

Advancing Urban Waste Management Using Industry 5.0 Principles: A Novel Smart Bin

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Abstract—Smart bins represent a fundamental pillar of sustainability within the paradigm of Industry 5.0, revolutionizing waste management practices through advanced technological integration, by playing a crucial role in optimizing waste management through the integration of Internet of Things (IoT) capabilities, advanced sensory, and actuation modules. This paper investigates the pivotal role of smart bins through a comprehensive analysis of prevailing commercial solutions that reveals their present characteristics and limitations. By discerning and emphasizing notable drawbacks in existing products, a novel smart bin concept design is proposed that extends current capabilities through a synergistic combination of advanced sensing, automation, and data analytics. This innovative approach targets identified gaps, adopting a high-level holistic strategy to enhance efficiency in technology-driven urban waste management practices. Through this research, a contribution is made to the ongoing discourse on innovative solutions for sustainable urban development, emphasizing the transformative potential of intelligent waste management systems.

Index Terms—smart bins, IoT, sensors, smart cities, automation

I. INTRODUCTION

Urbanization and population growth invariably drive increased waste production in modern societies [1], [2]. Particularly in economically thriving cities, where production rates have reached unprecedented levels, the greater diversity of products and services, results in more challenging management, treatment, and disposal of larger volumes of waste [3]. Recent trends in rapid urbanization and industrialization have significantly contributed to this surge in refuse production, posing challenges for disposal and treatment that current practices struggle to address [4]. Insufficient waste management infrastructure, sub-optimal collection systems, and limited recycling facilities exacerbate the problem, leading to improper disposal practices such as open burning and illegal dumping, not only risking disease outbreaks due to

the breeding of pathogens but also contributing to soil and water contamination from hazardous chemicals, posing long-term health risks [5], [6].

In the sphere of sustainability, a key component of Industry 5.0, technology-enabled smart bins have been developed to address the limitations of traditional waste management methods [7]. Industry 5.0 represents a paradigm shift in manufacturing, emphasizing the harmonious collaboration between humans and machines to achieve higher levels of productivity, efficiency, and sustainability. In essence, Industry 5.0 seeks to integrate advanced technologies with human ingenuity, leveraging automation while preserving the essential role of human expertise and creativity. Smart bins align with Industry 5.0 principles by embodying this collaboration through innovative design and functionality [8]. These advanced waste containers incorporate a mix of technologies, including sensors, data analytics, and automation, to transform the way waste is managed. Smart bins allow for the real-time tracking of waste quantities, optimization of collection routes and schedules, and the encouragement of effective garbage disposal practices. Additionally, the integration of robotics and diverse sensor and actuator arrays enables the immediate separation of materials, presenting a forward-looking solution to waste management challenges [9]. By leveraging advanced technology and data-driven approaches, these systems can operate more sustainably as well, minimizing resource wastage and environmental impact [10].

Despite the potential benefits, the progress and widespread acceptance of smart bins in modern societies remain limited. The instances observed often demonstrate only rudimentary functionalities, featuring too few sensors and capabilities. Notably, when it comes to waste sorting, the existing solutions are scarce, and the sorting capabilities they provide are either entirely reliant on manual intervention or are severely restricted in their automated functionalities. This paper endeavors to delve into the conceptual framework and attributes of smart

bins within academic research, delineate the state-of-the-art (SotA), and pinpoint discernible gaps. In this context, a market analysis is conducted to identify the prevailing commercially available solutions. By synthesizing these findings, a novel smart bin design is introduced that combines pertinent technologies, aiming to comprehensively address identified gaps and drawbacks.

II. RELEVANT RESEARCH

In an attempt to comprehensively chart academic research on smart bins, several reviews have been published. Sosunova and J. Porras conducted an extensive and well-structured study focused on city-level solid waste management (SWM) through a systematic literature review [11]. The primary objective of the review was to create a holistic understanding of city-level SWM practices, including an exploration of smart bins. With a robust dataset and an analysis of over 170 relevant literature sources, the study efficiently extracted information on the presence of hardware in smart garbage bins. This meticulous approach facilitated a thorough mapping of various sensors and actuators employed in existing applications.

Ayodeji Noiki *et al.* in 2021, explored the potential of smart bins to enhance urban waste management in response to the escalating urbanization trend, which has led to a significant surge in waste generation in modern cities [12]. The study comprehensively examined over 25 identified cases of smart bins, categorized into several distinct groups. The review recognized numerous improvements and innovations in the field, indicating promising results. The study did identify a bottleneck in the wide application of smart bin technologies, resulting in relatively low adoption rates, highlighting that the implementation costs of smart bins remain high. Additionally, the review primarily emphasized IoT-enabled smart bins with data transfer capabilities and did not elaborate on waste separation capabilities and the reasons behind the scarcity of relevant cases in this area, akin to previous studies. Exploring this aspect further would enhance the completeness of the study and provide valuable insights into potential advancements in waste separation technologies.

In 2021, Sirsat and Bardekar conducted a study akin to the aforementioned one, albeit with a narrower scope, concentrating on 15 notable cases [13]. Similar to the prior research, this review also displayed a predominant focus on IoT-enabled solutions. The study articulated a clear acknowledgment of the potential for improvement in the realm of smart bins, posed inquiries regarding existing solutions for waste classification to enhance recycling, and offered insights into system costs.

In their relevant work, the authors of this present study delve into an extensive examination of nearly 80 cases drawn from over 1400 published papers, with a predominant focus on smart bins equipped with waste separation capabilities [14]. Research findings, presented as a journal review paper, currently under revision, target the development of a holistic picture of the state of the art regarding research and development on smart bins and underscore the scarcity of high-level solutions within academia pertaining to waste sorting

functionalities. This work aims to offer valuable insights that complement existing reviews and contribute to a deeper understanding of waste management strategies.

In conclusion, the examination of related academic work has significantly contributed to gaining a comprehensive understanding of the state of the art of smart bins, particularly in terms of IoT connectivity, smart functionalities, and sensor integration. Notably, the focus has been on live monitoring of fill levels and waste conditions. However, it is essential to acknowledge that none of the mentioned cases were identified as production-ready, an expected outcome given that many advancements in this domain result beyond academia when they enter the market. As the next step, engaging in market research and analysis becomes imperative to identify and evaluate commercially available smart bins, discerning their functionalities. This approach is pivotal to establishing a more complete and practical picture of the current trends and limitations in the landscape of smart bin technology.

III. MARKET ANALYSIS OF SMART BINS

A novel market for smart bins in urban waste management has been identified. Upon closer examination, 7 different commercial products have been distinguished and are depicted in Fig.1:

- 1) *BigBelly SC5.5* is a smart bin developed by the Boston-based original equipment manufacturer (OEM), BigBelly [15], serving as a waste container for outdoor urban environments. It facilitates manual sorting by the user by placing containers adjacent, each for specific types of trash. Features onboard diagnostics, fill level sensing, and an optional solar-powered compactor to enhance its overall volume capacity by automatically compressing deposited items.
- 2) *Binwise* is provided by the Atlanta-based company Conure and is also designed for outdoor placement in urban settings [16]. This intelligent bin is equipped with ultrasonic proximity sensors that allow for real-time fill-level monitoring. Its functionalities further include IoT connectivity for the generation of alert messages for collection and maintenance crews when the container is reaching capacity, aiming for the optimization of waste collection scheduling.
- 3) *Smart City Separation Station 3 (SCSS3)* is a smart waste disposal unit from the Czech Republic-based OEM, Binology L.L.C. [17]. It features a multiple-bin rack for manual recyclable separation by the users, extendable to up to 9 individual containers to adapt to different separation scenarios. It incorporates IoT connectivity via GPS and GSM with cloud software. Moreover, this product includes ultrasonic fill-level monitoring, solar-powered compaction modules, and air quality sensing for monitoring waste deterioration.
- 4) *Garby* is a product developed by the Netherlands-based startup, Plaex Technologies in Enschede [18]. *Garby* serves as a smart bin, mainly intended for interior spaces, such as offices. It employs a vision-based smart

TABLE I
SUMMARIZED FEATURES OF THE AVAILABLE SMART BINS.

Product	Bigbelly SC5.5	Binwise	Binology SCSS3	Garby	Terra Public Can	Bin-e	Trashbot
Environment	Outdoors	Outdoors	Outdoors	Indoors	Outdoors	Indoors	Indoors
Sensing	Y	Y	Y	Y	Y	Y	Y
Fill level	Y	Y	Y	Y	Y	Y	N
Weight	N	N	N	N	N	N	N
Gas	N	N	N	N	Y	N	N
Environment	N	N	Y	N	Y	N	N
RFID	N	N	N	N	Y	N	N
Vision	N	N	N	N	N	Y	Y
IoT	Y	Y	Y	Y	Y	Y	Y
GPS	Y	Y	Y	Y	Y	Y	Not referred
GSM	N	N	Y	N	N	N	N
Other features	N	N	Deodorization, Sterilization	N	Safety lock	N	N
Actuation	Compaction	N	Compaction	N	Compaction	Waste routing, Compaction	Robot-based sorter
Solar powered	Y	N	Y	N	Y	N	N
Waste sorting	Y	N	Y	Y	Y	Y	Y
Manual sorting	Y	N	Y	N	Y	N	N
Automated sorting	N	N	N	Y	N	Y	Y
Single item	N	N	N	N	N	Y	Y
Multiple items	N	N	N	N	N	N	N

classifier for single-item automatic sorting. It also uploads data on deposited articles to an online dashboard aimed at tracking their overall impact on sustainability.

- 5) *Terra Public Can* was created and commercialized by the Croatia-based company Include d.o.o. [19]. It is an outdoor deployment smart bin. It assists in manual sorting through indication decals on the containers' outer casing. *Terra Public Can* is solar-powered, it incorporates fill-level sensing, a pressure, humidity, and temperature (PHT) sensor, GPS, server communication, and an RFID lock. An optional compaction feature is available to increase its overall volume capacity.
- 6) *Bin-e* developed by the Poland-based company Bine z.o.o [20], is a device targeting smart recycling for indoor locations. *Bin-e* features a 4-bin configuration and individual item manual deposition on a single entry point. Deposited items go through artificial intelligence (AI) based visual object recognition for automated sorting of metals, paper, and plastic. The system further includes fill-level sensors, compaction mechanisms for plastic and papers, and real-time cloud data management.
- 7) *Trashbot*, created by the USA-based OEM Clean-Robotics Inc., is a waste sorting solution mainly for interior spaces. *Trashbot* is equipped with an AI vision-based classifier and a robotic actuator for waste routing [21]. The user deposits a single item on the designated entry orifice and following its classification the device guides the item to its corresponding container robotically. It features cloud connectivity and integrated data analytics.

A more analytical depiction for each product's capabilities is presented in Table I.

IV. PROPOSED NOVEL SMART BIN CONCEPT

Following the analysis of existing solutions in the market and insights from related academic work, a novel intelligent bin concept is proposed. This concept features a single IoT-enabled device with multiple internal compartments (Fig. 2). The process begins with mixed trash being inserted through the entry point and entering a buffer, where material flow is controlled via a regulating opening. The waste is then systematically deposited onto a conveyor belt with limited width, ensuring a linear formation.

In this setup, the waste input is transported along a conveyor belt. During this process, a series of inductive and capacitive proximity sensors are used to discern specific composition traits, mainly the identification of metal or wet components. Additionally, a Fourier Transform Infrared (FTIR) module is employed to detect plastics. Items exhibiting these specific traits are deflected sideways by linear actuators, directing them into dedicated individual buckets. The remaining items advance on the conveyor where they undergo visual inspection facilitated by a camera module coupled with AI capabilities and access to open trash databases, as well as an appropriate lighting source which is instrumental for precise identification [22]. This inspection enables the detection of recognizable objects such as bottles, pieces of paper, or cardboard, and subsequently, these items are further sorted into separate containers. Finally, the residual waste that does not meet any of the specified criteria is directed into a general waste bucket.

Load cells are strategically positioned beneath the metal and general waste containers to detect any weight increase, as these buckets are more likely to receive denser items. To effectively monitor the trash levels in each container, fill level sensing is integrated via ultrasound sensors, positioned over each compartment. Furthermore, to enhance the buckets'



Fig. 1. Examined commercial smart bins indicative images. a)BigBelly SC5.5, b) Binwise, c) Binology SCSS3, d) Terra Public Can d) Garby, e) Bin-e, f) Trashbot

capacity, compaction mechanisms can also be incorporated over certain compartments, exerting pressure on the deposited contents and reducing their overall volume. For comprehensive monitoring, a BME680 sensor is included to track temperature, humidity, and air quality inside the bin.

The proposed concept follows a modular approach, allowing for customization by adjusting the conveyor’s length and the number of buckets to accommodate diverse waste management scenarios. Depending on specific requirements, the type of sensors can be flexibly tailored as well. To ensure efficient waste management, all buckets are designed for easy removal by collection crews. Additionally, data collected from the integrated sensors is transmitted via WIFI for further analysis. A summary of all sub-systems included in this concept is

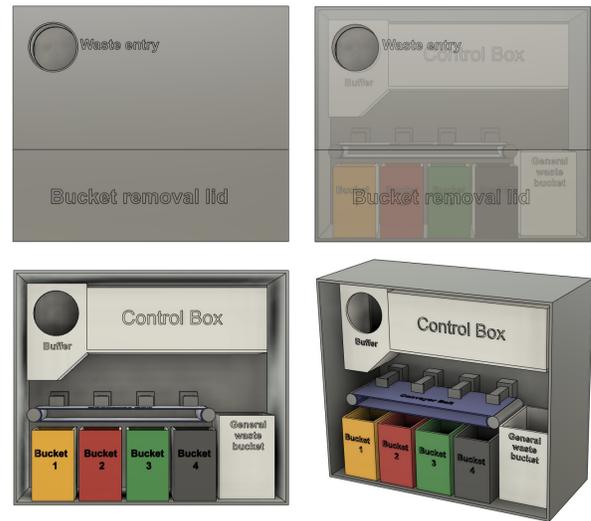


Fig. 2. Concept proposal for a smart bin with integrated waste separation capabilities

TABLE II
PROPOSED SMART BIN CONCEPT TABLE OF INDICATIVE INTEGRATED FEATURES.

#	Feature	Description	Category
1	Waste entry buffer	Initial compartment for mixed waste.	Structure
2	Buckets	Multiple buckets for waste sorting.	Structure
3	Controller	Electronics and controller board compartment	Structure
4	Ultrasound sensor	Fill level sensing	Sensing
5	BME680 sensor	Environment and air quality monitoring	Sensing
6	Inductive sensor	Metal detection	Sensing
7	Capacitive sensor	Wet waste detection	Sensing
8	FTIR sensor	Plastics identification	Sensing
9	RGB Camera	Object recognition	Sensing
10	Load cell	Bin Weight monitoring	Sensing
11	Conveyor belt	Waste routing (for classification)	Actuation
12	Linear actuator	Waste routing (deposition to buckets)	Actuation
13	Automated lid	Contactless operation	Actuation
14	Buffer flow regulator	Motorized opening at the bottom of the buffer for controlled material flow.	Actuation
15	Compactor press	Waste compaction for increased capacity	Actuation
16	AI	Optical Waste classification.	Function
17	IoT	Data transfer	Function

presented concisely in Table II. In the 'Category' row, the modules are classified into four distinct classes. 'Structure' encompasses the structural building blocks comprising the main body of the smart bin, including the frame and the control board. 'Sensing' and 'Actuation' categories pertain to modules dedicated to sensing and actuation functionalities respectively.

'Function' serves as an additional category reserved for hardware related to AI and connectivity modules.

The proposed concept presents several advantages over existing commercial solutions. Firstly, it supports multiple-waste entry, eliminating the need for inputting items one at a time. This functionality is further enhanced by the sophisticated waste routing system, integrating a conveyor-based circulation mechanism and a robot-based actuation system to sort various types of waste into individual containers. Additionally, the comprehensive array of sensors and connectivity modules is selected to cover the entire spectrum of sensing solutions encountered in commercial solutions, such as fill-level sensing, weight and environment conditions monitoring, while offering additional functionalities in terms of composition identification, through the use of metal and plastic detection, using inductive and FTIR sensors respectively. Lastly, the design's modularity enables easy reconfiguration of the bin to accommodate changes in material recovery needs and overall waste collection and separation requirements. This is achieved through reprogramming of the classifier and the array of buckets, ensuring adaptability.

V. DISCUSSION

The identified commercial solutions demonstrate alignment with established trends in the literature. As indicated by the data presented in Table I, sensing functionalities prominently include fill-level sensing, with nearly all commercial smart bins (86%) incorporating this feature. In that realm, the Terra Public Can specifically stands out by offering Gas and Environment sensing, along with an RFID reader for automatic locking. Environmental sensing is also encountered on the SCSS3 in the form of air quality sensing to monitor the degradation of deposited organic waste. Additionally, computer vision is employed in three distinct instances (Garby, Bin-e, and Trashbot) for sorting purposes. No other forms of sensing, such as Weight monitoring, humidity detection, or composition-based identification methods were detected.

In terms of connectivity, all identified products are equipped with IoT functionalities, primarily for collection scheduling or data analysis of deposited waste. GPS connectivity is mentioned in nearly all cases (86%), with the exception of Trashbot, which did not specify the utilized technology. Notably, only one product (Binology SCSS3) refers to the utilization of GSM communication for data transfer.

Considering actuation, all but one product (Binwise) indicate a form of actuation (86%). Four out of the seven cases feature automatic compaction capabilities (57%), while one device exhibits automatic locking. Three out of seven present some form of mechanized waste routing. Within the context of waste sorting, only one bin does not mention waste sorting in any form (Binwise). Among the other six products, four incorporate manual sorting by the users, facilitated via external annotations and multiple individual containers. Two smart bin instances (Bin-e and Trashbot) provide automated sorting capabilities, albeit limited to one item at a time and designed for indoor use in workspaces and offices.

Finally, an interesting common feature among several products (43%) is the integration of solar power collection technology. The proposed concept aims to comprehensively address the identified shortcomings in smart bin functionalities. Sensing forms a crucial aspect, with fill-level monitoring serving as the baseline. To enhance accuracy, weight monitoring is integrated to efficiently complement fill-level sensing, particularly for heavy waste that may occupy containers with reduced volume. Environmental sensing is introduced to monitor waste quality, enabling prioritized collection in instances of increased waste deterioration.

In terms of waste classification, the conceptualized bin features multiple internal individual containers and an automated sorting mechanism. This design supports efficient waste segregation, a critical element in modern societies fostering recycling, material recovery, and circularity. The optimization of waste classification involves a combination of visual inspection and composition identification. The proposed approach utilizes AI-driven data fusion, incorporating machine vision for overall assessment, inductive proximity sensing for metal identification, capacitive sensors to locate wet waste, and an integrated FTIR sensor module for discerning specific plastics. To facilitate circulation within the system, a mechanism is introduced, consisting of a controlled flow buffer, a conveyor belt, and a series of mechanical linear side diverters. This combination ensures a regulated item flow, efficient categorization, and robust separation into the designated containers. The integrated design of sensing, classification, and circulation in the proposed concept addresses key limitations identified in current smart bin solutions, presenting a holistic and advanced approach to waste management.

VI. CONCLUSION

In conclusion, an investigation aimed to define the state of the art in smart bins was conducted by examining relevant research and conducting market analysis. The findings revealed that smart bins represent a novel and evolving field, with limited highly developed examples in current research. The market analysis identified seven distinct commercially available solutions, providing valuable insights into the existing landscape. The cumulative analysis resulted in a comprehensive understanding of the capabilities of technology-enabled waste bins. Leveraging this knowledge, a novel smart bin concept is proposed, addressing both existing and non-encountered functionalities. The proposed concept capitalizes on a synergistic combination of sensing subsystems to enhance the bin's overall capabilities. Additionally, it introduces a dedicated system for automated waste classification, circulation, and physical separation into individual containers. The envisioned smart bin concept aspires to transcend conventional functionalities, resembling a miniaturized material recovery facility. This innovative approach positions the smart bin as a localized solution deployed directly in neighborhoods. The ultimate goal is to contribute to the optimization of municipal waste management practices, marking a significant step towards more efficient and sustainable waste handling in urban areas.

The next steps of this work primarily involve further developing and refining the proposed concept, transitioning into a working smart bin prototype. The prototype will subsequently undergo deployment for experimentation and performance validation under real operating conditions, to analyze its performance and inform further iterations and potential enhancements.

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