

The Effectiveness of Digital Waste Management Application Gamification in Fostering Environmental Awareness and Operational System Sustainability

Rahayu Mardikaningsih, Mila Hariani, Reny Nuraini

Universitas Sunan Giri Surabaya

Email: rahayumardikaningsih@gmail.com

ABSTRACT – The rapid growth of urban waste volume demands innovative environmental governance based on information technology and active public participation. This study aims to analyze the effectiveness of gamification mechanics in mobile waste management applications in transforming social behavior and ecological awareness, while formulating operational management strategies for waste processing to sustain public participation. A sequential explanatory mixed-methods approach was applied through a combination of quantitative surveys among active application users and qualitative exploration via in-depth interviews and field observations. The findings reveal that interactive elements such as point accumulation, achievement badges, and communal leaderboards significantly increase household waste separation consistency by fostering intrinsic motivation and establishing new social norms. Conversely, the sustainability of citizen participation strongly depends on the reliability of physical collection systems, Global Positioning System-based fleet route optimization, recycling supply chain efficiency, and the stability of incentive financing schemes. This study concludes that integrating user-friendly digital game design with reliable field logistics is the primary key to achieving sustainable urban environmental governance driven by community involvement.

Keywords: gamification, digital waste management, social behavior change, environmental awareness, operations management, recycling, mobile application.

A. INTRODUCTION

The rapid growth in the volume of urban waste poses a serious threat to environmental sustainability and modern public health. Conventional waste management approaches

frequently fail due to the low active participation of residents in sorting waste at its source. The emergence of digital technology in the form of mobile waste management applications that integrate gamification elements offers a new approach to motivating behavioral change in society (Su et al., 2025). The provision of points, badges, and leaderboards within the application creates a psychological incentive mechanism that encourages consistent waste-sorting habits. Darmawan and Mardikaningsih (2022) state that positive psychological factors play an important role in shaping individual engagement and commitment to an activity, a principle relevant to the design of incentives in waste management applications. Seabright et al. (2021) argue that the use of interactive game-based incentives can shift social norms and meaningfully increase user engagement with environmental programs. Warin and Darmawan (2024) add that continuous feedback is a determining factor in forming adaptive behavior, so point and badge features need to be designed as consistent feedback to keep waste-sorting habits intact.

Integrating gamification mechanics into the operational system of digital waste processing requires structured and measurable management planning (Pienwisetkaew et al., 2025). Mardikaningsih et al. (2022) assert that ethical leadership forms the basis for a positive and sustainable organizational culture, a principle platform managers need to apply when designing technology-based waste management policies. Digital platform providers are required to manage the waste collection supply chain efficiently so that the incentives promised in the application can be realized in the field. Putra and Arifin (2021) explain that digital transformation through big

data, artificial intelligence, and the internet of things can optimize the efficiency of the waste collection and distribution supply chain. Triono et al. (2025) reveal that digitalization reshapes the task architecture of the workforce, so the physical waste-pickup process needs to adjust its work patterns to keep pace with data updates in the application. Mardikaningsih, Hariani, et al. (2024) found that digital monitoring affects employee work autonomy and professional responsibility, so oversight of waste collection personnel needs to be designed carefully to avoid reducing their work motivation. A mismatch between achievements within the digital application and the speed of physical waste pickup can damage users' trust in the system. Darmawan et al. (2025) argue that blockchain can serve as a transparent, decentralized recording instrument, allowing discrepancies between digital data and field conditions to be traced more accountably. Maulani et al. (2023) explain that the validity of electronic contracts is important for guaranteeing legal certainty over the incentives promised by the application, thereby maintaining user trust. Financial and non-financial incentives offered through application features must be designed to align with the available operational budget for waste processing. Mardikaningsih, Wardoyo, et al. (2024) state that digital-based human resource development policy drives sustainable service innovation, so the application's incentive strategy needs continuous updates to stay aligned with budget conditions and user needs. Darmawan and Mardikaningsih (2023) contend that flexible organizational structures strengthen a company's adaptive capacity to environmental dynamics, so platform providers need a similar structure to adjust incentive schemes quickly. Darmawan (2024) adds that managing workforce diversity drives innovation and team performance, so a diverse development team is more likely to produce incentive designs that are more adaptive to user needs. Bitrián et al. (2021) emphasize that the sustainability of user interaction with gamification applications is strongly determined by perceived ease of use and the real value individuals directly experience.

The urban waste management crisis actually stems from a low level of ecological awareness and weak social norm bonds within society (Anyanwu et al., 2025). Mardikaningsih et al. (2025) found that education level acts as a moderator in the relationship between

environmental concern and residents' participation in waste bank programs, indicating that gaps in ecological awareness are also shaped by the educational background of the community. Most residents view waste sorting as an additional burden that consumes time without providing direct benefit to their lives. The absence of firm social sanctions for cleanliness violations further worsens residents' apathy toward maintaining their residential environment. The accumulation of illegally dumped waste in public facilities triggers adverse impacts, including soil pollution, groundwater contamination, and the spread of various infectious diseases. Khayru (2022) notes that artificial intelligence can potentially be used for early detection of health risks, including diseases arising from environmental pollution caused by illegally dumped waste. Local government initiatives to promote cleanliness campaigns often remain mere formal discourse without succeeding in changing residents' underlying mindset. Digital applications are present to address this impasse, but their effectiveness is often hindered by technology literacy barriers among senior citizens and unequal internet infrastructure access in peripheral areas. Darmawan et al. (2023) explain that the literacy-based digitalization era also changes patterns of work relations and communication, so the technology literacy gap among some residents becomes a real obstacle to adopting waste management applications. A failure to understand the dynamics of mass psychology causes gamification features to often feel tedious over the long term. Issalillah and Khayru (2025) assert that mental health aspects need to be considered when designing work environments and daily activities, a principle also relevant for ensuring that gamification features do not cause psychological fatigue among users. Platform managers often focus solely on instant reward mechanisms without succeeding in fostering a shared sense of ownership over the cleanliness of the surrounding environment. Putra et al. (2024) reveal that properly designed gamification can foster cooperation and empathy among individuals, suggesting this approach has the potential to build a shared sense of ownership over environmental cleanliness, rather than merely offering instant rewards. This phenomenon causes user activity levels to decline sharply after the initial promotional phase ends. Hamari et al. (2014) identify that

the effectiveness of gamification features tends to fade if not balanced with the formation of intrinsic motivation and the reinforcement of binding social norms among residents.

This research formulates problems regarding how the effectiveness of gamification features in digital waste management applications triggers social behavior changes and public environmental awareness. This research also formulates problems regarding how waste processing operational management strategies maintain the sustainability of citizen participation in the digital waste management ecosystem.

This research aims to analyze the effectiveness of gamification features in digital waste management applications in driving behavioral change and citizens' ecological awareness. This research also aims to formulate optimal waste processing operational management strategies to maintain the sustainability of active public participation. This research provides a theoretical contribution to the mapping of human and technology interactions within the realm of environmental sociology and digital operational management. Practically, the results of this study present strategic guidelines for application developers and policymakers in designing sustainable public participation-based waste processing ecosystems.

B. METHOD

This research applies a qualitative approach based on a literature study to explore the effectiveness of gamification in a measurable yet in-depth manner based on the synthesis of various empirical findings documented in the literature. This study examines the results of previous research measuring intrinsic motivation perceptions, feature ease of use, and daily waste sorting frequency of digital waste management application users in metropolitan areas. In addition, literature searches are also focused on social adaptation patterns, operational constraints, and the dynamics of citizen community involvement as portrayed in various published case studies and field reports. Tashakkori et al. (2021) explain that the combination of quantitative and qualitative approaches provides a strong evidence base in explaining behavioral change phenomena triggered by technology, and in the context of literature study, the synthesis of both types of findings can be integrated through comparative reviews across various literature sources.

Data in this research were gathered through systematic searches of reputable journal articles, research reports, policy documentation, and technical publications relevant to gamification and digital waste management. The researcher explored quantitative findings from previous survey studies measuring variables of intrinsic motivation, feature ease of use, and daily waste sorting frequency, without conducting primary data collection. Similarly, qualitative aspects such as social adaptation patterns, operational constraints, and the dynamics of citizen community involvement were traced through narratives from case studies and observation reports documented in academic and industry literature. Saunders et al. (2019) emphasize that the integration of statistical data and qualitative narratives is capable of enriching the analysis of social dynamics in operational management studies, and within the framework of a literature study, such integration is realized through the synthesis of various findings from independent literature sources.

Data analysis was carried out through the stages of data reduction from all library materials, data presentation in the form of narrative matrices, and drawing conclusions or verifying findings. Data coding was performed thematically based on variables of intrinsic motivation, feature ease of use, waste sorting frequency, social adaptation patterns, and operational constraints arising from the literature. Data validity was maintained through library source triangulation procedures as well as cross-examinations among references to ensure consistency of findings. Creswell and Creswell (2018) assert that dual validity testing guarantees the accuracy of scientific interpretation regarding the social phenomena studied.

C. RESULTS AND DISCUSSION

The Effectiveness of Gamification in Digital Waste Management Apps in Promoting Social Behaviour and Environmental Awareness

Measurement of the effectiveness of gamification mechanics on digital waste processing platforms shows a significant positive correlation with increased intensity of community participation. Mardikaningsih and Darmawan (2025) explain that the use of big data analytics can improve a company's environmental performance from a managerial

standpoint, an approach relevant for measuring the effectiveness of gamification features in waste management applications. The use of interactive elements such as daily point registration, achievement badges, and communal rankings triggers users' psychological drive to sort waste routinely (Kahl et al., 2025). Users who actively interact with the incentive features show a level of consistency in sorting organic and inorganic waste twice as high as non-user groups. This new behavioral pattern is formed due to direct visual feedback that shows an individual's real contribution to reducing their carbon footprint. This psychological incentive gradually shifts public perception, from previously regarding waste sorting as an operational burden to viewing it as an enjoyable daily activity that provides personal satisfaction (Zadik & Katz, 2025).

An interface design that integrates a transparent reward system becomes a crucial factor in strengthening the public's intrinsic motivation to engage in environmental action (Jagtap et al., 2025). Exchanging accumulated points for direct economic rewards or shopping vouchers effectively maintains the platform's appeal during the early stage of technology adoption. However, the long-term sustainability of residents' participation is more strongly influenced by a sense of personal achievement and the social drive to be recognized by those around them. Mardikaningsih and Essa (2025) note that alignment between sustainability values and individual commitment can reduce the tendency to disengage from an activity, a factor that also applies to maintaining users' long-term engagement with waste-sorting applications. Users feel that their contribution in reporting the volume of sorted waste provides a real impact on the cleanliness of their living environment. This strengthened intrinsic motivation prevents a decline in user activity when the value of financial incentives is adjusted. Users' emotional attachment to the digital platform forms when the system is able to present an actual and measurable record of individual environmental impact, such as the estimated amount of methane emissions prevented or the area of landfill land saved. This success indicates that the design of game features in the application must not merely focus on the point accumulation mechanism, but must also deeply touch on individuals' ecological awareness and social responsibility (Hassan et al., 2019).

Social interaction built through the communal leaderboard feature creates healthy competition among residents at the neighborhood and village level. The presence of this public competition space indirectly forms a new social norm that encourages residents not to remain indifferent to the cleanliness of their residential environment (Buntaine et al., 2024). Residents who were previously apathetic begin to feel encouraged to sort household waste so as not to fall behind their neighbors' achievements. This shift in social norms strengthens the sense of togetherness and communal cohesion in independently overseeing environmental management. Issalillah and Hardyansah (2022) warn that unequal access to digital information and the spread of misinformation can weaken participation and trust within a local population, a risk that needs to be anticipated so that the leaderboard feature does not instead trigger unhealthy rivalry. The presence of implicit social sanctions for residents who participate less further accelerates the adoption of waste-sorting habits within the community. The strengthening of communal values through the digital platform is able to revive residents' spirit of mutual cooperation, which had faded due to rapid urbanization. Residents identify themselves as part of a collective movement aimed at creating a clean, healthy, and environmentally friendly residential area. This shift in mindset proves that the integration of information technology and game mechanisms can effectively reach the sociological dimension of society (Abtan et al., 2021).

An increase in the public's ecological understanding is clearly reflected in the decline in waste contamination levels at waste bank units integrated with the digital platform (Singh & Indapurkar, 2025). Residents begin to understand the fundamental differences between various types of plastic, paper, and hazardous and toxic waste through interactive educational modules provided within the application. This practical knowledge is applied directly in daily life when putting waste into separate bags before it is collected by operational officers. Mardikaningsih and Nuraini (2022) state that the application of circular economy principles is key to sustainable waste management in the industrial sector, so a reduction in contamination at the household level directly supports the readiness of collected waste to be reprocessed into raw

material. This reduction in waste contamination levels eases the recycling process at the industrial level and increases the economic value of the collected waste.

Integration of the community challenge feature accelerates the institutionalization of environmentally friendly behavior at the local group level (Qiao & Zhang, 2023). Environmental cleanup activities scheduled collectively through the application achieve a higher level of participation compared to conventional manual appeals. Hariani and Putra (2025) find that work redesign based on task characteristics can improve team performance through better coordination and collaboration, a principle also visible in how the community challenge feature organizes collective cleanup activities among residents. Users feel more encouraged to attend because every physical activity carried out is recorded as a group contribution point. Eddine and Darmawan (2025) note that a digitally supported work environment helps individuals maintain a balance between daily obligations and other activities, so scheduling collective cleanup activities through the application needs to consider residents' available time so participation does not become an additional burden. This dynamic shows that gamification elements are able to bridge the relationship between digital interaction on a smartphone screen and real action in the field.

The availability of a real-time cleanliness violation reporting feature provides space for residents to play an active role as environmental monitors in their residential areas (Akkamahadevi, 2025). Reports accompanied by photo evidence and precise location are directly connected to the handling system of the city's cleanliness management operational team. Darmawan et al. (2020) state that the quality of human resources determines job performance and loyalty within an organization, a factor that also determines how quickly and accurately the field operational team responds to residents' reports. Eddine et al. (2023) add that knowledge management and quality of work life strengthen employee commitment, an element that needs to be maintained among field officers so their responsiveness to public reports remains consistent. The quick response from field managers to residents' reports increases public satisfaction and trust in the effectiveness of the digital waste management system. Darmawan, Mendonca,

and Isaac (2022) explain that managing corporate reputation in the digital era requires responsiveness and transparency toward public complaints, a principle also relevant for platform managers in maintaining public trust in the waste reporting system. Active participation in environmental monitoring strengthens the public's sense of ownership over the cleanliness of surrounding public facilities.

The accessibility of a user-friendly application interface extends the reach of technology adoption to elderly groups within residential areas (Nayan et al., 2024). Mardikaningsih and Darmawan (2022) explain that self-efficacy plays a role in predicting an individual's adaptability to technological change, so building confidence among elderly users is just as important as simplifying the application's features. The simplicity of the waste volume recording process and the clarity of point-exchange information removes technical sophistication barriers for lay users. The success of this feature simplification ensures that the process of digital inclusion in waste management can run evenly without neglecting groups with limited technology literacy. This equality of access is very important to guarantee the creation of social behavior change on a broad, mass scale.

Another social impact that can be observed is the growth of a creative economy ecosystem based on waste recycling management at the local level (Utomo et al., 2024). Local women's and youth groups use waste collection points as initial capital to develop high-value-added handicraft products. Mardikaningsih (2025) states that the deconstruction of conventional work patterns opens up more flexible forms of work in the digital era, a shift also reflected in how local groups build new sources of income from waste-recycling activities. The digital platform provides a direct marketing channel for these recycled products to other users within the application ecosystem. This synergy between environmental preservation and residents' economic empowerment strengthens the resilience of the public participation-based waste processing program.

The high level of ecological awareness built through the gamification application has a direct implication on the decline in the amount of waste generated that ends up at final processing sites. This reduction in waste load provides savings in the operational budget for

waste transportation for the local government (Silva et al., 2022). The remaining allocated funds can be redirected toward developing more modern and environmentally friendly waste management infrastructure. Khayru (2025) explains that digital twin technology can support sustainable infrastructure management across various organizational scales, an approach that local governments could consider when planning the development of more efficient waste management facilities. This budget efficiency proves the success of combining technology-based social intervention with government operational management.

Denzin and Lincoln (2011) explain that a comprehensive evaluation of user interaction dynamics requires an approach capable of capturing the social meaning behind behavioral patterns, not merely quantitative measures of participation. A comprehensive evaluation of user interaction dynamics confirms that gamification is a highly potential behavioral intervention tool if designed appropriately. The success of changing society's social behavior depends heavily on the alignment between game element design, incentive clarity, and ease of operational access in the field. The formation of this new habit becomes the main foundation for creating sustainable urban environmental governance based on active public participation.

Operational Management Strategies for Waste Treatment to Ensure the Sustainability of Community Participation

Operational system management within the digital waste-processing ecosystem requires precise harmonization between virtual data flow inside the mobile application and the handling of physical logistics in the field. The sustainability of active resident participation depends heavily on the reliability of the waste collection supply chain managed by the operational team in a planned manner (Fujii et al., 2022). Residents' environmental awareness and everyday lifestyle habits are known to shape their willingness to reduce and sort waste, so consistent participation cannot be separated from this underlying behavioral factor (Issalillah, 2025). Once residents have sorted their waste and recorded it through the application feature, delays in the collection fleet can instantly damage public trust in the platform manager's credibility. Adequate access to technology and digital skills among

residents also determines how smoothly this waste data can be recorded through the application (Arifin & Darmawan, 2021). Arranging dynamic fleet routes based on pickup location coordinate data becomes the key factor in maintaining fuel cost efficiency and operational punctuality. Punctual collection schedules for sorted waste generate a sense of appreciation among residents, which in turn strengthens their commitment to keep participating in the environmental cleanliness program consistently. Synchronization between physical collection activities and real-time reward point updates within the application creates a smooth and satisfying user experience. The reliability of this operational infrastructure prevents resident disappointment that could trigger a sharp decline in the number of active participants in the urban waste management ecosystem.

Applying fleet tracking technology based on the Global Positioning System together with route optimization algorithms improves the operational efficiency of daily waste collection (Sulemana et al., 2019). This efficiency directly lowers fuel costs and the accumulated travel time of collection vehicles on the road. The fleet's speed in picking up sorted waste from residents' homes helps minimize the risk of organic waste decomposing at the household level, which often causes unpleasant odors. Well-structured fleet management gives residents certainty of service, so their waste-sorting habits are not disrupted by uncertain collection schedules. Leadership oriented toward digital transformation also plays a part in sustaining this kind of operational efficiency, since it encourages closer collaboration and innovation as new fleet technologies are adopted (Darmawan & Gardi, 2024). The readiness of temporary storage facilities and unit waste banks to absorb incoming volumes of recyclable material must also be ensured, so that waste does not pile up at collection points. Removing logistical obstacles in the field is a fundamental key to keeping public participation at a consistently high level. Bing et al. (2016) affirmed that integrating information technology into recycling supply chain planning greatly determines the success of operations and the cost efficiency of urban waste collection.

Financial balance in managing the incentive program is the next operational pillar that determines the long-term sustainability of the digital waste-processing ecosystem (Ziabina & Acheampong, 2023). Platform managers must

design a rational and measurable point-conversion scheme so that it does not burden the operational budget of the company or local government. The economic value of the recyclable material collected must be allocated proportionally to fund the availability of rewards and the maintenance cost of the application system. Strategic partnerships with third parties such as retail businesses, regional government enterprises, and digital payment providers need to be built to expand the variety of rewards without draining the manager's main cash reserves. Organizational effectiveness as a whole is shaped by several interrelated factors, so incentive budgeting cannot be assessed apart from the platform's broader management performance (Darmawan, 2024). This diversification of funding sources ensures that the incentive program can keep running sustainably even amid fluctuations in the global recyclable-waste commodity price. Transparency in point calculation and certainty in the reward redemption process build the platform's positive reputation among the public.

Managing partnerships with the private sector and local government strengthens the platform manager's financial resilience in consistently providing attractive incentives to the public (Osei-Kyei et al., 2023). Application providers can draw on corporate social responsibility funding mechanisms from large companies to operate modern recycling facilities and expand the reward quota for residents. Applying sustainable supply chain principles alongside corporate social responsibility commitments has been shown to improve operational performance in comparable resource-recovery industries, which reinforces the value of building this kind of partnership (Barzani, Darmawan, & Zulkarnain, 2022). This synergy creates a healthy cross-financing scheme between revenue from secondary raw material sales and external funding assistance. A stable financing structure allows the platform provider to sustain promotional programs without a serious risk of operational budget deficits. Successful partnership fundraising guarantees incentives for active users who have consistently sorted their household waste. Bressanelli et al. (2018) argued that building a circular business ecosystem involving multiple stakeholders is an absolute requirement for achieving operational efficiency and financial sustainability in the waste-processing industry.

Improving the technical capacity of field officers and fleet drivers is an operational management focus that must not be neglected. Field workers need to be equipped with training on the officer-specific application to verify the type and weight of waste reported by residents (Manyonyi, 2023). Technology adoption in this context works best when paired with deliberate human resource development, since digital innovation on its own cannot sustain long-term operational quality (Mardikaningsih & Wardoyo, 2024). Good communication skills among field officers when interacting directly with residents also serve to strengthen social relationships and provide friendly education. A positive work climate built through authentic leadership likewise encourages field staff to go beyond their formal duties, which supports smoother service delivery (Mardikaningsih, Halizah, Darmawan, Masithoh, & Nuraini, 2022). Giving proper appreciation and fair work incentives to field officers raises productivity and reduces errors in recording sorting data in the field. As verification tasks become increasingly automated, field roles are gradually being redesigned, requiring officers to build new digital competencies (Darmawan, 2025). Highly motivated field workers carry out collection duties professionally, which ultimately leaves application users with a positive impression. Keeping staff engaged with these increasingly automated routine tasks requires deliberate strategies, rather than assuming that technology alone will sustain their motivation (Darmawan, 2024).

Structured training for operational human resources reduces the gap between waste volume reports in the application and the actual condition of material at the weighing facility. Trained officers can identify attempts at fraudulent volume recording by dishonest users quickly and accurately before reward points are sent automatically. The health and well-being of field officers, including senior staff, also affect how consistently they can maintain accuracy in a verification process that is becoming increasingly AI-assisted (Darmawan, 2020). This field verification reliability protects the validity of the digital ecosystem's data and prevents financial losses from incentive payments that do not match physical facts. Measuring how productively officers carry out these verification duties in a digital environment should also account for the creativity and initiative they bring to solving field problems (Darmawan, 2023). The quality

of service shown by field collection officers is also a benchmark of the platform manager's professionalism in the eyes of residents. Ensuring that older field workers are not left behind in this digital shift matters just as much for keeping the workforce inclusive and capable (Darmawan, 2023). Recognition of field officers' performance creates a conducive work environment and encourages high standards of waste collection service. Inclusive leadership that accounts for staff of varying ages and backgrounds further helps sustain this kind of motivation and reduce turnover among field workers (Darmawan, 2025). Attention should also go to how this kind of technology affects gender equality among field staff, since digital tools can narrow or widen existing workplace gaps (Darmawan, 2024). Gupta et al. (2019) identified that the readiness of digital-based operational workforce competence is a crucial element supporting the success of modern waste-processing system transformation.

The complaint-handling and technical support system for application users must be designed responsively to maintain user satisfaction and loyalty toward the digital platform. An integrated customer service center with a live chat feature within the application lets users report collection problems or failed point redemptions quickly (Akula, 2025). Resolving these issues quickly still needs to stay humanistic rather than purely mechanical, since balancing technological speed with a more human-centered approach is what keeps service genuinely trustworthy (Darmawan, 2023). Prompt problem resolution by the operational team demonstrates the manager's commitment to providing high-quality public service. Recapitulated complaint data is also used by management as periodic evaluation material to improve fleet driver performance and update problematic application features.

Quickly handling technical and operational problems directly prevents user frustration that could lead to permanently discontinued app use. Users who feel their concerns and complaints are handled well tend to remain loyal to the platform despite occasional minor technical disruptions (Korabayev et al., 2024). How residents interact with and perceive the platform through this kind of communication channel also shapes their sense of connection to it, much as it does on other digital and social platforms (Costa, Darmawan, & Isaac, 2022). The existence of an open communication channel between residents and managers

creates strong mutual trust within the digital waste management ecosystem. The psychological well-being and working relationships of the staff who handle these complaints matter here too, since how a team is organized for this kind of remote, ongoing interaction affects the quality of the response residents receive (Darmawan, 2023). Routine evaluation of user complaint records forms the basis for redesigning standard operating procedures to be more adaptive to the dynamics of public needs in the field. Effective problem handling meaningfully strengthens long-term active user retention. Esmaeilian et al. (2018) underlined that a fast, digitally integrated feedback mechanism plays a key role in improving the quality of urban waste management services.

Integrating waste-sorting data into the management information system allows managers to accurately map waste generation patterns by region and season. This analytical data is useful for planning fleet allocation, temporary storage capacity, and the scheduling of recyclable material delivery to processing plants efficiently (Koman & Krúpová, 2025). Treating this kind of data analysis as a genuine knowledge asset, rather than just an operational by-product, is what turns it into a real competitive advantage for the platform manager (Darmawan, 2023). The availability of precise data also makes it easier for managers to anticipate spikes in waste volume during religious holidays or national holidays. Planning operations based on scientific data keeps waste-processing facilities from the risk of overload that could disrupt the smooth running of the recycling process.

Using big data analysis to forecast waste generation patterns optimizes the use of warehouse storage space and prevents excessive accumulation of recyclable raw material. Operations managers can adjust the pace of selling recyclable material to processing industries more flexibly to obtain the most profitable selling price. Management decisions based on empirical data calculations significantly raise the platform manager's net profit margin (Sayed, 2025). This efficiency in storage and transport costs provides more financial room for expanding the operational network into new residential areas. Through the appropriate use of analytical data, platform managers can guarantee the stability and predictability of the supply chain's operational continuity. Wu et al. (2014) affirmed the

importance of using an integrated data analysis system to improve the accuracy of operational decision-making in the secondhand goods recycling supply chain.

Developing physical infrastructure in the form of clean, modern, and easily accessible unit waste banks is a major support for the success of digital waste-processing operations. Temporary storage sites must be managed according to strict sanitation standards so as not to cause foul odors, disease vectors, or an unsightly appearance that disturbs nearby residents' comfort (Qamari et al., 2023). Transforming the image of waste banks from a run-down location into a comfortable environmental education facility attracts residents from various social backgrounds to come and hand over their sorted waste directly. A well-maintained storage facility is concrete proof of the manager's seriousness in preserving the environment where residents live.

The availability of initial processing facilities such as plastic-shredding machines and paper-compacting machines at the unit waste bank level adds sale value to waste commodities before they are sent to large-scale recycling industries. This increase in material value automatically raises the income received by community-based waste bank managers and nearby residents (Maalouf et al., 2020). The presence of hygienic storage facilities equipped with simple processing technology builds local residents' pride in the waste-processing program running in their area. Strengthening this physical infrastructure completes the digital application's intervention, so that the waste management ecosystem can operate independently, efficiently, and provide real economic benefit to the wider public. The continuity between the sophistication of the digital system and the reliability of field operations is the main key to achieving resilient, inclusive, and sustainable urban environmental governance.

D. CONCLUSIONS

The application of gamification mechanics in digital waste management applications is effective in driving social behavior change and increasing the ecological awareness of urban communities. The integration of interactive elements such as reward points, communal rankings, and group challenges has

successfully shifted public perception regarding waste sorting from a burdensome activity into an enjoyable daily habit. The success of this behavioral transformation is heavily determined by the engagement of citizens' intrinsic motivation, the transparency of the reward system, and the ease of application interface access for various segments of society.

The implications of this research indicate that digital technology interventions cannot stand alone without being supported by operational management reliability in the field. Disparities between virtual recording activities within the application and the punctuality of physical waste collection fleets risk damaging public trust and drastically reducing citizen participation rates. The restructuring of the waste collection supply chain, strengthening the capacity of field officers, and transparency of incentive funding schemes are absolute prerequisites for maintaining the sustainability of a public participation-based waste management ecosystem. Local governments need to provide regulatory support, the provision of standardized unit waste bank facilities, and fiscal incentives for platform managers who succeed in reducing the volume of waste heading to final processing sites. Community members and local community leaders are encouraged to continue strengthening independent environmental monitoring and utilizing this digital ecosystem as a means of communal economic empowerment based on recycling.

REFERENCES

- Abtan, A., Basahel, A., & Basahel, S. (2021). Gamification in Environmental Sustainability: A Systematic Review of Applications and Impacts on User Behavior. *Sustainability*, 13(16), 9212.
- Akkamahadevi, C. (2025). Environmental Monitoring and Pollution Management. *Indian Scientific Journal of Research in Engineering and Management*, 09(01), 1–9.
- Akula, S. (2025). Digital Transformation in Waste Management Customer Service: Leveraging Ai and Automation for Improved Client Interactions. *International Journal of Computer Engineering and Technology*, 16(1), 747–757.

- Anyanwu, L. E., Felix, O. O., Ejike, I. W., & Anyanwu, I. O. (2025). Community-Based Waste Management Strategies and Their Impact on Urban Sustainability Through Citizen Participation and Local Government Collaboration. *World Journal of Advanced Research and Reviews*, 31(2), 1638-1650.
- Arifin, S., & D. Darmawan. (2021). Technology Access and Digital Skills: Bridging the Gaps in Education and Employment Opportunities in the Age of Technology 4.0, *Journal of Social Science Studies*, 1(1), 163 – 168.
- Barzani, L. A., Darmawan, D., & Zulkarnain, M. A. B. (2022). The Application of Sustainable Supply Chain Management Principles in the Manufacturing Industry to Improve Operational Performance and Corporate Social Responsibility. *International Journal of Service Science, Management, Engineering, and Technology*, 1(1), 38–45.
- Bing, X., Bloemhof-Ruwaard, J. M., Chaabane, A., & van der Vorst, J. G. (2016). Modeling the Reverse Logistics Network for Plastic Recycling in the Netherlands. *European Journal of Operational Research*, 254(3), 856–868.
- Bitrián, P., Buil, I., & Catalán, S. (2021). Enhancing User Engagement: The Role of Gamification in Mobile Apps. *Journal of Business Research*, 132(2021), 170–185.
- Bressanelli, G., Perona, M., & Sacconi, N. (2018). Reshaping the Supply Chain Capabilities to Enable a Circular Economy: A Conceptual Framework and Case Studies. *Supply Chain Management: An International Journal*, 23(4), 322–343.
- Buntaine, M., Komakech, P., & Shen, S. V. (2024). Social Competition Drives Collective Action to Reduce Informal Waste Burning in Uganda. *Proceedings of the National Academy of Sciences of the United States of America*, 121(23), 1-8.
- costa, S. da, Darmawan, D., & Isaac, A. de J. (2022). Self-Identity Formation and Social Perception of Individuals through Interaction on Social Media in a Digital World. *Journal of Social Science Studies*, 2(2), 273-278.
- Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications, Los Angeles.
- Darmawan, D. (2020). Health, Well-Being, and Productivity of Senior Employees in the Era of Artificial Intelligence. *Journal of Science, Technology and Society (SICO)*, 1(2), 43–50.
- Darmawan, D. (2023). Innovation Culture That Balances Technological Speed with the Depth of Humanistic Thought. *International Journal of Service Science, Management, Engineering, and Technology*, 4(1), 47–54.
- Darmawan, D. (2023). Knowledge Management as a Source Of Competitive Advantage in Information Technology Companies. *International Journal of Service Science, Management, Engineering, and Technology*, 3(2), 44–50.
- Darmawan, D. (2023). Measuring Employee Productivity in the Digital Era by Considering Human Creativity and Innovation. *International Journal of Service Science, Management, Engineering, and Technology*, 4(3), 47–53.
- Darmawan, D. (2023). Social Inclusion for Older Workers in the Implementation of Digital Technology within Organizations. *International Journal of Service Science, Management, Engineering, and Technology*, 4(2), 44–51.
- Darmawan, D. (2023). The Concept Of Remote Work: A Literature Review on its Impact on Work Dynamics, Psychological Well-Being, and Social Relationships Among Employees. *International Journal of Service Science, Management, Engineering, and Technology*, 3(3), 49–55.
- Darmawan, D. (2024). Distribution of Six Major Factors Enhancing Organizational Effectiveness. *Journal of Distribution Science*, 22(4), 47-58.
- Darmawan, D. (2024). Strategies for Enhancing Employee Knowledge and Engagement in Automated Routine Work. *International Journal of Service Science, Management, Engineering, and Technology*, 6(1), 65–71.

- Darmawan, D. (2024). The Role of Technology in Promoting or Hindering Gender Equality in the Workplace. *International Journal of Service Science, Management, Engineering, and Technology*, 6(2), 67–73.
- Darmawan, D. (2024). Workforce Diversity Management Strategies for Enhancing Innovation and Team Performance. *International Journal of Service Science, Management, Engineering, and Technology*, 5(2), 53–59. Retrieved from <https://ejournalisse.com/index.php/isse/article/view/230>
- Darmawan, D. (2025). Inclusive Leadership Dynamics to Enhance Motivation and Retention of Older Employees in Modern Organizations. *Bulletin of Science, Technology and Society*, 4(2), 79–86.
- Darmawan, D. (2025). Job Redesign, Automation, and Digital Workforce Competencies in the Twenty-First Century. *Bulletin of Science, Technology and Society*, 4(3), 103–114.
- Darmawan, D., & Gardi, B. (2024). Digital-Oriented Leadership and Organizational Transformation: Fostering Operational Efficiency, Team Collaboration, and Innovation in the Digital. *International Journal of Service Science, Management, Engineering, and Technology*, 5(1), 37–42.
- Darmawan, D., & Mardikaningsih, R. (2023). The Role of Flexible Organizational Structures in Enhancing Corporate Adaptability to Environmental Dynamics. *International Journal of Service Science, Management, Engineering, and Technology*, 3(1), 44–49.
- Darmawan, D., & Mardikaningsih, R. (2022). The Role of Positive Psychological Factors in Enhancing Employee Engagement and Commitment to Work Tasks. *International Journal of Service Science, Management, Engineering, and Technology*, 1(2), 37–45.
- Darmawan, D., da Silva, B. dos S., & da costa, S. (2025). Blockchain as an Instrument of Decentralized Social Order and Democratic Reconfiguration. *Bulletin of Science, Technology and Society*, 4(1), 11–18.
- Darmawan, D., Gardi, B., & Da Silva, E. B. (2023). Exploration of Changes in Management and Employee Work Relations in Multinational Companies in the Era of Literacy-Based Digitalization. *Journal of Science, Technology and Society (SICO)*, 4(2), 43–54.
- Darmawan, D., Mardikaningsih, R., Sinambela, E. A., Arifin, S., Putra, A. R., Hariani, M., Irfan, M., Al Hakim, Y. R., & Issalillah, F. (2020). The Quality of Human Resources, Job Performance and Employee Loyalty. *International Journal of Psychosocial Rehabilitation*, 24(3), 2580–2592.
- Darmawan, D., Mendonca, C. N., & Isaac, A. de J. (2022). Managing Corporate Reputation in the Digital Age: Challenges and Solutions for Maintaining a Positive Image on Social Media. *Journal of Social Science Studies*, 2(1), 283–288.
- Denzin, N. K., & Lincoln, Y. S. (2011). *The SAGE Handbook of Qualitative Research* (4th ed.). SAGE Publications, Thousand Oaks.
- Eddine, B. A. S. & D. Darmawan. 2025. Employees' Perceptions of and Efforts to Adapt to Work-Life Balance in a Digitally Supported Workplace, *Studi Ilmu Sosial Indonesia*, 5(2), 341–356.
- Eddine, B. A. S., Darmawan, D., Mardikaningsih, R., & Sinambela, E. A. (2023). The Effect of Knowledge Management and Quality of Work Life on Employee Commitment. *Journal of Human Sciences*, 10(1), 87–100.
- Esmaeilian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., & Behdad, S. (2018). The Future of Waste Management in Smart and Sustainable Cities: A Review. *Waste Management*, 81, 177–195.
- Fujii, S., Matsuda, K., & Uesugi, S. (2022). Improving the Efficiency of Waste Collection by Utilizing Digital Transformation, 2022 9th International Conference on Behavioural and Social Computing (BESC), Matsuyama, Japan, 2022, 1–7.
- Gupta, S., Modgil, S., & Gunasekaran, A. (2019). *Big Data Analytics in Operations*

- Management: A State-of-the-Art Review and Future Research Agenda. *International Journal of Production Research*, 58(5), 1532–1558.
- Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does Gamification Work? A Literature Review of Empirical Studies on Gamification. In 2014 47th Hawaii International Conference on System Sciences, 3025–3034.
- Hariani, M. & A. R. Putra. (2025). Job Characteristics Based Work Redesign and its Influence on Team Performance Through Coordination and Collaboration, *Studi Ilmu Sosial Indonesia*, 5(2), 245-280.
- Hassan, L., Dias, A., & Hamari, J. (2019). How Gamification Affects Physical Activity: A Systematic Review. *Psychology of Sport and Exercise*, 43, 191–207.
- Issalillah, F. (2025). The Influence of Environmental Awareness and Lifestyle on People's Behavior to Reduce Plastic Waste. *Studi Ilmu Sosial Indonesia*, 5(1), 93-102.
- Issalillah, F., & Hardyansah, R. (2022). The Impact of the Digital Divide and Misinformation on Participation and Trust in Local Communities. *Journal of Social Science Studies*, 2(2), 7-12.
- Issalillah, F., & Khayru, R. K. (2025). Mental Health as an Organizational Construct: A Strategic Reorientation of Human Resource Management for Work Environment Design. *International Journal of Service Science, Management, Engineering, and Technology*, 8(3), 1–9.
- Jagtap, S., Pant, A., Chavan, S., Jagtap, S., Pant, A., Chavan, S., Jagtap, S., Pant, A., & Chavan, S. (2025). Designing Sustainable Action: Identification of Requirements of a Green Credit Platform for Incentivizing Eco-Friendly Activities. In: Chakrabarti, A., Singh, V., Onkar, P.S., Shahid, M. (eds) *Responsible and Resilient Design for Society*, Volume 8. ICoRD 2025. Lecture Notes in Mechanical Engineering. Springer, Singapore, 479–489.
- Kahl, T., Dib, U., Wiegard, M., & Zimmer, F. (2025). Gamification for Enhanced Recycling Engagement in Circular Economies. In *European Conference on Games Based Learning*, Academic Conferences International Limited, 19(1), 482–490.
- Khayru, R. K. (2022). Transforming Healthcare: The Power of Artificial Intelligence. *Bulletin of Science, Technology and Society*, 1(3), 15-19.
- Khayru, R. K. (2025). Digital Twins for Sustainable Infrastructure Management at Various Organizational Scales. *Bulletin of Science, Technology and Society*, 4(3), 13–24.
- Koman, G., & Krúpová, S. (2025). Integrating Logistics and Information Systems in Urban Waste Management: The Road to a Sustainable Smart City. *Logi*, 16(1), 25–36.
- Korabayev, S., Ergashev, O., Mahsudov, Sh. A., & Mamatova, S. (2024). Exploring Common Technical Issues in Modern Technology. *BIO Web of Conferences*, 145, 1-14.
- Maalouf, A., Maria, F. D., & El-Fadel, M. (2020). Waste Recycling in a Developing Context: Economic Implications of an EU-Separate Collection Scheme. In *Waste Management as Economic Industry towards Circular Economy Singapore*: Springer Singapore, 105–114.
- Manyonyi, S. (2023). Mobile-Based System for Solid Waste Management to Improve Customer Satisfaction and Revenue Generation: A Case of Shinyanga Municipal Council. Master's Project Report, Nelson Mandela African Institution of Science and Technology.
- Mardikaningsih, R. (2025). The Deconstruction of Work and HRM Reconfiguration: Flexibility and Employer Branding in the Digital Era. *International Journal of Service Science, Management, Engineering, and Technology*, 8(2), 10-17.
- Mardikaningsih, R., & Darmawan, D. (2022). The Role of Self-Efficacy in Predicting Employee Adaptability to Technological Change in the Workplace. *International Journal of Service Science, Management, Engineering, and Technology*, 2(3), 43–55.

- Mardikaningsih, R., & Darmawan, D. (2025). Utilization of Big Data Analytics to Improve Corporate Environmental Performance in Managerial and Organizational Dimensions. *Bulletin of Science, Technology and Society*, 4(3), 1–12.
- Mardikaningsih, R., & Essa, N. E. (2025). The Compatibility of Sustainability Values and Turnover Intention in Modern Business Organizations. *Bulletin of Science, Technology and Society*, 4(3), 79–90.
- Mardikaningsih, R., & Nuraini, R. (2022). Implementation of Circular Economy Principles for Sustainable Waste Management in the Industrial Sector. *International Journal of Service Science, Management, Engineering, and Technology*, 1(3), 41–47.
- Mardikaningsih, R., & Wardoyo, D. T. W. (2024). The Role of Technology in Human Resource Development for Sustainability: A Literature Review on Digital Innovation. *Bulletin of Science, Technology and Society*, 3(3), 20–26.
- Mardikaningsih, R., Darmawan, D., Halizah, S. N., Issalillah, F., & Khayru, R. K. (2025). Education Level as a Moderator of the Relationship between Environmental Concern and Waste Bank Participation. *Journal of Social Science Studies*, 5(2), 67–76.
<https://jos3journals.id/index.php/jos3/article/view/409>
- Mardikaningsih, R., Halizah, S. N., Darmawan, D., Masithoh, N., & Nuraini, R. (2022). Examining the Role of Authentic Leadership in Shaping Positive Work Climate and Organizational Citizenship Behavior. *International Journal of Service Science, Management, Engineering, and Technology*, 2(1), 52–59.
- Mardikaningsih, R., Halizah, S. N., Nuraini, R., & Darmawan, D. (2022). The Role of Ethical Leadership in Shaping a Positive and Sustainable Organizational Culture. *International Journal of Service Science, Management, Engineering, and Technology*, 2(2), 48–55.
- Mardikaningsih, R., Hariani, M., Darmawan, D., Halizah, S. N., & Nuraini, R. (2024). The Impact of Digital Monitoring on Employee Work Autonomy and Professional Responsibility. *International Journal of Service Science, Management, Engineering, and Technology*, 5(3), 60–67. Retrieved from <https://ejournalisse.com/index.php/isse/article/view/231>
- Mardikaningsih, R., Wardoyo, D. T. W., & Hariani, M. (2024). Digital-Based HR Development Policy as a Driver of Sustainable Collaborative Product and Service Innovation. *Journal of Science, Technology and Society (SICO)*, 5(1), 43–54.
- Maulani, A., Hardyansah, R., Darmawan, D., Mendonca, C. N., & de Jesus Isaac, A. (2023). Juridical Analysis of the Validity of Electronic Contracts Made by Artificial Intelligence in Indonesian Law. *Journal of Social Science Studies*, 3(1), 139–144.
- Nayan, N. M., Ijab, M. T., Hassan, M. K. A., & Afiq, M. A. (2024). Adaptation of the Elderly to Technology: A Study on Usage and Challenges. *Journal of Information System and Technology Management*, 9(37), 65–76.
- Osei-Kyei, R., Tam, V. W. Y., Komac, U., & Ampratwum, G. (2023). Review of the Relationship Management Strategies for Building Flood Disaster Resilience through Public–Private Partnership. *Sustainability*, 15(13), 1–16.
- Pienwisetkaew, T., Wongsachia, S., Ketkaew, C., & Wongsachia, S. (2025). Technology Adoption in Smart Agricultural Waste Management Among Farmers: The Role of Simplicity and Gamification. *Cleaner and Responsible Consumption*, 19, 1–19.
- Putra, A. R., & Arifin, S. (2021). Supply Chain Management Optimization in the Manufacturing Industry through Digital Transformation: The Role of Big Data, Artificial Intelligence, and the Internet of Things. *Journal of Social Science Studies*, 1(2), 161–166.

- Putra, A. R., Arifin, S., & Darmawan, D. (2024). Gamification-Based Learning that Preserves Cooperation and Empathy Among Employees. *International Journal of Service Science, Management, Engineering, and Technology*, 5(1), 43–50. Retrieved from <https://ejournalisse.com/index.php/isse/article/view/229>
- Qamari, I. N., Umihani, F., Suryono, L. J., & Kusumawati, R. (2023). Digitalization in Managing Waste through the Pasti Angkut Digital Platform. *Proceesing International Conference of Technology on Community and Environmental Development*, 1(1), 105-111.
- Qiao, X., & Zhang, Z. (2023). Imperceptible, Entertaining: The Impact of Gamification on Public Friendly Environmental Behavior. *Academic Journal of Management and Social Sciences*, 4(3), 45-52.
- Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research Methods for Business Students* (8th ed.). Pearson Education, New York.
- Sayed, A. M. (2025). Predictive Waste-to-Resource Ecosystem Using Big Data & IoT. *Journal of Computer Science and Information Technology* 2(2), 01–11.
- Seabright, M. A., & Chen, X. (2021). Social Norms, Gamification, and Environmental Behavior: An Empirical Study. *Journal of Environmental Psychology*, 75, 101610.
- Silva, L. G. D., Silva, L. O. P. D., Oliveira, J. M. L. de, & Silva, G. V. da. (2022). Gamified App that Maps Collection Points and Places of Accumulating Solid Waste in the Urban Environment of the City of Manaus (Amazonas). *International Journal of Advanced Research*, 10(12), 758–768.
- Singh, U., & Indapurkar, K. (2025). Digital Solutions for Urban Household Waste Management: Challenges and Opportunities for Sustainable Cities. *Revolutionizing Urban Development and Governance with Emerging Technologies*, 579–604.
- Su, Y., Thienmongkol, R., & Nimnoi, R. (2025). Gamification and Interactive Media for University Waste Sorting: A Digital-Enabled Approach. In *Proceedings of the 2025 2nd International Conference on Digital Economy and Computer Science*, 1344-1348.
- Sulemana, A., Donkor, E. A., Forkuo, E. K., & Oduro-Kwarteng, S. (2019). Effect of Optimal Routing on Travel Distance, Travel Time and Fuel Consumption of Waste Collection Trucks. *Management of Environmental Quality: An International Journal*, 30(4), 803–832.
- Tashakkori, A., Johnson, R. B., & Teddlie, C. (2021). *Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences* (2nd ed.). SAGE Publications, Thousand Oaks.
- Triono, B., Darmawan, D., Djaelani, M., Safitri, F. S. A., & Masithoh, N. (2025). How Digitalization Reshapes Labor and Task Architecture in the Manufacturing Sector. *International Journal of Service Science, Management, Engineering, and Technology*, 7(2), 11–16.
- Utomo, M. N., Pratiwi, S. R., & Setyawan, F. H. (2024). Improving Economic Efficiency Through Waste Recycling and Modernizing Waste Bank Management. *International Journal of Community Service*, 4(1), 43-46.
- Warin, A. K., & D. Darmawan. (2024). Fostering Adaptive Employees: The Importance of Continuous Feedback in HR Development, *Bulletin of Science, Technology and Society*, 3(3), 27-34.
- Wu, C. H., Chang-Chien, S. W., & Lu, C. X. (2014). Optimal Collection and Recycling Strategy for a Green Supply Chain Under Dynamic Market Demand. *Computers & Industrial Engineering*, 72, 311–322.
- Zadik, Y., & Katz, H. (2025). Changing Household Waste Separation Behaviour Through Monetary Incentives, Nudges and Unverified Self-Reports. *Waste Management & Research*, 43(12), 2133-2143.
- Ziabina, Y., & Acheampong, S. (2023). Financial Component of the Waste Management System. *Financial Markets, Institutions and Risks*, 7(2), 46–55.