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MORALITY BEFORE KNOWLEDGE

CIRCLE: A digital platform for circular food waste management in achieving sustainable food security

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ABSTRACT
Background: Food loss and waste (FLW) pose a major global challenge, threatening food security, economic stability, and environmental sustainability. In Indonesia, despite abundant resources, inefficiencies in production and distribution still lead to significant waste and nutritional inequality. Overcoming this issue requires an integrated and sustainable system that improves redistribution efficiency. Supported by digital innovations such as Artificial Intelligence (AI), the Internet of Things (IoT), and data analytics, the circular economy approach offers a strategic solution. In response, the CIRCLE platform was developed as a smart and sustainable digital system for food redistribution. **Methods**: This study uses a descriptive method through a literature review to identify theories, concepts, and best practices on circular economy, based digital platforms for reducing FLW. Secondary data from scientific publications and institutional reports were analyzed to form the conceptual basis for designing the CIRCLE (Circular Utilization of Food Resources) platform. **Findings:** The literature emphasizes the importance of multi-stakeholder collaboration and the application of AI, IoT, and data analytics to develop efficient and sustainable food distribution systems. The implementation of user-centered design and gamification is also recommended to enhance user engagement and awareness. **Conclusion**: The CIRCLE platform represents an innovative and sustainable digital solution to reduce food waste, strengthen food security, and foster collaboration toward achieving SDG 2 and SDG 12 in Indonesia. **Novelty/Originality of this article:** This study introduces the CIRCLE platform as a distinctive integration of circular economy principles and digital technologies, including AI, IoT, and gamification, within a unified system for reducing food loss and waste in Indonesia.

KEYWORDS: food loss and waste; digital platform; sustainable food system.

1. Introduction

Globally, food loss and waste (FLW) have become a serious issue threatening food security, environmental sustainability, and the achievement of the Sustainable Development Goals (SDGs). The FAO (2025) estimates that around 8.2 percent of the world's population still experienced hunger in 2024, or approximately 673 million people. Although this figure has slightly decreased compared to the previous year, hunger remains on the rise in some regions of Africa and West Asia, indicating disparities in progress across regions. The FAO (2024) report on food security financing also highlighted the limitations of public spending and private investment in low- and middle-income countries, which hinder efforts to address the root causes of malnutrition. These findings

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emphasize that global food security requires better food distribution as well as strong financial and institutional commitments.

In Indonesia, the food paradox is evident: an agrarian country with abundant resources still produces significant food waste. According to the Food Waste Index Report (UNEP, 2024), Indonesia generates more than 14.7 million tons of household food waste annually. Much of this food never reaches consumers due to supply chain inefficiencies or deliberate disposal of still-edible food (Baig et al., 2019). Data from SIPSN (2024) indicate that more than 60% of national waste is poorly managed, highlighting the need for integrated strategies linking waste management and FLW reduction. Food loss typically occurs along the supply chain from production to distribution, whereas food waste refers to edible food discarded at retail and consumer levels (Santeramo & Lamonaca, 2021). Globally, food waste contributes to pollution, resource depletion, and threatens food security (Kummu et al., 2021). This underscores the urgency of transforming Indonesia's food system to be more equitable, efficient, and sustainable.

Food loss and waste have social, economic, and environmental impacts. Between 2000 and 2019, Indonesia reportedly suffered economic losses of approximately IDR 213–551 trillion per year, equivalent to 4–5% of GDP. Decomposing food waste contributes about 7.29% of total national greenhouse gas emissions (~1,702.9 Mt CO_2) (Bappenas, 2021). Reducing FLW is thus a vital part of sustainable development strategies, not only for food security but also to maximize socio-economic benefits, such as increasing income for farmers and industry actors, enhancing brand reputation, and improving customer loyalty (De Boni et al., 2022; Stone et al., 2019), in line with SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production) (Sarangi et al., 2024).

The circular economic approach is a key strategy to address FLW by converting food waste into resources such as compost, animal feed, or bioenergy, thereby closing material loops and improving resource efficiency (Cuadrado-Osorio et al., 2022). Digital transformation strengthens this strategy: smart technologies such as AI, IoT, and big data analytics enhance supply chain efficiency, stakeholder coordination, demand forecasting, and real-time stock monitoring (Aamer et al., 2025; Ahmadzadeh et al., 2023; Jagtap et al., 2021; Onyeaka et al., 2023).

Several studies have explored digital technologies for FLW reduction. Venessa & Aripradono (2023) showed that gamification in mobile applications (points, badges, leaderboards) can motivate users in Indonesia to reduce food waste. Kawengian et al. (2024) developed a GPS-based application to efficiently distribute surplus food from restaurants to underprivileged communities, ensuring that only edible food is distributed while separating inedible waste. In the United States, Gittelsohn et al. (2022) developed BUD (Baltimore Urban Food Distribution), facilitating the distribution of healthy food from producers to corner stores in low-income areas using collective purchasing and delivery. These studies demonstrate that digital interventions and gamification can enhance food redistribution but also highlight limitations when applied in different contexts.

Moreover, previous research emphasizes the importance of user-centered design (UI/UX) in digital platforms to ensure usability and engagement. Kamarulredzuan et al. (2024) note that intuitive interfaces improve accessibility, while Widagdo et al. (2024) highlight that gamification elements such as challenges, achievements, and interactive feedback increase motivation and participation.

Global digital platforms such as Too Good to Go, OLIO, and BUD have proven successful in certain regions but have present research gaps. Too Good to Go has over 75 million users across 17 countries, with 134,000 active business partners, and has saved more than 200 million portions of food. OLIO, a peer-to-peer community-based platform, allows free food sharing but has not yet integrated smart technologies (AI/IoT) to optimize distribution efficiency. BUD, while effectively connecting producers with 38 corner stores in Baltimore, has limited reach and was not designed for social-ecological surplus food redistribution on a large scale.

To address these gaps, this study introduces CIRCLE (Circular Utilization of Food Resources), a digital platform integrating AI to match donors and recipients based on

location, capacity, and distribution timing; IoT to monitor food conditions during storage and transport (e.g., temperature and humidity); and gamification (challenges, achievements, leaderboards, interactive feedback) to enhance user participation. By combining supply chain efficiency, fair redistribution, food safety monitoring, and user engagement in a single circular economy–based platform, CIRCLE is expected to be a superior solution compared to OLIO, Too Good To Go, and BUD, particularly in developing countries like Indonesia.

2. Methods

This study employs a descriptive approach based on a literature review to design and develop the digital platform CIRCLE (Circular Utilization of Food Resources) as a solution to reduce food loss and waste (FLW). This approach allows for a systematic analysis of technological components, operational mechanisms, and the relevance of circular economy principles in surplus food redistribution (Jaya et al., 2024). It also provides a solid scientific foundation for platform design while evaluating best practices and global trends in FLW reduction. This methodology aims to ensure the study is transparent, measurable, and replicable. Readers can understand literature selection, analysis procedures, and the logic behind technology integration in CIRCLE. Moreover, it demonstrates how the combination of AI, IoT, and gamification effectively supports FLW reduction in alignment with circular economy principles.

The literature analyzed was selected based on publications between 2019–2025, focusing on food waste reduction, the application of AI, IoT, and gamification, including scientific studies, government reports, and documentation of international FLW platforms such as Too Good to Go, OLIO, and BUD. Key sources include Scopus, Google Scholar, PubMed, as well as official government and platform documents. These criteria ensure that the theoretical foundation of the platform is relevant, up-to-date, and applicable in both local and global contexts.

2.1 Data analysis and synthesis

The analysis was conducted descriptively and qualitatively, synthesizing concepts, best practices, and operational mechanisms from relevant literature. The synthesis was then linked to the design of CIRCLE, where artificial intelligence (AI) analyzes donor and recipient data, including location, storage capacity, food types, and distribution schedules. AI automatically matches the most optimal donor–recipient pairs, enabling faster, more efficient surplus distribution while minimizing food waste.

Internet of Things (IoT) monitors food conditions during storage and transportation, including temperature, humidity, and storage duration. Data is sent to the platform in real-time, allowing the system to provide early warnings if food quality is at risk, ensuring safety and freshness until received by the recipients. Gamification is implemented through challenges, achievements, leaderboards, and interactive feedback, enhancing user engagement and motivation. Active users who contribute to FLW reduction earn points or virtual rewards, creating both intrinsic and social motivation to continue participating in the platform. The analysis also emphasizes the integration of digital technologies with circular economic principles, including waste reduction, distribution efficiency, and equitable access to food.

2.2 Platform design and operational simulation

The platform design emphasizes user-centered UI/UX, focusing on an interface that is intuitive, easy to use, and comfortable. Gamification is integrated to further increase user engagement and motivation (Kamarulredzuan et al., 2024; Widagdo et al., 2024). The platform is visualized through a flow diagram showing integration of AI, IoT, and gamification in a single system. The distribution flows from surplus providers to the

CIRCLE platform and then to recipients. The connection between digital mechanisms and circular economy principles, closing material loops and optimizing food redistribution.

3. Results and Discussion

3.1 CIRCLE (circular utilization of food resources): Digital ecosystem innovation for managing food surplus and organic waste

The escalating issue of food loss and waste has become a global concern with far-reaching implications for environmental integrity and national food security. Recent estimates by the United Nations Environment Programme indicate that approximately 1.05 billion tons of food, equivalent to nineteen percent of food available to consumers, was wasted globally in 2022, illustrating the severity of inefficiencies within contemporary food systems (UNEP, 2024). In parallel, the Food and Agriculture Organization highlights food waste reduction as a strategic triple-win opportunity that strengthens food security, enhances environmental sustainability, and improves economic efficiency, particularly as global surplus continues to coexist paradoxically with persistent hunger (FAO, 2022).

Indonesia faces similar structural challenges. According to the National Development Planning Agency, the country generates between 115 and 184 kilograms of food waste per capita each year, leading to economic losses estimated at more than 550 trillion rupiah, or nearly five percent of national gross domestic product (Bappenas, 2021). Further assessments identify food waste as the largest contributor to national waste generation, comprising over forty percent of Indonesia's total annual waste composition (Bappenas, 2023). These conditions reflect not only environmental pressures but also deep-rooted gaps in redistribution mechanisms, waste processing infrastructure, and public awareness, underscoring the urgent need for an integrated and technologically supported approach.

To address these multidimensional challenges, the CIRCLE platform (Circular Utilization of Food Resources) is conceptualized as a digital ecosystem grounded in the principles of circular economy. Drawing on circular resource flow models which emphasize maintaining the highest possible value of materials within continuous loops (Ellen MacArthur Foundation, 2021), CIRCLE restructures food management into a system where surplus food is redistributed efficiently, unavoidable organic waste is transformed into productive resources, and users gain access to educational tools that foster sustained behavioral change. The platform integrates real-time tracking, intelligent matching algorithms, AI-based food safety verification, and gamification mechanisms to encourage participation across individuals, communities, businesses, and governmental institutions, thereby strengthening multi-sector collaboration and advancing a more resilient food governance structure.

CIRCLE consists of eight interconnected features that collectively create an adaptive and inclusive food management ecosystem. The Map feature offers an interactive visualization of donors, beneficiaries, and distribution routes, enabling transparent monitoring of supply flows. The Forum facilitates communication and coordination among stakeholders from community organizations, non-profits, local governments, and private-sector actors. The Connect module enables data-driven matching to ensure efficient redistribution of surplus food. The Bank feature operates as a digital waste bank through which users can convert waste deposits into points or economic value. The Recycle module supports the transformation of organic waste into compost, animal feed, or bioenergy. The Safe module provides AI-supported verification of food safety based on image analysis. The Score dashboard visualizes user contributions and their measurable impacts, while the Learn module offers access to educational resources, regulatory frameworks, and practical guidance related to food management and the Sustainable Development Goals.

Together, these features position CIRCLE not merely as a redistribution mechanism but as a comprehensive and transformative platform for sustainable food governance. Through its combination of digital innovation, behavioral incentives, and circular resource management principles, CIRCLE provides a concrete pathway to reducing food waste in Indonesia while also cultivating broader public awareness of the social, economic, and environmental value of food. The platform aims to not only respond to immediate inefficiencies but also to promote long-term systemic change toward a more equitable, resilient, and sustainable food future.

3.1.1 Platform cover and login page design

The CIRCLE application introduces users to its digital ecosystem through a thoughtfully designed cover page and login interface. The cover page features a trash can icon with a friendly smile rendered in calming blue tones, signaling a welcoming and inclusive environment for community participation. Users are greeted with the invitation "Step into the CIRCLE, and be part of the change," which reinforces the platform's ethos of collaborative engagement in sustainable waste management. Following this, the registration page presents a straightforward account creation form that captures essential user information while maintaining simplicity and clarity. This design approach fosters user confidence, encourages active involvement, and establishes an approachable first impression, thereby setting the stage for effective interaction with the platform's comprehensive features.

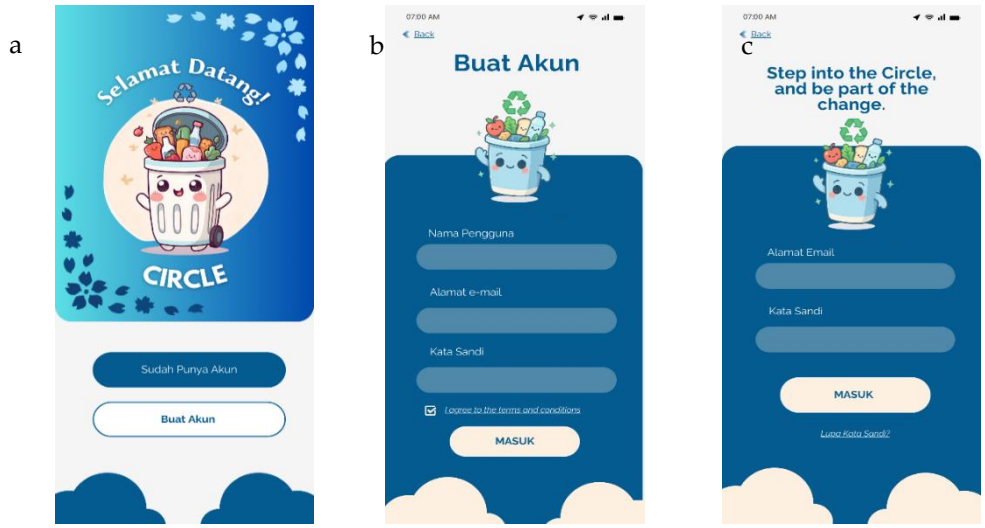

Fig. 1. User interface design of the CIRCLE platform: (a) Welcome page; (b) Account registration page; (c) Login Page

3.1.2 Main menu design and CIRCLE map feature

The main menu of the CIRCLE application is designed to be visually appealing and functionally intuitive, incorporating environmental imagery and the sustainability-oriented slogan "Where Leftovers Spark New Life." This design choice emphasizes the mission of promoting responsible food management while reinforcing environmental awareness. Users can easily locate the nearest participation points and access the platform's primary features, including Map, Forum, Connect, Bank, Recycle, Safe, Score, and Learn, through an organized and accessible interface. The menu structure prioritizes usability and navigation efficiency, ensuring that users can quickly engage with the platform's diverse functionalities while maintaining focus on the overarching sustainability objectives.

Furthermore, the Map feature provides an interactive visualization that enables users to monitor the locations of food sources, waste banks, beneficiaries, and distribution

routes in real time. By displaying detailed information on proximity, food availability, provider type, and operating hours, the map facilitates optimized route planning and resource allocation. This feature enhances the efficiency and transparency of food redistribution, empowering users to make informed decisions regarding collection and delivery while minimizing potential waste. Real-time data visualization serves as a critical operational tool that supports strategic decision-making and promotes active engagement within the CIRCLE ecosystem.

a b

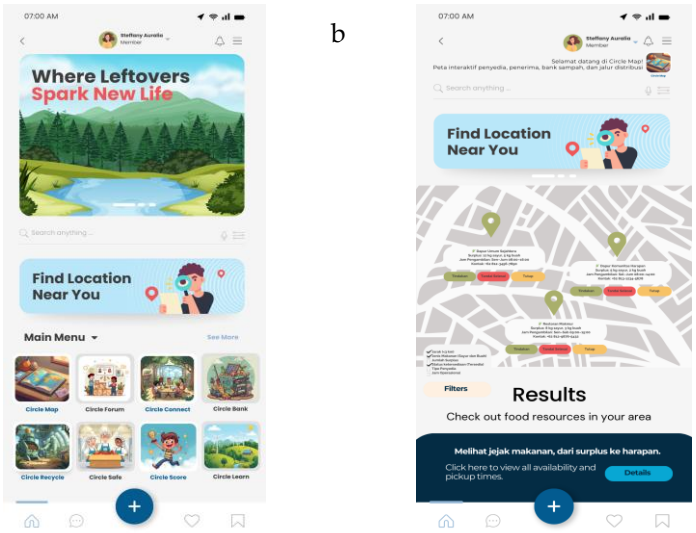

Fig. 2. User interface design of the CIRCLE platform: (a) main menu design: (b) CIRCLE map feature

3.1.3 CIRCLE forum feature

The Forum feature functions as a collaborative digital space where stakeholders including food providers, volunteers, and beneficiaries can interact, exchange information, and coordinate efforts. Users can access ongoing activity agendas and view community contribution rankings, which not only provide transparency but also incentivize participation through recognition and acknowledgment. By fostering communication and knowledge sharing, the Forum strengthens community cohesion and encourages collective action toward reducing food waste. This feature embodies the platform's goal of creating a participatory environment in which collaboration and shared responsibility are central to sustainable outcomes.

a b

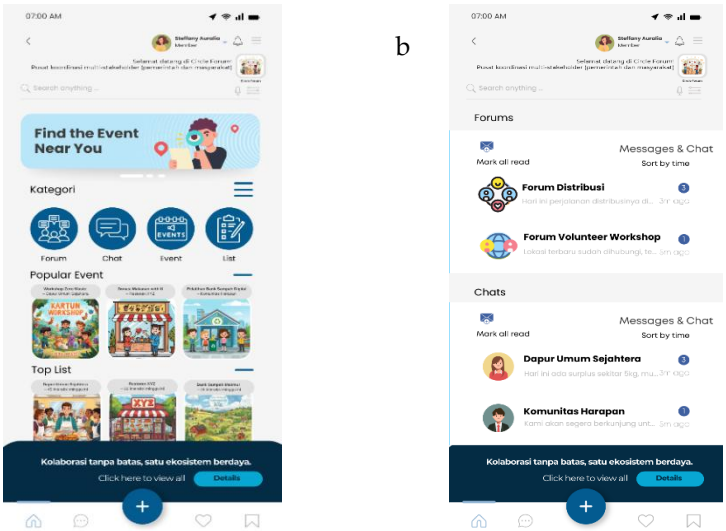

Fig. 3. CIRCLE forum feature: a) main page of the forum feature; b) forum and chat list

3.1.4 CIRCLE connect feature

Connect operates as an intelligent matching system that links food surpluses with suitable recipients and logistics providers in real time. Users input details regarding surplus type, quantity, and location, allowing the system to generate recommendations for the nearest recipients, optimal delivery routes, estimated transit times, recipient capacity, availability status, and priority needs. This algorithmic coordination ensures that surplus food is directed efficiently to areas of highest demand, thereby reducing waste and enhancing the reliability of the redistribution process. Connect integrates logistical considerations with user behavior modeling to optimize operational effectiveness across the network of contributors and beneficiaries.

a b

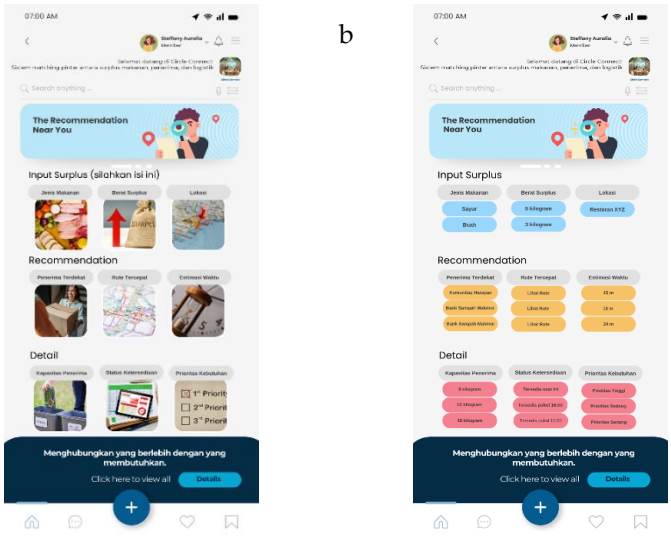

Fig. 4. CIRCLEs connect feature: a) main page of the connect feature; b) input menu

3.1.5 CIRCLE bank feature

The Bank feature transforms organic waste collection into a structured and quantifiable activity. Users deposit waste items, which are recorded with details such as type, weight, location, and time of deposit, and are subsequently converted into digital reward points. This system not only encourages participation by providing tangible incentives but also establishes a transparent record of contributions, promoting accountability and recognition within the community. The digital waste bank operates circular economy principles by converting waste into economic value, simultaneously educating users about the benefits of resource recovery and sustainable consumption practices.

Recycle supports the transformation of organic waste into beneficial products, including compost, animal feed, or bioenergy. This feature offers users access to statistical data, innovations, collaborative initiatives, and knowledge-sharing platforms where progress and experiences can be documented and exchanged. By fostering engagement with both practical and educational aspects of organic waste processing, Recycle contributes to community empowerment and strengthens the collective capability to implement sustainable waste management practices. The module facilitates the dissemination of expertise and encourages collaborative problem-solving within the broader CIRCLE ecosystem.

Safe serves as an AI-powered, photo-based food safety verification system that evaluates the condition and suitability of food for distribution. Users can view detailed analyses, including visual documentation, condition reports, and food system assessments, which collectively enhance transparency and reliability. By providing verified information about food safety, this feature ensures that all stakeholders can engage in redistribution

activities with confidence, reinforcing trust in the platform's operational integrity and contributing to the broader goal of safe, equitable food management.

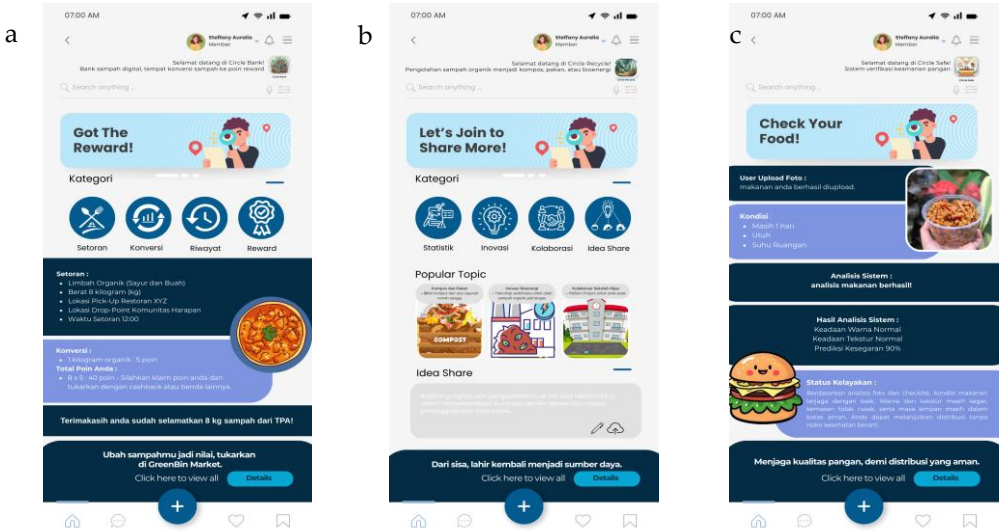

Fig. 5. CIRCLEs connect feature: (a) Bank feature; (b) Recycle feature; (c) Safe feature

3.1.6 CIRCLE score feature

Score functions as a gamification dashboard that quantifies and visualizes user contributions to food redistribution and waste management activities. Through badges, leaderboards, and impact summaries, users receive recognition for their efforts and are motivated to increase participation. The feature translates community engagement into measurable outcomes, displaying tangible environmental and social impacts such as food saved and emissions reduced. By linking individual actions to collective results, Score reinforces behavioral change, enhances user retention, and strengthens the platform's capacity to drive meaningful sustainability outcomes.

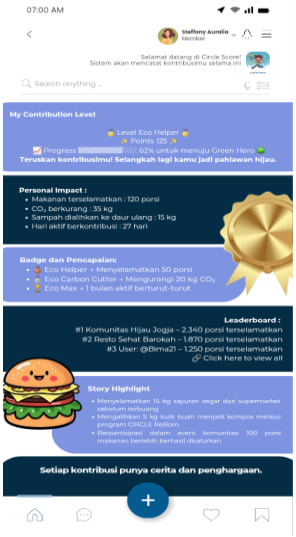

Fig. 6. CIRCLE score feature

3.1.7 CIRCLE learn feature

Learn is a digital literacy center that provides users with access to a diverse array of educational content related to food management, including news updates, government regulations, instructional materials, and practical guidance. By facilitating ongoing knowledge acquisition and regulatory comprehension, Learn empowers users to make

informed decisions and apply best practices within the CIRCLE ecosystem. This feature reinforces the platform's commitment to education and capacity building, fostering a culture of sustainable food management and awareness that aligns with the principles of circular economy and social responsibility.

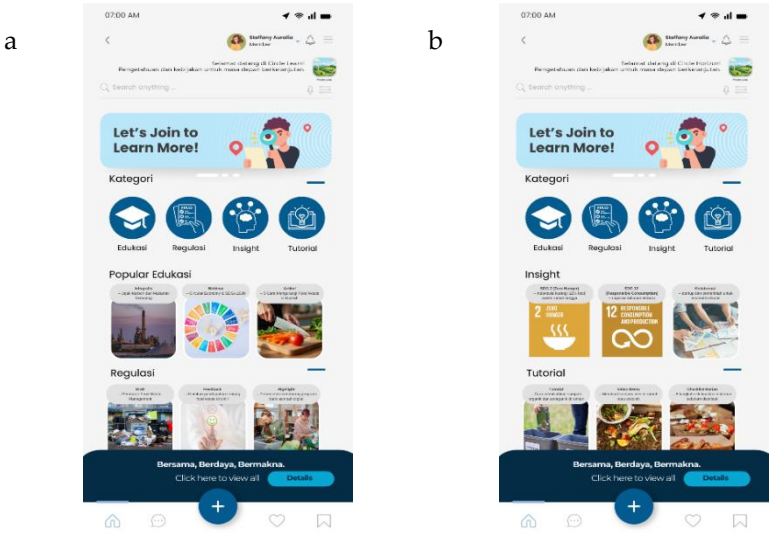

Fig. 7. CIRCLE learn Feature: a) education and regulation menus; b) insight and tutorial menus

3.2 Designing the CIRCLE platform

The development of CIRCLE (Circular Utilization of Food Resources) began with the growing urgency to address food waste, which remains a significant challenge in Indonesia. The volume of food waste continues to increase and contributes not only to economic losses but also to social and environmental consequences, especially in efforts to build sustainable food security. Responding to this situation, CIRCLE was designed as a digital platform that brings together various stakeholders to optimize the reuse of surplus food and encourage the management of organic waste based on circular economy principles.

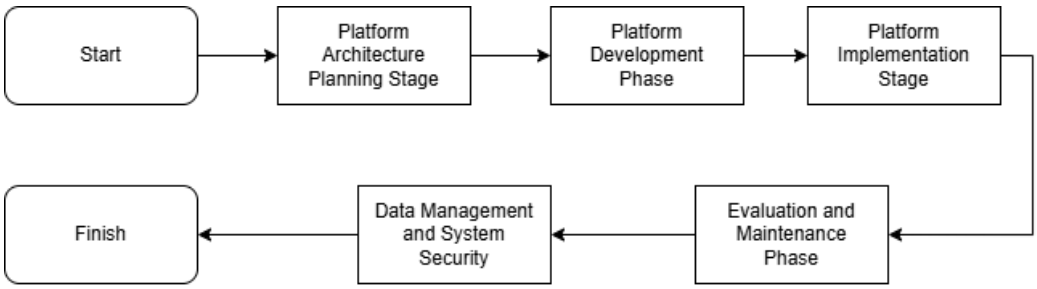

Fig. 8. Flowchart of the CIRCLE platform design stage

Conceptually, the platform design process is divided into four essential stages: planning, development, implementation, and evaluation and maintenance. These stages are supported by strong data security systems, information management frameworks, and monitoring mechanisms that ensure the platform operates effectively and remains sustainable in the long term.

3.2.1 Platform architecture planning and development stages

The first stage in designing the CIRCLE platform is planning, which focuses on identifying problems and user needs. Initial analysis was conducted through a literature study which showed that there are still imbalances in food distribution, low sustainability

literacy, and a lack of collaborative forums between stakeholders regarding food surplus issues in Indonesia. Therefore, the planning stage resulted in a design with eight main features, namely Map, Forum, Connect, Bank, Recycle, Safe, Score, and Learn. These eight features are designed to provide comprehensive solutions, ranging from food distribution, waste management, food safety verification, to education and sustainability literacy.

The development phase includes system architecture design, user interface, and supporting technology integration. At this stage, a centralized database is designed to manage information on food surplus, distribution logs, transactions, and user contribution history. An artificial intelligence module is applied in Safe feature to analyze food quality through digital images and checklists.

In addition, a recommendation algorithm is developed in the Connect feature to match surpluses with recipients and the most efficient distribution channels. In terms of user experience, the interface is designed based on human-centered design principles, prioritizing simplicity, accessibility, and clarity of information. At this stage, a data security system is also embedded in the form of end-to-end encryption, multi-layered authentication, and user activity monitoring mechanisms to prevent misuse.

3.2.2 Platform implementation stage

The platform implementation stage is realized in the form of developing web-based and mobile application prototypes. Limited trials are conducted in specific communities to assess the feasibility and effectiveness of features, particularly Map, Connect, and Bank, which are the main pillars of food distribution and waste management. The implementation also involves multi-stakeholder integration, where food providers can record their surplus, recipient communities can access distribution, while food banks play a role in stock management. Furthermore, to support operations, a real-time notification system is provided, such as notifications of surplus availability, warnings of unfit food, and user contribution achievements.

3.2.3 Evaluation and maintenance phase

The evaluation and maintenance phase aims to ensure the sustainability of the system. Technical evaluations are conducted to assess server reliability, food verification algorithm accuracy, and application responsiveness. Social and environmental evaluations focus on the impact generated, such as the amount of surplus distributed, the volume of organic waste successfully processed through the Recycle feature, and the estimated reduction in carbon emissions displayed on the Score feature. Furthermore, user experience-based evaluations are collected through feedback in the Connect forum and the Learn module, so that feature improvements can continue to be made. Continuous maintenance includes algorithm updates, security system enhancements, and the development of new modules in line with the dynamics of community needs and government regulations.

3.2.4 Data Management and System Security

As an integral part of the overall process, data management and system security are inseparable elements. The data collected, ranging from surplus location information, distribution, transactions, to user contributions, is processed and stored with high encryption standards and periodic backups. User identities are anonymized to maintain privacy, with a maximum data retention policy of twelve months before being deleted or permanently archived. System monitoring is carried out through activity log recording and periodic audits to ensure transparency and accountability. With its comprehensive design, CIRCLE is expected to provide innovative solutions to food waste issues, not only as a food distribution application but also as a digital ecosystem that strengthens collaboration, educates the public, and creates sustainable social and environmental impacts.

3.3 CIRCLE application usage mechanism

The CIRCLE usage mechanism is systematically designed so that every stakeholder can actively contribute to reducing food waste while strengthening sustainable food security. These stages not only regulate operational flows, but also cover aspects of security, transparency, and data management. Based on the chart above, the CIRCLE Platform usage mechanism consists of user profile registration, food data input and validation, needs matching, and many more.

In the initial stage, users are required to register by filling in their basic identity and selecting their role in the CIRCLE ecosystem, such as beneficiary, volunteer, distribution partner, or waste contributor. This process is equipped with a digital verification system to ensure data validity. This security is important so that food distribution is accountable and minimizes the potential for misuse. Then users can enter surplus food data through a digital interface that includes food type, quantity, location, condition, and estimated shelf life. The data is then verified using a validation algorithm and AI-based food safety check that can identify food suitability based on visual parameters and expiration dates. This stage functions as a food safety filter to ensure the quality of the food distributed.

Third stage is intelligent matching system; validated data will be processed by an algorithm-based matching system. This system considers geographical location, nutritional needs of recipients, logistical capacity, and urgency. With a real-time recommendation approach, the risk of food waste can be reduced while ensuring that recipients receive supplies that meet their needs. After matching, distribution can be carried out through independent options or logistics partners integrated with the platform. All movements are recorded through a transparent monitoring dashboard that can be accessed by both donors and recipients. The system is equipped with real-time status notifications (e.g., “in transit” or “received”) and geo-tracking features to ensure the security and accuracy of distribution.

In addition to food surpluses, the community can deposit inorganic waste (plastic, cardboard, bottles) into the Bank system. Each deposit is recorded and automatically converted into digital points that can be exchanged for vouchers, environmentally friendly products, or marketplace credit. This mechanism encourages the community to participate in waste management while creating new economic value from waste. Further step is organic waste processing, food scraps or organic waste that is unfit for consumption can be processed into compost, animal feed, or bioenergy. This process is facilitated by community partners or processing facilities connected to the platform. Users participating in this program can monitor the progress of processing, and the final results can be resold through Bank Market.

Every contribution to food distribution, waste collection, and educational participation will be recorded as points that accumulate in the gamification system. These points determine the level of contribution, ranging from Eco Helper to Food Guardian. In addition, users also receive badges, positions on the leaderboard, and impact reports in the form of the amount of food saved and carbon emissions reduced. Through the Learn feature, users can access educational content (articles, infographics, webinars), food regulations, SDG insights, and practical field tips. This stage not only improves user literacy but also builds collective awareness of the importance of food management within the circular economic framework

After the interaction is complete, the system provides a feedback channel for users. This input is processed through an internal analytics system for periodic evaluation and development of new features that are more suited to the needs of the community. Thus, CIRCLE is adaptive and responsive to field dynamics.

All user data, distribution, waste deposits, and contributions are managed in a centralized database with data security and privacy protection principles. Multi-layered encryption, double authentication, and role-based access controls are implemented to ensure information security. Aggregate data analysis is used to map food and waste

surplus trends, while supporting food security policy-making at the regional and national levels.

3.4 Technical architecture and system infrastructure of CIRCLE

The technical architecture of CIRCLE is designed to ensure that all platform functions ranging from surplus food redistribution to waste processing and community literacy operate reliably, securely, and efficiently. The architecture integrates a multilayered system that connects the user interface, application logic, databases, and monitoring services into a cohesive operational framework. This structure enables real-time data processing, seamless communication between stakeholders, and the accurate execution of core platform features.

At the foundation of the system lies a centralized database that stores information on food surplus entries, user profiles, transaction histories, distribution records, waste deposits, and activity logs. This database supports rapid data retrieval and high-volume input, ensuring that operational activities remain responsive as user numbers grow. The application layer incorporates intelligent algorithms, including the recommendation system used in Connect and the image-based verification model embedded in Safe. These components process user data, generate contextual insights, and facilitate decision-making to direct food or waste resources to the most appropriate endpoints.

The system architecture also integrates real-time services such as geo-tracking, notification delivery, and distribution monitoring. These services rely on an event-driven communication model that updates users continuously about status changes in ongoing redistribution activities, community contributions, and system alerts. To ensure user accessibility, the platform is deployed in both web-based and mobile versions, each optimized through human-centered design principles that prioritize clarity, ease of navigation, and functional simplicity.

Data protection forms a core part of architecture. End-to-end encryption, multi-factor authentication, anonymization mechanisms, and role-based access controls safeguard user information and prevent unauthorized access. The system undergoes periodic audits, vulnerability testing, and performance reviews to maintain integrity and ensure that the platform remains resilient against misuse, data breaches, or operational disruptions. By combining robust technical components with adaptive monitoring tools, the architecture enables CIRCLE to function as a scalable, secure, and future-oriented digital ecosystem.

3.5 System integration and user interaction model

The effectiveness of CIRCLE relies not only on its technical infrastructure but also on the integration of its features and their connection to user interaction flows. The platform is structured so that all components: Map, Forum, Connect, Bank, Recycle, Safe, Score, and Learn are operate as an interconnected system rather than as standalone tools. This integration ensures consistency, reduces operational friction, and creates a holistic digital environment where users can transition smoothly between activities. The user interaction model begins with registration and profile identification, which determine each user's role within the ecosystem. These roles influence access rights, feature visibility, and recommended activities, resulting in a personalized and efficient user experience. The interaction flow continues through key stages such as data input, validation, matching, distribution, waste deposition, knowledge access, and community engagement. Each action triggers automated processes, such as notifications, status updates, or safety verification that guide users and maintain operational continuity.

Integration across features is achieved through shared databases, unified dashboards, and synchronized monitoring tools. For example, surplus food submitted through Connect is automatically linked to distribution records visualized in Map, while safety results generated in Safe are incorporated into user decision-making and community reporting. Likewise, contributions recorded in Bank or Recycle are reflected in Score, which then

provides users with real-time progress indicators and impact summaries that reinforce participation. The interaction model also emphasizes transparency and collaboration. The Forum enables dialogue, coordination, and exchange of field experiences among stakeholders, complementing the data-driven mechanisms of the platform with collective intelligence. Meanwhile, Learn supports continuous literacy improvement, ensuring that users have access to updated guidance, regulations, and best practices relevant to sustainable food management. By combining integrated system operations with intuitive interaction flows, CIRCLE strengthens engagement, promotes accountability, and enhances the overall effectiveness of its sustainability mission. This cohesive model allows the platform to function not only as a digital tool but also as a participatory ecosystem that aligns technological innovation with community-led environmental action.

3.6 SWOT analysis of CIRCLE Platform

The SWOT analysis was conducted to identify the strengths, weaknesses, opportunities, and threats that could influence the design of the CIRCLE platform. This framework serves as a strategic foundation for the effective and sustainable development of the platform in addressing food waste issues in Indonesia. SWOT is widely recognized as one of the most popular strategic planning tools (Phadermrod et al., 2019). It provides a logical and structured approach to examining internal and external factors, both positive and negative that may affect a business or project (Miino et al., 2025).

3.6.1 Strengths

The CIRCLE platform demonstrates several key strengths that enhance its potential for reducing food waste in Indonesia. It comprises eight core components Map, Forum, Connect, Bank, Recycle, Safe, Score, and Learn, which together address food redistribution, waste management, food safety verification, and sustainability education in a unified ecosystem. This integrated, multi-feature design enables CIRCLE to tackle food waste across the entire value chain, aligning with circular economy principles and promoting sustainable behavior. The Safe feature employs an artificial intelligence module to assess food quality through images and checklists, while Connect uses a recommendation algorithm to match surpluses with the most efficient recipients. The platform's interface follows human-centered design principles, prioritizing simplicity and accessibility, and the Score and Learn features incorporate reward-based mechanisms that encourage user participation and behavioral change, supporting sustained engagement (Nkwo et al., 2021). Additionally, CIRCLE implements end-to-end encryption, multi-factor authentication, and user activity monitoring to prevent misuse, reinforcing user trust and supporting broader adoption. By combining these technological, user-centered, and secure features, the platform aligns with the principles of the Circular Economy, particularly in redistribution, reuse, and recycling.

3.6.2 Weaknesses

Despite its strengths, the CIRCLE platform faces several internal limitations. Uneven digital infrastructure, including limited internet connectivity and server capacity in certain regions, may hinder access and usability. The complexity of its multi-feature design can create confusion for users with limited digital literacy, potentially reducing engagement. Furthermore, managing and maintaining a large database involves high operational costs, posing challenges for long-term sustainability. Addressing these weaknesses will require strategies such as user-friendly interface adjustments, low-data functionality, and sustainable operational planning to ensure equitable access and consistent performance.

3.6.3 Opportunities

Externally, the CIRCLE platform has significant opportunities to grow and make a meaningful contribution to reducing food waste. Increasing public awareness of sustainability issues and government support in developing a circular economy provide a strong foundation for the continuous growth of the CIRCLE platform. The presence of food-conscious communities, non-governmental organizations, and smart city initiatives across various regions can serve as strategic partners in implementation. Moreover, the increasing trend of digitalizing public services creates an opportunity for the CIRCLE platform to integrate with existing systems, such as food banks or online donation platforms. These opportunities align with the global commitment to the Sustainable Development Goals (SDGs), particularly Goal 12 on Responsible Consumption and Production, which emphasizes reducing food loss and waste through innovation, collaboration, and the efficient use of resources (United Nations, 2015).

3.6.4 Threats

Despite its great potential, the CIRCLE platform still faces several threats that need to be anticipated in order to maintain its sustainability. First, competition with similar platforms in the future could reduce the appeal of the CIRCLE platform if innovation is not continuously pursued. Second, data security risks and the potential for misuse of information could undermine user trust and platform integrity. In technology adoption literature, security concerns have been shown to significantly inhibit uptake (Phaphoom et al., 2015). Finally, regulatory uncertainty regarding food distribution and waste management policies at local level could also hinder the consistent implementation of the CIRCLE platform in various regions.

Taken together, the SWOT analysis indicates that the CIRCLE platform has strong potential to serve as an innovative digital solution for food waste reduction in Indonesia. Its strengths and opportunities align closely with national sustainability goals and global circular economy practices. However, effectively addressing weaknesses and anticipating threats will require careful planning, strategic partnerships, and continuous development. With these considerations, CIRCLE can become a scalable, inclusive, and impactful platform that contributes meaningfully to a sustainable and circular food ecosystem.

3.7 Indicators of success and sustainability impact

The effectiveness of the CIRCLE platform in reducing food waste and strengthening sustainable food governance is evaluated through a series of indicators that capture behavioral change, environmental improvements, socio-economic benefits, and system-wide collaboration. These indicators ensure that the platform's contribution is not only operational but also transformative, reflecting progress across multiple dimensions of sustainability. The first category of indicators focuses on behavioral change among users and communities. These include increases in active participation, consistency in food redistribution activities, volunteer engagement, and user retention across the platform's features. The frequency of user contributions, participation in literacy modules, and sustained involvement in waste management functions demonstrate the extent to which CIRCLE successfully fosters awareness, responsibility, and long-term commitment toward sustainable practices. Behavioral improvements serve as a foundational measure of success, as they indicate growing adherence to responsible food management and the strengthening of community-driven environmental values.

The environmental dimension is assessed through measurable reductions in food waste volume, organic waste processing rates, and estimated decreases in carbon emissions. The platform tracks the amount of surplus food redistributed through the intelligent matching system, the volume of organic waste converted into compost, feed, or bioenergy, and the environmental value generated from these activities. By quantifying

ecological outcomes, CIRCLE provides a transparent picture of its contribution to reducing resource inefficiencies and mitigating the environmental pressures associated with wasted food. Socio-economic indicators highlight the platform's role in strengthening food access, promoting local economic cycles, and increasing community resilience. These include the number of beneficiaries reached, the equitable distribution of surplus food across regions, improvements in nutritional access for vulnerable groups, and the economic value created through the digital waste bank. Waste deposits converted into points support micro-economic empowerment and encourage the community to adopt circular practices, reflecting how the platform transforms previously discarded materials into valuable assets.

The institutional and systemic dimension evaluates CIRCLE's ability to build collaboration between diverse stakeholders. This includes the quality of coordination among donors, volunteers, logistics partners, food banks, community organizations, and local authorities. Indicators such as response accuracy, distribution transparency, data integration, and multi-stakeholder participation demonstrate the platform's capacity to function as a governance tool that strengthens partnerships and supports more coherent and inclusive decision-making in food management. Overall, these interconnected indicators confirm that CIRCLE operates not merely as a technological solution but as a comprehensive ecosystem that drives long-term behavioral, environmental, and socio-economic improvements. Through an integrated approach that combines community empowerment, digital innovation, and circular resource management, the platform provides a sustainable pathway toward reducing food waste while fostering a more equitable and resilient food system.

4. Conclusions

The CIRCLE platform presents a promising digital solution to address food waste in Indonesia through its integrated features Map, Forum, Connect, Bank, Recycle, Safe, Score, and Learn. These components collectively facilitate food redistribution, waste management, food safety verification, and sustainability education, creating a unified ecosystem that aligns with circular economy principles and encourages behavioral change among users. The SWOT analysis indicates that the platform's strengths and external opportunities provide a solid foundation for sustainable development and potential scalability. Nevertheless, limitations such as uneven digital infrastructure, complex multi-feature navigation, high operational costs, data security risks, and regulatory uncertainties need to be addressed to ensure effective adoption and long-term viability. Strategic planning, user-centered design, robust governance, and stakeholder collaboration are essential to mitigate these challenges.

Future research should focus on pilot testing in selected regions to assess usability, community acceptance, and the effectiveness of platform features in reducing food waste. Studies could also explore integration with existing food donation systems, behavioral impacts, and policy alignment to enhance scalability and social impact. In conclusion, with careful implementation, continuous improvement, and collaborative partnerships, the CIRCLE platform has the potential to become a scalable and impactful digital tool that strengthens Indonesia's transition toward a sustainable and circular food ecosystem.

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Author Contribution

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During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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