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Development of an Automatic Trash Sorting System with Incentive Mechanism (A Review)

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Abstract The rapid urbanization and population growth have led to the tremendous growth of solid waste production, and low household recycling rates. This review has examined the recent literature on the applications of automated sorting of solid wastes, Internet of Things (IoT) based monitoring of wastes and reward-based recycling schemes. It has been suggested that sorting using sensors enhances the accuracy and efficiency of segregation, while automated sorting systems reduce human error. Incentive programs improve the participation and adherence of users to the proper waste disposal.Integration of IoT also facilitates real time monitoring, efficiency in operation and transparency. With all these developments, there are system integration, scaling and long-term evaluation of behavioral effects issues. Literature indicates that automation, IoT monitoring, and incentive mechanisms should be combined to provide a holistic and long-term system to enhance the waste management practices.

***Index Terms*—** Automated trash sorting, IoT monitoring, incentive -based recycling, smart waste management, sustainable waste systems.

I. INTRODUCTION[1]

Urbanization and unending population increase has accelerated the extraction of waste to a worldwide serious issue. Cities are getting more developed, and the products that people consume continue to grow, which is why the solid waste amount is growing. Literature estimates that waste is expected to increase to 3.40 billion tonnes by 2050 and it is only about 13.5 per cent of waste that is recycled currently. This demonstrates that there is a huge disparity between the quantity of waste generated and recycling system capacity. Household recycling activities are low in most of the congested urban centers due to busyness, ignorance and lack of easy access to recycling centres. This issue has become very serious as experienced in different countries. The rate of recycling of household in China was only about 25% in the 2010s. Since 2012 Singapore had reported around 20% household recycling efficiency. In Malaysia, household recycling rate is poor 15.4 years on even after implementation of waste management programs as early as 1993. These figures expose that, there are still a large number of recycling systems that are not yet fully developed and are finding it difficult to cope with the growing volume of waste. Thus, to achieve sustainable urban development and to turn to a circular economy, it is important to enhance the work of recycling [1]. Increasing the recycling rates will help to recover the useful materials, to conserve the natural resources and to decrease the number of waste, which is deposited in the landfills. It may also make people adopt the practice of waste management. Various solutions have been presented to address the issue of low recycling rates, including recycling charges, tough regulations by the government, and online recycling. Incentive based recycling systems are regarded as one of the best strategies due to the fact that people are emboldened to engage in the exercise since the system rewards them or gives them a benefit. Nevertheless, there are still some problems with the existing incentive-based recycling. Certain recycling processes are not efficient in manpower, scheduling, and transportation hence increased costs and reduced profits. Long term planning to manage the changes in the market is also missing and sharing of information across residents and waste collectors, recycling companies and government agencies is usually not much. Due to such poor coordination, the recycling process may be chaotic and inefficient. One of the studies indicate that the availability of convenient facilities and the improvement of services can help boost the interest of people living in the area in taking part in recycling efforts [2].

To address these issues, this research seeks to come up with a smart system of waste recycling using incentives. The proposed system is aimed at increasing operational efficiency, improving communication between stakeholders, and increasing the number of people interested in engaging in recycling. With intelligent technology and a powerful reward system, the system believes that it will be able to boost recycling, enhance the services of waste management, and minimize the production of waste at home as a part of sustainable development [1].

II. REVIEW OF RELATED LITERATURE

2.1 Research on the use of waste management in recent times emphasizes the increased use of automation and digitalization to enhance the effectiveness of traditional waste disposal systems. The automated trash sorting systems use sensors, microcontrollers, and mechanical components and are able to sort the trash into categories, including organic, inorganic, and metal [7]. Although these systems already show the potential to conduct material detection and mechanical

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sorting, their performance depends on the type of waste and the size of the waste, which means that currently, the technical approach to attaining homogeneous accuracy is not achievable [7].

2.2 In addition to the classification aspect, other researchers stress the need to involve the populace in recycling activities more. Recycling systems which are incentive-based use sensing devices, mechanical parts, and rewarding practices to motivate the practice of waste separation [8]. The goal of these systems is to ensure behavioral issues related to inappropriate waste disposal as well as to enhance environmental responsibility [8].

2.3 Besides automation and incentives, the monitoring system based on IoT has been designed to tackle operational inefficiencies associated with the previous methods of manual inspection, most of which may be subject to human error, and negligence [8]. These systems allow tracking the amount of garbage and classification in real-time and enhance the system responsiveness and minimization of resource waste [8]. Altogether, these works prove the current attempts to modernize waste management using the technological innovation and the user engagement strategy. 2.4 Although it has been proven that reward schemes increase participation, little attention has been given to the psychological factors behind this. [10] applied the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) to discover that the perceived ease of use and social pressure are also equally powerful as monetary rewards. This affirms your conclusion that an incentivebased system needs to be integrated with convenient, userfriendly amenities to work in the long run [10].

2.5 The IoT integration will enable real-time monitoring and operational transparency. But with the growing scale of systems in cities with rapid growth, the latency of data appears as a problem. [11] discusses how Edge Computing can be used with smart bins to process classification data on the device, eliminating the need for cloud servers and making the system responsive even in case of poor network connectivity. This will deal with the system integration and scaling problems as noted in your current review [11].

2.6 World statistics show that it is only 13.5 percent that is being recycled. To fight it, OECD (2022) and World Bank (2018) stress that technological innovation should be accompanied by the behavioral change and policy. The 2025 statistics recently reveal that cities with Pay-As-You-Throw (PAYT) programs and automated IoT bins have reduced their mixed municipal waste by 40 percent, which confirms your suggestion that a concerted, technology-based approach is the most sustainable way to go [12].

2.7 Recent work suggests that standard sensor-based systems are being replaced with hybrid deep learning systems to address the weaknesses of homogeneous accuracy. [13] proposed adding a Vision Transformer (ViT) to the conventional ResNet models to enhance classification in crowded spaces, a method known as Garbage FusionNet. In addition to that, [14] proves that VGG19 architectures have now reached a 88 percent accuracy rate when it comes to detecting five major types of waste (plastic, metal, paper, cardboard and glass). In real-time use cases, YOLOv5s has become a popular algorithm because it can detect objects in high-speed, meaning that automated bins can scan and sort objects within milliseconds [15].

2.8 Recent research has started using psychological models to measure the reason why users use automated recycling systems. They used the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) to determine that monetary rewards are the most important in the initial usage, but the key factors in the long-term usage are the perceived ease of use and social pressure [17]. In 2025, pilot programs have been conducted successfully, with the use of incentives in the form of a vending-machine that provide vouchers or discounts on retail stores, which led to a noticeable improvement in the number of young people who have volunteered in urban settings [18].

2.9 The smart waste management market is expected to increase by 15% CAGR by 2033, indicating a global demand to shift towards a circular economy [19]. Tough environmental laws and Extended Producer Responsibility (EPR) initiatives are compelling the municipalities to abandon manual sorting. [20] reports indicate that to achieve the 2030 sustainability goals, there is only the option of technological intervention since the conventional manual system is not able to keep up with the 5.5% per annum growth in municipal solid waste.

3.0 Recent studies have not confined to single-technology solutions, but instead have changed to integrated designs that incorporate high accuracy recognition together with instantaneous physical rewards. A system that is registered at [21] uses the YOLO (You Only Look Once) algorithm to recognize images with a classification accuracy of over 95%. The paper will be of particular interest because it considers the high maintenance of conventional bins with the help of STM32 microcontrollers and transfer learning (such as ResNet-34) to classify six large waste streams, such as fabrics and hazardous materials. Importantly, the research found that when a points based system of rewards was incorporated the participation of residents rose to 63 percent as compared to a baseline of 18 percent.

3.1 Smart waste systems are becoming more and more linked with sustainability through so-called Circular Ecosystems wherein digital platforms offer transparency. [22] emphasize that digital platforms that reward users encourage accountability because users can see their contributions in real-time and identify their contributions by traceability. Moreover, as [23] insist, to motivate behavioral change in the long term, rewards should be not only the new but also the tangible ones and tied to the key needs, i.e., grocery discounts or utility credits. This implies that the Incentive Mechanism in your paper can be scaled by collaborating with local vendors to provide high value everyday rewards. 3.2 The development of Smart Waste Management 4.0 (SWM 4.0) implies the combination of AI, IoT, and Big Data. [24] has suggested that AI has reshaped the waste life cycle, as it facilitates "dynamic adaptation." As an example, multi-sensor retrofits (ultrasonic (fill-level), load-cell (weight), and gas sensors (air quality)) are now used in systems to develop a secure, low-cost IoT ecosystem [25]. These systems not only sort, but optimize the collection routes in real-time,

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decreasing operational costs by 13 percent and transportation distances by up to 36 percent.

III. RESEARCH GAP IDENTIFIED

While there has been great progress in the development of automated waste classification techniques and incentivebased recycling systems, available studies are still disjointed and small in scale. In the majority of research efforts, the focus is on enhancing technical aspects for sensor accuracy and mechanical efficiency, or on behavioural interventions to improve the participation in recycling, with few studies combining both elements into a comprehensive and scalable framework [1, 6]. Moreover, although incentive-based systems are shown to encourage user compliance, most of them still depend on manual or semi-automated processes which do not provide real-time monitoring of user compliance which is required to achieve the necessary user engagement and to facilitate data-driven decision making for long-term sustainability [1], [8], [9]. Automated sorting technologies tend to focus on the accuracy of classifications and optimization of hardware, while user behavioural reinforcement and long-term participation outcomes are neglected [6], [7]. Besides, global waste management reports have revealed that the inefficiencies of operational coordination, communication with stakeholders and scalability of systems are still present, especially in fasturbanizing regions [4], [5]. The above challenges suggest that technological developments are not enough and that there is a need to combine behavioral and managerial elements. Thus, the need for a comprehensive and technology-enabled waste management system with automated waste classification, IoT-based monitoring, and incentive-based engagement to improve operational efficiency, user engagement, and the sustainability of waste management practices is pressing.

IV. METHODOLOGY

The research method used in this study was systematic literature review to analyze the literature that was done on automated trash sorting systems, waste monitoring with the IoT and incentive systems for waste recycling. Peerreviewed journals, conference papers and international reports were used to gather relevant studies in the field of automated waste classification systems [7], IoT-based monitoring technologies [9] and incentive-based recycling models [1] [8]. Waste management reports from around the world were also examined to give a wider perspective on the waste management issues and practices of the world at present [5]. The following keywords were used for literature search: automatic trash sorting, waste classification using sensors, IoT-based waste monitoring, incentive-based recycling, and smart waste management systems. Recent technological advances (the last five years, 2018–2025) were emphasized to ensure that the review was relevant. The studies that were included in the study focused on the automated waste segregation technologies, the integration of IoT in waste management and incentive or reward based waste recycling mechanisms published and reported in credible academic journals or conference proceedings. Research work that was not relevant to waste management technologies or that did not have enough technical and/or behavioral analysis was excluded. The literature collected from the references was analyzed using the qualitative synthesis approach, which focused on those technological components common to automated sorting systems, the effectiveness of sensor-based waste classification, the impact of incentive mechanisms on the participation in recycling, the opportunities opened by IoT monitoring for the improvement of the operational efficiency, and the current gaps or limitations of the collected literature. The results of different studies were then summarised and organised into themes to identify common themes, similarities and areas for further research.

V. RESULTS

After studying, analyzing and reviewing the literature, the following main findings were drawn: The results obtained from the previous studies demonstrated the potential of sensor based smart bin system in detecting and classifying the organic and inorganic waste materials, in addition to the metal waste material with an increased sorting accuracy and decreased human errors in segregation processes [6, 7]. Research also showed that both servo-controlled and mechanically driven sorting mechanisms are able to effectively and quickly divert waste into the correct compartments, thus proving the viability of automatic waste sorting technologies [7]. Moreover, many studies highlighted how incentive-based recycling systems positively impact user behavior, by boosting participation and the correct disposal of waste [1, 8]. The literature also emphasized the trustworthiness of the IoT monitoring system to provide real-time monitoring of waste levels, activities of users, and system performance, which ultimately enhances the operational efficiency, transparency, and data management capacities of the system [9]. Furthermore, global waste management reports highlighted the need for innovation and sustainability in waste management as the amount of solid waste and the recycling rate continues to rise worldwide [5]. The studies examined overall, consistently indicate that the integration of automated classification, mechanical sorting, IoT monitoring, and incentive-based measures offers a promising and effective way to improve waste segregation efficiency and foster increased user participation in sustainable waste management.

VI. DISCUSSION

The literature review shows that, automated waste segregation systems are technically and socially feasible solutions to address modern waste management challenges. Research has demonstrated that classification technologies based on sensors are able to enhance sorting efficiency and to substantially decrease human error in waste separation processes [6] and [7]. Combined with mechanical sorting systems, such waste management solutions can sort nearly all metal, organic, and inorganic waste streams without time delays and prove the reliability and efficiency of automation in waste management. In addition to technological automation, behavioural measures are also important to boosting participation in recycling. Some studies suggest that incentive-based schemes can have a positive effect on compliance and participation with recycling services, such as a rewards-based scheme for recycling could lead to increased recycling rates and better waste disposal practices [1], [8]. The results highlight the need for the use of behavioral reinforcement strategies to enhance the effectiveness of technological innovations. Moreover, Internet of Things (IoT) technology is now an integral part of the modern waste management systems. By using the Internet of Things (IoT) for monitoring, one can have real-time information about the level of waste, system performance and user participation, which enhances the operational efficiency, transparency and data-driven decision making process [9]. Worldwide, the rising volume of solid waste and the poor rate of recycling underline the importance of new and sustainable waste management solutions. The study of the Organisation for Economic Co-operation and Development [4] and the World Bank [5] indicate technological solutions as a key factor and the behavioural studies show that waste segregation works better when framed by motivational mechanisms and technological systems [2]. Overall, these studies suggest that a more comprehensive and sustainable framework for optimizing waste management systems can be realized by integrating all three elements: automation, IoT monitoring, and incentive measures. Despite the progress of these developments, there are still gaps in the existing literature on large-scale implementation, long-term behavioral impact assessment and optimization of classification accuracy for smaller waste materials. Future research should thus be directed towards improving the performance of the algorithms, sensor calibration, and system scalability in various community environments. The reviewed studies overwhelmingly highlight the potential of automated classification, IoT-based monitoring, and incentive-driven participation in the future of effective and sustainable waste segregation systems.

VII. CONCLUSION

This review has discussed the recent research on automated trash sorting systems, IoT-based trash monitoring, and incentive-based recycling processes. It has been demonstrated in the literature that sensor-based classification systems enhance the efficiency of waste segregation and minimise human error. The use of IoT in waste management promotes transparency, monitoring, and operational management in smart waste systems. Moreover, there is an increased user involvement and adherence to the recycling practice using incentive-based methods.

Reports around the world point to the necessity of new methods of waste management because there is a growing amount of waste and low recycling statistics. The surveyed literature shows that automation, real-time tracking, and behavioral reinforcement can be a promising and long-term solution to enhancing the waste segregation practice.

Nevertheless, even with the current progress in smart waste technologies, the system integration, scalability, and the ability to assess the impact of the long-term behavioral aspects are still open gaps. Future studies will aim at the enhancement of classification accuracy, the optimization of the incentives models, and the assessment of the implementation at the scale of a community.

On the whole, the literature implies that the use of technological innovation and behavioral strategies is critical to the effective solution of the current waste management problems.

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