EcoCity: Waste Recycling & Awareness Website

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***Abstract*—Improper waste disposal is a growing global concern, with traditional methods such as manual sorting proving inefficient, time-consuming, and unsustainable. This often leads to public confusion, improper waste segregation, and low engagement in recycling practices, further worsening environmental challenges. EcoCity is a comprehensive web platform designed to promote sustainable waste management and recycling awareness among users. By integrating AI-powered image recognition (Google Gemini via Genkit) for waste identification, geolocation for locating nearby recycling centers, a digital marketplace for reusable and second-hand items, and a carbon footprint calculator to track environmental impact, the system provides practical and interactive tools for eco-friendly living. Built using Next.js and Firebase, the platform ensures a scalable and efficient architecture while incorporating gamification techniques such as rewards and progress tracking to encourage user participation. EcoCity aims to educate individuals, promote responsible consumption, and empower communities to actively engage in sustainable behavior, creating an effective digital solution for waste reduction and environmental awareness.**

***Index Terms*—Waste Management, Recycling, Sustainability, AI Waste Classification, Image Recognition, Carbon Footprint Calculator, Digital Marketplace, Circular Economy, Gamification, Next.js, API, Google Gemini, Genkit, Environmental Awareness, Sustainable Development, Smart Waste Management**

I. INTRODUCTION

A. Significance

Waste management and recycling have become pressing global issues, as improper disposal of waste leads to environmental degradation. In today's world, where waste disposal is a growing concern, traditional methods like manual sorting or centralized collection have proven inefficient, unsustainable on a large scale, and face challenges in scalability. This is often compounded by public confusion and a lack of engagement regarding proper disposal methods.

EcoCity addresses this gap by harnessing the modern web Furthermore, by creating a connection enhances sustainable waste management and recycling awareness. Unlike traditional approaches, this platform leverages the AI-powered image recognition to automatically identify and categorize waste, providing users with clear disposal instructions. It integrates this with a GPS-based locator for nearby recycling centers.

A digital marketplace to promote a circular economy for reusable items, and a carbon footprint calculator. By merging these technologies with gamification to motivate user engagement, EcoCity aims to educate users, empower communities to adopt eco-friendly behaviors, and create an effective, integrated tool for waste reduction and awareness.

B. Background

The rapid expansion of web and mobile technologies has transformed how communities access information and manage daily tasks. However, in the critical area of waste management, traditional methods persist. "Waste management and recycling have become pressing global issues", as "improper disposal of waste leads to environmental degradation". These "traditional methods, such as manual sorting or centralized collection, have proven inefficient and unsustainable on a large scale". This inefficiency is often compounded by a lack of public awareness and confusion regarding correct waste segregation and disposal methods. As a result, ineffective waste handling practices continue to pose serious environmental and sustainability challenges for modern societies.

While digital platforms hold immense value for disseminating information, a dedicated, integrated tool to address these specific challenges in sustainability is

often lacking. To address these gaps, the "EcoCity" platform was conceptualized as a web-based solution to enhance "sustainable waste management and recycling awareness". The platform integrates modern technologies, including "AI-powered image recognition for waste identification", "GPS/Google Maps to help users locate nearby recycling centers", and a "marketplace for buying and selling reusable and electronic waste". By blending these tools with user engagement strategies like gamification and a carbon footprint calculator, the system provides a comprehensive technology to develop a platform that shifts toward eco-friendly behaviors and is responsible for waste disposal.

II. LITERATURE REVIEW

A. History

Over the past few decades, waste management has evolved from a simple disposal issue into a "pressing global" challenge, with "improper disposal of waste" leading to significant "environmental degradation". Traditional communication and management channels, such as "manual sorting or centralized collection," have consistently "proven inefficient and unsustainable on a large scale". These methods often fail to provide clear, accessible guidance to the public, resulting in low or incorrect recycling participation. As a result, research and development have shifted toward technology-driven solutions to enhance public awareness and efficiency. Initially, this focused on automating the sorting process itself. Studies demonstrated the feasibility of "using artificial intelligence and machine learning for waste management". This led to explorations of "deep learning models like Convolutional Neural Networks (CNNs)" for the "automated classification and segregation of waste in smart cities", which showed high accuracy in identifying materials from an image.

Finally, to address the challenge of public motivation, behavioral studies highlighted the effectiveness of "gamification and reward systems in motivating individuals to adopt" eco-friendly habits. This was complemented by research into "personal carbon footprint calculation", which analyzed how "interactive" tools that "provide immediate, understandable feedback" could effectively "encourage behavioral change".

B. Comparison with Existing Implementation

Several existing platforms and waste management frameworks rely on traditional methods, such as "manual sorting or centralized collection". While these systems are established, they "have proven inefficient and unsustainable on a large scale" and "often face challenges in efficiency and scalability". They depend on static information, such as municipal websites or printed guides, which fail to provide the immediate, item-specific, and actionable guidance that the public needs, leading to confusion and poor recycling outcomes.

Conventional digital tools used in research contexts often focus on singular aspects of the problem, lacking integration. For instance, "numerous studies have demonstrated the feasibility of using artificial intelligence", often with "Convolutional Neural Networks (CNNs), for the automated classification and segregation of waste". However, these are frequently industrial-scale solutions, not user-facing tools that provide "detailed, natural-language disposal instructions" to address the "what do I do with this?" problem directly. Similarly, while "personal carbon footprint calculation". Popular digital marketplaces, such as those that facilitate a "consumer-to-consumer (C2C) market for pre-owned items", plays a role in reuse. However, they are not purpose-built for the "circular economy" and are disconnected from a wider sustainability ecosystem. EcoCity differentiates itself by being a "direct practical implementation" of this theory while "integrating all these tools into a single, cohesive web platform". It combines an AI identifier, a dynamic carbon calculator, recycling locator and a dedicated marketplace, enhancing them with the "Gamification features" to "encourage user participation". Existing platforms may offer one of these features, but they lack this unified, holistic approach to promoting sustainable behavior.

C. Problem Definition

Improper waste disposal and inefficient recycling, exacerbated by public confusion and outdated manual systems, demand an automated and engaging solution. Ecocity addresses this as a cohesive web platform that merges technology with sustainability. It utilizes AI for waste identification, geolocation for recycling centers, and a digital marketplace to promote a circular economy, creating an all-in-one tool to educate users and motivate sustainable behavior. This integrated

approach fosters a proactive community, turning individual actions into a collective environmental impact.

III. SYSTEM REQUIREMENT & ANALYSIS.

A. Frontend: Next.js (React.js), shaden/ui, Tailwind CSS, React Hook Form & Zod

The frontend is developed using Next.js (React.js), which serves as the core framework for building the user interface. It is designed to handle both static and dynamic content efficiently by utilizing Server-Side Rendering (SSR) for dynamic pages and Static Site Generation (SSG) for content-heavy sections like guides. The UI is constructed using shaden/ui, a component library built on Radix UI primitives, which provides customizable and accessible components. Styling is managed by Tailwind CSS, a utility-first framework that allows for rapid, responsive design directly within the component files. For client-side form handling and schema validation, the project uses React Hook Form & Zod to ensure data integrity and a smooth user experience.

B. Backend: Node.js, Next.js API Routes

The project's backend architecture is designed to be scalable, secure, and seamlessly integrated with the frontend. Node.js serves as the server-side runtime environment, which is utilized directly via the Next.js framework. This approach allows Next.js to act as both the frontend and the backend runtime, making it a truly full-stack application & eliminating the need for a separate backend server. This integration is achieved through Next.js API Routes and Server Components, which handle all server-side logic. These server components enable the execution of complex operations such as handling API requests, interacting with external services, or calling AI models securely on the server side, without exposing sensitive data or logic to the client. This streamlined method ensures a consistent architecture, simplifies development, and provides a performant backend foundation with minimal overhead and added complexity. It also improves maintainability by centralizing server-side logic within the Next.js framework. Furthermore, it enhances scalability and supports efficient integration of future features and services, ensuring long-term system adaptability and enhanced performance.

C. Database: Cloud Firestore, React Context, Local Storage

For data storage and synchronization, the project utilizes Cloud Firestore, a NoSQL real-time database provided by Firebase. Firestore serves as the main repository for all persistent user data, including user profiles, addresses, and reward records, as outlined in backend. Json. To maintain a live and responsive user experience, the project employs custom React hooks such as useDoc and use Collection. These hooks listen directly to Firestore updates and automatically re-render UI components when data changes. On the client side, the React Context API is used to handle global state management across the application. The Cart Provider component is a prime example of this, maintaining the user's shopping cart state across different pages without requiring redundant data fetching. Additionally, browser Local Storage is leveraged for storing non-critical, client-side data, such as user-listed marketplace products and cart items. This enables an offline-first experience, allowing users to continue browsing or managing their listings even if internet connectivity is temporarily unavailable. This combination creates a balanced ecosystem for both real-time and offline data management.

D. AI Framework & Service: Genkit, Google AI (Gemini Flash)

Artificial Intelligence is a key component of the project, integrated using Genkit, a framework for orchestrating AI-powered workflows. The AI logic is implemented in the genkit file, where reusable and testable AI flows are defined, providing a structured way to develop, monitor, and deploy these functionalities. The main AI feature is the AI Waste Classification Flow, which uses Google's Gemini Flash model. This flow is orchestrated by Genkit to analyze user-uploaded images of waste materials. Through the careful prompt engineering, the model processes the image (which is encoded as a data URI) and is instructed to return a structured JSON response. This response, defined by a Zod schema within the flow, classifies the waste type (e.g., plastic, metal) and provides proper disposal instructions, AI-driven recycling guidance.

E. Authentication & Security: Firebase Authentication, Firestore Security Rules

User authentication and data protection form the core of the application's security model. The project implements Firebase Authentication to manage secure user sign-up and login processes, supporting standard email and password-based authentication. This service automatically handles token management, user sessions, and route protection, ensuring that only authenticated users can access personalized features like their profiles or rewards. To complement authentication, the project uses Firestore Security Rules to enforce strict data access control at the database level. These rules, defined in the firestore.rules file, follow a user-ownership policy. This policy ensures that each user can only read or write documents that are directly associated with their own unique ID (uid). This mechanism prevents unauthorized access and guarantees that sensitive user information might remain private, protected and isolated, sporadic actions into a consistent, measurable, and rewarding eco-friendly habit, which will significantly & effectively enhance long-term sustainable user engagement.

F. Development & Deployment Tools: TypeScript, VS Code, npm, Firebase App Hosting

The entire project is written in TypeScript, as specified in the tsconfig file. TypeScript enhances code reliability by enforcing type safety, which reduces the likelihood of runtime errors. It also improves developer productivity through better autocompletion and error detection within the code editor, Visual Studio Code. npm is used as the package manager for all project dependencies. For deployment, the application uses Firebase App Hosting, a managed, secure, and scalable environment specifically optimized for Next.js applications. The deployment configuration is defined in the apphosting.yaml file. Firebase App Hosting automates the Continuous Integration and Continuous Deployment pipeline, ensuring that updates are built, tested, and deployed seamlessly. This results in a stable, production-ready hosting environment with minimal manual setup, and allows environment variables and API keys to be secured.

G. Data Analytics and Reporting Module

A core non-functional requirement is the implementation of a robust data analytics and reporting engine. This module will be designed to anonymously aggregate user data, such as waste disposal patterns, recycling center searches, and marketplace transactions. The system shall process this data to generate actionable insights for municipalities and environmental organizations, identifying waste hotspots, tracking the diversion of materials from landfills, and measuring the platform's overall environmental impact. This data-driven approach is crucial for validating the platform's effectiveness and guiding future urban sustainability. Additionally, it supports real-time monitoring of system usage trends for better decision-making. It also enables continuous improvement of platform features based on user behavior analysis and usage patterns over time for optimization.

H. Gamification and User Engagement System

To address the critical requirement of sustained user motivation, which is a common challenge in environmental platforms, the software must incorporate a structured and deeply integrated gamification layer. This system is not merely an add-on but a core component designed to foster continuous interaction and positive reinforcement. It shall include features such as a dynamic point-based rewards system, where users earn "eco-points" for beneficial actions like correctly sorting waste using the AI identifier, completing educational quizzes, or logging visits to recycling centers. Furthermore, the platform will award digital badges for achieving significant recycling milestones, creating a tangible and shareable representation of their progress. To leverage social motivation, public leaderboards will be implemented to foster a sense of friendly competition and community, encouraging users to improve their habits relative to their peers. The analysis confirms that integrating these gamification elements directly with the user's personal profile dashboard and activity history is essential. This integration ensures that the user's profile becomes a personalized hub of their achievements, transforming what might be isolated, sporadic actions into a consistent, measurable, and rewarding eco-friendly habit, which will significantly enhance long-term engagement.

IV. METHODOLOGY

A. Overview

EcoCity platform operates as an integrated full-stack web application built on the Next.js 15 framework, which serves both the frontend user interface and the backend server logic. The system's workflow begins when a user accesses the application and is presented with a unified authentication page that handles both login and multi-step registration. This module interfaces directly with Firebase Authentication to securely manage user credentials and sessions. Once authenticated, the user's state is managed globally, making their ID available to all components for personalization and security.

The methodology uses a hybrid data strategy, combining Cloud Firestore for secure user data like profiles, which are protected by ownership-based firestore.rules, with Local Storage for client-side data like cart items. Core features are powered by external APIs: the Genkit framework and Google AI (Gemini) model drive the "AI Waste Identifier", while the "Recycling Center Locator" uses the browser's geolocation API and the OpenStreetMap (Nominatim) API.

B. Proposed System Architecture and Implementation

The EcoCity platform is designed as an integrated full-stack web application built on a modern, layered framework to ensure functionality and scalability. The system's architecture is organized into distinct tiers, with a high-level block diagram illustrating the fundamental data flow and component interactions. It begins with the User Interface layer, where users access the system through web and mobile applications. This layer communicates directly with the Backend Server, which is built on Next.js and orchestrates all core operations. The server, in turn, interfaces with three critical service layers: the Database (Firestore) for persistent data storage, the AI Service (Gemini) for processing image classification tasks, and the Authentication (Firebase Auth) system for securing user access. The user interface also utilizes browser Local Storage for managing client-side data such as cart items and marketplace listings. This streamlined flow ensures that user requests are efficiently processed through a coordinated pipeline of specialized components.

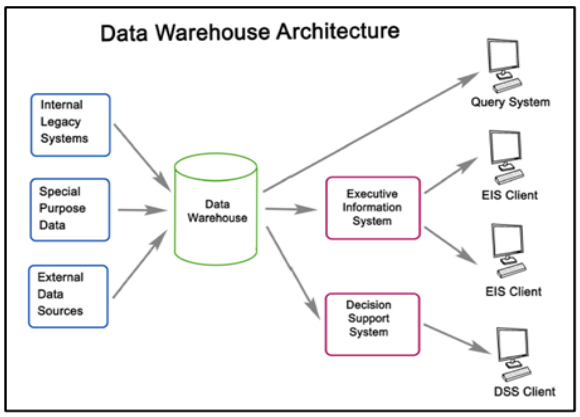


Fig 4.1 System Architecture Diagram

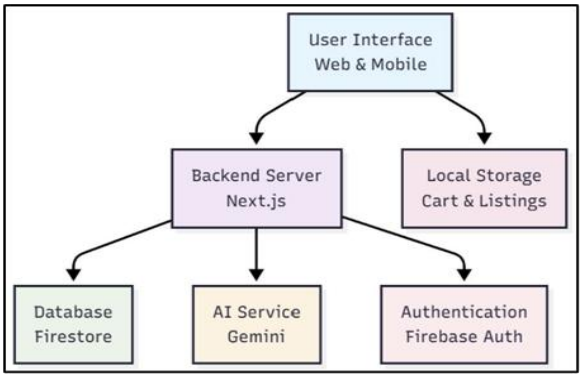


Fig 4.2 System Block Diagram

V. DISCUSSIONS & RESULTS

A. Discussion

The development of the EcoCity platform successfully transitioned from a conceptual blueprint to a fully deployed, functional application. The initial problem definition stage was critical, yielding a clear roadmap that directly linked key urban sustainability challenges such as public confusion about recycling and a lack of engagement to the specific platform features. This foundational work ensured that the final product was purpose-built, with modules like the AI Waste Identifier and the Rewards system designed as direct solutions to these identified problems. The resulting system architecture, built on a modular four-layer model using Next.js and Firebase, provided a scalable and efficient foundation that streamlined the entire development process.

A significant achievement was the robust integration of data management and security. The hybrid database approach, combining Cloud Firestore for secure user data with local Storage for instantaneous marketplace

functionality, proved optimal for performance and user experience. The implementation of Firestore Security Rules was critical, ensuring data integrity by restricting users to access only their own information. Comprehensive testing validated all system components, from form validations and security rules to the AI model's accuracy, confirming the platform's reliability.

Finally, the integrated system was evaluated for performance, meeting all expectations for a modern web application. The platform exhibits excellent load times and general UI responsiveness, with features leveraging localStorage providing instantaneous feedback. The AI classification, while the most time-intensive operation, delivers results within an acceptable 2-4 second window for its analytical task. The successful configuration for CI/CD via Firebase App Hosting marks the culmination of the development cycle, positioning EcoCity as a deployable and maintainable solution ready for public use.

B. Results

This screen displays the vibrant homepage of the EcoCity website, serving as the ultimate welcoming gateway for our community of users. From this central starting point, visitors are granted seamless and rapid access to explore all of the platform's essential features, utilizing a comprehensive set of navigation tools

Fig 5.1 Home Page

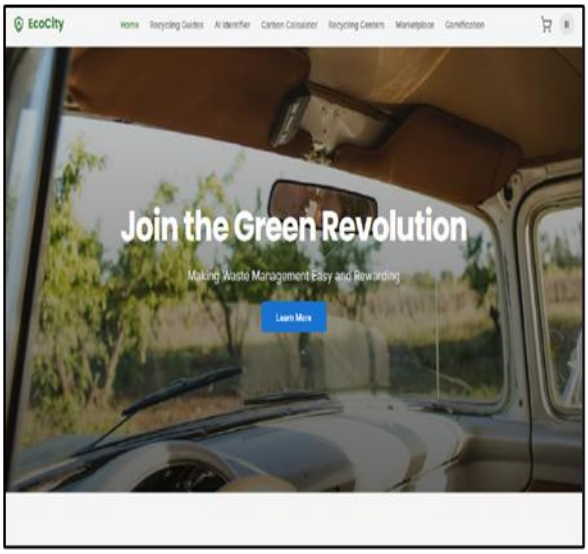


Fig 5.2 Sign Up Page

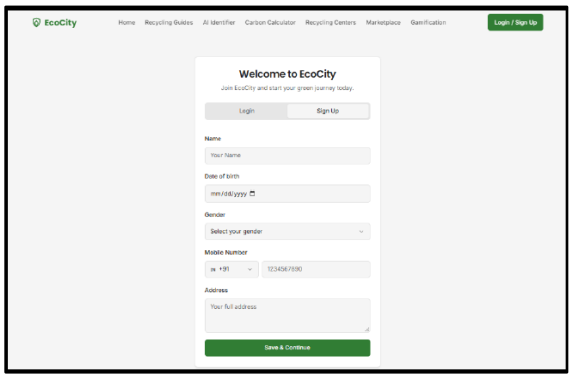


Fig 5.3 Login Page

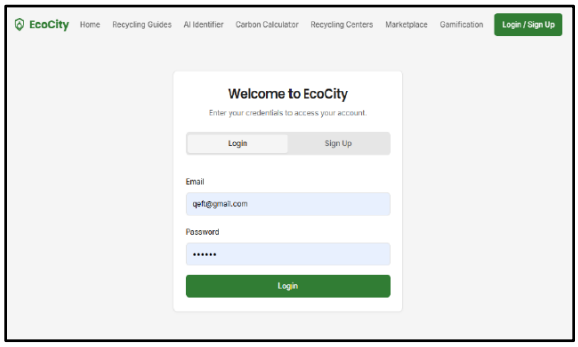


Fig 5.4 Firestore Database

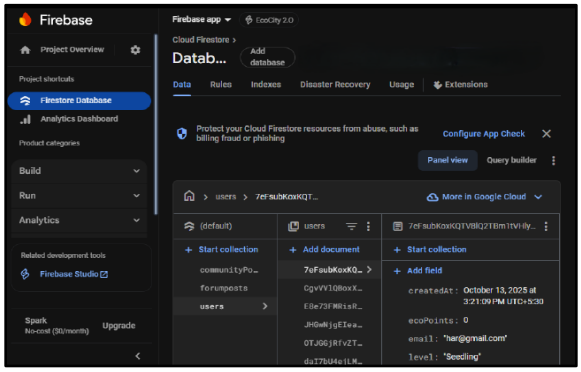


Fig 5.5 Marketplace Page

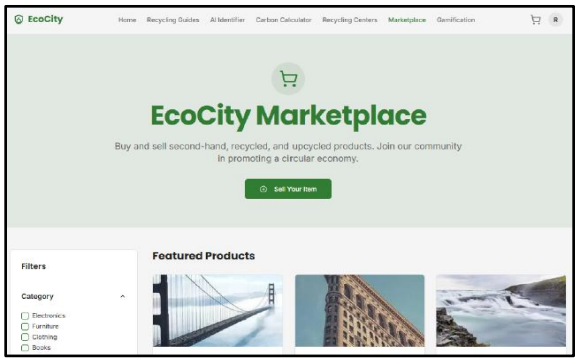
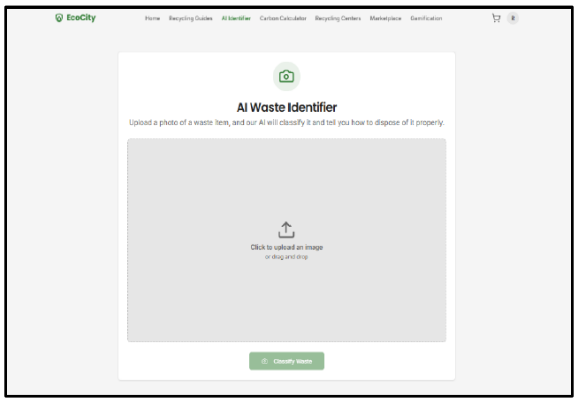


Fig 5.6 AI Waste Identifier Page



VI. CONCLUSION

In conclusion, the EcoCity platform represents a comprehensive integration of modern web technologies, artificial intelligence, and sustainability-focused design. The project has successfully moved from concept to full-scale implementation, addressing real-world environmental challenges through innovative digital solutions. By incorporating features such as the AI-Powered Waste Identifier, Carbon Footprint Calculator, Recycling Center Locator, and Digital Marketplace, EcoCity empowers users to make informed, eco-conscious decisions in their daily lives. The use of Next.js for frontend and server-side rendering, combined with Firebase's serverless infrastructure, ensures high scalability, security, and performance. The implementation of Firestore Security Rules and Firebase Authentication provides strong user protection, while the integration of local Storage ensures smooth and responsive client-side interactions. The application's hybrid data model balances efficiency and security, offering users both speed and reliability.

Moreover, the integration of Google's Generative AI (Gemini) via the Genkit framework elevates the system's intelligence, allowing for dynamic, real-time waste classification and personalized recommendations. This AI-driven interactivity enhances user engagement and contributes directly to promoting sustainable behavior. It also improves decision-making accuracy and supports more efficient sustainable waste management practices.

The successful configuration of Continuous Integration and Deployment (CI/CD) through Firebase App Hosting further demonstrates the project's readiness for production, ensuring consistent updates and minimal downtime. Comprehensive testing across all modules ranging from UI responsiveness and API integration to AI accuracy and data validation confirmed the platform's robustness and reliability.

Overall, EcoCity stands as a well-rounded, forward-thinking solution that merges technology, the growing need for sustainable waste management but also inspires behavioral change by making eco-friendly living accessible, interactive, and rewarding. This project lays a strong foundation for future expansion, potentially integrating community-driven challenges, AI-based sustainability insights, and advanced analytics to further support global environmental awareness and action.

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