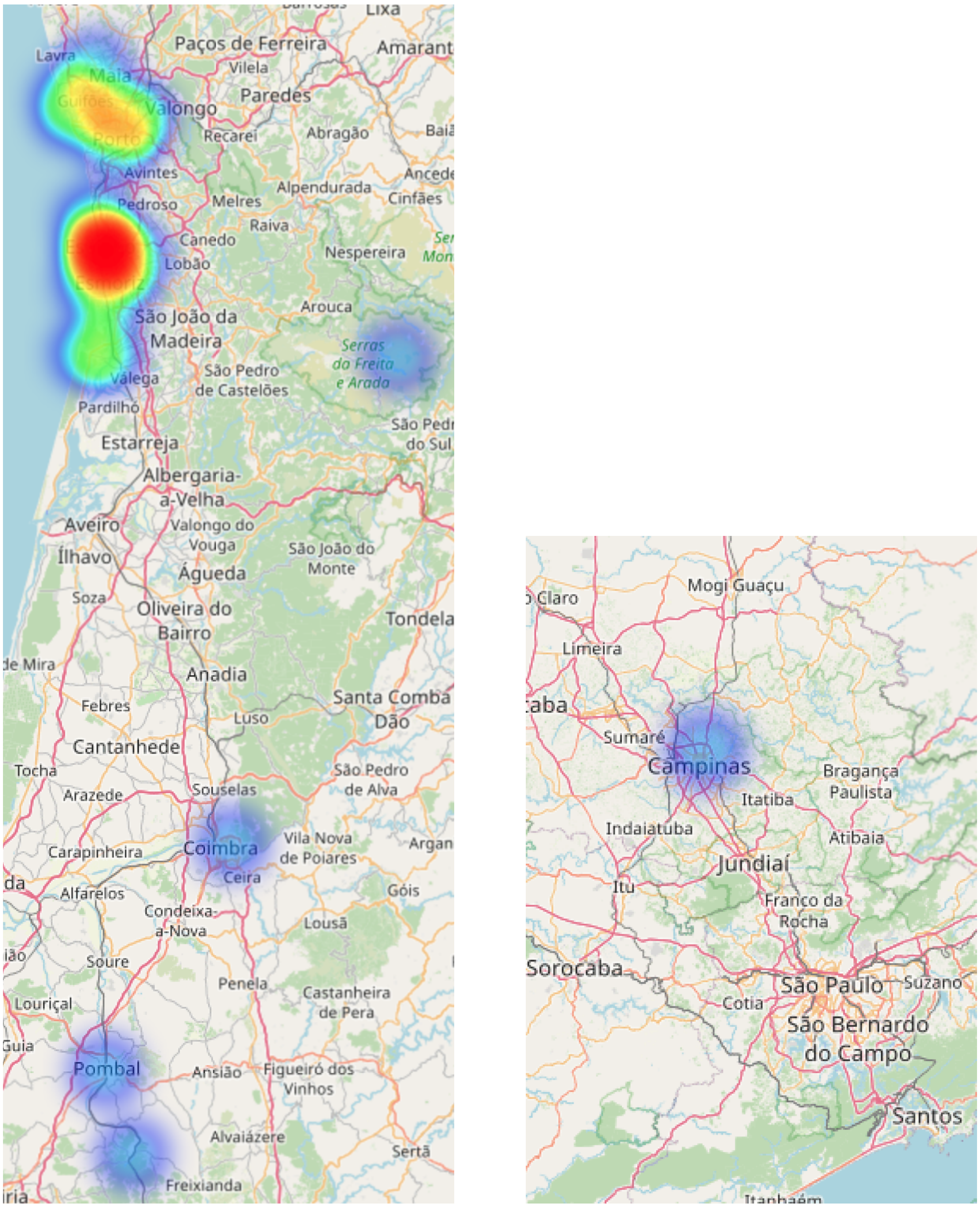
(a) Control group



(b) Experimental group

Figure 7.3: Time spent on the homepage, in seconds

To further contextualize user engagement, a heatmap of geographic submissions was generated based on GPS data attached to videos and photos. Figure 7.4 represents the spatial distribution of contributions during the evaluation period. The highest activity density is concentrated in **Portugal**, particularly along the northern coastal region near Porto and extending southward toward Coimbra. In contrast, a smaller cluster of activity was observed in **Brazil**, primarily centered around Campinas.



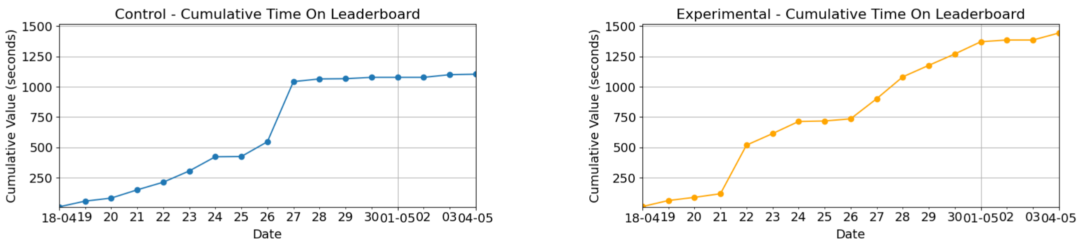
(a) Portugal (b) Brazil

Figure 7.4: Submission heatmap

The following subsections provide further insights into participant behaviors and motivational triggers by examining interaction patterns with specific components of the incentive scheme.

7.1.1 Leaderboard Interactions

The leaderboard component was designed to foster friendly competition while reinforcing recognition through ranking. Figure 7.5 shows the participants' interactions with the point and badge rankings.



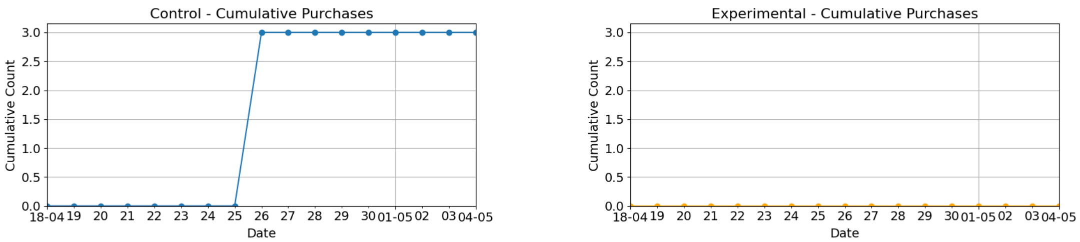
(a) Control group (b) Experimental group

Figure 7.5: Time spent on the leaderboard functionality, in seconds

Overall, users in the experimental group spent more time interacting with this feature, and, once again, the control group showed a more sporadic engagement pattern, with occasional peaks paired with extended periods of inactivity. Interestingly, towards the end of the evaluation period, the control group temporarily surpassed the other group in leaderboard activity. However, that behavior was once again overcome by the steadier and more sustained engagement patterns observed in the experimental group, which spent approximately 5 more minutes on the leaderboard functionality by the end of the study.

7.1.2 Store and Purchases

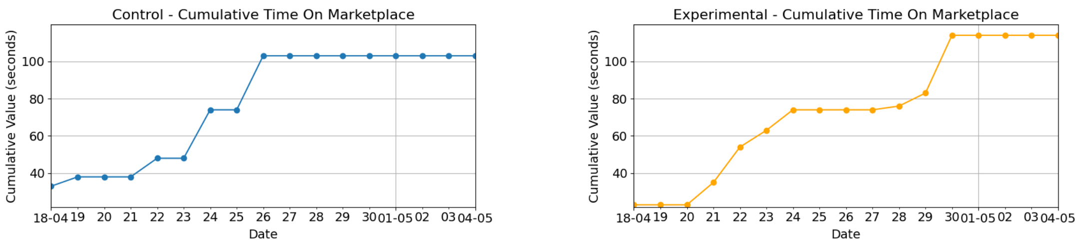
The store functionality was intended to reinforce motivation by providing a tangible outlet for users to redeem tokens earned through contributions. However, as shown in Figure 7.6, data from both groups indicate that the feature was underutilized, which may be correlated with the clarifications made to categorize this component as fictitious, potentially reducing its perceived value. As shown in Figure 7.6a, only the control group recorded purchases.



(a) Control group (b) Experimental group

Figure 7.6: Purchases made

Accordingly, engagement metrics with the store interface also remained low across both groups (Figure 7.7), though the experimental group users showed an upward trend near the end of the experiment, visible in Figure 7.7b, eventually overcoming the control group, which led the engagement times mid-study. Although this increase was not tied to any purchases, it likely stemmed from high token possession by some participants, which led to the exploration of the functionality.

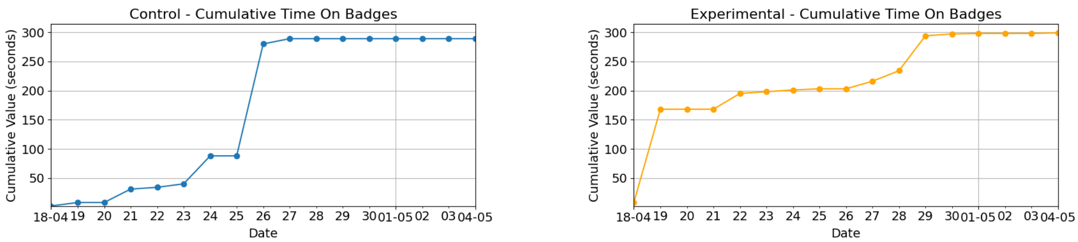


(a) Control group (b) Experimental group

Figure 7.7: Time spent on the store functionality, in seconds

7.1.3 Badges Engagement

The badge system was implemented as a gamification strategy to reward progress while reinforcing a sense of achievement. Figure 7.8 indicates the engagement patterns with the badge page across both groups.



(a) Control group (b) Experimental group

Figure 7.8: Time spent on the badge functionality, in seconds

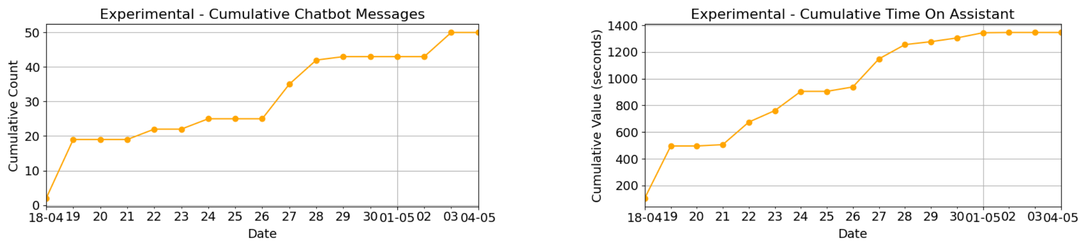
During the first half of the study, experimental users interacted more with the highlighted feature. Although both groups registered noticeable spikes in the engagement levels, the one in the experimental group occurred earlier, reflecting a more thorough initial platform exploration. Despite these peaks, even though the cumulative times ended up being very similar, the experimental group showed a more consistent and sustained usage pattern, in contrast to the control group's more erratic engagement.

Engagement with the page flattened in both groups toward the end of the evaluation period. However, the experimental group ended the trial with a higher interaction level, maintaining a steadier pace which suggests a longer-term interest in the feature. This mirrors trends observed in the previous data analyzed, where the experimental group consistently demonstrated a more sustained interaction across multiple platform components.

7.1.4 Assistant Interactions

The assistant is the differentiation point between the two groups formed, thus playing a central role in the evaluation process. Figure 7.9 presents two dimensions of user engagement with the chatbot: the number of messages sent by participants (Figure 7.9a) and the cumulative time spent on the component's interface, represented in Figure 7.9b.

User interaction with the assistant was powerful in the early days of the study, with over 20 messages being sent in the first four days. This initial surge likely reflected the novelty of the feature, as well as participants' interest and curiosity in understanding its capabilities. However, the assistant did not simply trigger a short-term spike in activity. In fact, engagement levels, measured both by the number of messages and by time, continued to rise steadily throughout the evaluation period. This gradual engagement curve suggests that, beyond novelty, the assistant maintained engagement over time. The mentioned trend is also visible in the time metric, which mirrors the number of messages sent.



(a) Messages sent to the assistant

(b) Time spent on the assistant functionality, in seconds

Figure 7.9: Engagement with the assistant functionality

7.2 Participation Flow

To provide transparency and contextualized results, this section outlines how participants from both groups progressed through the study stages. Although 28 individuals were initially recruited and evenly assigned to the existing groups, subsequent participant behavior had some oscillations, as perceived in Figure 7.10. As such, for analytical clarity, participants are categorized into three engagement levels:

- **Level 1**: Participants who did not install the application.
- **Level 2**: Participants who installed the app but did not make submissions.
- **Level 3**: Active participants who made submissions.

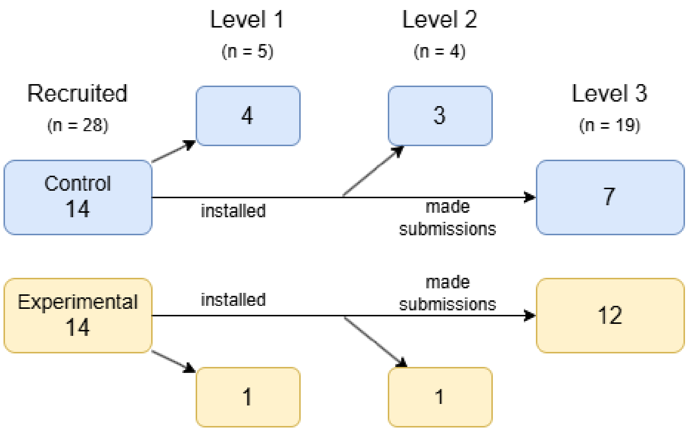


Figure 7.10: Participant flow

In the control group, only 10 out of 14 participants installed the application, with seven users reaching *Level 3*. On the other hand, 13 out of 14 participants in the experimental group installed the application, and, among those, 12 users progressed to *Level 3*, suggesting a better onboard when compared to the control group. This difference is especially evident at *Level 2*, where the control group had three participants who failed to submit reports, compared to only one in the experimental group. One possible explanation for this divergence is the presence of the assistant in the experimental condition, as periodic motivational messages delivered through the push notification system may have helped enhance early activation and retention.

In this case, all *Level 3* participants made at least two submissions. Only these participants were eligible to complete the post-study evaluation survey. All individuals in this category submitted this task, making them the sole basis for the analyses conducted in Sections 7.3 and 7.4. As a result, all feedback and motivational assessments are exclusively derived from users who actively used the platform.

7.3 Feature Perceptions

In addition to behavioral data, participants were asked to evaluate each platform feature across five motivational dimensions using the five-point Likert scale questions detailed in Chapter 6, ranging from 1 ("totally disagree") to 5 ("totally agree"). The evaluation targeted the store, badges, leaderboard, and the assistant for experimental participants only. This section provides a comparative analysis of how each feature was perceived in terms of motivation, engagement, recognition, and accomplishment levels across both groups, based on average scores according to the defined scale.

To ensure the validity of group comparisons, one experimental participant was excluded from the following perception analysis due to consistently anomalous responses, which were identified as a strong statistical outlier. In the following graphs represented in Figures 7.11 through 7.15, there are no data regarding the control group in the *assistant* column, since the functionality is exclusively available to experimental users.

One of the survey questions targeting feature ease returned consistently high scores across all features and groups, as it is visible in Figure 7.11. Although the groups' responses were similar overall, the experimental group rated the leaderboard and badges slightly easier to understand than the control group. Despite being a novel element, the assistant also received high ratings for clarity. These results suggest that participants generally understood the purpose and functionality of the features, reinforcing the reliability of the motivational ratings discussed in the following subsections.

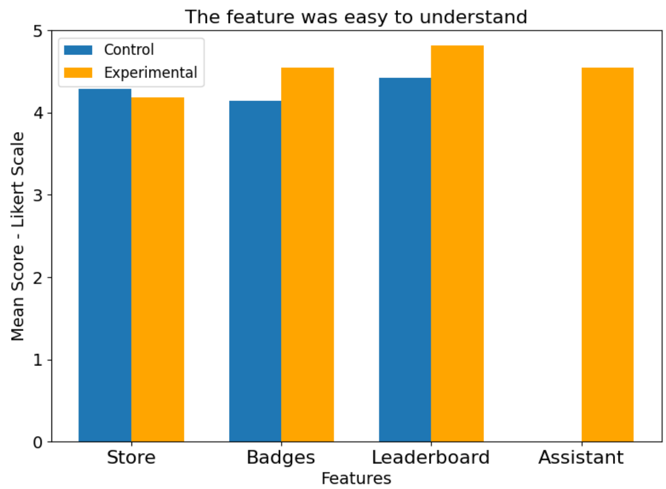


Figure 7.11: Perceived ease of understanding for each feature

7.3.1 Motivation to Contribute

The question corresponding to this matter evaluates whether each feature encouraged participants to submit more reports. As shown in Figure 7.12, the leaderboard and badge features were rated as the most motivating components by both groups. The leaderboard, in particular, received the highest average score from both groups, suggesting that competitive elements played a significant role in sustaining motivation in both groups, which aligns with the high leaderboard usage registered in Subsection 7.1.1. Badges also scored highly among participants, with control users reporting slightly higher motivation from this feature than experimental users. This mirrors the leaderboard and store results, reinforcing the idea that these gamified elements were effective motivators on their own, even without assistant support.

In contrast, the store received lower motivation scores, likely reflecting its fictional nature during the study, which may have diminished its perceived value as a tangible reward system. Although central to the experimental condition, the assistant was rated as a moderate motivator, which may suggest that while adding value through feedback and support, it was not perceived as a key direct driver for new submissions.

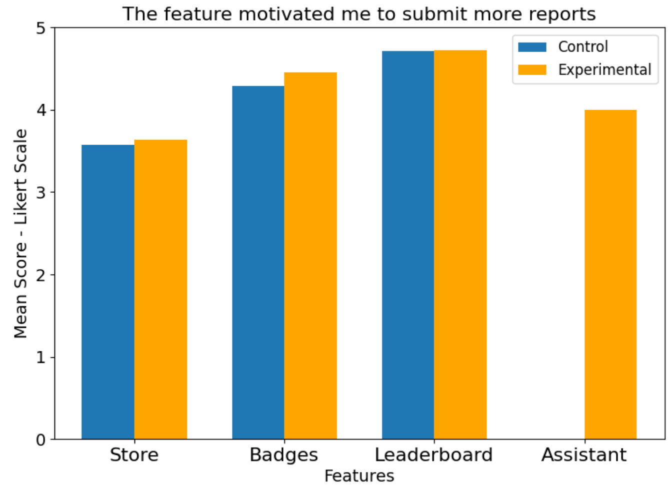


Figure 7.12: Perceived motivation derived from each feature

7.3.2 Platform Engagement

Apart from the behavioral data gathered, participants were also asked whether each feature made the platform more engaging. As displayed in Figure 7.13, perceived feature contribution to platform engagement followed a similar pattern to the motivation question. The badge and especially the leaderboard features received the highest ratings in both groups. While the leaderboard clearly stood out in the experimental group as the most engaging feature, the control group showed a more balanced appreciation of the rest of the features.

Interestingly, the assistant received strong engagement scores among participants, which were, in fact, higher than it did concerning the motivation dimension. This metric aligns with previous assumptions, suggesting that the assistant still played a meaningful role in maintaining user interest and interaction with the platform and is further reinforced by the steady engagement patterns verified on the assistant page (Figure 7.9).

7.3.3 Feeling of Recognition

This dimension assessed whether each feature helped users to feel recognized for their participation and contributions. As shown in Figure 7.14, the leaderboard and badges were again the top-performing features. Notably, both received higher ratings from the experimental participants, which may not only reflect their visibility within the platform but also the indirect influence of the assistant. The assistant may have amplified the perceived feeling of recognition by encouraging users to return or by contextualizing their efforts, as the experimental group felt their achievements on leaderboards and badges were much more significant.

However, considering its interactions are private and not a public display of achievement, the assistant's comparatively low recognition scores indicate that it was not perceived as a primary source of recognition. Nevertheless, the difference in score between both groups implies that it may have contributed indirectly to an overall greater feeling of being acknowledged within

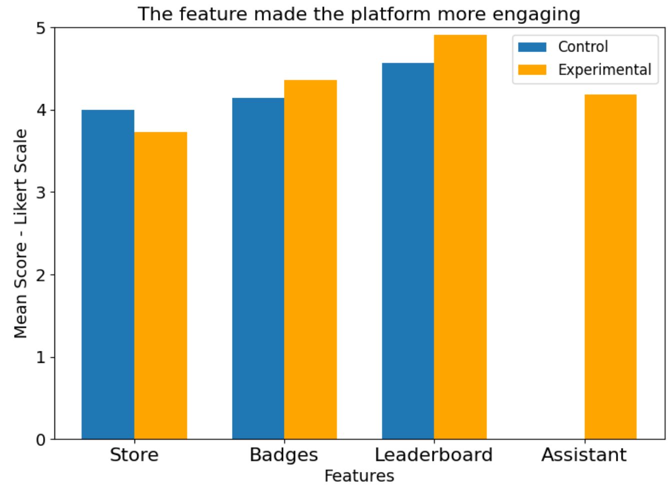


Figure 7.13: Perceived platform engagement derived from each feature

the general platform experience. Similarly, the store offered low to moderate recognition scores, which were consistent with prior trends and likely stemmed from its limited role in the platform's dynamics. Without real transactions, the store did not offer opportunities for users to be rewarded to their full potential.

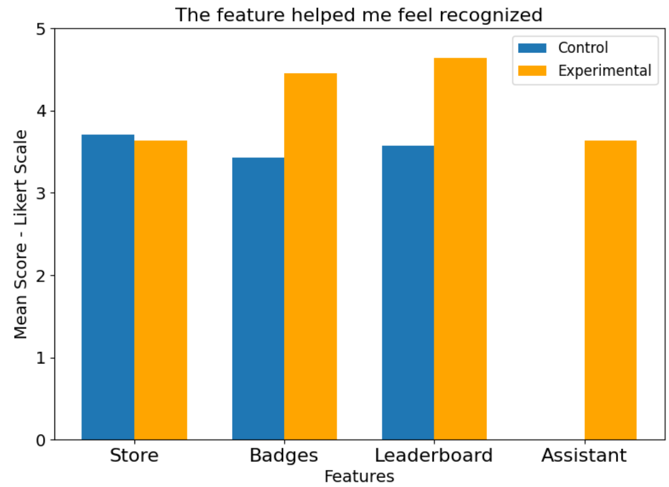


Figure 7.14: Perceived recognition derived from each feature

7.3.4 Sense of Accomplishment

The perceived sense of accomplishment produced similar results to the users' feeling of recognition (Figure 7.15), indicating a strong connection between both dimensions. It was most connected to the leaderboard and badges, which scored more closely when compared to the perceived feeling of recognition detailed above in Figure 7.14. Once again, patterns are similar, as the experimental group consistently reported a slightly higher sense of accomplishment from these top features, hinting at the assistant's potential role in framing their contributions and overall progress as more rewarding.

Similarly, the store offered a moderate sense of accomplishment, slightly lower than the feeling of recognition, perhaps linked to the transactional nature of earning and spending tokens, even though the items were fictitious.

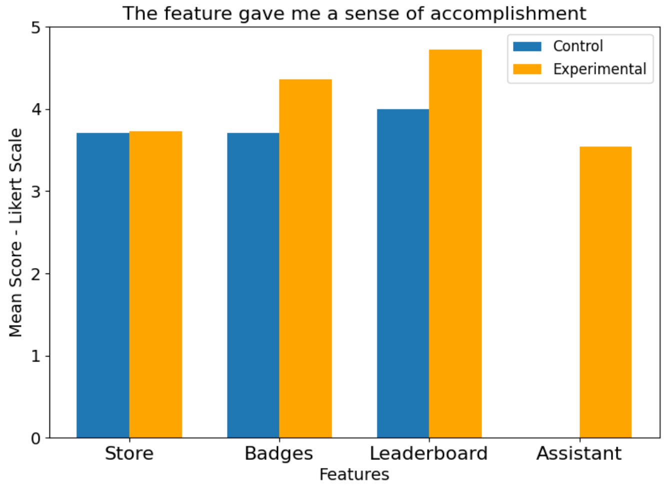


Figure 7.15: Perceived accomplishment derived from each feature

7.4 General Experience

Beyond perceptions of individual features, the study also aimed to understand the participants' overall experience with the platform. This was evaluated through the NPS, a measure of user loyalty and willingness to recommend the platform to others, paired with a task evaluation questionnaire from the IMI measuring device, which delves into the psychological foundations of user engagement with the primary task of uploading waste reports.

Consistent with the approach followed in Section 7.3, one participant was removed from the experimental group statistics due to a clear outlier profile in motivational and NPS ratings. This removal was conducted to improve the reliability of the results.

7.4.1 Net Promoter Score

As previously stated in Chapter 6, to assess participants' overall satisfaction and likelihood of recommending the platform, the NPS was collected through an 11-point scale question, asking the probability of recommending the platform to a friend or colleague, ranging from zero (not at all likely) to ten (extremely likely). Scores among both groups were grouped into three categories: detractors, whose votes ranged from 0 to 6; promoters, who gave a score of 9 or 10; and passives, who corresponded to the rest of the votes. The NPS ranges from -100%, if all respondents are detractors, to $+100\%$, if all are promoters, and is calculated according to the following expression:

$$\text{NPS} = \%\text{Promoters} - \%\text{Detractors} \tag{7.1}$$

As shown in Figure 7.16, NPS scores were relatively high across both conditions, with the control and experimental groups averaging 7.4 and 8.4, respectively, indicating a generally favorable perception of the platform. The 10% difference in the experimental group may suggest that the assistant contributed to the overall platform satisfaction.

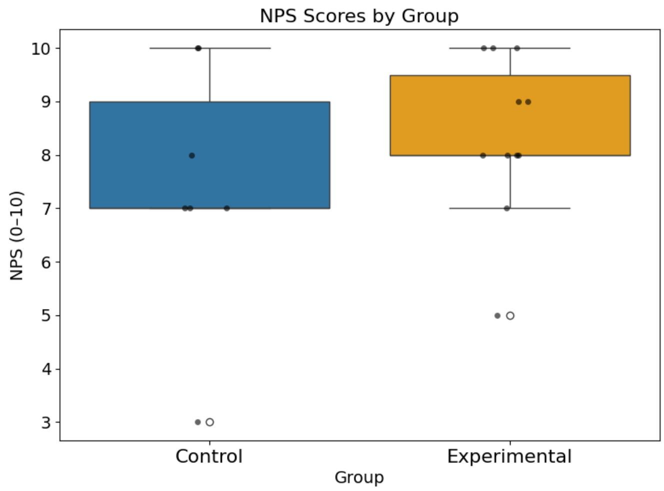


Figure 7.16: Distribution of Net Promoter Scores

Rating distribution also offers additional insights. As visualized in the box plot (Figure 7.16), while the control group's responses were more widely dispersed, the experimental group's scores were more concentrated. This tighter clustering may reflect a more consistent and positive experience among experimental participants aligning with their steadier behavioral patterns observed in Section 7.1.

Regarding the formal NPS scores, the control group included two promoters, four passives, and one detractor, resulting in an NPS of $+14,3\%$. On the other hand, the experimental group had five promoters, five passives, and one detractor, yielding a notably higher NPS of $+36,4\%$. Not only are these results positive, but they also reinforce the general trend of more stable and positive feedback among experimental users. However, since this score reflects the overall platform experience, it should be interpreted as the combined effect of various features, including the gamification mechanisms, assistant support, and the novelty of the platform, rather than isolating the findings into any single component.

7.4.2 Participant Feedback and Suggestions

In addition to structured survey responses, two participants from the experimental group and one from the control group offered qualitative insights into their platform experience.

Even though the system's goal of promoting environmental reporting was acknowledged, one experimental participant noted an ethical concern regarding the point accumulation system. In more extreme scenarios, the user pointed that it may discourage litter collection or even incentivize counterproductive behaviors, such as placing waste for the sole purpose of photographing it. Additionally, the user indicated the need for improved communication inside the app, expressing that the platform's purpose was not clear and would have remained as such without a prior explanation.

Another suggestion from the experimental group focused on the store interface. The participant recommended adding images to the virtual products to make the feature more visually engaging and appealing. This feedback indicates that visual design plays an important role in perceived value and user engagement, even for fictitious rewards. Notably, the store consistently received the lowest motivation and engagement ratings (Figures 7.12 and 7.13) and interaction time across both groups (Figure 7.7). These patterns suggest that the store's visual appeal and fictitious nature may have reduced its ability to capture attention. More broadly, this points out the importance of visual design to increase the attractiveness of digital incentives, particularly when their value is symbolic rather than tangible.

The control participant's feedback was generally positive, as it emphasized the platform's potential, its engaging design, and the clarity of its structure. However, the participant also pointed out two usability improvements: the ability to zoom while using the camera and a general increase in its speed. These suggestions highlight areas for potential refinement in future versions. Together, these comments complement the quantitative findings, highlighting the importance of clearly communicating the platform's civic goals, improving visual elements to sustain engagement, and optimizing core functionalities to reduce friction in user interaction.

7.4.3 Intrinsic Motivation Inventory

As stated in Chapter 6, the task evaluation version of the IMI covered four core dimensions: interest and enjoyment, perceived competence, perceived choice, and pressure. Each of the 22 questions was answered via a seven-point Likert scale ranging from 1 ("not at all true") to 7 ("very true"). The subscale scores are plotted in Figure 7.17.

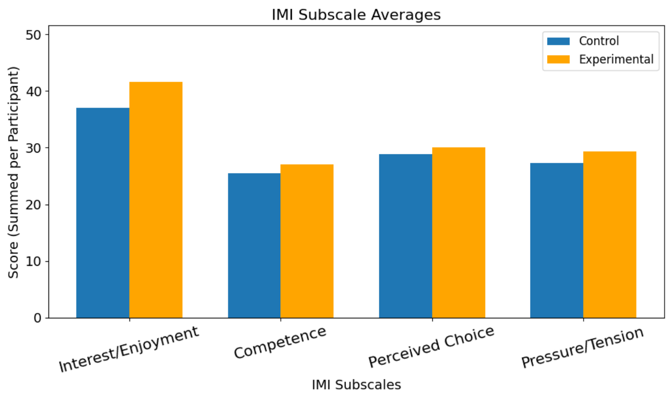


Figure 7.17: Average IMI subscale scores across groups

The experimental group outperformed the control group in three positive dimensions regarding motivation and overall well-being, suggesting a more intrinsically rewarding and autonomous experience overall. In particular, the most pronounced difference was observed in the interest and enjoyment subscale, a dimension widely recognized as a direct measure of intrinsic motivation. These insights reveal that users with access to the assistant found the reporting task more engaging and personally satisfying.

The findings are further supported by Figure 7.18, which contains a more detailed distribution of scores for the *Interest/Enjoyment* subscale. The box plot indicates a higher median score for the experimental group, as well as reduced intrinsic motivation variability in comparison to the other condition, indicating a more consistently positive experience. Nevertheless, this group also included one notable outlier not included in the evaluation, reflecting a participant who exceptionally reported low enjoyment, which consists of an isolated case that contrasts with the otherwise consistent trend.

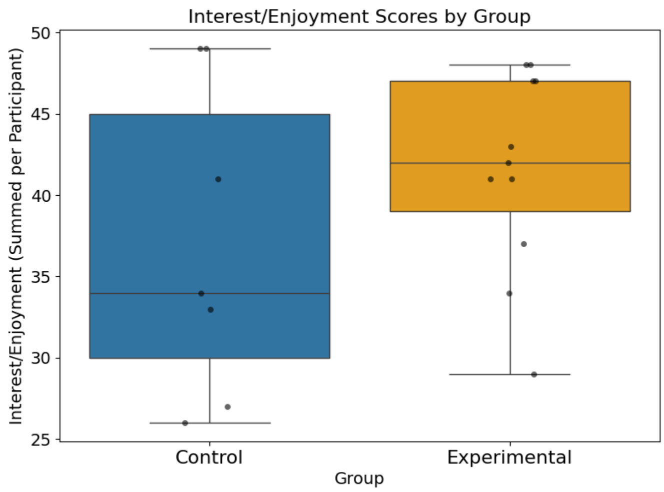


Figure 7.18: Distribution of IMI interest and enjoyment scores

Beyond enjoyment, the competence and perceived choice subscales also favored the experimental group, implying that users felt more capable and autonomous during reporting activities. While differences were modest, the competence levels suggest that immediate assistant feedback may have provided support to enhance users' confidence.

Likewise, despite both groups being exposed to the same gamified system, the gains in the perceived choice values indicate that experimental users felt more autonomous in their decision to upload content. This may reflect that the assistant did not frame participation as an obligation but rather as an act with social value, which is a subtle but important shift, as it potentially contributes to the conversion of extrinsic motivation into more intrinsic forms.

However, not all outcomes favored the experimental group, as it also indicated higher pressure and tension scores compared to the control group, translating to a slightly more stressful experience during the activity. Although the difference is relatively low, it may suggest that interacting with the assistant introduced a subtle cognitive pressure and possible task effort, perhaps stemming from a heightened sense of responsibility regarding the importance of users' submissions, seen as meaningful environmental actions.

Overall, these IMI results support the conclusion that the assistant enhanced core motivational qualities, such as enjoyment, competence, and autonomy, while only marginally increasing tension. In this way, the data gathered reflects a trade-off that, for most users, leaned toward a more enriching experience.

7.4.4 Power Analysis

To assess whether the experiment was adequately powered to detect differences in intrinsic motivation, a post-hoc power analysis was conducted using metrics from the *Interest/Enjoyment* subscale of the IMI survey, which serves as a direct indicator of intrinsic motivation. This approach compares the control and experimental groups' data by quantifying the observed effect as well as the study's ability to detect it statistically. The mentioned effect size was computed using **Cohen's** d for two independent samples with unequal sizes:

$$d = \frac{M_e - M_c}{SD_{\text{pooled}}} \tag{7.2}$$

$$SD_{\text{pooled}} = \sqrt{\frac{(n_c - 1) \cdot SD_c^2 + (n_e - 1) \cdot SD_e^2}{n_c + n_e - 2}} \tag{7.3}$$

Where:

- $M_c = 37.00$, $SD_c = 9.57$, $n_c = 7$ (control group)
- $M_e = 41.55$, $SD_e = 6.17$, $n_e = 11$ (experimental group, without the outlier)

Applying these values, the calculated effect size was $d \approx 0.60$, which can be categorized as a fair moderate effect according to conventional thresholds. Based on this, the power analysis revealed that the study had approximately **21.3% power** to detect such an effect, far below the standard 80% threshold typically required to draw statistically reliable conclusions. In order to reach the standard power threshold with an effect size of $d \approx 0.60$, the study would have required a sample size of 45 participants per group, totaling 90 participants.

7.5 Discussion

The findings of this study offer valuable insights into how personalized chatbots and gamified components interact to shape user motivation and engagement in a civic reporting crowdsensing context. This discussion aims to synthesize these results while interpreting them in light of the initial research questions and hypotheses that guided this work. The study set out to explore how participation can be incentivized in crowdsensing platforms (**Q1**) and what user behaviors and perceptions are associated with sustained contributions (**Q2**).

The evaluation was framed by three hypotheses: **H1** stating that higher perceived motivation is associated with increased engagement and participation; **H2** affirming that feedback mechanisms reduce early drop-off and enhance contribution rates; and lastly **H3** stating that emphasizing individual contribution impact increases perceived task significance. The primary experimental manipulation focused on the impact of an LLM-powered motivational assistant, allowing for an examination of how such intelligent support contributes to the efficacy of the overall incentive system experienced by both groups.

The contrasting trajectories observed in the two groups' engagement curves raise important considerations regarding user motivation over time. The early decline in the control group likely reflects a typical pattern in short-term digital interventions, where initial novelty drives early enthusiasm that gradually fades without sustained motivational input. While both groups participated meaningfully, experimental users consistently exhibited more sustained engagement throughout the study period, as reflected by their steadier submission patterns and higher cumulative interaction with the incentive features.

These steadier usage patterns, paired with stronger motivational perceptions, suggest that the presence of the motivational assistant played a key role in maintaining user commitment. Through periodic reminders, personalized encouragement, and immediate feedback, the assistant likely reinforced the sense of ongoing purpose and task relevance, preventing the natural decline often seen in gamified platforms. The experimental group not only submitted more waste reports but also spent more time interacting with the platform. These behavioral metrics were mirrored by psychological data, as experimental users reported higher scores for three intrinsic motivation subdimensions, namely enjoyment, perceived choice, and competence.

Although experimental users reported an increase of 12.3% in the *Interest/Enjoyment* subscale when compared to control users, this difference is not statistically significant $(t = 1.12, p = 0.2923)$. This outcome should be interpreted with caution given the study's limited sample size and overall low statistical power detected in Subsection 7.4.4. Nonetheless, the positive trend aligned with the behavioral and perceptual findings provides partial support for **H3**, as it reinforces the idea that the assistant had a meaningful influence on the improved motivational value of participation detected, which is highly related to the concept of task significance.

Moreover, while experimental users also submitted significantly more reports on average, this difference is not statistically significant $(t = 0.75, p = 0.4629)$. Nonetheless, the upward trend in submission frequency, combined with the low drop-off rates, hints at the assistant's effectiveness in boosting contribution rates, which is an important aspect of **Q1**. Beyond long-term engagement, the assistant also appears to have influenced early-stage platform adoption.

As detailed in Section 7.2, a noteworthy difference emerged in the number of users who installed the app but never submitted a report (*Level 2* participants). Specifically, **3 out of 10** control users dropped off after installation, compared to only **1 out of 13** in the experimental group. A Fisher's Exact Test was performed instead of a chi-squared test, as it provides a more accurate estimation in small sample conditions and low cell counts. Although the result was not statistically significant $(p = 0.281)$, the odds ratio of approximately 5.14 suggests that users in the control group were over five times more likely to disengage at this early stage. This practical difference, even if not conclusive, likely reflects the assistant's role in nudging hesitant or distracted users toward deeper engagement with the platform. Through periodic motivational push notifications, the assistant may have helped reduce early-stage drop-off by lowering initial friction, supporting both **H2** and **Q1** by illustrating how intelligent feedback mechanisms can improve onboarding and early participation.

The strong alignment between group-level IMI metrics and behavioral performance also offers strong evidence in support of **H1** and addresses the psychological dimension of **Q2**. Although survey anonymity prevented a direct correlation with user submission levels, the experimental group's higher scores in enjoyment, competence, and perceived choice were mirrored by their steadier and higher participation levels, suggesting that greater intrinsic motivation is indeed associated with more consistent engagement.

Importantly, the assistant did not act in isolation. Instead, it operated within a complete and functional incentive structure built around traditional gamified components such as badges, leaderboards, and a token-based tangible reward system. As reflected in both behavioral data and survey responses, these features were central in driving engagement. The leaderboard was the most influential motivator, consistently rated highest in terms of driving participation, recognition, and engagement across both groups.

These metrics underscore that the platform's foundational design with core incentive mechanisms was already effective at motivating users on its own, suggesting that the assistant served to strengthen these incentive elements rather than replace them. For instance, experimental users reported higher perceptions of recognition tied to both leaderboards $(t = 2.67, p = 0.028)$ and badges $(t = 2.42, p = 0.036)$ compared to control participants. Although differences in the perceived accomplishment for leaderboards $(t = 1.59, p = 0.155)$ and badges $(t = 1.16, p = 0.28)$ did not reach statistical significance, experimental users still rated these features higher. These substantial differences shown in Figures 7.14 and 7.15 support **H3** directly, suggesting that the assistant amplified users' sense of personal impact and reward.

When paired with the IMI results and behavioral metrics, this enhancement in recognition and accomplishment further supports the idea that the assistant appeared to increase users' sense of task significance. Although not optimal, higher pressure levels may indicate that participants truly recognized the importance of their participation. This subtle shift from a gamified task to a meaningful contribution indicates a deeper internalization of the platform's civic and environmental mission.

From a theoretical perspective, these outcomes resonate with Self-Determination Theory [37], which identifies "autonomy", "competence", and "relatedness" as key drivers of intrinsic motivation. The assistant appears to have reinforced these needs indirectly despite not being the highest-rated feature on its own. Although both groups interacted with the same gamified system, the higher choice perceived among experimental participants implies that the assistant helped to frame the task as meaningful and self-endorsed rather than compulsory.

The platform's incentive design also supports elements of Flow Theory [9], which emphasizes deep immersion, enjoyment, and sustained focus when users are engaged, especially in tasks that balance challenge and skill. For instance, the badge system contributed to this described state, as it offered a blend of easily attainable achievements with more demanding medals, keeping users both motivated by the early success but also gradually challenged by longer-term goals. Likewise, the friendly competition derived from the leaderboard also enhanced the flow by increasing task salience and continuous effort.

These motivational elements were reinforced by the platform's homepage, which acted as a central dashboard linking all key incentive components. As seen in the behavioral data (Figure 7.3), users spent a considerable time on the homepage, suggesting a more frequent contact with visual indicators such as user balance, leaderboard position, and badge progress. This continuous overview of the page may be directly connected to the visual progress indicators, which likely reinforced users' sense of progression and self-efficacy through constant feedback.

This persistent feedback loop aligns with **H2**, which posits that feedback mechanisms reduce drop-off and sustain engagement. The homepage's embedded indicators may have contributed to a continued participation by offering a clear and visible sense of advancement, particularly in contrast to the store. Notably, the mentioned feature, which lacked these visible indicators, garnered significantly less attention, suggesting the importance of progress visibility in driving sustained involvement, reinforcing **H2** within the broader Flow Theory [9] framework.

While these core features created the foundational conditions for the achieved flow, the assistant added a dynamic layer of support. Offering immediate feedback and periodic motivational prompts reinforced progress and contributed to maintaining engagement over time. These features together with the notification system may have helped participants to stay immersed especially when platform activity naturally fell. These insights are supported by the experimental group's steadier submission frequency and stabler engagement patterns observed across every feature in comparison to the control group, observed in Section 7.1.

From the perspective of Social Cognitive Theory [5], the assistant played an important role as a source of encouragement and verbal persuasion, affecting participants' self-efficacy. The experimental group's increased competence ratings, plotted in Figure 7.17, may have stemmed from the assistant's instant feedback. By affirming the value of each submission, it likely strengthened participants' belief in their ability to contribute effectively, which directly influences human behavior, according to Bandura [5]. However, the assistant's impact must not be interpreted as an isolated event. The leaderboard and badge system also offered visible progress markers along with ongoing social comparison, reflecting the interplay between personal, behavioral, and environmental factors outlined by Bandura [5].

These effects were most visible when analyzing features like the leaderboard and badges, which were rated as the most motivating elements across groups (Figures 7.12). More importantly, these were associated with higher perceptions of recognition and accomplishment in the experimental condition, as visible in Figures 7.14 and 7.15, suggesting that the assistant may have amplified the salience and personal relevance of the other gamified elements by framing them as environmentally impactful contributions. The assistant, though not a direct incentive on its own, may have helped participants to interpret gamification elements as environmental actions rather than just point-based milestones by providing them with real-time feedback and encouragement.

However, not all findings are unambiguously positive. The experimental group also reported slightly higher pressure and tension levels, revealing a potential trade-off. While the assistant aimed to support and encourage participation, it may have inadvertently increased the salience of the task (**H3**), transforming civic participation into a more morally weighted responsibility. Tension levels may arise when performing quality-dependent tasks that are to some extent framed or perceived as a relevant personal duty, which reflects that motivational drivers require a delicate balance between encouragement and pressure. Nonetheless, this finding contributes to a more nuanced understanding of motivational design, suggesting that emotional engagement, while effective in sustaining participation, may also require careful calibration to avoid unintended stress on users.

These interpretations are sustained by the coherent data observed. For example, the experimental group's NPS was higher on average and also more tightly clustered, as perceived in Figure 7.16. This consistency mirrors not only the reduced variability in the *Interest/Enjoyment* responses but also the steadier engagement trends observed across behavioral metrics. In contrast, the control group showed greater variance and more episodic usage, particularly in leaderboard and badge engagement, which aligns with their more fluctuating motivational scores.

Despite these promising patterns, the power analysis confirmed that the study was statistically underpowered to detect effects with high confidence values. However, the calculated effect size for interest and enjoyment can be categorized as a fair medium effect. The calculated Cohen's $(d \approx 0.60)$ suggests that the motivational impact of the assistant may be more substantial than the obtained significance levels suggest. Assuming similar results, the intrinsic motivation changes would require **45 participants per group** to achieve 80% statistical power in a future study. Nevertheless, the results provide compelling early evidence that motivational assistants can enhance behavioral engagement and intrinsic motivation in environmental crowdsourcing and crowdsensing applications, especially when embedded within thoughtful, gamified systems. Despite the restrained sample size, the observed trends point towards meaningful and consistent differences that justify further explorations in this area.

7.6 Limitations

Although the results of this study are promising, several limitations must be acknowledged. Apart from the anticipated ones addressed in Section 6.5 regarding sample size, study duration, and lack of real tangible rewards, certain constraints emerged in data collection and analysis.

A primary limitation relates to the difference between recruited and active participants. Although 28 individuals were initially recruited, not all participants followed through. As detailed in Section 7.2, only **19 participants were eligible to provide feature perceptions and general experience analytics**. Also, one participant from the experimental group was excluded as a statistical outlier due to anomalous motivational ratings that were massively different from the ones registered. This reduction in sample size, particularly in the control group, limits the study's statistical power while increasing the potential for bias in the observed effects.

Another limitation stemmed from the inconsistencies in participant onboarding, as not all participants installed the application simultaneously. This interval created unequal exposure windows, where some users had more time to explore and engage with the platform than others, which may have influenced the usage patterns and engagement metrics collected.

These limitations reflect common challenges in field-based digital experiments, where researchers have limited control over external conditions like different user behaviors. Acknowledging these issues ensures transparency and helps to contextualize findings by highlighting important design considerations for future platform iterations and similar follow-up studies conducted in this area.

7.7 Summary

This chapter presented and interpreted the results obtained in a 17-day experimental deployment of a gamified waste-reporting crowdsensing platform, comparing a control group with an experimental group with access to a motivational assistant powered by an LLM. Combining behavioral data with specific feature perceptions and self-assessed user feedback among four psychological dimensions revealed promising differences between the two groups.

The experimental group demonstrated higher participation levels with steadier engagement patterns across all major features, including substantially higher submission counts. Motivational self-assessments reinforced these trends, as the experimental group reported higher levels of enjoyment, competence, and perceived choice. Feature perception ratings highlighted the central role of badges and leaderboards, which were positively received across both groups, though experimental users perceived them as more personally rewarding in terms of recognition and accomplishment. Ranking and badge progress visual indicators on the homepage likely reinforced user involvement, while the assistant provided an additional layer of support through immediate feedback and periodic encouragement.

An additional insight emerged from participant flow, as the experimental group revealed a lower drop-off rate, hinting that the assistant's benefit may have begun as early as the onboarding stage by mitigating early drop-off through motivational messages delivered via push notifications. The alignment between IMI scores and usage trends further supports a link between intrinsic motivation and sustained contributions. However, while the component was associated with clear benefits, it also introduced a minor increase in perceived pressure, illustrating the need for a delicate balance between encouragement and cognitive load in crowdsensing scenarios.

Taken together, despite the low participant base, these results offer support for the hypotheses outlined at the start. **H1** is reinforced by the clear relationship between higher motivational ratings and more consistent engagement. Similarly, **H2** is tentatively supported by the lower inactivity and drop-off rates in the experimental group, suggesting that real-time feedback mechanisms may reduce early abandonment. Lastly, regarding task significance, **H3** is also partially supported, particularly through the statistically relevant increased sense of recognition, accomplishment tied to the gamified features in the experimental group, and general increased tension levels among experimental participants, which may indicate a more meaningful perception of the task.

Although the assistant likely made the difference in amplifying motivational value by narrowing the difference between platform and user goals, the findings indicate that the assistant enhanced existing incentive mechanisms rather than replacing them. Even though it was not perceived as a standalone motivator, it served to amplify the psychological impact of the existing gamified components, making users more aware of their progress and more confident in their contributions. Recognition and impact indeed stemmed from the badge, leaderboard, and store structures, however, the assistant most likely helped users to interpret those achievements as meaningful environmental actions, instead of merely point-based milestones.

These findings respond directly to the research questions posed, highlighting both the mechanisms that incentivize participation (**Q1**) and the user dynamics underlying sustained engagement (**Q2**). Chapter 8 builds on these findings by offering concluding reflections, implications for future development, and directions for future research.

Chapter 8

Conclusion

This dissertation investigated the design, implementation, and evaluation of a digital incentive system to foster citizen engagement in sustainability-focused crowdsensing platforms. The platform combined gamification elements, blockchain-based utility tokens, and a digital assistant aiming to promote intrinsic motivation and environmentally responsible behavior among users.

The study identified gaps in current incentive mechanisms through a structured literature review, particularly their limited adaptability and lack of personalization, resulting in a low interplay with participants' intrinsic motivation. Considering this, the platform introduced a more personalized approach to address the purest form of motivation. The solution was evaluated via a 17-day experimental protocol involving real users divided into control and experimental groups, allowing for a comparative analysis of engagement patterns, feature perceptions, and motivational outcomes.

8.1 Summary of Findings

The study provided evidence that the integration of a digital assistant within a gamified platform can contribute meaningfully to both behavioral engagement and motivational depth. Users who had access to the assistant demonstrated higher contribution rates paired with higher and steadier engagement levels. Survey feedback indicated that these participants felt more enjoyment, competence, autonomy, and interest in the task, all strong intrinsic motivation markers.

These patterns suggest that the assistant reinforced the impact of the platform's gamified and token-based features while also helping users to interpret their actions as valuable and environmentally significant. The consistent behaviors observed and positive feedback collected through the IMI and NPS provide early support for the idea that intelligent digital support can enhance platform engagement.

8.2 Contributions

The contributions of this work span both practical and theoretical domains. On a technical level, it demonstrates a working integration of a hybrid incentive system that merges blockchain-based tokenization, gamification, and an LLM-based personalized assistant within a single mobile application. From a scientific perspective, the study draws on well-established psychological theories regarding motivation, namely the Self-Determination Theory [37], Flow Theory [9], and Social Cognitive Theory [5], to guide system design and interpret the findings, explaining how each feature of the platform contributes to deeper user engagement. Methodologically, the work proposes a reproducible evaluation protocol based on behavioral telemetry, validated self-report instruments, and post-hoc statistical power analysis. The experiment also adapts an A/B testing design suitable for real-world deployments, making it valuable for future research in motivational design, digital sustainability, and hybrid incentive systems.

Empirical results show that the experimental group reported a 12.3% increase in average intrinsic motivation, as measured by the *Interest/Enjoyment* subscale of the IMI. This change corresponds to a moderate effect size of Cohen's $d \approx 0.60$, suggesting meaningful psychological gains even in the absence of statistical significance due to low sample power. Additionally, perceived recognition associated with core gamified features, namely leaderboards ($p = 0.028$) and badges ($p = 0.036$), was significantly higher in the experimental group, indicating that the assistant may have amplified the salience of users' progress and contributions.

8.3 Limitations

Nevertheless, several limitations must be acknowledged. Considering the restrictive power of the conclusions taken, despite clear trends found, the number of active participants fell short of the target calculated during the pre-study power analysis. Furthermore, the study duration was relatively short, preventing the observation of possible longer-term motivational shifts. The store rewards may have affected how users perceived the value of token-based incentives due to their fictitious nature. Lastly, the timing of participant onboarding varied slightly, leading to uneven exposure periods across the sample.

8.4 Future Work

These limitations highlight opportunities for future work. Scaling the platform to include a broader user base over a longer timeframe would help to confirm the assistant's impact with higher statistical significance and uncover long-term trends in user behavior. Adaptive and personalized incentive strategies using reinforcement learning or clustering methods could dynamically adjust how and when feedback is delivered, improving the platform's responsiveness to individual needs.

The development and integration of a waste classification algorithm would allow token distribution to be directly tied to data quality. That addition would strengthen the relationship between meaningful contributions and rewards, also enabling to address the assistant's impact on submission quality. An additional emphasis on quantifying environmental outcomes could also be placed on non-technical improvements. For instance, a tangible assessment of the platform's impact by detecting decreased waste accumulation in specific areas could create a tighter feedback loop between user actions and real-world results.

8.5 Alignment with UN Sustainable Development Goals

Beyond its specific contributions, this work demonstrated how engineering can address complex societal challenges, aligning directly with the global framework of the United Nations Sustainable Development Goals (SDGs). The project's most direct impact is on urban sustainability, technological innovation, and education for sustainable development.

First, the platform's core functionality directly addresses **SDG 11 (Sustainable Cities and Communities)**. The system provides a practical tool to improve waste management by creating an effective channel for citizens to report waste. It serves as an infrastructure that reduces the adverse environmental impact by connecting citizens to municipal services. This aligns with the goal of creating more resilient urban environments and fosters patterns of responsible consumption by making the consequences of waste more visible and actionable, a crucial first step towards a circular economy aligned with **SDG 12 (Responsible Consumption and Production)**.

Second, the dissertation embodies the principles of **SDG 9 (Industry, Innovation, and Infrastructure)**, as the project itself represents an innovation in digital infrastructure, integrating blockchain, LLMs, and gamification into a cohesive and resilient system. More importantly, it provides citizens with meaningful access to civic participation through modern ICT. The high usability scores (Figure 7.11) and positive user feedback (Figure 7.16) confirm that this access is not merely functional but also effective and empowering towards the goal of leveraging technology to strengthen the link between communities and governance.

Finally, the project contributes to **SDG 4 (Quality Education)** and **SDG 13 (Climate Action)** through its emphasis on the human element of sustainability. The LLM-powered assistant was designed not just to incentivize action but to educate users. It provides contextual information that links their personal contributions to broader environmental outcomes like climate change mitigation. The platform serves as an educational tool for sustainable development, aiming to transform short-term engagement into lasting and responsible behavior by fostering awareness and intrinsic motivation. In this way, the dissertation provides a model for how engineering can create engaging solutions that are not only technologically robust but also aligned with the UN's sustainable development goals, as it can be verified in more detail in Page iv.

8.6 Final Remarks

Ultimately, this study illustrates that digital assistance plays a nuanced role within gamified crowdsensing systems. The assistant did not replace traditional motivational structures, such as points, badges, or leaderboards, but rather complemented and enhanced them by guiding users, reinforcing effort, and framing participation as environmentally significant.

Gamified systems driven by intrinsic motivators can potentially convert short-term behaviors into longer-term action. The trade-offs observed in the perceived pressure and tension levels underscore the importance of thoughtful incentive design. Nevertheless, the limitations and trade-offs observed do not diminish the broader conclusion that intelligent digital support holds a genuine promise for improving engagement in crowdsourcing and crowdsensing platforms focused on promoting sustainable urban development.

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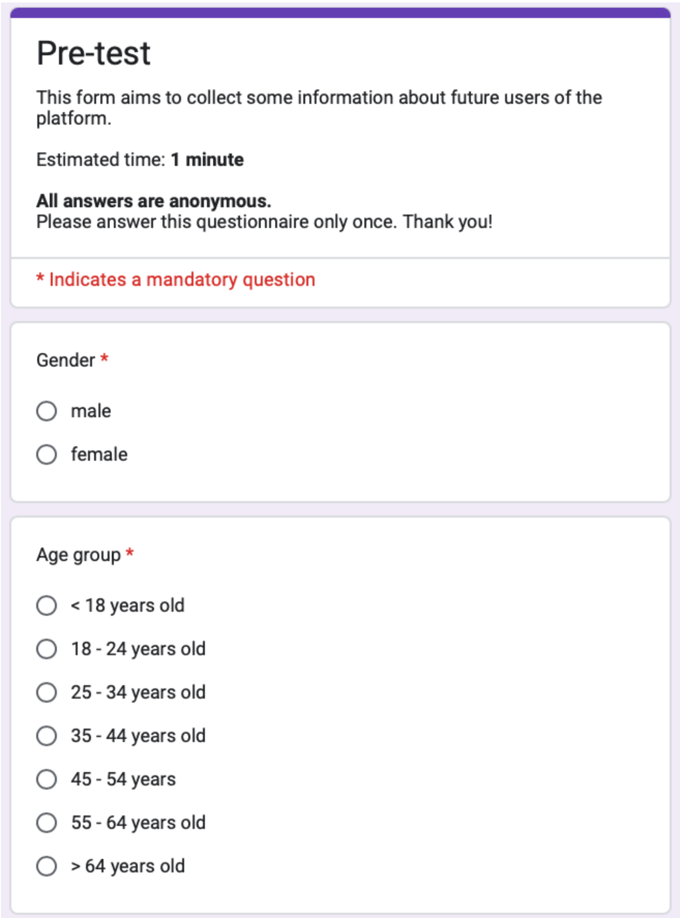
Appendix A

Pre-test Survey

This annex presents the the respondent's perspective of the pre-testing survey used to assess participants' demographics. The questionnaire was originally written in Portuguese and further translated into English to facilitate its interpretation in this document.



Pre-test

This form aims to collect some information about future users of the platform.

Estimated time: **1 minute**

All answers are anonymous.
Please answer this questionnaire only once. Thank you!

* Indicates a mandatory question

Gender *

- male
- female

Age group *

- < 18 years old
- 18 - 24 years old
- 25 - 34 years old
- 35 - 44 years old
- 45 - 54 years
- 55 - 64 years old
- > 64 years old

Figure A.1: Pre-test survey - Part I

On a scale of 1 to 5 (being 1 = Very low and 5 = Very high), how do you classify your technological proficiency? *

◯ 1 - I have difficulties with most technologies

◯ 2 - I can use basic applications or technologies

◯ 3 - I feel comfortable using smartphones and applications

◯ 4 - I learn new technologies with ease

◯ 5 - I'm very competent and I usually help others with technology issues

How often do you use your smartphone? *

◯ Rarely

◯ Sometimes

◯ Frequently

◯ Very Often

send Clear form

Figure A.2: Pre-test survey - Part II

Appendix B

Evaluation Questionnaire

This annex presents the respondent's perspective of the post-testing questionnaire used to assess participants' experience with the mobile application. The questionnaire was originally written in English, due to the IMI material found, and further translated into Portuguese to facilitate its understanding by the involved users.

Each participant group has its own survey. The only difference is that the control survey does not integrate the assistant's impact, shown in Figure B.5. Apart from that, the surveys are exactly the same.

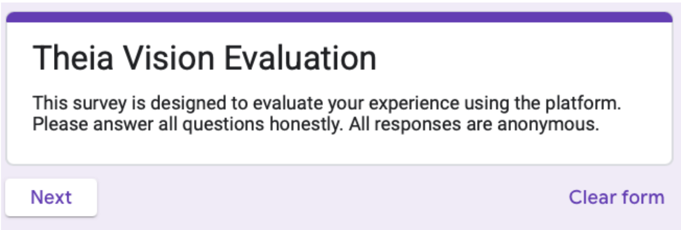
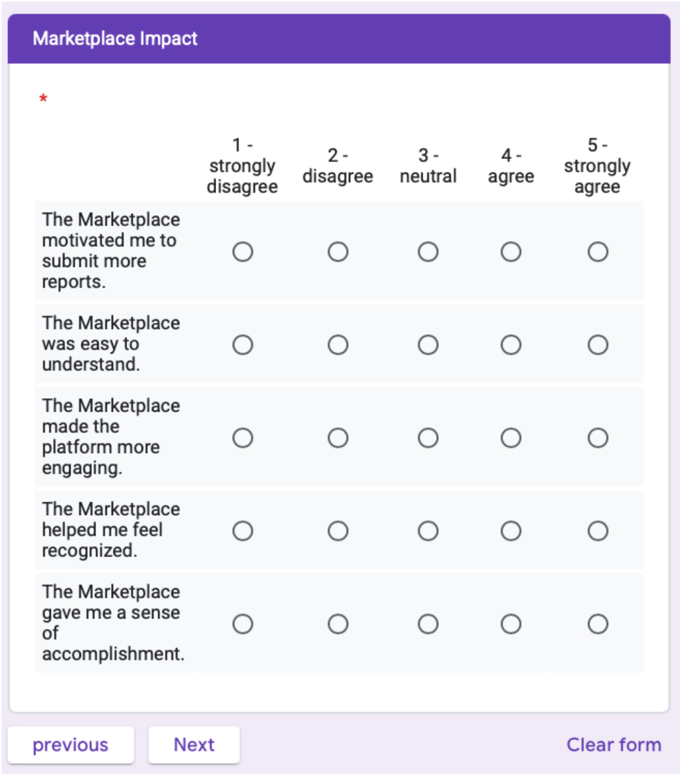


Figure B.1: Evaluation questionnaire - header

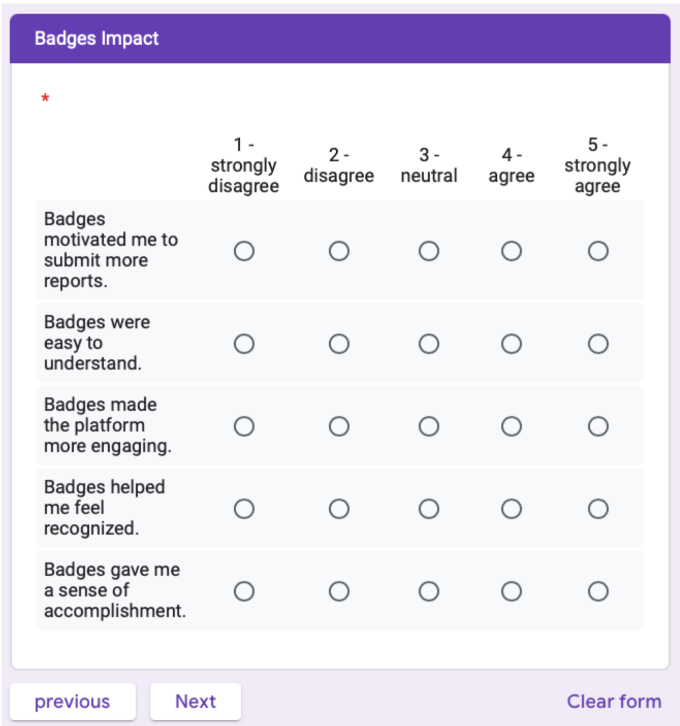

Marketplace Impact

*

	1 - strongly disagree	2 - disagree	3 - neutral	4 - agree	5 - strongly agree
The Marketplace motivated me to submit more reports.	○	○	○	○	○
The Marketplace was easy to understand.	○	○	○	○	○
The Marketplace made the platform more engaging.	○	○	○	○	○
The Marketplace helped me feel recognized.	○	○	○	○	○
The Marketplace gave me a sense of accomplishment.	○	○	○	○	○

previous Next Clear form

Figure B.2: Evaluation questionnaire - store impact

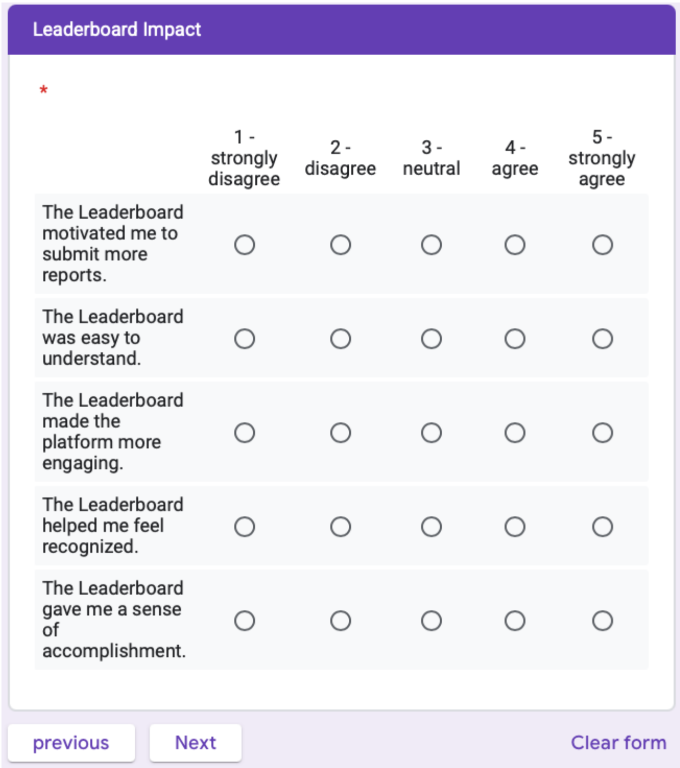

Badges Impact

*

	1 - strongly disagree	2 - disagree	3 - neutral	4 - agree	5 - strongly agree
Badges motivated me to submit more reports.	○	○	○	○	○
Badges were easy to understand.	○	○	○	○	○
Badges made the platform more engaging.	○	○	○	○	○
Badges helped me feel recognized.	○	○	○	○	○
Badges gave me a sense of accomplishment.	○	○	○	○	○

previous Next Clear form

Figure B.3: Evaluation questionnaire - badges impact



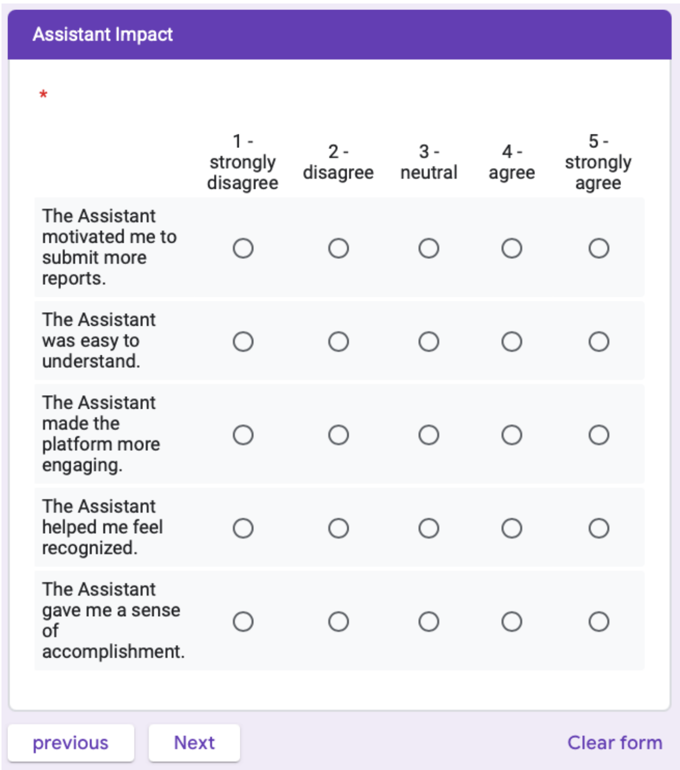
Leaderboard Impact

*

	1 - strongly disagree	2 - disagree	3 - neutral	4 - agree	5 - strongly agree
The Leaderboard motivated me to submit more reports.	○	○	○	○	○
The Leaderboard was easy to understand.	○	○	○	○	○
The Leaderboard made the platform more engaging.	○	○	○	○	○
The Leaderboard helped me feel recognized.	○	○	○	○	○
The Leaderboard gave me a sense of accomplishment.	○	○	○	○	○

previous Next Clear form

Figure B.4: Evaluation questionnaire - leaderboard impact



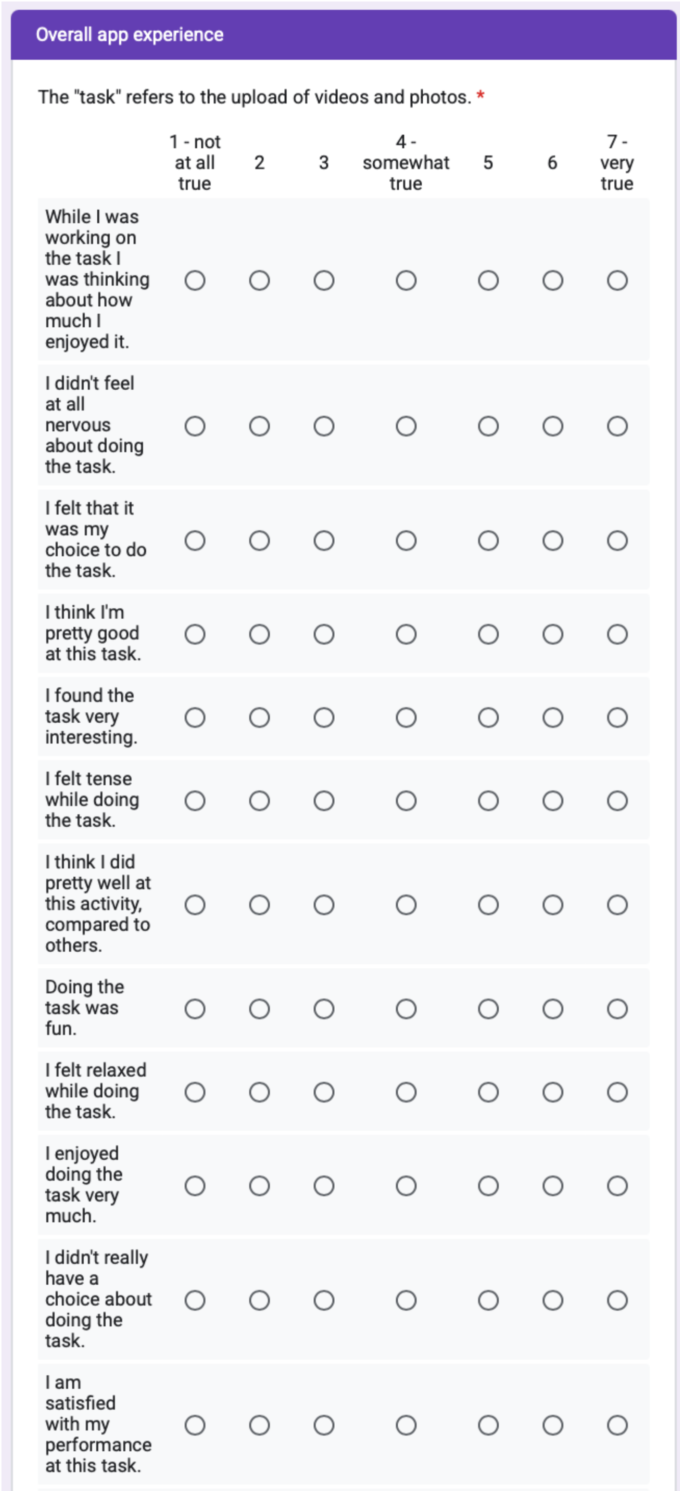
Assistant Impact

*

	1 - strongly disagree	2 - disagree	3 - neutral	4 - agree	5 - strongly agree
The Assistant motivated me to submit more reports.	○	○	○	○	○
The Assistant was easy to understand.	○	○	○	○	○
The Assistant made the platform more engaging.	○	○	○	○	○
The Assistant helped me feel recognized.	○	○	○	○	○
The Assistant gave me a sense of accomplishment.	○	○	○	○	○

previous Next Clear form

Figure B.5: Evaluation questionnaire - assistant impact



Overall app experience

The "task" refers to the upload of videos and photos. *

	1 - not at all true	2	3	4 - somewhat true	5	6	7 - very true
While I was working on the task I was thinking about how much I enjoyed it.	○	○	○	○	○	○	○
I didn't feel at all nervous about doing the task.	○	○	○	○	○	○	○
I felt that it was my choice to do the task.	○	○	○	○	○	○	○
I think I'm pretty good at this task.	○	○	○	○	○	○	○
I found the task very interesting.	○	○	○	○	○	○	○
I felt tense while doing the task.	○	○	○	○	○	○	○
I think I did pretty well at this activity, compared to others.	○	○	○	○	○	○	○
Doing the task was fun.	○	○	○	○	○	○	○
I felt relaxed while doing the task.	○	○	○	○	○	○	○
I enjoyed doing the task very much.	○	○	○	○	○	○	○
I didn't really have a choice about doing the task.	○	○	○	○	○	○	○
I am satisfied with my performance at this task.	○	○	○	○	○	○	○

Figure B.6: Evaluation questionnaire - general experience I

I was anxious while doing the task.	○	○	○	○	○	○	○
I thought the task was very boring.	○	○	○	○	○	○	○
I felt like I was doing what I wanted to do while I was working on the task.	○	○	○	○	○	○	○
I felt pretty skilled at this task.	○	○	○	○	○	○	○
I thought the task was very interesting.	○	○	○	○	○	○	○
I felt pressured while doing the task.	○	○	○	○	○	○	○
I felt like I had to do the task.	○	○	○	○	○	○	○
I would describe the task as very enjoyable.	○	○	○	○	○	○	○
I did the task because I had no choice.	○	○	○	○	○	○	○
After working on this task for a while, I felt pretty competent.	○	○	○	○	○	○	○

How likely are you to recommend this platform to a friend or colleague? *

	0	1	2	3	4	5	6	7	8	9	10	
Not at all likely	○	○	○	○	○	○	○	○	○	○	○	Extremely likely

Do you have any feedback or suggestions for improving the app?

Your answer

previous send Clear form

Figure B.7: Evaluation questionnaire - general experience II