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# IoT-Enabled Smart Waste Management Systems for Smart Cities: A Systematic Review

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**ABSTRACT** With urbanization, rising income and consumption, the production of waste increases. One of the most important directions in the field of sustainable development is the design and implementation of monitoring and management systems for waste collection and removal. Smart waste management (SWM) involves for example collection and analytics of data from sensors on smart garbage bins (SGBs), management of waste trucks and urban infrastructure; planning and optimization of waste truck routes; etc. The purpose of this paper is to provide a comprehensive overview of the existing research in the field of systems, applications, and approaches vis-à-vis the collection and processing of solid waste in SWM systems. To achieve this objective, we performed a systematic literature review. This study consists of 173 primary studies selected for analysis and data extraction from the 3,732 initially retrieved studies from 5 databases. We 1) identified the main approaches and services that are applied in the city and SGB-level SWM systems, 2) listed sensors and actuators and analyzed their application in various types of SWM systems, 3) listed the direct and indirect stakeholders of the SWM systems, 4) identified the types of data shared between the SWM systems and stakeholders, and 5) identified the main promising directions and research gaps in the field of SWM systems. Based on an analysis of the existing approaches, technologies, and services, we developed recommendations for the implementation of city-level and SGB-level SWM systems.

**INDEX TERMS** Smart city, smart waste management, Internet of Things, smart garbage bin.

## I. INTRODUCTION

According to one estimate,[1] the world population is projected to reach 9.9 billion by 2050, an increase of more than 25% from the current 2020 population of 7.8 billion. With the growth of the world's population and the gradual relocation of a large number of people to cities, the concept of smart cities is becoming ever more relevant. A smart city is a concept that entails integrating a range of information and communication technologies, such as the Internet of Things (IoT), to manage public space and city services in a sustainable manner.

Climate change and ensuing events, such as rising sea levels, flooding from changing river flows, and increased risk of greenhouse heat islands [1], are major challenges for sustainable development. Additionally, in accordance with [1], demographic changes, as well as technological, economic, social, and environmental challenges, should be identified as factors that create significant constraints for cities. One of the most important directions in the field of sustainable development is the design and implementation of monitoring and management systems for waste collection and removal. With urbanization, rising income and consumption, the production of waste increases. According to estimates [2], [3], the amount of waste is expected to increase to 2.2 billion tons by 2025 worldwide.

The effective organization of waste collection and processing is a necessary service and a challenging task for any large city. Therefore, smart waste management (SWM) can be seen as an essential part of a smart city, and it requires a complex multi-criteria approach [4]. SWM involves collection

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[1]2020 World Population Data Sheet Shows Older Populations Growing, Total Fertility Rates Declining, www.prb.org/2020-world-population-data-sheet/

and analytics of data from sensors on smart garbage bins (SGBs), garbage trucks and urban infrastructure; routes planning and optimization; information and decision support for users (drivers, dispatchers, citizens); waste classification and segregation; payments and benefits for citizens; monitoring of the ecological situation. Currently, such a system will most probably be based on IoT technology, forming an SWM system consisting of a large number (potentially billions) of smart devices that communicate with standard protocols, have physical and virtual characteristics, are intelligent (artificial intelligence-based), and are capable of measuring, calculating, transmitting, storing, and processing information. The use of SWM systems, i.e. the utilization of information and communication technology (ICT) in waste management, will improve the energy efficiency and environmental safety of solid-waste exports, improve citizens' quality of life, and reduce resource consumption [5].

The objective of this paper is to carry out a systematic analysis of the published research in the field of systems, applications, and approaches vis-à-vis the collection and processing of solid waste in SWM systems. Thus, our study aims to answer the following research questions (RQs):

1) Main RQ1: What approaches, methods and designs of SWM systems exist in the literature?
   - Sub-RQ1.1: What services, approaches, and technologies are used in the implementation of city-level SWM systems?
   - Sub-RQ1.2: What services, approaches, and technologies are used in the implementation of smart garbage bins (SGBs) or SWM systems with SGB-related services?
   - Sub-RQ1.3: Who are the stakeholders in SWM systems?
   - Sub-RQ1.4: What kind of information is shared between SWM systems and stakeholders in the existing SWM systems?
2) Main RQ2: What are the identifiable research gaps in the field of SWM systems based on published research?

These RQs will be answered by performing a systematic literature review on the topic. In total, 173 articles were included as primary studies and were explored during the review. To answer the RQs in detail, the following research directions were identified and considered during the research: 1) city-level SWM systems, 2) SGBs and SWM systems with SGB-related services, 3) stakeholders in SWM systems, and 4) information shared between SWM systems and stakeholders. We define city-level SWM systems as SWM systems, that operate on city-level. Such systems include the following main services: information and decision support for various stakeholders; route planning, optimization and scheduling; payments and benefits for service consumers; environmental services (analyze environmental parameters, minimize carbon emissions). We define SWM systems with SGB-related services as SWM systems, that operate on SGB-level and include services such as measurement of various parameters using SGB sensors, responding to user actions using SGB actuators, waste type identification and waste classification/segregation.

The remainder of the paper is organized as follows. Section 2 describes the related work on SWM systems. Section 3 provides the research methodology we followed in our literature review. Section 4 presents the results obtained from this literature review, and in Section 5, we discuss and analyze these results as well as give answers to our RQs. Section 6 concludes the paper.

## II. RELATED WORK

Several overviews of SWM systems and technologies have been provided by the researchers.

Many studies are focused on **city-level SWM systems services, approaches, and technologies**. For example, [4] provides a structured overview and analysis city-level services in SWM systems including concerns of architecture, DSS, GIS, dynamic scheduling, dynamic routing, social context and experimental data. When analyzing the systems considered in the article, the following characteristics are taken into account: physical infrastructure (SGB type and location, pneumatic pipes, fleet of trucks, depots, dumps, recycling, and processing), and software analytics (architecture, DSS, geographic information system (GIS), dynamic scheduling, dynamic routing, and social context). The focus of this review is on the energy-efficiency of IoT. It aims to present a wide range of models related to effective waste management. Special attention is given to garbage disposal. The authors see the need to define an efficient garbage collection model using IoT, which will relate to the inclusion of large-capacity garbage trucks as mobile warehouses, as well as to develop a model that allows to optimize the location of garbage bins for the maximum comfort of citizens. [6] reviews systems engineering approaches in the development of integrated solid-waste management for a smart city. Three systems engineering approaches—namely GIS, multi-criteria decision-making, and life-cycle analysis—to solid-waste management systems were reviewed. Based on the analysis authors concluded that systems should include a holistic, comprehensive, and interdisciplinary framework that combines technical, economic, and social components, stakeholders, and time frames. The use of ICT in solid-waste management increases the communication between different elements of the system and provides data for decision support and managerial activities. The authors in [7] provide a systematic review of ICTs and methods of operations research adopted in SWM, the processes of solid-waste management for which they were adopted, and which countries are investigating solutions for the management of solid waste in the 2010–2013 period. Devi provides a review of solid-waste management models in [8]. Nine waste management models are reviewed with the aim of finding out which existing model could be applied exclusively to Indonesia's transitioning villages through the lenses of sustainable urban planning by reviewing 10 existing models. The conclusion from the study is that the solid-waste management model needs to emphasize (1) the participation of local communities, (2) the pattern of waste transport and the type of waste management that does not require a large financial burden, and (3) the management infrastructure that can be put in place and maintained by the community/local organizations. The authors in [7] provide a systematic review of ICTs and methods of operations research adopted in SWM, the processes of solid-waste management for which they were adopted, and which countries are investigating solutions for the management of solid waste in the 2010–2013 period. As a result of the study, the authors concluded that China stood out among the countries with the most diverse offerings, while Malaysia made more contributions focusing on ICT integration and heuristics. Among the types of operational methods, GIS was used most often, usually in combination with other technologies. The most common operations research methods from 2010 to 2013 were mathematical optimization methods, multi-criteria decision analysis, and heuristic methods. The authors also point out the importance of the social aspect, which includes research in the field of citizens' environmental awareness and the analysis of approaches to citizens' waste management. The authors note that there is a need for more research on the implementation of operational technologies and ICT in the field of recycling and reverse logistics, as well as studies to support environmental regulations. The authors also note the lack of historical data on garbage collection management. This can lead to erroneous decision-making and inaccurate planning and forecasting. The authors believe that business intelligence tools and techniques, such as data mining and multivariate analysis to transform raw data into meaningful and useful information, could be a new way of learning about ICT for decision-making related to waste management. Devi provides a review of solid-waste management models in [8]. Nine waste management models are reviewed with the aim of finding out which existing model could be applied exclusively to Indonesia's transitioning villages through the lenses of sustainable urban planning by reviewing 10 existing models. The conclusion from the study is that the solid-waste management model needs to emphasize (1) the participation of local communities, (2) the pattern of waste transport and the type of waste management that does not require a large financial burden, and (3) the management infrastructure that can be put in place and maintained by the community/local organizations.

Another set of studies focus on **SGB-level services, approaches, and technologies approaches** that include various sensors, actuators, other IoT and communication technologies. Soni and Kandasamy analyze the types of SGBs in [9] by categorizing systems based on technology (sensors and data transfer), microcontroller, cloud technologies, GPS, and web technologies (web interface of SGB). They analyze 18 different smart bin systems but, unfortunately, report only the absence or presence of certain sensors and technologies. The result of the analysis is that the authors propose their own framework that considers the identified needs and shortcomings of existing solutions in this area. Reference [10] provides relatively detailed but unstructured review of IoT-enabled waste technologies and practices in spheres of 1) waste characterization, 2) waste quantification, and 3) waste management. The shortcomings of the existing waste management practices are highlighted, and a conceptual framework for a centralized waste management system is proposed. Reference [4] provides a structured overview and detailed analysis in the field of SWM systems with SGB-related services in IoT-enabled smart cities. It studies combinations of various sensors in SWM systems (capacity, weight, temperature, humidity, chemical, pressure), actuators, cameras, RFIDs, WSNs and GPS. Reference [11] describe and analyze various smart waste monitoring, segregation, and collection systems. The analysis of a total of 28 SWM systems is based on the technologies and sensors used. In [12], Topaloglu *et al.* perform a comparison of Wi-Fi, Cellular, Li-Fi, and drone-based systems for SWM purposes. The aim of this study was to propose a type-2 fuzzy multiple criteria methodologies for evaluating and ranking alternative waste collection systems in a smart city environment. The analysis showed that the drone and the visible light communication-based collection systems are the most appropriate for the study area. These technologies can be preferred and used in the smart city environment, particularly in the solid-waste collection context, and the rankings were almost robust to weight changes. The methodology proposed in this study can be applied to solid-waste collection problems in other cities and regions. Chaudhari provides an overview of an IoT-based waste collection management system for smart cities in [13]. A description of the functional, basic characteristics and advantages of the systems under consideration is provided. The result of the analysis is that the authors propose their own SWM. The review does not contain any complaints or shortcomings; there is no pivot table or other way to compare systems with each other. One of the findings of the study is that there is still insufficient discussion of the possibility of using genetic algorithms as an optimization method for waste collection. The authors of [11] describe and analyze various smart waste monitoring, segregation, and collection systems. The analysis of a total of 28 SWM systems is based on the technologies and sensors used. As a result of the study, the authors offer a schematic general design of a smart garbage management system using the cloud and a generalized description of the segregation scenario of trash using embedded and GSM technology.

**Stakeholders in SWM systems** are practically not explored in terms of finding all primary and secondary stakeholders, the connections between them, their interests and existing needs. Reference [10] briefly discusses the role of citizens, government departments and private companies in terms of data collected through various applications on smartphones. In [7] the authors indicate the importance of social aspects, including research in the field of environmental awareness and analyses of approaches to waste management for citizens.

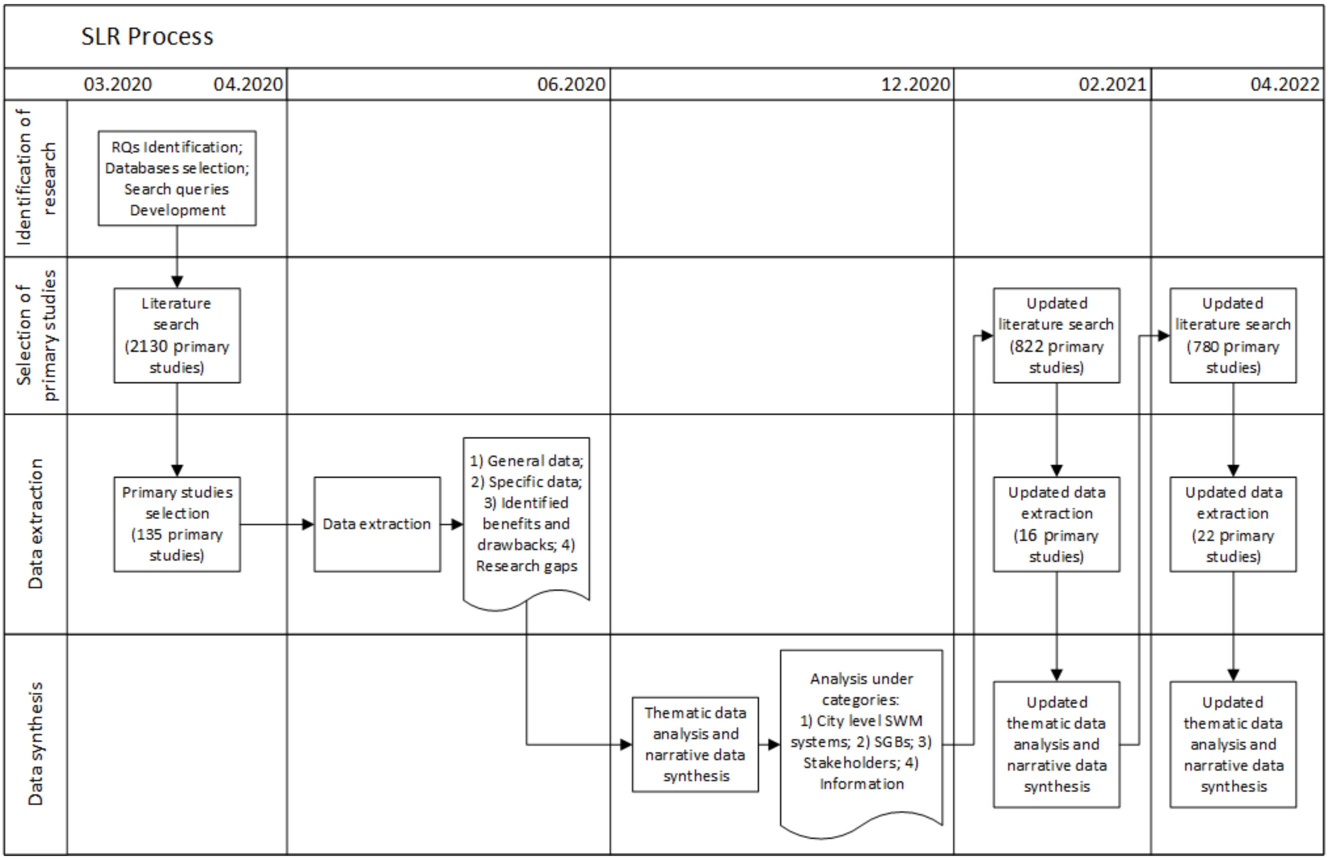


**FIGURE 1.** SLR methodology.

None of the reviewed studies classifies and considers the entire amount of **information in the system shared between**stakeholders, IoT devices and other system components. However, [10] briefly discusses data obtained using mobile apps, various devices and embedded sensors carried by citizens. The authors note that data is collected essentially everywhere by different organizations, but the communication between different sources and integrated data cloud that can be shared between different stakeholders is missing.

The existing studies have pointed out that solid-waste management systems in smart cities consist of several layers: from the top managerial level to the detailed implementation of elements of the system. At the top level, are described the roles of various stakeholders and waste management in general. The lower levels provide solutions to data collection and transfer from garbage bins, as well as the use of this information for informed decision-making. This paper aims to build a holistic picture of the various solid-waste management systems presented in the literature.

## III. METHODOLOGY

We have chosen the systematic literature review (SLR) as the method of reviewing and analyzing the existing SWM system approaches presented in the literature. The SLR uses data from previously published (primary) studies for the purpose of research synthesis. Research synthesis is the collective term for a family of methods for summarizing; integrating; and, when possible, combining the findings of different studies on a topic or RQ. Such synthesis can also identify crucial areas and questions that have not been adequately addressed in past empirical research [14]. The purpose of an SLR is to provide an exhaustive summary of the available literature relevant to the RQs [14]. The SLR follows a formal protocol that will be described in this section. The SLR used in this study consists of the following stages (Fig. 1), as proposed by Kitchenham [14]:

1) Identification of research
    a) RQs for the literature review
    b) Selection of the databases
    c) Development of the search queries
2) Selection of primary studies based on the inclusion and exclusion criteria
3) Data extraction process
4) Data synthesis

The selections made in each step are briefly described in the following subsections.

### A. IDENTIFICATION OF THE RESEARCH

The SLR protocol uses the RQs that are presented in Section 1. Thus, the objective of this paper is to find reports on existing SWM systems and their characteristics and then possible research gaps in SWM development. The literature searches were carried out in five different databases (as proposed by Kitchenham [14])—namely Institute of electrical and electronics engineers (IEEE), Association for computing machinery (ACM), Elsevier, Springer, and Web of Science (WoS). These databases were selected because they represent the main venues for technical papers, such as those focusing on smart cities and SWM systems. The keywords used for the searches were selected based on the study RQs, with an emphasis on smart and sustainable cities, waste management and technologies such as IoT. The following search queries were used.

**Search Query 1**:

*("IoT" OR "Internet of Things") AND ("Waste" OR "Waste management" OR "Recycling") AND (("Smart" OR "Sustainable") AND ("City" or "Cities")) AND ("Application" OR "System" OR "Architecture" OR "Design")*

**Search Query 2**:

*("IoT" OR "Internet of Things") AND ("Waste" OR "Waste management" OR "Recycling") AND (("Smart" OR "Sustainable") AND ("City" OR "Cities"))*

Search Query 1 represented the original objectives of the study, but it was found to be too specific to some of the databases. As such, Query 2 was developed to extend the search. We used different variations of these two search queries across different databases to improve the output of our searches. In ACM and WoS – Search Query 1; in IEEE – Search Query 2; in Elsevier – Search Query 2 + ("Waste" OR "Waste management" OR "Recycling" OR "Garbage") in title, keywords, or abstract + Subject area: Computer Science; and in Springer – Search Query 2 with content type: conference paper or article. The searches were limited to papers published between 2014 and 2022. The searches were run in April 2020, February 2021 and subsequently in April 2022, and a total of 3,732 articles were found based on these search queries.

### B. SELECTION OF PRIMARY STUDIES BASED ON THE INCLUSION AND EXCLUSION CRITERIA

During the selection of papers to the analysis, we used the traditional inclusion and exclusion criteria. We included a paper if it described 1) an IoT-enabled waste management system/application (or design/architecture) that is used or could be used in smart cities, 2) SGB implementation, 3) an SWM or SGB overview, 4) a description of technologies and approaches to managing the removal of solid waste, or 5) a description of use cases and analysis of the results of the implementation of such systems. We also had the following commonly used set of exclusion criteria: 1) full text of the paper is not available or we do not have access; 2) paper is not written in English; 3) paper is only an abstract or in poster form; 4) paper is a description of a workshop, etc. (thus not a research article); and 5) paper is a duplicate (paper found multiple times in different databases). Using the inclusion criteria presented above, the papers were included or excluded based on the full text. Out of 3,732 articles, 173 were selected for further data extraction (Table 1).

**TABLE 1.** Database searches and primary studies included in different steps of the literature review.

| Database | First search/ included | Second search/ included | Third search/ included | Total included |
|---|---|---|---|---|
| IEEE | 150 / 65 | +47 / +11 | +67/+19 | 95 |
| ACM | 394 / 9 | +35 / +0 | +81/+1 | 10 |
| Elsevier | 141 / 14 | +68 / +0 | +23/+0 | 14 |
| Springer | 1292 / 29 | +651 / +0 | +607/+0 | 29 |
| WoS | 153 / 18 | +21 / +5 | +2/+2 | 25 |
| **TOTAL** | **2130 / 135** | **+822 / +16** | **+780/+22** | **173** |

### C. DATA EXTRACTION PROCESS

A list of extracted data items was created based on the RQs. The following data were extracted from the selected primary studies: 1) general data (authors, title, publication year, digital object identifier (DOI), uniform resource locator (URL), and abstract), 2) specific data based on article type (see Table 2), 3) identified benefits and drawbacks, and 4) research gaps and future needs identified in the paper. A Google form[2] was used to record the extracted data.

**TABLE 2.** Data extraction based on the type of article.

| Type of article | Extracted data |
|---|---|
| High-level ecosystem description | ecosystem descriptions, stakeholders, information (shared between stakeholders), and services (provided/needed) |
| Technical system description | system descriptions, information (needed and shared in the system), elements of the system, features, sensors, used IoT technologies, used communication technologies, and microcontroller |
| Practical implementations | system (pilot) description, location of system implementation, implemented/tested features, duration of the test, and test participants |
| Reviews article | subject of review, systems under study, analysis criteria, and analysis result |

While extracting the data, we identified different types of articles and the data collected from those (Table 2 ).

### D. DATA SYNTHESIS

We performed thematic data analysis and narrative data synthesis for the extracted data. Quantitative synthesis was used for the "duration of the test" and "number of test participants" categories. To answer the RQs in a holistic manner,

[2] https://forms.gle/jFwQ5yGrxzTtaBnN6

**TABLE 3.** Primary studies and their links with the research questions.

(ID column: A = ACM, E = Elsevier, I = IEEE, S = Springer, W = WoS;
Category column: ID = Implementation and Design, HL = High level, SWM = Smart Waste Management, SGB = Smart Garbage Bin)

| ID | Title | Ref. | Category | RQ 1.1 | RQ 1.2 | RQ 1.3 | RQ 1.4 | Tests |
|---|---|---|---|---|---|---|---|---|
| A2 | Blockchain Based Smart Park: Cleaning Management | [16] | ID SWM, HL SWM SGB | * | * | | * | |
| A3 | Design of Beverage Packaging Identification and Recycling System Based on Zedboard | [17] | SGB | | * | | * | |
| A4 | SWAM: A Novel Smart Waste Management Approach for Businesses Using IoT | [18] | ID SWM, ID SWM SGB | * | * | * | * | |
| A7 | Low-Energy Smart Trash Bin Architecture for Dynamic Waste Collection System | [19] | SGB | | * | | * | * |
| A8 | Enabling Smart Waste Management with Sensorized Garbage Bins and Low Power Data Communications Network | [20] | HL SWM SGB | | * | | * | |
| A9 | RecycHongs: Mobile App Co-Design | [21] | ID SWM | * | | * | * | |
| A10 | A Cloud-Based Dynamic Waste Management System for Smart Cities | [22] | ID SWM, HL SWM SGB | * | * | | * | * |
| A11 | An Empirical Study on Coverage-Ensured Automotive Sensing Using Door-to-Door Garbage Collecting Trucks | [23] | ID SWM | * | | | * | |
| A12 | Dynamic Polling Algorithm for Low Energy Garbage Level Measurement in Smart Trash Bin | [24] | SGB | | * | | * | |
| A13 | E-Waste Management Using Machine Learning | [25] | HL SWM | * | | | | |
| E2 | Proposing the use of blockchain to improve the solid waste management in small municipalities | [26] | ID SWM | * | | * | * | * |
| E6 | Application of Blockchain Technology in Incentivizing Efficient Use of Rural Wastes: A case study on Yitong System | [27] | ID SWM | * | | * | * | |
| E7 | BIN-CT: Urban waste collection based on predicting the container fill level | [28] | ID SWM, HL SWM SGB | * | * | | * | * |
| E8 | Custom Block Chain Based Cyber Physical System for Solid Waste Management | [29] | ID SWM | * | | * | * | |
| E10 | Greedy randomized adaptive search procedure to design waste collection routes in La Palma | [30] | ID SWM, HL SWM SGB | * | * | | * | * |
| E12 | Product Service System-based Municipal Solid Waste circular management platform in Campania Region (Italy): a preliminary analysis | [31] | HL SWM | * | | * | * | |
| E13 | Route optimization of an electric garbage truck fleet for sustainable environmental and energy management | [32] | ID SWM, HL SWM SGB | * | * | | * | * |
| E16 | A stochastic optimization framework for planning of waste collection and value recovery operations in smart and sustainable cities | [33] | ID SWM | * | | | * | * |
| E17 | Design, implementation, and evaluation of an Internet of Things (IoT) network system for restaurant food waste management | [34] | ID SWM, SGB | * | * | * | * | * |
| E20 | Improving logistic efficiency of WEEE collection through dynamic scheduling using simulation modeling | [35] | ID SWM, HL SWM SGB | * | * | | * | * |

**TABLE 3.** ***(Continued.)*** **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| E22 | The smart waste collection routing problem: Alternative operational management approaches | [36] | ID SWM, HL SWM SGB | * | * | | * | * |
| E26 | A Cyber - based DSS for a Low Carbon Integrated Waste Management System in a Smart City | [37] | ID SWM | * | | * | * | * |
| E27 | Assessing dynamic models for high priority waste collection in smart cities | [38] | ID SWM, HL SWM SGB | * | * | * | * | * |
| E28 | Smart Waste Collection System Based on Location Intelligence | [39] | ID SWM, SGB | * | * | | * | * |
| I2 | A LoRa-based IoT Sensor Node for Waste Management Based on a Customized Ultrasonic Transceiver | [40] | SGB | | * | | * | * |
| I3 | A Smart Bin Implementantion using LoRa | [41] | SGB | | * | | * | * |
| I4 | An infrared-based sensor to measure the filling level of a waste bin | [42] | SGB | | * | | * | * |
| I5 | An IoT Based Green Waste Management System For Bangladesh | [43] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I6 | An NB-IoT-based smart trash can system for improved health in smart cities | [44] | SGB | | * | | * | * |
| I7 | Architecture for Waste Management in Indian Smart Cities (AWMINS) | [45] | HL SWM SGB | | * | | * | |
| I8 | Blockchain and IoT Based Formal Model of Smart Waste Management System Using TLA+ | [46] | ID SWM | * | | * | * | |
| I9 | Development of semi-adaptive Waste Collection Vehicle Routing Algorithm for agglomeration and urban settlements | [47] | ID SWM, HL SWM SGB | * | * | | * | |
| I11 | Internet of Things Based Wireless Garbage Monitoring System | [48] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I13 | IoT based smart garbage monitoring & collection system using WeMos & Ultrasonic sensors | [49] | ID SWM, ID SWM SGB | * | * | | * | |
| I15 | IoT BasedSmart Waste Management System: India prospective | [50] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I16 | IoT Cloud based Smart Bin for Connected Smart Cities - A Product Design Approach | [51] | SGB | | * | | * | * |
| I17 | Public Private Partnership in Smart city waste management - a Business Case | [52] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I18 | Smart Waste Management System for Crowded area : Makkah and Holy Sites as a Model | [53] | ID SWM, ID SWM SGB | * | * | | * | * |
| I20 | A Serverless IoT Architecture for Smart Waste Management Systems | [54] | HL SWM SGB | | * | | * | |
| I21 | A Smart IoT System for Waste Management | [55] | ID SWM, HL SWM SGB | * | * | | * | |
| I22 | An Intelligent Bin Management System Design for Smart City using GSM Technology | [56] | SGB | | * | | * | * |
| I23 | An IoT Enabled Smart Waste Management System in Concern with Indian Smart Cities | [57] | SGB | | * | * | * | * |
| I24 | An IoT-Based Architecture for Waste Management | [58] | HL SWM, HL SWM SGB | * | * | | * | |
| I26 | Automatic Waste Segregator Bin Using Robotic Arm | [59] | SGB | | * | | * | * |

**TABLE 3.** ***(Continued.)*** **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I27 | Design and Development of Smart Trash Bin Prototype for Municipal Solid Waste Management | [60] | ID SWM, HL SWM SGB | * | * | | * | * |
| I28 | Developing a Self-Powered Enlarging Smart Waste Bin | [61] | HL SWM, ID SWM SGB | * | * | | * | * |
| I29 | Digital waste management using LoRa network a business case from lab to fab | [62] | ID SWM, ID SWM SGB | * | * | | * | * |
| I30 | Efficient IOT Based Smart Bin for Clean Environment | [63] | SGB | | * | * | * | |
| I31 | Framework for route optimization of solid waste collection | [64] | ID SWM, HL SWM SGB | * | * | | * | |
| I32 | Garbage Monitoring and Disposal System for Smart City Using Iot | [65] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I33 | IoT-Enabled Smart City Waste Management using Machine Learning Analytics | [66] | ID SWM, ID SWM SGB | * | * | | * | * |
| I34 | Recycle.io: An IoT-Enabled Framework for Urban Waste Management | [67] | ID SWM SGB | | * | | * | |
| I36 | Smart and green urban solid waste collection system for differentiated collection with integrated sensor networks | [68] | HL SWM, HL SWM SGB | * | * | | * | |
| I37 | Smart Dual Dustbin Model for Waste Management in Smart Cities | [69] | SGB | | * | | * | |
| I38 | Smart Garbage Management System | [70] | SGB | | * | | * | |
| I39 | Smart Waste Bin: A New Approach for Waste Management in Large Urban Centers | [71] | SGB | | * | | * | |
| I42 | A cloud integrated wireless garbage management system for smart cities | [72] | ID SWM SGB | | * | | * | * |
| I45 | A waste city management system for smart cities applications | [73] | ID SWM, HL SWM SGB | * | * | | * | * |
| I47 | Design a smart waste bin for smart waste management | [74] | SGB | | * | * | * | * |
| I48 | Design of smart bin for smarter cities | [75] | SGB | | * | | * | |
| I49 | Dynamic Routing for Waste Management using IoT for Cost-Efficient Service | [76] | ID SWM, HL SWM SGB | * | * | * | * | * |
| I50 | Implementation of an smart waste management system using IoT | [77] | SGB | | * | * | * | |
| I51 | Intellectual trash management using Internet of Things | [78] | ID SWM, HL SWM SGB | * | * | * | * | |
| I52 | Internet of Bins: Trash Management in India | [79] | ID SWM, HL SWM SGB | * | * | * | * | |
| I53 | IoT based solid waste management system for smart city | [80] | SGB | | * | | * | * |
| I54 | IoT based waste management: An application to smart city | [81] | ID SWM, HL SWM SGB | * | * | | * | * |
| I55 | Multi-objective decision-making framework for effective waste collection in smart cities | [82] | ID SWM, HL SWM SGB | * | * | | * | |
| I56 | Optimization of Garbage Collection Using Genetic Algorithm | [83] | ID SWM, HL SWM SGB | * | * | | * | * |
| I57 | Smart city solid waste management leveraging semantic based collaboration | [84] | ID SWM, HL SWM SGB | * | * | | * | * |
| I59 | Smart waste management using Internet-of-Things (IoT) | [85] | HL SWM, HL SWM SGB | * | * | | * | * |

**TABLE 3.** *(Continued.)* **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I60 | The Smart Cheap City: Efficient Waste Management on a Budget | [86] | ID SWM SGB | | * | | | * |
| I61 | Towards an architecture for smart garbage collection in urban settings | [87] | ID SWM, HL SWM SGB | * | * | | * | * |
| I62 | Waste management using solar smart bin | [88] | SGB | | * | | * | |
| I64 | A Decision Support Approach for Postal Delivery and Waste Collection Services | [89] | ID SWM | * | | * | * | * |
| I65 | An integrated node for Smart-City applications based on active RFID tags; Use case on waste-bins | [90] | SGB | | * | | * | * |
| I66 | Cloud-based smart waste management for smart cities | [91] | HL SWM | * | | * | * | |
| I67 | eBin: An automated food wastage tracking system for dormitory student's mess | [92] | SGB | | * | * | * | * |
| I68 | IoT based solid waste management system: A conceptual approach with an architectural solution as a smart city application | [93] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I70 | Smart city technology based architecture for refuse disposal management | [94] | ID SWM | * | | | * | * |
| I71 | Smart Solutions for Smart Cities: Using Wireless Sensor Network for Smart Dumpster Management | [95] | ID SWM, SGB | * | | * | * | * |
| I72 | Using genetic algorithm for advanced municipal waste collection in Smart City | [96] | ID SWM, HL SWM SGB | * | * | | * | * |
| I73 | WasteApp: Smarter waste recycling for smart citizens | [97] | ID SWM | * | | * | * | * |
| I74 | A versatile scalable smart waste-bin system based on resource-limited embedded devices | [98] | SGB | | * | | * | * |
| I75 | Robust waste collection exploiting cost efficiency of IoT potentiality in Smart Cities | [99] | ID SWM, HL SWM SGB | * | * | | * | * |
| I76 | Smartbin: Smart waste management system | [100] | ID SWM SGB | | * | | * | * |
| I77 | Top -- k Query Based Dynamic Scheduling for IoT-enabled Smart City Waste Collection | [101] | ID SWM, HL SWM SGB | * | * | | * | * |
| I78 | Dynamic cargo routing on-the-Go: The case of urban solid waste collection | [102] | ID SWM, ID SWM SGB | * | * | * | * | * |
| I79 | Intelligent system for valorizing solid urban waste | [103] | HL SWM SGB | | * | * | * | |
| I81 | Recyclable, Eco-Friendly, On-Demand Bin (ReDBin) | [104] | HL SWM, HL SWM SGB | * | * | * | * | |
| I82 | Automated Smart Garbage Monitoring System with Optimal Route Generation for Collection | [105] | ID SWM, ID SGB SWM | * | * | | * | |
| I83 | IOT Assisted MQTT for Segregation and Monitoring of Waste for Smart Cities | [106] | SGB | | * | * | * | * |
| I84 | AN IoT Based Waste Segreggator for Recycling Biodegradable and Non-Biodegradable Waste | [107] | ID SWM SGB | | * | | * | * |
| I85 | From Smart City to Smart Citizen: rewarding waste recycle by designing a data-centric IoT based garbage collection service | [108] | ID SWM | * | | * | * | * |
| I86 | Holistic Solution Design and Implementation for Smart City Recycle Waste Management Case Study: Saensuk City | [109] | ID SWM SGB | | * | * | * | * |

**TABLE 3.** ***(Continued.)*** **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I87 | A cloud based smart recycling bin for waste classification | [110] | SGB | | * | | * | * |
| I88 | Waste Management Improvement in Cities using IoT | [111] | ID SWM SGB | | * | * | * | |
| I89 | Energy saving smart waste segregation and notification system | [112] | SGB | | * | * | * | * |
| I90 | IoT-enabled Smart Waste Disposal System: a Use Case for the Context Management Platform | [113] | HL SWM SGB | | * | | * | * |
| I91 | Smart City IoT System - CollectMyWaste | [114] | ID SWM, HL SWM SGB | * | * | * | * | |
| I92 | Toward a Deep Smart Waste Management System based on Pattern Recognition and Transfer learning | [115] | ID SWM, HL SWM SGB | * | * | * | * | |
| I93 | Architecture, Concept and Algorithm for Data Analytics based Zero Touch Waste Management in Smart Cities | [116] | ID SWM | * | | | * | |
| I94 | Garbage Zero (Garb0): An IoT Framework for Effective Garbage Management in Smart Cities | [117] | HL SWM, | * | * | | * | |
| I95 | Smart Solid Waste Management System Using Blockchain and IoT for Smart Cities | [118] | HL SWM | * | | | * | |
| I96 | Smart Waste Collection Monitoring System using IoT | [119] | HL SWM SGB | | * | | * | |
| I97 | Enhanced Smart Waste Management System With Incinerator Compartment | [120] | SGB | | * | | * | * |
| I98 | Solid waste management and monitoring system for smart cities: development of a low-cost sustainable IoT architecture using GPRS/GSM | [121] | SGB | | * | | * | * |
| I99 | e-TapOn: Solar-Powered Smart Bin with Path-based Robotic Garbage Collector | [122] | SGB | | * | | * | |
| I100 | Intelligent Garbage Monitoring System Using IoT | [123] | SGB | | * | | * | * |
| I102 | A CNN-Based Smart Waste Management System Using TensorFlow Lite and LoRa-GPS Shield in Internet of Things Environment | [124] | SGB | | * | | * | * |
| I103 | IoT based Smart City Garbage Bin for Waste Management | [125] | SGB | | * | | * | |
| I104 | A Smart Waste Management and Segregation System that Uses Internet of Things, Machine Learning and Android Application | [126] | SGB | | * | | * | * |
| I105 | Smart bin for Clean Cities using IOT | [127] | SGB | | * | | * | |
| I106 | Smart Trash Bin Segregation and Identify and Create Alerts on the Level of Waste Present in the Trash Bin | [128] | SGB | | * | | * | * |
| I107 | Computer-Vision Enabled Waste Management System for Green Environment | [129] | SGB | | * | | * | |
| I108 | Intelligent Waste Management for Smart Cities | [130] | SGB | | * | | * | |

**TABLE 3.** *(Continued.)* **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I109 | Framework of Automated Robotic Dustbin (ARD) for Garbage Collection in Smart Cities with Priority Scheduling Approach | [131] | SGB | | * | | * | |
| I110 | Cloud-based Smart IoT Sustainable Solution for Waste Sorting and Management | [132] | SGB | | * | | * | * |
| I111 | Investigating Efficient Municipal Solid Waste Collection Through Technology | [133] | SGB | | * | | * | |
| I112 | IoT based Smart Garbage System | [134] | SGB | | * | | * | |
| S1 | A Software-Defined Networking (SDN) Architecture for Smart Trash Can Using IoT | [135] | ID SWM, ID SWM SGB | * | * | | * | * |
| S3 | Application of Sensors Using IoT for Waste Management System | [136] | SGB | | * | | * | * |
| S6 | Energy-Efficient Waste Management System Using Internet of Things | [137] | HL SWM SGB | | * | | * | |
| S8 | Implementation of IoT for Trash Monitoring System | [138] | ID SWM SGB | | * | | * | |
| S9 | IOT Based Garbage Monıtorıng and Clearance Alert System | [139] | ID SWM SGB | | * | | * | |
| S12 | Optimal Management of Solid Waste in Smart Cities using Internet of Things | [140] | ID SWM | * | | | * | * |
| S13 | Smart Bin with Automated Metal Segregation and Optimal Distribution of the Bins | [141] | SGB | | * | | * | * |
| S15 | Smart Monitoring for Waste Management Using Internet of Things | [142] | HL SWM SGB | | * | | * | * |
| S16 | Smart Solid Waste Collection and Management System | [143] | SGB | | * | | * | * |
| S17 | Smart Waste Management System Using IoT | [144] | SGB | | * | | * | * |
| S22 | Cloud-Based Scheme for Household Garbage Collection in Urban Areas | [145] | ID SWM, ID SWM SGB | * | * | | * | * |
| S23 | Garbage Monitoring System Using Internet of Things | [146] | SGB | | * | | * | * |
| S27 | IoT Based Market and Waste Management System for a Smart City | [147] | SGB | | * | | * | * |
| S28 | IoT-Based Smart Waste Management System in a Smart City | [148] | HL SWM, HL SWM SGB | * | * | | * | |
| S32 | Smart Waste Management for Segregating Different Types of Wastes | [149] | SGB | | * | | * | |
| S33 | Smart Waste Monitoring Using Wireless Sensor Networks | [150] | SGB | | * | | * | * |
| S34 | An IoT-based waste management system monitored by cloud | [151] | SGB | | * | | * | * |
| S39 | IoT-Based Green Environment for Smart Cities | [152] | SGB | | * | | * | * |
| S40 | IoT-Based Monitoring and Smart Planning of Urban Solid Waste Management | [153] | SGB | | * | | * | |
| S41 | IoT-Based Smart Garbage Management System | [154] | SGB | | * | | * | |
| S45 | Sustainable WAsTe Collection (SWAT): One Step Towards Smart and Spotless Cities | [155] | ID SWM SGB | | * | * | * | * |
| S46 | The Big Bucket: An IoT Cloud Solution for Smart Waste Management in Smart Cities | [156] | SGB | | * | | * | |

**TABLE 3.** ***(Continued.)*** **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| S47 | Use of Gamification Techniques to Encourage Garbage Recycling. A Smart City Approach | [157] | HL SWM, HL SWM SGB | * | * | * | * | * |
| S49 | Supporting Data Communications in IoT-Enabled Waste Management | [158] | SGB | | * | | * | * |
| S50 | SWM-PnR: Ontology-Based Context-Driven Knowledge Representation for IoT-Enabled Waste Management | [159] | ID SWM, HL SWM SGB | * | * | * | * | * |
| S52 | Smart Waste Collection Platform Based on WSN and Route Optimization | [160] | ID SWM, HL SWM SGB | * | * | | * | * |
| S54 | High Capacity Trucks Serving as Mobile Depots for Waste Collection in IoT-Enabled Smart Cities | [161] | ID SWM, HL SWM SGB | * | * | * | * | * |
| S55 | Waste Management as an IoT-Enabled Service in Smart Cities | [162] | HL SWM, HL SWM SGB | * | * | * | * | * |
| S56 | Effective Waste Collection with Shortest Path Semi-Static and Dynamic Routing | [163] | ID SWM, HL SWM SGB | * | * | * | * | * |
| W6 | Implementation of IoT Based Waste Segregation and Collection System | [164] | SGB | | * | | * | * |
| W9 | Optimal Path Planning for Selective Waste Collection in Smart Cities | [165] | ID SWM, HL SWM SGB | * | * | | * | * |
| W10 | Smart recyle trash management systems for smart city using IOT | [166] | SGB | | * | | * | |
| W13 | A Low Power IoT Sensor Node Architecture for Waste Management Within Smart Cities Context | [167] | SGB | | * | | * | * |
| W15 | A stochastic multi-agent system for Internet of Things-enabled waste management in smart cities | [5] | ID SWM | * | | | * | * |
| W16 | Decision support for optimizing waste management | [168] | ID SWM, HL SWM SGB | * | * | | * | * |
| W18 | Intelligent System for Garbage collection: IoT technology with Ultrasonic sensor and Arduino Mega | [169] | SGB | | * | | * | |
| W20 | Smart Waste Collection System with Low Consumption LoRaWAN Nodes and Route Optimization | [170] | ID SWM, HL SWM SGB | * | * | * | * | * |
| W24 | Developing and evaluating prototype of waste volume monitoring using Internet of Things | [171] | SGB | | * | | * | * |
| W26 | Smart City Aplication: Internet of Things (IoT) Technologies eased Smart Waste Collection Using Data Mining Approach and Ant Colony Optimization | [172] | ID SWM, ID SWM SGB | * | * | | * | * |
| W27 | Smart City Platform Development for an Automated Waste Collection System | [173] | HL SWM, HL SWM SGB | * | * | * | * | |
| W29 | Implementation of spatial smart waste management system in Malaysia | [174] | ID SWM, ID SWM SGB | * | * | * | * | * |
| W31 | Mobile Waste Management for Smart Cities: Monitoring Sanitation Through Living Labs | [175] | ID SWM | * | | * | * | * |
| W32 | Waste management strategy at a public university in smart city context | [176] | HL SWM, HL SWM SGB | * | * | | * | |
| W33 | Dissipation of Waste using Dynamic Perception and Alarming System: A Smart City Application | [177] | ID SWM | * | | * | * | * |
| W34 | iEcoSys - An Intelligent Waste Management System | [178] | ID SWM SGB | | * | | * | * |

**TABLE 3.** ***(Continued.)*** **Primary studies and their links with the research questions.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| W35 | Multi-agent gathering Waste System | [179] | ID SWM, ID SWM SGB | * | * | * | * | * |
| W37 | IoT-Aware Waste Management System Based on Cloud Services and Ultra-Low-Power RFID Sensor-Tags | [180] | ID SWM SGB | | * | | * | * |
| W38 | An integrated model for management of hazardous waste in a smart city with a sustainable approach | [181] | ID SWM | * | | * | * | * |
| W39 | Data-driven analytical framework for waste-dumping behaviour analysis to facilitate policy regulations | [182] | ID SWM | * | | | * | * |
| W40 | A Smart Waste Management Solution Geared towards Citizens | [183] | ID SWM, ID SWM SGB | * | | * | * | * |
| W41 | IoT-Based Smart Waste Bin Monitoring and Municipal Solid Waste Management System for Smart Cities | [184] | ID SWM, ID SWM SGB | * | * | * | * | * |
| W42 | Internet of things-based urban waste management system for smart cities using a Cuckoo Search Algorithm | [185] | HL SWM SGB | | * | | * | * |
| W43 | Smart Prediction and Monitoring of Waste Disposal System Using IoT and Cloud for IoT Based Smart Cities | [186] | ID SWM SGB | | * | | * | * |

the extracted data were categorized using thematic analysis with the following categories: 1) city-level SWM systems, 2) SGB and SWM systems with SGB-related services, 3) stakeholders in SWM systems, and 4) information shared between SWM systems and stakeholders. These categories are our first outcome of the performed data synthesis. A mind map that includes a holistic view of the topics in SWM systems is presented in Figure 7. This mind map is further used as a conceptual basis for compiling the pivot tables.

- To answer RQ1.1, we analyzed the data extracted and made a pivot table reflecting the services and communication technologies for each of the considered city-level SWM systems (Table 4). To analyze the changes in the terminology used in the articles from 2014 to 2022, we used KH Coder.[3]
- To answer RQ1.2, we made a pivot table presenting the sensors (IoT technologies) and the communication technologies and services for each of the considered SGBs and SWM systems with SGB-related services (Table 5). We also used KH Coder to analyze the changes in terminology from 2014 to 2022.
- To answer RQ1.3, we analyzed the stakeholders in each of the considered SWM systems (Table 7). Based on the analysis, we identified the direct stakeholders (directly involved in the process of the delivery, removal, and management of waste disposal) and indirect stakeholders (indirectly involved in the process of waste collection and removal) in the SWM systems.
- To answer RQ1.4, we created, based on article analyses (Tables 8 and 9), a summary diagram that shows the information that is transmitted in the SWM system between various stakeholders and system components.
- To answer RQ2, we analyzed the research needs and gaps identified in the articles.

## IV. RESULTS

The number of selected primary studies for each year describing city-level SWM systems and SGBs or SWM systems with SGB-related services is shown in Fig. 2. One can see that the number of SGB-related articles increased until 2018 and then started decreasing slightly. The number of city-level SWM descriptions has remained at a rather constant level.

The titles and abstracts of the selected primary studies were analyzed using KH Coder to find the general categories covered in solid-waste management research. KH Coder analyzes the content of the titles or abstracts and forms clusters of topics and their links (co-occurrence of the words) emphasized in the primary studies. The outcome of the analysis based on the titles is presented in Fig. 3 and based on the abstracts in Fig. 4. The titles of the primary studies (Fig. 3) clearly emphasize the **smart city and waste management** (red (04) and grey (09) clusters) and provide clusters for **different elements of the SWM systems** (SGB in pink (08), light-green (07) and orange (06); route planning in green (01) and blue (05), and sensor solutions in yellow (02) and purple (10)). The analysis based on abstracts (Fig. 4) reveals similar (but different) clusters: smart city (red (04)), waste

[3]KH Coder is a free software used for quantitative content analysis or text mining. It is also utilized for computational linguistics.

**TABLE 4. City level SWM systems.**

(Data analysis: 1 – real time data, 2 - historical data; Information support: A – City administration, Au – Authorities, C-Citizens, D – Dispatchers, DO – Disposal organization, Dr – Drivers, P – Police, Wd – Waste department)

**The first 10 rows of the table are presented below. To see the full version of the table (89 rows), please follow the link https://doi.org/10.5281/zenodo.6499370 https://zenodo.org/record/6499370/files/Table%20A1.%20City%20level%20SWM%20systems.xlsx?download=1**

| System type | | ID | Communication Technologies | Services | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Data | | User support | | | | Payments and benefits | | | Optimize the planning of waste collection operations | | | | | Environment | | |
| | | | | | | | | | | | | | Trucks / Drivers | | | | | | | |
| | | | | Data analytics | Data fusion and predictive analytics | City Dashboard (Map) | Notifications for drivers | Information support | Complaints and revues for citizens | Blockchain-based monitoring | Pay-as-you-throw | Rewards | Route planning | Route optimization | Scheduling | SGB positioning | Door-to-Door Garbage Collection | Waste classification / segregation | Measure Environmental parameters | Minimize Carbon Emissions |
| High level SWM System | Basic High level SWM Systems | I28 | WIFI, Mobile | 1 | | | | | | | | | | + | | | | | | |
| | | I81 | RFID+, Internet | | | + | | | | | | | + | + | | | | + | + | |
| | | I36 | RFID, short range wireless, WIFI, Mobile | 1 | | | | | | | | | + | | + | | | + | | |
| | | W32 | Internet | | | | | | | | + | + | + | + | | | | + | | |
| | | I66 | - | | | | | C, A, Wd | | | + | | + | + | + | | | | | |
| | | E12 | - | | + | | | C, Au | | | | | | | | | | | | |
| | | W27 | - | | + | + | | | | | | | | | | | | + | | |
| | | S55 | | 1 | | + | | | | | | | | + | + | | | | | |
| | | A13 | - | 1,2 | + | | | | | | | | | | | | | | | |
| | | I94 | LoRa | 1 | | | + | C, Dr | | | | | | + | | | | | | |
| | | I95 | - | 1 | | | | C | | + | | + | | | | | | | | |
| | | … | | | | | | | | | | | | | | | | | | |

management (purple (03)), SGB (yellow (02)), route planning (green (07)). We also found some new clusters in abstracts: increasing waste production due to urban population growth (dark-green (5)).

KH Coder was also used to analyze the trends in solid-waste management system research on a yearly basis. The outcome of the analysis was divided into trends in SWM systems (Fig. 5) and trends in SGBs (Fig. 6). Figure 5 clearly

**TABLE 5.** SGBs and SWM systems with SGB-related services.

(Fill level: U – Ultrasonic, O – Optical, IR – Infrared; Gas analyzer: AQ – Air quality; Information support: A – City administration, Au – Authorities, C- Citizens, D – Dispatchers, DO – Disposal organization, Dr – Drivers, P – Police, Wd – Waste department)

**The first 10 rows of the table are presented below. To see the full version of the table (126 rows), please follow the link https://doi.org/10.5281/zenodo.6499370 https://zenodo.org/record/6499370/files/Table%20A2.%20SGBs%20and%20SWM%20systems%20with%20SGB-related%20services.xlsx?download=1**

| System type | ID | Sensors (Measurements) | | | | | | | | | | | | | | | Actuators | | | | | | Solar panel | Communication Technologies | Services | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | | | Monitoring | | | | Identification and classification | | | | | |
| | | Fill level sensor | Weight sensor (load cell) | GPS | Camera | Temperature sensor | Humidity sensor | Moisture sensor | Gas analyzer (CO, NO2) | Lid sensor | Metal sensor | Rain sensor | RFID reader | IR Sensors | PIR Sensor | Person detection | lid control | alarm signals / reports | Servomotor | DC motor | Conveyor belt | Robotic Arm | | | show bins on the Map | video monitoring | existence of harmful materials and gases | e-buttons | SGB identification | waste type identification | individual waste amount | person identification | waste classification / segregation | Information support |
| High level SWM System with SGB-related Services | S52 | U | | + | | | | | | | | | | | | | | | | | | | | WIFI | + | | | | | | | | | |
| | W20 | U | + | + | | + | | | | | | | | | | | | | | | | | | LoRa | | | | | | | | | | |
| | W42 | | | + | + | | | | | | | | | | | | | | | | | | | Mobile | | | | | | + | | | + | |
| | I92 | + | | | + | | | | | | | | | | | | | | | | | | + | - | | | | | | | | | | D |
| | I90 | U | | | | | | | | | | | | | | | + | | | | | | | - | | | | | + | | | | | C |
| | I7 | + | | + | | | + | | + | + | | | | | | | | | | | | | | GPRS, RFID | | | | | | | + | | + | |
| | I21 | U | | + | | | | | + | | | | | | | | | | | | | | | LoRa, WIFI | | | | | | | | | | |
| | I27 | U | + | + | | | | | | | | | | | | | | + | | | | | | RFID, Internet | + | | | | + | + | | | | |
| | S15 | IR | | + | | | | | + | | | + | | + | | | | | | | | | | WIFI, Mobile | | | | | | | | | | |
| | I51 | U | | + | + | | | | | | | | | | | | | | | | | | | Mobile | | + | | | | | | | | |
| | … | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**TABLE 6.** Physical infrastructure of SWM systems.

| Basic Physical infrastructure | Second level of physical infrastructure | ID |
|---|---|---|
| SGB | SGB | see Table A2 |
| Truck | Truck | A11, I17, I29, E17 |
| | Low Capacity Trucks (LCTs) and High Capacity Trucks (HCTs) | E16, I77, S54, S28 |
| Points of intermediate waste storage | Control Station | I71 |
| | Waste Collection Depot | E16, S12, S56, W38 |
| | Mobile Waste Collection Depot | S54 |
| Control Station (dispatchers) | Control Station (dispatchers) | S22 |
| Regions / Sectors of waste collection | Regions / Sectors of waste collection | E16, I64, S12, W15, S56 |
| Dump | Dump | I18, W15, E20, S54 |
| | Not recyclable by-products sanitary landfill | E26, I36 |
| Plants and Facilities | Waste processing plant | I77, W15, E20, E10, S54, S47, E17, E6 |
| | Facility for waste valorization (mechanical, physical, thermal) | E26, A9 |
| | Waste treatment facilities | W38 |
| | Waste recycling facilities | W38 |
| | Disposal facilities | W38 |
| Points of waste collection | | I36, W15, I56, W38 |
| Retailers | | E20 |
| Production centers | | W38 |
| Pipes for transporting waste | | I18 |

shows the trends in city-level SWM research, from technical implementation issues (2014–2016) to more holistic citywide waste management with emerging IoT technology. The SGB and SWM systems with SGB-related services research follow a similar path from node-based data and approaches (2014–2016) to integration into citywide systems with additional focus on people participation and environmental aspects (2017–2022; Fig. 6).

To answer the RQs in a holistic manner, we divide the results under the identified SWM categories into subsections presented in Fig. 7.

### A. CITY-LEVEL SWM SYSTEMS

A large set of primary studies emphasizes the system-level elements and operation of SWM systems with some low-level details. We define city-level SWM systems as SWM systems, that operate on city level and include such main services as information and decision support for various stakeholders; route planning, optimization and scheduling; payments and benefits for service consumers; environmental services (e.g. minimize carbon emissions). The collected data concerning the services and operations are presented in Table 4. Fig. 8 presents the categorization of the primary studies.

The city-level primary studies on SWM systems were divided into high-level descriptions and design- and implementation-related studies. The primary studies with high-level descriptions presented architectural and service concepts for SWM systems. The set of city-level primary studies on design and implementation presented more practically oriented studies on SWM systems. These studies were further classified into several subcategories based on their

**TABLE 7.** Stakeholders in SWM systems.

| Stakeholders | | ID |
|---|---|---|
| Primary | Citizen | S55, I66, E12, S47, W33, I11, S50, E26, E2, E8, I8, I78, I73, A9, W27, I79, W29, I67, I32, I15, S50, I5, E2, E8, W40, W41, I85, I86, I88, I89, I92 |
| | Driver | I71, I51, I52, I68, W29, W35, S50, I17, A4, I64, W20, E27, I49, S54, S56, S55, I23, I50, E6, S50, I5, E8, W40, W41, I83, I85, I88, I89, I91 |
| | Waste collection company | S55, S45, E6, S50, E17, E8, W41, I88, I89, I91 |
| | Dispatcher of waste collection company | S55, S45, E6, S50, I85, I92, I91 |
| | Janitor | S55, S45, I88, I89 |
| | Government | S55, E6, E17, I88 |
| | Authorities | W40, E12, W31, E17, W29, I81, W27, I68, I30, I88, I89 |
| | City administration | S55, I66, S50, E8, I11 |
| | Municipality/ District administration / local authority | E2, S55, W29, I85, I89 |
| | Waste trucks owning company | S55 |
| | Waste department | I66, E17, I5, W29, I15, E2, E8, I47, I91 |
| | Waste disposal organization | E17, E17, I66, W38 |
| | Waste recycling company | E2, I66, S50, W38 |
| | Waste treating company | W38 |
| | Dump (Dump manager) | S54, S55, W38 |
| Secondary | Police | S55, S45, W33, E12 |
| | Firefighters | S45 |
| | Municipal corporation | E27, I32, I15, E8, I88 |
| | Production center | W38 |
| | Health/environmental emergencies management organization | E12 |
| | Farmer | E6 |
| | Volunteer | W33 |
| | Importers and exporters | I66 |
| | Recycling industry | I66, W38 |
| | Disposal industry | I66, W38 |
| | Food industry | I66 |
| | Healthcare | I66 |
| | Research | I66 |
| | Environment protection and related organizations | I66 |
| | Tourism industry | I66 |

**TABLE 8.** Data shared between SWM system and stakeholders by Source.

**The first 10 rows of the table are presented below. To see the full version of the table (92 rows), please follow the link https://doi.org/10.5281/zenodo.6499370 https://zenodo.org/record/6499370/files/Table%20A6.%20Data%20shared%20between%20SWM%20system%20and%20stakeholders.xlsx?download=1**

| Information by Entity (2) | | ID |
|---|---|---|
| Person | Identification | A2, W34, E26, A8, S47, I24, E8, E2, E17, W37, W39, I86 |
| | Location | A2, S55 |
| | Personalized waste weight | W37 |
| | User's behavior | W37, W39 |
| | Time of waste dumping | W39 |
| | Daily waste collection amount | W37, W39 |
| | Mistaken habits of waste sorting | W37, W39 |
| Truck characteristics | Max capacity | I64, E16, I27, E7, I75, S12, W15, W9, E13, E22, W16, S54, W38, I93 |
| | Truck type (HCT / LCT) | E16, I77, I54, I75, S54, S28 |
| | Id | S12, S55, E17 |
| … | | |

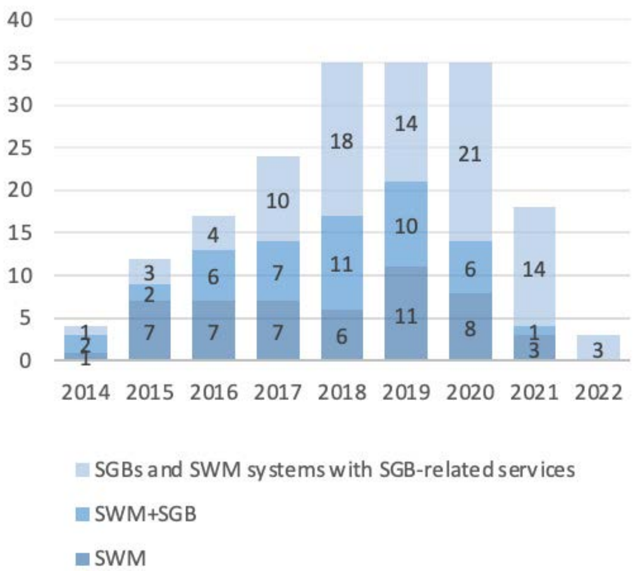


**FIGURE 2.** Number of selected primary studies for each year (2014–2022).

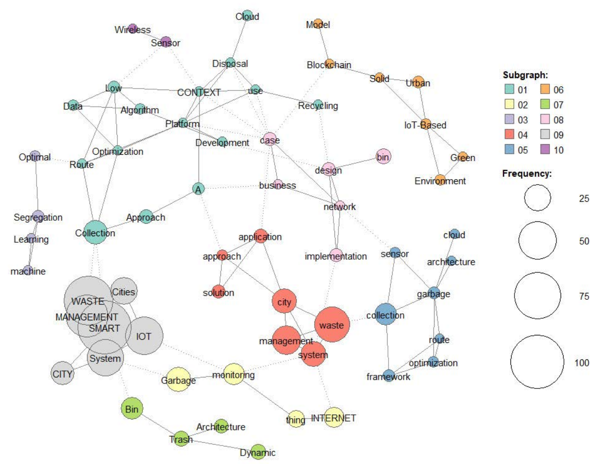


**FIGURE 3.** Title-based clusters of primary study topics.

focus. Fig. 9 presents the categorization of data (in relation to the SWM-level services) collected for both subcategories of SWM system-level studies. The full data set is presented in Table 4 and will be used for the analysis of the RQs in the discussion section.

The first category of city-level services includes real-time and historical **data analyses** and predictive analyses. Many authors suggest using real-time data analysis to optimize route planning and dynamic driver scheduling, and in customer support systems. Fewer authors also use statistics (historical data) for the same purposes; some studies also suggest making predictions based on this data (for example, predicting road traffic or calculating route times).

Another category of services presented in primary research is **user support**. In this category, we identified map-based systems (location of waste collection points for service consumers, routes for drivers), driver support systems

**TABLE 9.** Data shared between SWM system and stakeholders.

| Information by Entity (1) | | ID |
|---|---|---|
| Waste | Waste type | A2, E26, I21, I7, S32, I16, I26, I27, S13, I57, I73, I79, W10, I81, W6, I18, I36, S8, W15, A9, I8, S56, I9, E10, E22, W16, S28, S47, I20, I68, S46, I66, E2, E6, I32, W27, W32, W38, W39, W41, W42, I83, I84, I86, I87, I88, I89, I90, I96, I102, I103, I104, 106, I107, I109, I110, I112 |
| | Costs | A2, I67, I79, E20, E22, W38 |
| | Waste quality | I6 |
| | Waste value recovery variable = percentage of value recovered= recycling yield | E16 |
| | Waste type data (image recognition) | W42, I86, I87, I90, I102, I107, I110 |
| | Waste level data (image recognition) | I92 |
| | Packaging data (image recognition) | A3, I36, S8, I87 |
| | Barcode data (barcode recognition) | A3, I36 |
| | Useful products into which the recyclable waste is possible to transform | I8 |
| SGB characteristics | Capacity | E16, I27, I28, E7, I33, I75, I75, I76, W15, E27, W9, I49, I31, E22, W38, I93 |
| | ... | |

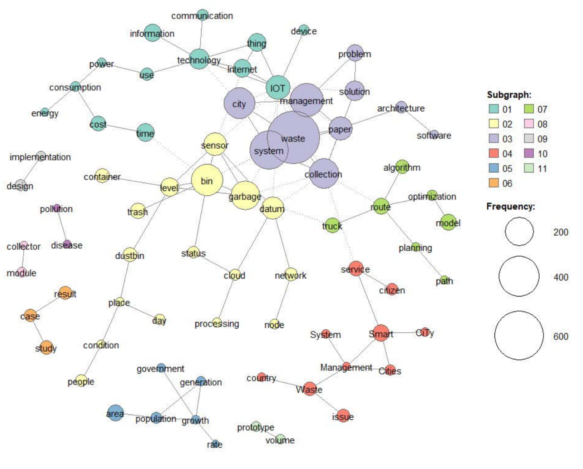


**FIGURE 4.** Abstract-based clusters of primary study topics.

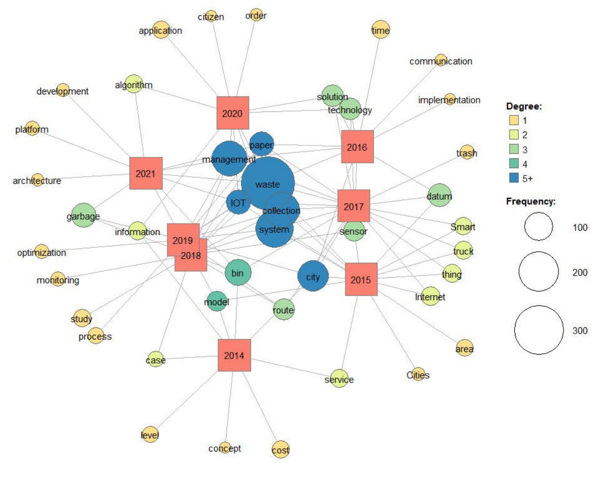


**FIGURE 5.** Trends in SWM system research.

(for example, voice guidance when driving along a route), information support for various stakeholders (schedules, prices, garbage sorting manuals), services for services consumers' feedback (complaints and reviews).

Some articles suggest using **payment and benefit systems**. The idea of controlling the amount of garbage thrown out on the basis of the blockchain is quite common. Another option, pay-as-you-throw systems, charges users based on how much waste they submit. Reward systems can also be used as an additional motivation for environmentally conscious citizens.

One of the most important and most frequently encountered in primary studies group of services is the **optimization**

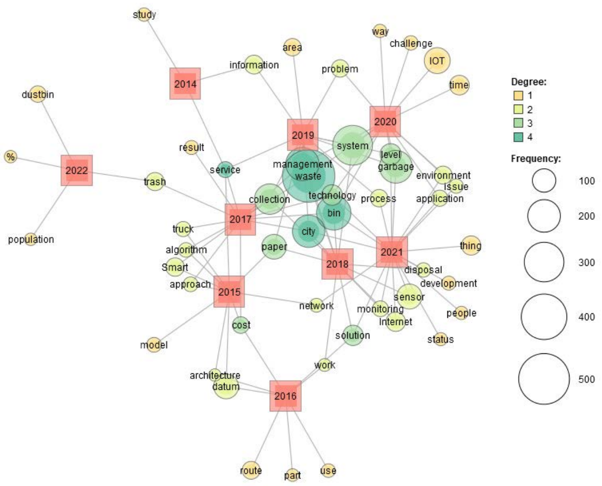


**FIGURE 6.** Trends in SGB research.

**of the planning of waste collection operators**. The main direction in it is the routes planning and optimization based on real-time data and statistics. Some studies also mention the importance of driver scheduling, which can be either static or dynamic. The end goal can be financial (fuel savings, saving drivers time), environmental aspects (minimizing harmful emissions) or traffic aspects (reducing the number of garbage trucks on the streets, minimize number of garbage trucks on the streets during rush hours). Another aspect of the optimization is the optimization of the garbage bins positioning for more convenient garbage disposal and the convenience of citizens.

**Waste classification and segregation** can be carried out both at the SGB level (using sensors and actuators) and at the city level. At the city level, this service includes information support for citizens, as well as services for optimization of the planning of waste collection operators.

The last group of services we have identified is **environmental services**. In some primary studies, it is proposed to measure various environmental parameters using sensors (gas, air quality, temperature) installed on garbage trucks, SGBs, urban infrastructure. Based on the analysis of the data obtained, it is proposed to draw conclusions about the environmental situation in the city. Another common service is the minimization of carbon emissions. This service is directly related to the routes planning and optimization.

We also collected data concerning the various communication techniques used in (or proposed for) SWM systems, as well as various services emphasized in the SWM systems. Communication techniques include very near proximity solutions (e.g., RFID, near field communication (NFC), and Zigbee), mid-range technologies (e.g., Bluetooth and Wi-Fi), and wide area networks (e.g., mobile networks and fixed Internet solutions). The proposed services can be divided into groups based on the purpose of the service. In the analysis, we identified services related to data, user support, waste collection planning, payments and benefits related to waste, and general environmental monitoring services

### B. SWM SYSTEMS WITH SGB-RELATED SERVICES

The second-highest number of primary studies was related to SGB implementation issues and SWM systems with SGB-related services. We define SWM systems with SGB-related services as SWM systems, that operate on SGB level and include such main services as measure various parameters using SGB sensors, responding to user actions using SGB actuators, identification and classification on SGB level (for example, waste type identification, person identification, waste classification / segregation). We collected all the data under this category, and present the collected data in Table 7. Fig. 10 shows the thematic categorization of the SGB-related papers under subcategories.

The SGB-related papers can be roughly divided into high-level SWM systems with SGB-related service (SWM systems that involve the use of low-level elements (sensors, actuators), but in the current implementation only emulate them or synthesize sensor data), SWM systems with SGB-related service design and implementation (SWM systems that include both: city-level and SGB-level services), and SGB implementations. In each of these categories, we collected information related to the proposed or used sensors and actuators, communication technologies, and services. These are illustrated in Fig. 11, and the collected data are presented in Table 5. For a more detailed description of the use of various sensors and actuators, see Section 5.B.

### C. PHYSICAL INFRASTRUCTURE OF SWM SYSTEMS

Each SWM system consists of various physical elements. We analyzed the primary studies to identify the physical elements used to construct SWM systems. In addition to the SGBs described in the previous subsection, the primary studies described also trucks and various facilities (waste plants, dumps, control stations, etc.). All of these physical elements are important, as SWM is a process or pipeline from consumers through SGBs to recycled products or landfills. Fig. 12 and Table 6 present the primary studies emphasizing different physical elements.

### D. STAKEHOLDERS IN SWM SYSTEMS

Another important aspect related to SWM systems is their stakeholders. Different physical elements and services related to them are always tied to some stakeholders. This study identified a set of primary and secondary stakeholders. Primary stakeholders are directly affected by the SWM system, while secondary stakeholders are indirectly affected. The primary stakeholders include the users of the SWM system (both SGBs and services provided by SWM), operators of the SWM system (e.g., waste truck drivers and waste collection companies), and the public stakeholders governing waste management in the given area. Secondary stakeholders

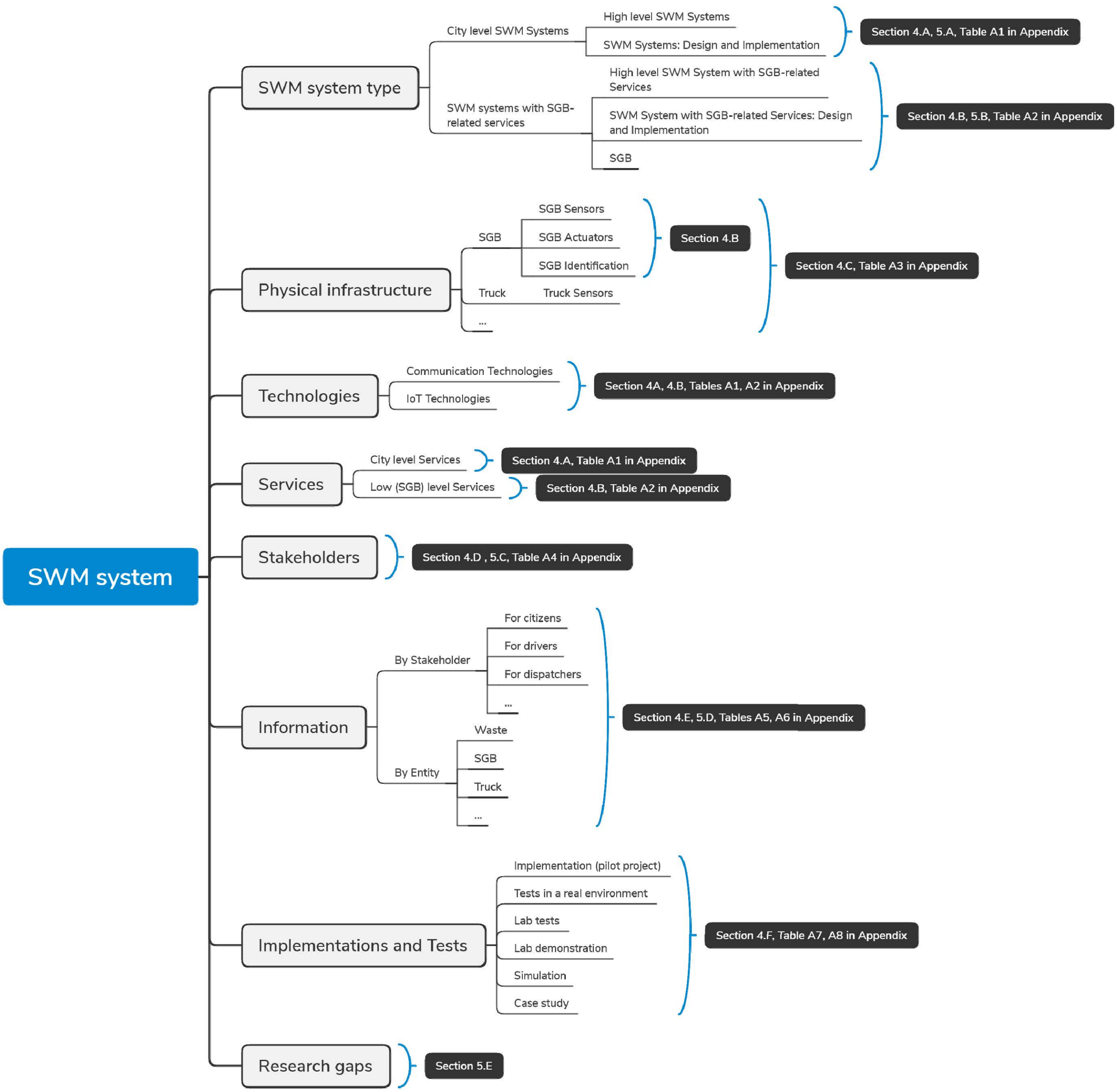


**FIGURE 7.** Holistic view of the topics in SWM systems.

may include industries affected by waste management, public organizations (e.g., health care), and other public services (e.g., firefighters). A more detailed classification is presented in Fig. 13 and in Table 7.

### *E. DATA SHARED BETWEEN SWM SYSTEM AND STAKEHOLDERS*

Another important information that we collected from the selected primary studies is the data collected, transferred, and used in the SWM system. SGBs have an important role in data collection, though they are not the only data source; for example, trucks and other elements of the SWM provide data to the SWM system. The information transmitted in the system can be sorted based on the objects to which it belongs (e.g., SGBs and trucks) or based on the stakeholders involved (e.g., authorities and citizens). We propose a classification that considers both approaches. This is illustrated in Fig. 14. The figure is divided into data production and data consumption, and these parts are presented in detail in subsequent figures (Fig. 15, 16).

The raw data on SWM systems come from various sources (Fig. 15). For example, SGB-related data in the

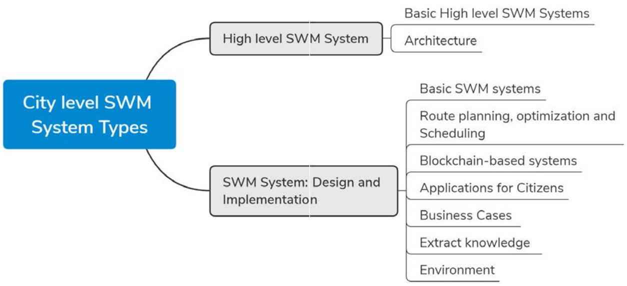


**FIGURE 8.** City-level SWM system types.

SWM system in our classification includes SGB sensor data, SGB characteristics and other SGB data (a full analysis of these data is presented in Table 8). The other data provided by the SWM system consist of data provided by the different elements (e.g., trucks, roads, or facilities). The full analysis of the primary studies in terms of the data provided by different entities is presented in Table 9.

In addition to data collection and usage, it is important to know who uses the data and what they are used for. This represents the consumption side of the SWM data and forms the basis for services within the SWM system. In the end, the enabled services are the goal—not the data as such. This was included in Table 9 and is summarized in Fig. 16.

### F. SWM SYSTEM IMPLEMENTATIONS

The primary studies were also analyzed in terms of the implementation levels of the proposed systems. Some papers present only the SWM concept with no actual implementation or tests, and some have implemented the system in simulation environment or tested the solutions solely in a laboratory environment. Nevertheless, several primary studies have involved running tests in real environments or have used real pilots (see Tables 10 and 11). These studies are presented in Tables 12 and 13.

The countries in which the tests in real environments and pilot implementations were carried out are shown in Fig. 17. This illustration shows that Asian countries have been active in implementing real tests with SWM systems.

## V. DISCUSSION

The aim of this literature review was to study the systems, applications, and approaches vis-à-vis the collection and processing of solid waste in the reported SWM systems. The data that were collected and analyzed for this extensive literature review are summarized in Section 4. Next, we will present the analysis and findings for each of the RQs we started with. The main RQ—that is, RQ1, which focuses on the approaches, methods, and designs of SWM systems—was divided into a set of sub-questions that we studied to get an answer to RQ1.

**TABLE 10.** City-level SWM system implementations in primary studies.

| Implementation type | Amount |
|---|---|
| Not tested (0) | 29 |
| Lab tests (1) | 12 |
| **Tests in a real environment (2)** | 3 |
| **Pilot implementation (3)** | 9 |
| Case study (4) | 12 |
| Simulation (5) | 27 |
| Lab demonstration (6) | 3 |

**TABLE 11.** SGB-level SWM system implementations in primary studies.

| Implementation type | Amount |
|---|---|
| Not tested (0) | 44 |
| Lab tests (1) | 49 |
| **Tests in a real environment (2)** | 6 |
| **Pilot implementation (3)** | 6 |
| Case study (4) | 11 |
| Simulation (5) | 25 |
| Lab demonstration (6) | 9 |

### A. SUB-RQ1.1: WHAT SERVICES, APPROACHES, AND TECHNOLOGIES ARE USED IN THE IMPLEMENTATION OF CITY-LEVEL SWM SYSTEMS?

It became evident from the primary studies that the SWM concept needed to be divided into city-level SWM system descriptions and low-level element descriptions—especially the SGB studies. Both levels use technologies to provide different services. At the SWM level, various communication technologies, from very short-range technologies to Internet-wide communication, are proposed for the transfer of information. Apart from the communication with the local elements of the SWM system, such as SGBs, the system-level communication mainly utilizes Wi-Fi and mobile networks for data transfer. The data are then used in the SWM system to provide various services.

Most parts of the systems analyze real-time data (used in most routing and optimization systems, business cases, and basic SWM systems). The use of the analyzed historical data is much less common. In many of the city-level studies, the data are first analyzed, and then these data (or part thereof) are provided through interfaces—for example, the city dashboard—for various stakeholders. The city dashboard could, for example, display the locations of SGBs, information about SGBs (type of waste, fullness,

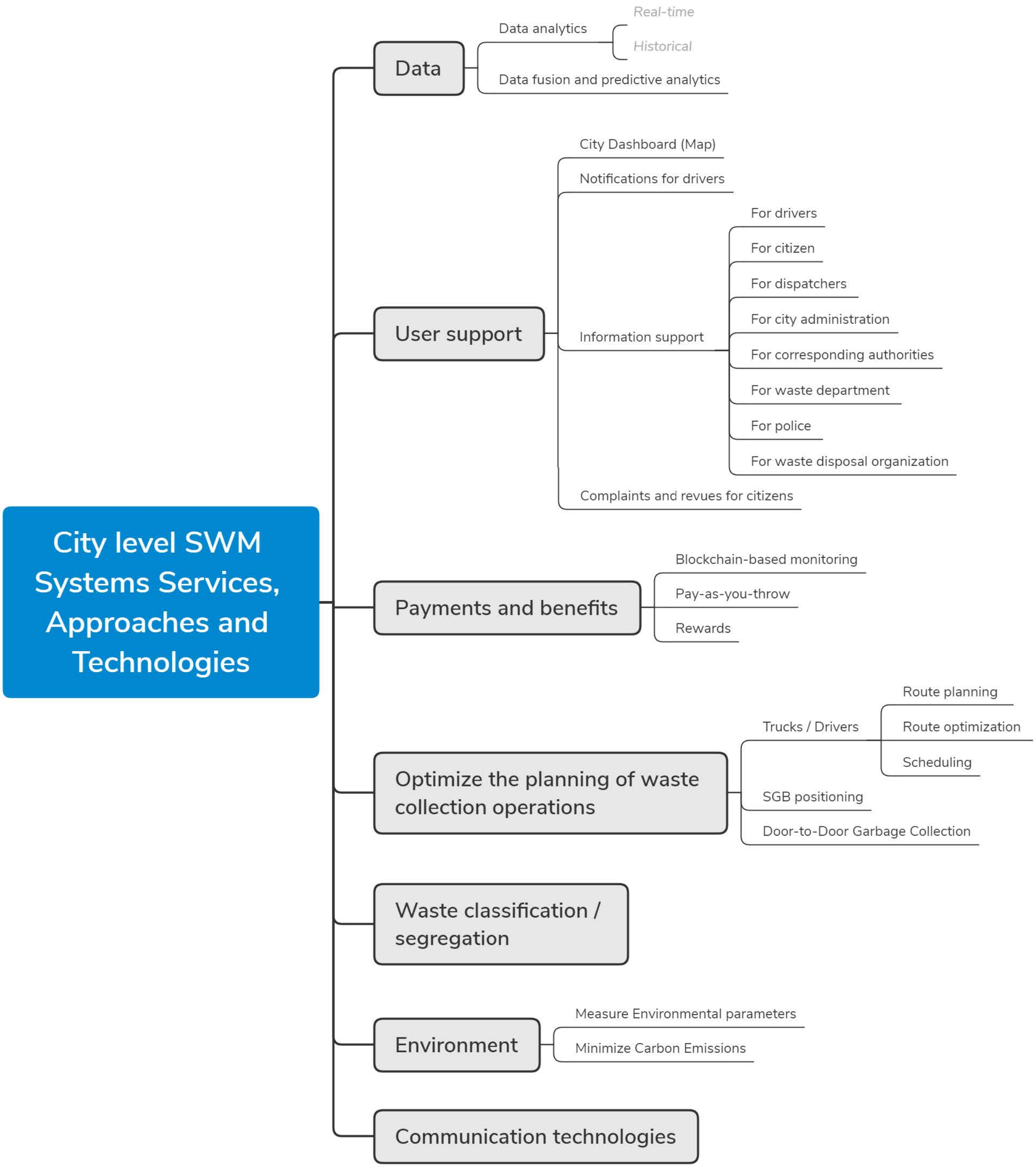


**FIGURE 9.** **Data collected from SWM system-level primary studies.**

etc.), location of trucks, truck routes, and the location of waste-processing facilities and dumps. The city dashboard can also be used as a part of routing planning and optimization system for drivers, information support systems for citizens, and information support systems for dispatchers. In addition to the city dashboard, SWM systems also provide information support for various stakeholders: citizens, city administration, waste department, drivers, dispatchers, waste disposal organizations, corresponding authorities, and emergency services (see Section 4.E).

Both city administration and citizens are the primary targets of SWM services. With the SWM system, the city administration (and other authorities) can have a big picture of waste management activities and process efficiency in the city. Detailed data on the process (SGBs, trucks, etc.) enable both real-time decision support and planning, as well as monitoring. Together with the waste department or company responsible for the waste collection, the city administration may plan for reuse, circular economy, and remanufacturing solutions. City administration may also follow the implementation and

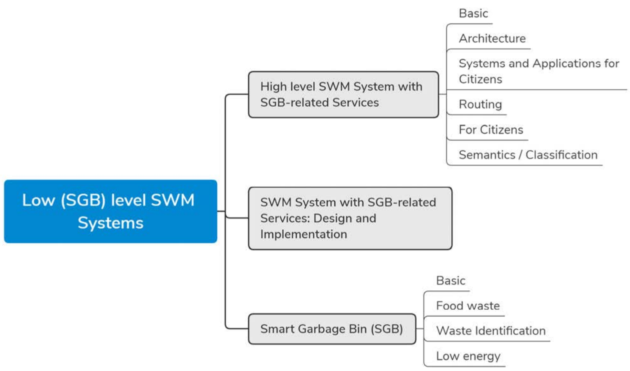


**FIGURE 10.** **Categorization of SGB-related primary studies.**

efficiency of the process. Citizens may both use the data in the system and provide data to the system. In its simplest form, the system may guide citizens to the nearest SGB or just increase their awareness and knowledge. As such, the system may change the behavior of citizens and encourage them to engage in better waste management or even volunteer activities. Citizens may also use open data to follow their own activities or the activities of the other stakeholders. One of the most important parts of this kind of SWM system is the ability to participate in the activities (e.g., by marking dummy garbage bins into the system or by giving feedback and reviews). The feedback could be about the quality of garbage collection in a specific area, complaints about drivers not following schedules, reports on breakdowns or overflowing garbage bins, and so on. City administration could thus get valuable feedback for the planning.

In most cases, the SWM systems aim to optimize the waste collection processes by organizing timely garbage disposal while minimizing costs (fuel and working hours of drivers) and improving the environmental situation. The most commonly used services for this are route planning, optimization and scheduling (static or dynamic). Some authors also offer optimization of the location of SGBs, typically in combination with route optimization or planning. Door-to-door garbage collection is used in several SWM systems with the aim of improving urban ecology.

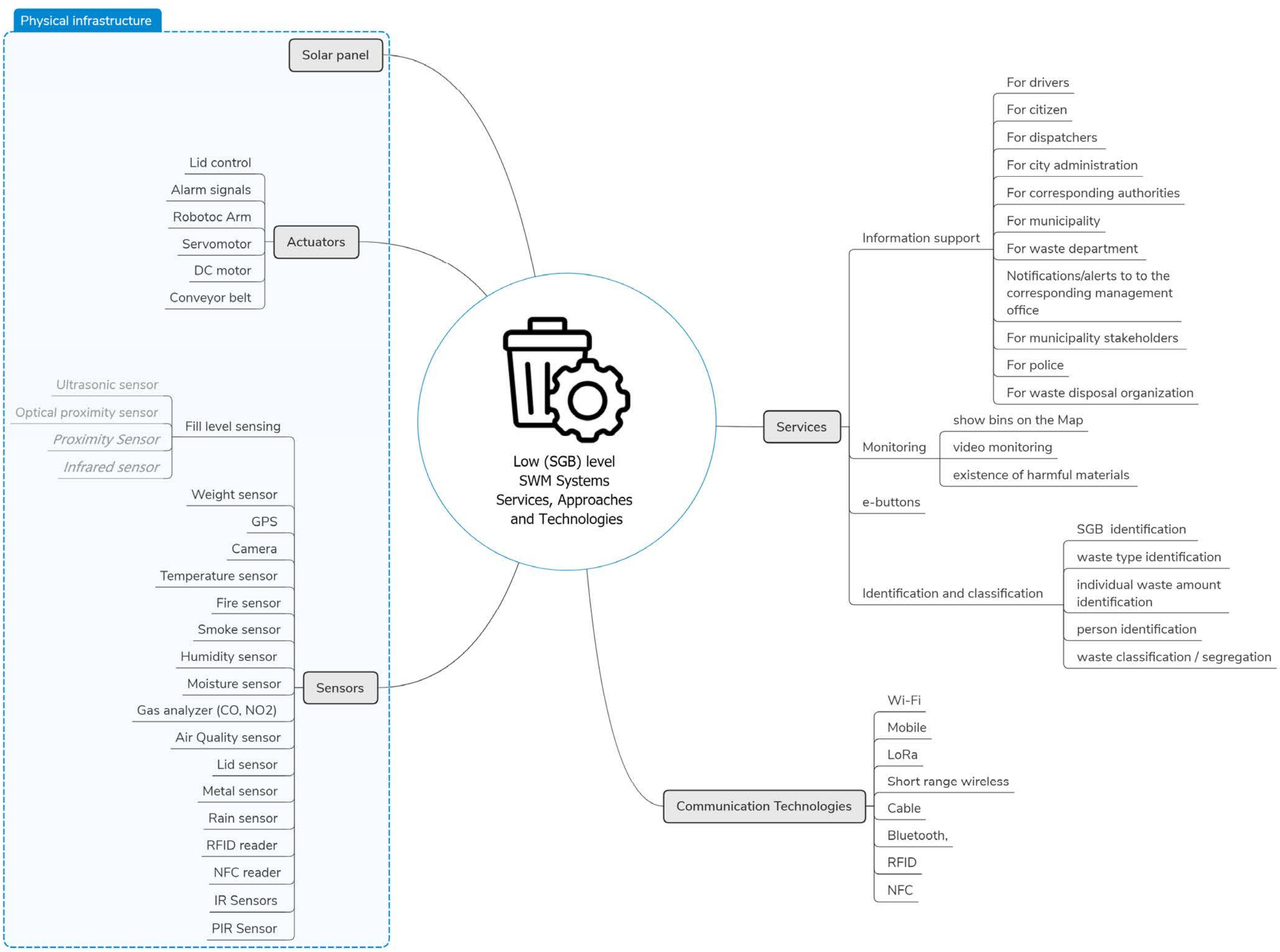


**FIGURE 11.** **Data collected from SGB-related primary studies.**


**FIGURE 12.** Physical infrastructure of SWM systems.

As such, the proposed SWM systems can be roughly divided into a) systems that improve internal processes and b) systems that disseminate the information by providing a holistic real-time view. A small number of studies propose economic and ecological features for the SWM system. Economic features can be either incentive (e.g., rewards) or punishment (e.g., payments) based. The monitoring of citizens' waste sorting and the calculation of payments in many SWM systems can be based on blockchain technology. Blockchain technology ensures the decentralization and security of transactions owing to its use of cryptographic hash functions and public key cryptographic systems. The pay-as-you-throw usage-pricing model, by which users are charged a rate based on amount of waste, is quite common in SWM systems that calculate the personal cost of waste disposal. Some systems use rewards for citizens who correctly sort and separate garbage. The ecological aspects are linked to waste segregation and the measurement of environmental impact.

This study identified the following goals of city-level SWM systems implementation: 1) timely garbage disposal, 2) optimization of the movement of garbage trucks, 3) minimization of costs (fuel and working hours of drivers), 4) improvement of the environmental situation in the city, 5) citizens' increased awareness regarding the separate collection of waste, 6) citizens' increased motivation to donate waste separately, and 7) the provision of information to the city administration and various city services regarding the process of waste collection. These goals can be fulfilled as follows:

- To enable (1) timely garbage disposal, we recommend the following services: route planning, notifications for drivers, information support for drivers and dispatchers, city dashboard, real-time data analytics, and route optimization.
- To (2) optimize the movement of garbage trucks and (3) minimize costs (fuel and working hours of drivers), we recommend route planning, route optimization, SGB positioning, real-time and historical data analytics, notifications for drivers, information support for drivers and dispatchers, city dashboard, data fusion, and predictive analytics.
- To (4) improve the environmental situation in the city, we recommend implementing the following services: the minimization of carbon emissions and waste classification/segregation and the measurement of

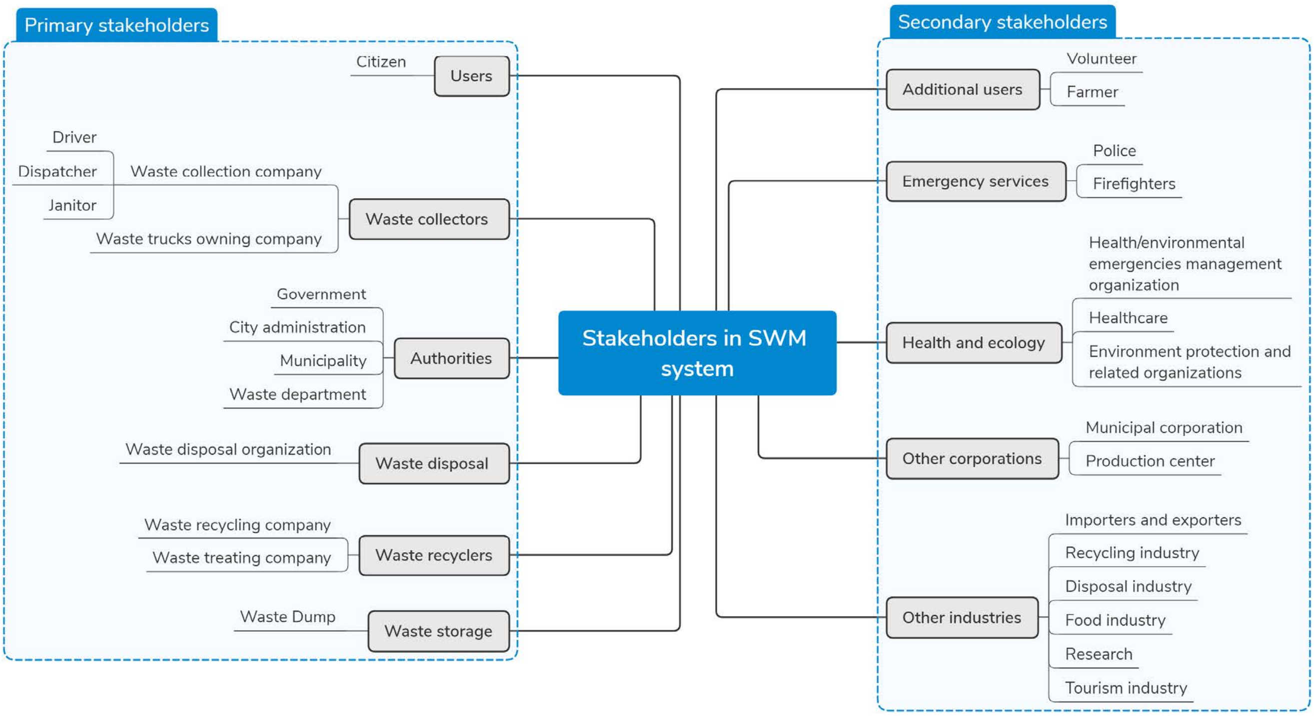


**FIGURE 13.** Stakeholders involved in SWM systems.

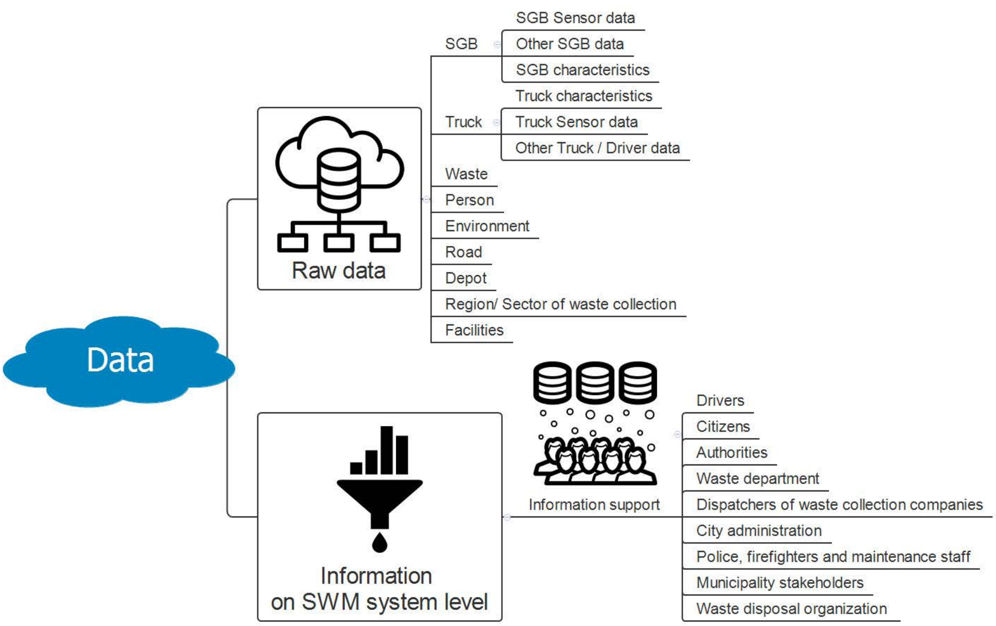


**FIGURE 14.** Data production and consumption in SWM systems.

environmental parameters. Additionally, the recommendations given in (2) optimization of the movement of garbage trucks (5) citizens' increased awareness regarding the separate collection of waste and (6) citizens' increased motivation to donate waste separately can be used to improve the environmental situation in the city.

- To (5) increase the awareness of citizens regarding the separate collection of waste, we recommend information support for citizens; this includes access to the data about the process of waste collection from the cloud (I66, I11, I78, and W40), the location of the nearest SGB/waste collection point (I8, W33, and W40), citizens' education in the field of SWM-based analysis of

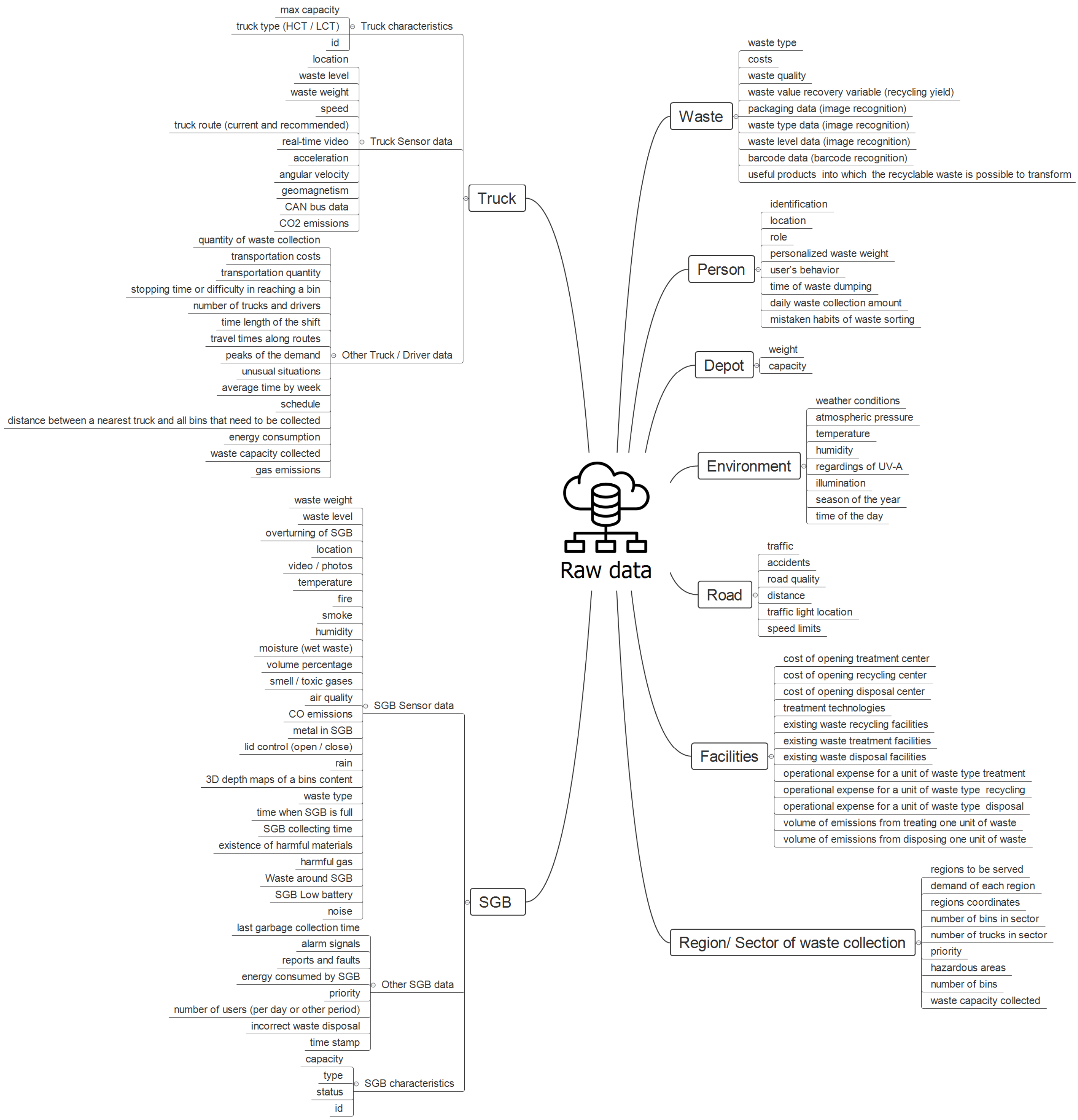


**FIGURE 15.** **SWM systems raw data.**

citizens' behavioral choices with respect to SWM (E12), citizens' awareness regarding recycling, participation through gamification (S47 and A9), decision support, recommendations (S50), and a list of municipality notifications (I85).

- To (6) increase the motivation of citizens to donate waste separately, we recommend blockchain-based monitoring and rewards for increasing citizens' awareness of the strategic role they play in preserving the environment while ensuring personal and community economic benefits according to the "pay-as-you-throw" principle (E26); information support for citizens, which includes access to data about the process of waste collection from the cloud (I66, I11, I78, and W40), finding the nearest SGB/waste collection point (I8, W33, and W40), decision support,

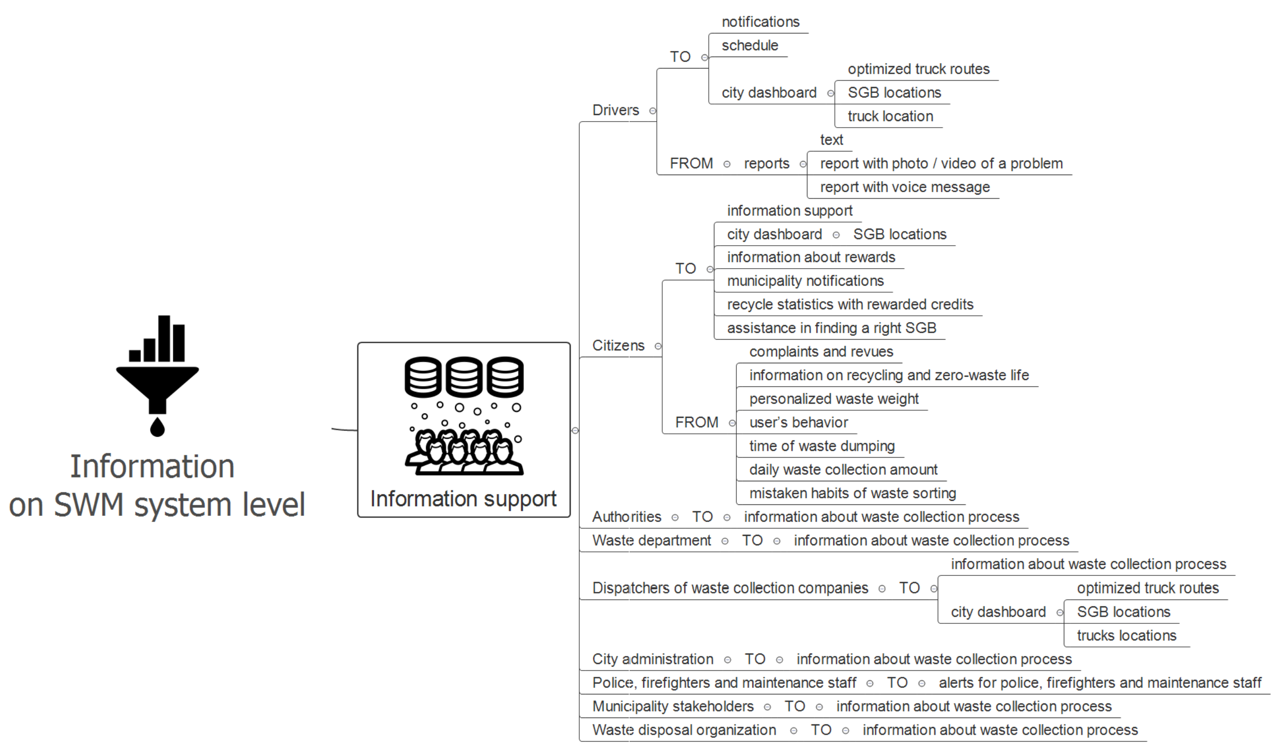


**FIGURE 16.** Use of the collected data.

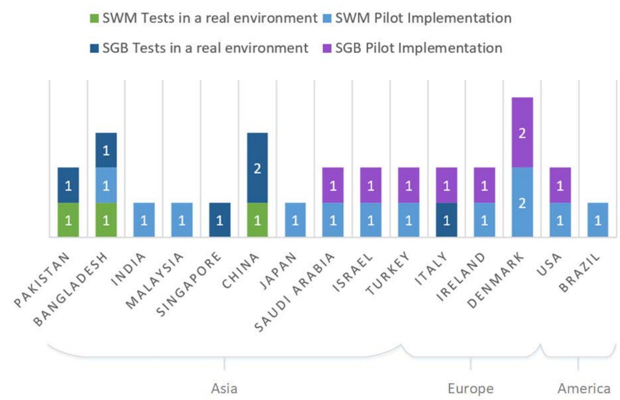


**FIGURE 17.** Tests in a real environment and pilot implementations.

recommendations (S50), and recycle statistics with rewarded credits (I85).

- To (7) inform the city administration and various city services about the process of waste collection, we recommend information and decision support for city administration, which includes access to data about the process of waste collection from the cloud; the big picture, which includes SGBs and truck positioning, truck routes, fuel, and time consumption (I66); decision support; recommendations (S50); assistance in delivering an effective plan for the government and citizens for garbage management (I11); and verification of the work done by the municipal operator (E8).

### B. SUB-RQ1.2: WHAT SERVICES, APPROACHES AND TECHNOLOGIES ARE USED IN THE IMPLEMENTATION OF SGB AND SWM SYSTEMS WITH SGB-RELATED SERVICES?

The SGB level of SWM systems focuses on actual implementations of SGBs. Like the city-level SWM systems, the SGB level utilizes communication technologies from very short-range communication to Internet-wide technologies. As most of the communication is related to the sensors and the transmission of their measurements, short-range technologies (e.g., Bluetooth and Zigbee) are mostly emphasized.

The primary studies present a wide variety of sensors and actuators, as well as services based on the data provided by them. The majority of the primary studies propose the use of a fill-level sensor (usually ultrasonic sensor; in some papers, optical proximity sensor or infrared sensor). The fill-level sensor, together with the SGB positioning service, enables the commonly used cost-optimizing garbage collection service through route planning and optimization. In some studies, weight and temperature sensors provide extra information for waste collection management. In addition, several papers propose the use of RFID/NFC readers or Quick response (QR) codes for different identification (SGB, waste type, and individuals) purposes. For person detection, passive infrared (PIR) sensors and infrared (IR) sensors are typically used. Waste type identification can also be performed

**TABLE 12.** City-level SWM system implementations in primary studies.

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https://zenodo.org/record/6499370/files/Table%20A7.%20City-level%20SWM%20system%20implementations%20in%20primary%20studies.xlsx?download=1

| System type | | ID | Tests | | | |
|---|---|---|---|---|---|---|
| | | | Type | Place / Data | Duration | How many people involved |
| High level SWM System | Basic High level SWM Systems | I28 | 1, 5 | | | |
| | | S47 | 1 | | 08-11.20217 | |
| | | S55 | 5 | Real and synthetic data (St. Petersburg, Russia) | | 6 trucks, 24 bins |
| | | I59 | 5 | | | |
| SWM System: Design and Implementation | Basic SWM Systems | I54 | 1 | | | |
| | | I11 | 1 | | | |
| | | I15 | 1 | | | |
| | | I32 | 1 | | | |
| | | I33 | 2 | Pakistan | 15.03.2018-25.03.2018 | |
| | | E17 | 2 | Suzhou, China | 2012-2015 | 6265 catering companies, 36084 bins, 28 trucks |
| | | … | | | | |

using temperature sensors, gas and air quality sensors, metal sensors, moisture sensors, rain sensors, and cameras (image, video, and barcode recognition); it can also be based on SGB identification. The waste classification/segregation service typically uses the same sensors and the following actuators: DC motors, servomotors, conveyor belts, and robotic arms. Gas sensors can be installed both inside the SGB for measuring the gases and outside the SGB for city pollution monitoring. Generally, the following gases can be measured inside the SGB: carbon monoxide (CO), carbon dioxide (CO2), methane (CH4), and ammonia (NH3). Additionally, some SWM systems measure air quality and hazardous gas: nitrogen oxide (NOx), hydrogen sulfide (H2S), sulfur dioxide (SO2), and ammonia (NH3). Alarm signals service can be based on lid sensor, smoke and fire sensor data.

Although Table 5 shows a wide variety of sensors, most of them remain minor details in the studies. Service-wise, the sensors mainly enable monitoring, identification, and classification services. Monitoring is mainly based on the above-mentioned sensors and provides the fill-level and location of the SGB. Some studies propose the use of cameras to monitor either the bin contents or the near vicinity of the SGB. The identification service (based on RFID or other) provides some additional information about waste type (due to SGB type or identifiers in waste bags) or the users of the SGB. This information can be linked to SWM system-level services.

The following goals of SGB-level SWM systems implementation were identified: 1) waste sorting and segregation, 2) timely garbage disposal, 3) the prevention of damage and unauthorized access to SGB, and 4) the improvement of the environmental situation in the city. The goals can be fulfilled as follows:

- Waste sorting and segregation (1) can be based on SBG identification (RFID/NFC card or QR code) or waste type identification (using a temperature sensor, gas and air quality sensors, a metal sensor, a moisture sensor, and a rain sensor). Waste segregation can be performed using a DC motor or servomotor.
- For (2) timely garbage disposal fill-level (typically ultrasonic) sensors, GPS sensors are required to provide the necessary data for the city-level route planning and optimization service.

**TABLE 13.** SGB level SWM system implementations in primary studies.

**The first 10 rows of the table are presented below. To see the full version of the table (79 rows), please follow the link https://doi.org/10.5281/zenodo.6499370 https://zenodo.org/record/6499370/files/Table%20A8.%20SGB%20level%20SWM%20system%20implementations%20in%20primary%20studies.xlsx?download=1**

| System type | ID | Tests | | | |
|---|---|---|---|---|---|
| | | Type | Place / Data | Duration | How many people involved |
| High level SWM System with SGB-related Services | I54 | 1 | | | |
| | W20 | 4 | Salamanca, Spain | | |
| | W42 | 4,5 | | | |
| | S52 | 5 | Malaga city, Spain | | |
| | I90 | 5 | | | |
| | I27 | 5 | | | |
| | S15 | 5 | | | |
| | A10 | 5 | | | |
| | S47 | 1 | | 08-11 2017 | |
| | S50 | 6 | | | |
| ... | | | | | |

- To (3) prevent damage and unauthorized access to SGB, the following are recommended: person identification service, lid actuator, alarm signals, and fire and smoke sensors.
- To (4) improve the environmental situation in the city, the following sensors and services are recommended: gas and air quality sensors, existence of harmful materials and gas services, and waste classification/segregation service.

### C. SUB-RQ1.3: WHO ARE THE STAKEHOLDERS IN THE SWM SYSTEM?

In this literature review, we studied the proposed SWM systems presented in the selected primary studies and, in addition to technological features, identified the different stakeholders of such a system. The results presented in Section 4.D show that there are two distinct categories of stakeholders at the SWM system level—namely, primary and secondary stakeholders. The **primary stakeholders** are directly linked with the SWM system, as they use, operate, or organize waste-related activities. Many SWM systems in the primary studies emphasize operation efficiency and open information dissemination as their main services, and as such, the most frequently referenced stakeholders are citizens, authorities, waste collection companies, and drivers (there are small differences in how these stakeholders have been referred to in the primary studies). The **secondary stakeholders** are indirectly affected by the SWM system. These were much less emphasized in the selected primary studies. Studies mainly emphasized public organizations, such as police or fire departments; waste-related industries, such as the food or recycling domain; or addressed the impacts of waste, such as environmental or health issues.

In considering the SWM systems in a smart city environment, understanding the stakeholders is of utmost importance for the implementation of the system. This links directly to the information we need to collect and disseminate in our system (see Section 5.D), as well as to the services that are enabled by the system.

### D. SUB-RQ1.4: WHAT KIND OF INFORMATION IS SHARED BETWEEN SWM SYSTEMS AND STAKEHOLDERS IN EXISTING SWM SYSTEMS?

SWM systems are built to provide various services for stakeholders and to achieve the intended impacts. In addition to the physical infrastructure (e.g., SGBs and trucks), the SWM system needs to consider what information needs to be collected, transferred, and used in the system to provide the intended services. It is clear from the selected primary studies that the provided information should be divided into two layers:

raw data at the SGB level and processed information at the SWM system level. The raw data at the SGB level consist of various SGB sensor data (for example, waste weight and CO emissions), SGB characteristics (for example, capacity and type), user data (for example, location, time of waste dumping, and user behavior), truck sensor data (for example, speed, location, and waste level), truck characteristics (for example, max. capacity and truck type), region data (for example, number of SGBs and trucks), waste data (for example, waste type and costs), and other related data (see Fig. 15). These data will then be analyzed by algorithms for SWM system-level services, such as route planning and optimization, environmental impact estimation, or decision support. Another layer of data is information received from stakeholders and provided to stakeholders by the system (see Fig. 16).

### E. MAIN RQ2: WHAT ARE THE IDENTIFIABLE RESEARCH GAPS IN THE FIELD OF SWM SYSTEMS BASED ON PUBLISHED RESEARCH?

The main RQs of this study focused on existing knowledge on SWM systems and possible gaps within the study in this domain. Subsections 5.A–5.D covered the various aspects of reported SWM systems in the selected set of primary studies, and based on this, we conclude that even though there is a good amount and broad coverage of SWM-related research, there exists several research gaps.

- Some research gaps in city-level SWM systems and SGB-level SWM systems were already mentioned in sections 5.A and 5.B. We single out 4 main areas. First, optimization of the garbage collection process, reduction of labor and resource costs, increase in efficiency and comfort of citizens. This requires the implementation and testing of route optimization services, analysis of statistical and real-time data. There are many theoretical works on this topic, but there are few pilot projects with a detailed analysis of the results of the implementation of such systems. Second important research gap is improvement of the ecological situation in the city. This requires the services of optimization and planning of routes (reduction of harmful emissions), measurement and assessment of air quality, as well as the development and implementation of environmentally friendly methods of storage, processing and disposal of waste. The third challenge us increasing environmental awareness and motivation of the citizens. Citizens engagement and motivation can be achieved through increased environmental awareness, reward-based motivation, or social motivation. To increase citizens' ecological awareness, it is necessary to provide citizens with information about existing environmental problems, ways to solve them, and explain the importance and significance of the personal contribution of each. Last challenge is informing city authorities: providing big picture, informing about existing problems and needs, forecasting.
- In addition to citizens and city authorities listed above, in Section 4.D (Fig. 13) we have presented a set of primary and secondary stakeholders. The primary stakeholders have been considered in the primary studies quite broadly, but the design activities of SWM systems could benefit from a more holistic view that links information, services, stakeholders, and possible impacts. This would help in designing systems that would change the impacts of SWM systems.
- We have a similar idea about the set of data transmitted between various components of the SWM system and stakeholders. The research on SWM systems would definitely benefit from a holistic data / information model. Even the syntax of the information could be defined so that different secondary systems could benefit from the collected and analyzed data.

The main weakness of the current studies (and thus also a gap) is that none of them aims to propose a general holistic view at any level of operation. Almost half of the primary studies focus on SGB implementations without any common line. We believe that the results presented in Section 4 provide a good starting point for generating such a general approach at the SGB level. The same applies to SWM system-level research. In the presence of a large number of studies describing individual aspects of the design, development, implementation of SWM systems in various locations to solve various problems, there is no general description that would unite all the accumulated results. Such an approach could combine a large number of theoretical and practical results, and based on it, it would be possible to develop an automated decision support system, based on that city authorities will be able to implement, develop, improve the waste management system in the city based on current tasks, taking into account the characteristics of the city. Another important stakeholder is citizens, who, using the decision support system, will be able to receive recommendations on how to solve local problems (for example, untimely garbage collection, too frequent garbage collection, unauthorized garbage dump near their home), as well as receive the necessary information and raise their environmental awareness (for example, how to sort waste properly). The limitations of the proposed system are related to the lack of a sufficient number of real-life test results analysis and pilot projects (Tables 12 and 13). For example, most algorithms for optimizing the routes of garbage trucks have only been tested using computer simulations. The main challenges for the creation of the proposed DSS will be the study of practical developments in the field of SWM. Our results on SWM stakeholders, information, and services can be used as a basis for the creation of a general system-level approach and the standardization of information syntax and semantics.

### F. THREATS TO VALIDITY

For the evaluation of the validity of the study, we report on construct, internal, and external validity, as well as reliability [15].

*Construct validity* aims to ensure that theoretical constructs are interpreted and measured correctly [15]. In this study, the SLR guidelines by Kitchenham [14] were followed as closely as possible to ensure the construct validity of the literature review. The first author planned and executed the processes, while the second author supervised and ensured proper use of the methodology and, as such, construct validity.

*Internal validity* focuses on the study design, particularly whether the results follow from the data [15]. Literature reviews will always have some limitations in terms of internal validity, as search queries, the selection of primary studies, and data collection will reflect some personal flavors. The validity of the search queries was ensured by conducting test searches to find the proper keywords. Tools such as NAILS,[4] LDA analysis (within NAILS), and KH Coder[5] were used for the test searches to ensure proper coverage. Still, the validity of the search query is rather subjective and, as such, introduces some limitations regarding internal validity. The selection of the primary studies may be another limitation of the internal validity, as the inclusion and exclusion of primary studies based on titles, abstracts, and contents happen in phases and always contain some subjective flavor. The data collection is the third possible threat to internal validity, as the data collected based on the RQs always reflect some subjective perception. Both the primary study selection and data collection limitations were decreased by peer supervision. The authors did their part of the work, and each author checked the decisions or compared them to his or her own results.

*External validity* focuses on whether claims for the generality of the results are justified [15]. In this study, we collected the results from a set of primary studies and presented them in various tables. As such, the tables present the data as they are in the primary studies (with the limitations presented in internal validity), but the conclusions and summaries from these data are based on the perceptions of the researchers, and as such, they are subject to researcher bias. Nevertheless, we have aimed to analyze the results at a high enough level (without unnecessary details) to enable the generalizability of the results. We have also presented research needs and gaps that can be emphasized in subsequent studies.

*Reliability* focuses on whether the study would yield the same results if other researchers replicated it [15]. Literature reviews are always subject to researcher bias based on the RQ set. This study follows the guidelines given by Kitchenham [14] and presents queries and refinements so that other researchers can repeat the study. The inclusion and exclusion of primary studies, as well as data collection, even with the given criteria, are the hardest to replicate. We provide our data set openly in Zenodo so that other researchers may use it as a basis for their own studies, replications, or extensions.

[4]Network Analysis Interface for Literature Studies, nailsproject.net.

[5]KH Coder is a free software for quantitative content analysis or text mining, khcoder.net.

## VI. CONCLUSION

In this paper, we conducted a systematic analysis of the published research in the field of systems, applications, and approaches vis-à-vis SWM systems. This study resulted in 173 primary studies selected for analysis and data extraction from the 3,732 articles that were initially retrieved. The following research directions were considered during the research: 1) city-level SWM systems, 2) SGBs and SWM systems with SGB-related services, 3) stakeholders in SWM systems, and 4) information shared between SWM systems and stakeholders. Additionally, we studied the physical infrastructure of SWM systems and SWM system implementations. The collected and analyzed data of this extensive literature review are summarized in Section 4.

We learned from the analysis that effective organization of waste collection and processing can be considered at different levels: high (city) level and low (SGB) level. In most cases, the city-level SWM systems aim to optimize waste collection processes by organizing timely garbage disposal while minimizing costs (fuel and working hours of drivers) and improving the environmental situation. As such, the proposed SWM systems can be roughly divided into a) systems that improve internal processes and b) systems that disseminate the information by providing a holistic real-time view. A small number of studies propose economic and ecological features for the SWM system. The economic features can be either incentives (e.g., rewards) or punishments (e.g., payments) based. The ecological aspects are linked to waste segregation and measuring environmental impact. The SGB level of SWM systems focuses on various implementations of SGBs and SWM systems with SGB-related services. The primary studies present a wide variety of sensors and actuators, as well as services, based on the data provided by the sensors.

We also identified research gaps in the field of SWM systems based on our analysis of the literature. We single out the following areas: 1) optimization of the garbage collection process, reduction of labor and resource costs, increase in efficiency and comfort of citizens; 2) improvement of the ecological situation in the city; 3) increasing environmental awareness and motivation of the citizens; 4) informing city authorities: providing big picture, informing about existing problems and needs, forecasting. The main weakness of the current studies (and thus also a gap) is that none of them aims to propose a general holistic view at any level of operation. Our results on SWM stakeholders, information, and services can be used as a basis for the creation of a general system-level approach and the standardization of information syntax and semantics.

## REFERENCES

[1] A. Arroub, B. Zahi, E. Sabir, and M. Sadik, "A literature review on smart cities: Paradigms, opportunities and open problems," in *Proc. Int. Conf. Wireless Netw. Mobile Commun. (WINCOM)*, Oct. 2016, pp. 180–186, doi: 10.1109/WINCOM.2016.7777211.

[2] J. W. Levis, M. A. Barlaz, J. F. DeCarolis, and S. R. Ranjithan, "A generalized multistage optimization modeling framework for life cycle assessment-based integrated solid waste management," *Environ. Model. Softw.*, vol. 50, pp. 51–65, Dec. 2013, doi: 10.1016/j.envsoft.2013.08.007.

[3] S. E. Vergara and G. Tchobanoglous, "Municipal solid waste and the environment: A global perspective," *Annu. Rev. Environ. Resour.*, vol. 37, no. 1, pp. 277–309, Nov. 2012, doi: 10.1146/annurev-environ-050511-122532.

[4] T. Anagnostopoulos, A. Zaslavsky, K. Kolomvatsos, A. Medvedev, P. Amirian, J. Morley, and S. Hadjieftymiades, "Challenges and opportunities of waste management in IoT-enabled smart cities: A survey," *IEEE Trans. Sustain. Comput.*, vol. 2, no. 3, pp. 275–289, Jul. 2017.

[5] T. Anagnostopoulos, A. Zaslavsky, I. Sosunova, P. Fedchenkov, A. Medvedev, K. Ntalianis, C. Skourlas, A. Rybin, and S. Khoruznikov, "A stochastic multi-agent system for Internet of Things-enabled waste management in smart cities," *Waste Manage. Res., J. Sustain. Circular Economy*, vol. 36, no. 11, pp. 1113–1121, Nov. 2018, doi: 10.1177/0734242X18783843.

[6] V. R. S. Cheela and B. Dubey, "Review of application of systems engineering approaches in development of integrated solid waste management for a smart city," in *Water Resources and Environmental Engineering II*. Singapore: Springer, 2019, doi: 10.1007/978-981-13-2038-5_16.

[7] A. V. de Souza Melaré, S. M. González, K. Faceli, and V. Casadei, "Technologies and decision support systems to aid solid-waste management: A systematic review," *Waste Manage.*, vol. 59, pp. 567–584, Jan. 2017, doi: 10.1016/j.wasman.2016.10.045.

[8] N. P. Adriyanti, A. Gamal, and O. C. Dewi, "Solid waste management models: Literature review," in *Proc. 2nd Int. Conf. Smart Grid Smart Cities (ICSGSC)*, Aug. 2018, pp. 37–40, doi: 10.1109/ICSGSC.2018.8541350.

[9] G. Soni and S. Kandasamy, "Smart garbage bin systems—A comprehensive survey," in *Proc. Int. Conf. Intell. Inf. Technol.*, 2018, pp. 194–206, doi: 10.1007/978-981-10-7635-0_15.

[10] B. Esmaeilian, B. Wang, K. Lewis, F. Duarte, C. Ratti, and S. Behdad, "The future of waste management in smart and sustainable cities: A review and concept paper," *Waste Manage.*, vol. 81, pp. 177–195, Nov. 2018, doi: 10.1016/j.wasman.2018.09.047.

[11] K. Dhyani and N. Patel, "Smart trash monitoring and segregation system using emerging technology—A survey," in *Proc. Int. Conf. Adv. Inform. Comput. Res.*, 2019, pp. 667–674, doi: 10.1007/978-981-13-3140-4_60.

[12] M. Topaloglu, F. Yarkin, and T. Kaya, "Solid waste collection system selection for smart cities based on a type-2 fuzzy multi-criteria decision technique," *Soft Comput.*, vol. 22, no. 15, pp. 4879–4890, Aug. 2018, doi: 10.1007/S00500-018-3232-8.

[13] M. S. Chaudhari, B. Patil, and V. Raut, "IoT based waste collection management system for smart cities: An overview," in *Proc. 3rd Int. Conf. Comput. Methodologies Commun. (ICCMC)*, Mar. 2019, pp. 802–805, doi: 10.1109/ICCMC.2019.8819776.

[14] S. Kitchenham and B. Charters, "Guidelines for performing systematic literature reviews in software engineering," Softw. Eng. Group School Comput. Sci., Math. Keele Univ. Keele, Staffs, U.K., Dept. Comput. Sci., Univ. Durham, Durham, U.K., EBSE Tech. Rep. EBSE-2007-01, 2007.

[15] F. Shull, J. Singer, and D. I. K. Sjøberg, Eds., *Guide to Advanced Empirical Software Engineering*. London, U.K.: Springer, 2008, doi: 10.1007/978-1-84800-044-5_11.

[16] J. Zeng, J. Zhang, and Y. Liu, "Blockchain based smart park: Cleaning management," in *Proc. 2nd Int. Conf. Blockchain Technol. Appl.*, Dec. 2019, pp. 53–58, doi: 10.1145/3376044.3376046.

[17] S. Li, K. Sun, M. Qi, and J. Liu, "Design of beverage packaging identification and recycling system based on zedboard," in *Proc. 7th Int. Conf. Inf. Technol., IoT Smart City*, Dec. 2019, pp. 175–180, doi: 10.1145/3377170.3377219.

[18] S. Faye, F. Melakessou, W. Mtalaa, P. Gautier, N. AlNaffakh, and D. Khadraoui, "SWAM: A novel smart waste management approach for businesses using IoT," in *Proc. 1st ACM Int. Workshop Technol. Enablers Innov. Appl. Smart Cities Communities*, Nov. 2019, pp. 38–45, doi: 10.1145/3364544.3364824.

[19] S. K. T. Utomo, T. Hamada, and N. Koshizuka, "Low-energy smart trash bin architecture for dynamic waste collection system," in *Proc. 2nd Int. Conf. Future Netw. Distrib. Syst.*, Jun. 2018, pp. 1–7, doi: 10.1145/3231053.3231077.

[20] P. Fedchenkov, A. Zaslavsky, and I. Sosunova, "Enabling smart waste management with sensorized garbage bins and low power data communications network," in *Proc. 7th Int. Conf. Internet Things*, Oct. 2017, pp. 1–2, doi: 10.1145/3131542.3140264.

[21] J. Naskova, "RecycHongs: Mobile app co-design," in *Proc. ACM Conf. Companion Publication Designing Interact. Syst.*, Jun. 2017, pp. 337–340, doi: 10.1145/3064857.3079188.

[22] S. Sharmin and S. T. Al-Amin, "A cloud-based dynamic waste management system for smart cities," in *Proc. 7th Annu. Symp. Comput. Develop.*, Nov. 2016, pp. 1–4, doi: 10.1145/3001913.3006629.

[23] Y. Chen, J. Nakazawa, T. Yonezawa, T. Kawasaki, and H. Tokuda, "An empirical study on coverage-ensured automotive sensing using door-to-door garbage collecting trucks," in *Proc. 2nd Int. Workshop Smart*, Dec. 2016, pp. 1–6, doi: 10.1145/3009912.3009921.

[24] S. Kristanto, T. Yashiro, N. Koshizuka, and K. Sakamura, "Dynamic polling algorithm for low energy garbage level measurement in smart trash bin," in *Proc. 2nd Int. Conf. IoT Urban Space*, May 2016, pp. 92–94, doi: 10.1145/2962735.2962748.

[25] H. Li, Z. Jin, and S. Krishnamoorthy, "E-waste management using machine learning," in *Proc. 6th Int. Conf. Big Data Comput.*, May 2021, pp. 30–35, doi: 10.1145/3469968.3469973.

[26] A. S. L. França, J. A. Neto, R. F. Gonçalves, and C. M. V. B. Almeida, "Proposing the use of blockchain to improve the solid waste management in small municipalities," *J. Cleaner Prod.*, vol. 244, Jan. 2020, Art. no. 118529, doi: 10.1016/j.jclepro.2019.118529.

[27] D. Zhang, "Application of blockchain technology in incentivizing efficient use of rural wastes: A case study on Yitong system," *Energy Proc.*, vol. 158, pp. 6707–6714, Feb. 2019, doi: 10.1016/j.egypro.2019.01.018.

[28] J. Ferrer and E. Alba, "BIN-CT: Urban waste collection based on predicting the container fill level," *Biosystems*, vol. 186, Dec. 2019, Art. no. 103962, doi: 10.1016/j.biosystems.2019.04.006.

[29] A. Thada, U. K. Kapur, S. Gazali, N. Sachdeva, and S. Shridevi, "Custom block chain based cyber physical system for solid waste management," *Proc. Comput. Sci.*, vol. 165, pp. 41–49, Jan. 2019, doi: 10.1016/j.procs.2020.01.068.

[30] A. Expósito-Márquez, C. Expósito-Izquierdo, J. Brito-Santana, and J. A. Moreno-Pérez, "Greedy randomized adaptive search procedure to design waste collection routes in La Palma," *Comput. Ind. Eng.*, vol. 137, Nov. 2019, Art. no. 106047, doi: 10.1016/j.cie.2019.106047.

[31] M. Casazza, D. Huisingh, S. Ulgiati, V. Severino, G. Liu, and M. Lega, "Product service system-based municipal solid waste circular management platform in Campania region (Italy): A preliminary analysis," *Proc. CIRP*, vol. 83, pp. 224–229, Jan. 2019, doi: 10.1016/j.procir.2019.03.085.

[32] O. Erdinç, K. Yetilmezsoy, A. K. Erenoğlu, and O. Erdinç, "Route optimization of an electric garbage truck fleet for sustainable environmental and energy management," *J. Cleaner Prod.*, vol. 234, pp. 1275–1286, Oct. 2019, doi: 10.1016/j.jclepro.2019.06.295.

[33] P. J. Shah, T. Anagnostopoulos, A. Zaslavsky, and S. Behdad, "A stochastic optimization framework for planning of waste collection and value recovery operations in smart and sustainable cities," *Waste Manage.*, vol. 78, pp. 104–114, Aug. 2018.

[34] Z. Wen, S. Hu, D. De Clercq, M. B. Beck, H. Zhang, H. Zhang, F. Fei, and J. Liu, "Design, implementation, and evaluation of an Internet of Things (IoT) network system for restaurant food waste management," *Waste Manage.*, vol. 73, pp. 26–38, Mar. 2018, doi: 10.1016/j.wasman.2017.11.054.

[35] V. Elia, M. G. Gnoni, and F. Tornese, "Improving logistic efficiency of WEEE collection through dynamic scheduling using simulation modeling," *Waste Manage.*, vol. 72, pp. 78–86, Feb. 2018, doi: 10.1016/j.wasman.2017.11.016.

[36] T. R. P. Ramos, C. S. de Morais, and A. P. Barbosa-Póvoa, "The smart waste collection routing problem: Alternative operational management approaches," *Expert Syst. Appl.*, vol. 103, pp. 146–158, Aug. 2018, doi: 10.1016/j.eswa.2018.03.001.

[37] S. Digiesi, F. Facchini, G. Mossa, G. Mummolo, and R. Verriello, "A cyber–based DSS for a low carbon integrated waste management system in a smart city," *IFAC-PapersOnLine*, vol. 48, no. 3, pp. 2356–2361, 2015, doi: 10.1016/j.ifacol.2015.06.440.

[38] T. Anagnostopoulos, K. Kolomvatsos, C. Anagnostopoulos, A. Zaslavsky, and S. Hadjiefthymiades, "Assessing dynamic models for high priority waste collection in smart cities," *J. Syst. Softw.*, vol. 110, pp. 178–192, Dec. 2015, doi: 10.1016/j.jss.2015.08.049.

[39] J. M. Gutierrez, M. Jensen, M. Henius, and T. Riaz, ''Smart waste collection system based on location intelligence,'' *Proc. Comput. Sci.*, vol. 61, pp. 120–127, Jan. 2015, doi: 10.1016/j.procs.2015.09.170.

[40] T. Addabbo, A. Fort, A. Mecocci, M. Mugnaini, S. Parrino, A. Pozzebon, and V. Vignoli, ''A LoRa-based IoT sensor node for waste management based on a customized ultrasonic transceiver,'' in *Proc. IEEE Sensors Appl. Symp. (SAS)*, Mar. 2019, pp. 1–6, doi: 10.1109/SAS.2019.8705980.

[41] D. Ziouzios and M. Dasygenis, ''A smart bin implementantion using LoRa,'' in *Proc. 4th South-East Eur. Design Autom., Comput. Eng., Comput. Netw. Social Media Conf. (SEEDA-CECNSM)*, Sep. 2019, pp. 1–4, doi: 10.1109/SEEDA-CECNSM.2019.8908523.

[42] A. Premgi, F. Martins, and D. Domingos, ''An infrared-based sensor to measure the filling level of a waste bin,'' in *Proc. Int. Conf. Eng. Appl. (ICEA)*, Jul. 2019, pp. 1–6, doi: 10.1109/CEAP.2019.8883303.

[43] M. I. Zahur, M. S. Rahman, A. Akther, and K. M. Alam, ''An IoT based green waste management system for Bangladesh,'' in *Proc. 1st Int. Conf. Adv. Sci., Eng. Robot. Technol. (ICASERT)*, May 2019, pp. 1–6, doi: 10.1109/ICASERT.2019.8934475.

[44] Y. Zhu, G. Jia, G. Han, Z. Zhou, and M. Guizani, ''An NB-IoT-based smart trash can system for improved health in smart cities,'' in *Proc. 15th Int. Wireless Commun. Mobile Comput. Conf. (IWCMC)*, Jun. 2019, pp. 763–768, doi: 10.1109/IWCMC.2019.8766748.

[45] A. Sharma and R. B. Battula, ''Architecture for waste management in Indian smart cities (AWMINS),'' in *Proc. Int. Conf. Inf. Commun. Technol. Converg. (ICTC)*, Oct. 2019, pp. 76–83, doi: 10.1109/ICTC46691.2019.8939764.

[46] S. Latif, A. Rehman, and N. A. Zafar, ''Blockchain and IoT based formal model of smart waste management system using TLA+,'' in *Proc. Int. Conf. Frontiers Inf. Technol. (FIT)*, Dec. 2019, pp. 1–6, doi: 10.1109/FIT47737.2019.00064.

[47] O. Dolinina, V. Pechenkin, N. Gubin, J. Aizups, and A. Kuzmin, ''Development of semi-adaptive waste collection vehicle routing algorithm for agglomeration and urban settlements,'' in *Proc. IEEE 7th IEEE Workshop Adv. Inf., Electron. Electr. Eng. (AIEEE)*, Nov. 2019, pp. 1–6, doi: 10.1109/AIEEE48629.2019.8976918.

[48] Yanglu, A. Yadav, and A. Khan, ''Internet of Things based wireless garbage monitoring system,'' in *Proc. 3rd Int. Conf. I-SMAC (IoT Social, Mobile, Anal. Cloud) (I-SMAC)*, Dec. 2019, pp. 103–107, doi: 10.1109/I-SMAC47947.2019.9032540.

[49] S. K. Memon, F. K. Shaikh, N. A. Mahoto, and A. A. Memon, ''IoT based smart garbage monitoring & collection system using WeMos & ultrasonic sensors,'' in *Proc. 2nd Int. Conf. Comput., Math. Eng. Technol. (iCoMET)*, Jan. 2019, pp. 1–6, doi: 10.1109/ICOMET.2019.8673526.

[50] R. K. Singhvi, R. L. Lohar, A. Kumar, R. Sharma, L. D. Sharma, and R. K. Saraswat, ''IoT BasedSmart waste management system: India prospective,'' in *Proc. 4th Int. Conf. Internet Things, Smart Innov. Usages (IoT-SIU)*, Apr. 2019, pp. 1–6, doi: 10.1109/IoT-SIU.2019.8777698.

[51] M. Srinivas, S. Benedict, and B. C. Sunny, ''IoT cloud based smart bin for connected smart cities—A product design approach,'' in *Proc. 10th Int. Conf. Comput., Commun. Netw. Technol. (ICCCNT)*, Jul. 2019, pp. 1–5, doi: 10.1109/ICCCNT45670.2019.8944558.

[52] M. Falch and M. Maestrini, ''Public private partnership in smart city waste management—A business case,'' in *Proc. Smart Cities Inf. Commun. Technol. (CTTE-FITCE)*, Sep. 2019, pp. 1–6, doi: 10.1109/CTTE-FITCE.2019.8894820.

[53] R. Elhassan, M. A. Ahmed, and R. Abdalhalem, ''Smart waste management system for crowded area: Makkah and holy sites as a model,'' in *Proc. 4th MEC Int. Conf. Big Data Smart City (ICBDSC)*, Jan. 2019, pp. 1–5, doi: 10.1109/ICBDSC.2019.8645576.

[54] E. Al-Masri, I. Diabate, R. Jain, M. H. L. Lam, and S. R. Nathala, ''A serverless IoT architecture for smart waste management systems,'' in *Proc. IEEE Int. Conf. Ind. Internet (ICII)*, Oct. 2018, pp. 179–180, doi: 10.1109/ICII.2018.00034.

[55] W.-E. Chen, Y.-H. Wang, P.-C. Huang, Y.-Y. Huang, and M.-Y. Tsai, ''A smart IoT system for waste management,'' in *Proc. 1st Int. Cognit. Cities Conf. (IC3)*, Aug. 2018, pp. 202–203, doi: 10.1109/IC3.2018.00-24.

[56] B. Prasad, S. Dalmia, S. Dasari, and N. Arya, ''An intelligent bin management system design for smart city using GSM technology,'' in *Proc. 7th Int. Conf. Rel., Infocom Technol. Optim., Trends Future Directions (ICRITO)*, Aug. 2018, pp. 557–563, doi: 10.1109/ICRITO.2018.8748636.

[57] P. Devi, W. S. Ravindra, and S. K. L. V. S. Prakash, ''An IoT enabled smart waste management system in concern with Indian smart cities,'' in *Proc. 2nd Int. Conf. Trends Electron. Informat. (ICOEI)*, May 2018, pp. 64–69, doi: 10.1109/ICOEI.2018.8553764.

[58] S. Aleyadeh and A.-E.-M. Taha, ''An IoT-based architecture for waste management,'' in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, May 2018, pp. 1–4, doi: 10.1109/ICCW.2018.8403750.

[59] E. K. D. More, S. Divya, G. Kalyani, and R. Gowthami, ''Automatic waste segregator bin using robotic arm,'' in *Proc. 3rd IEEE Int. Conf. Recent Trends Electron., Inf. Commun. Technol. (RTEICT)*, May 2018, pp. 1555–1558, doi: 10.1109/RTEICT42901.2018.9012120.

[60] F. R. Maulana, T. A. S. Widyanto, Y. Pratama, and K. Mutijarsa, ''Design and development of smart trash bin prototype for municipal solid waste management,'' in *Proc. Int. Conf. ICT Smart Soc. (ICISS)*, Oct. 2018, pp. 1–6, doi: 10.1109/ICTSS.2018.8550013.

[61] N. Alsbou, M. A. Samad, M. Alhashem, and A. S. A. Abuabed, ''Developing a self-powered enlarging smart waste bin,'' in *Proc. 14th Int. Wireless Commun. Mobile Comput. Conf. (IWCMC)*, Jun. 2018, pp. 683–689, doi: 10.1109/IWCMC.2018.8450470.

[62] M. J. Beliatis, H. Mansour, S. Nagy, A. Aagaard, and M. Presser, ''Digital waste management using LoRa network a business case from lab to fab,'' in *Proc. Global Internet Things Summit (GIoTS)*, Jun. 2018, pp. 1–6, doi: 10.1109/GIOTS.2018.8534562.

[63] S. Murugaanandam, V. Ganapathy, and R. Balaji, ''Efficient IoT based smart bin for clean environment,'' in *Proc. Int. Conf. Commun. Signal Process. (ICCSP)*, Apr. 2018, pp. 715–720.

[64] K. Al-Jubori and U. Gazder, ''Framework for route optimization of solid waste collection,'' in *Proc. Smart Cities Symp.*, Apr. 2018, pp. 1–6, doi: 10.1049/CP.2018.1407.

[65] P. Chowdhury, R. Sen, D. Ray, P. Roy, and S. Sarkar, ''Garbage monitoring and disposal system for smart city using IoT,'' in *Proc. 2nd Int. Conf. Green Comput. Internet Things (ICGCIoT)*, Aug. 2018, pp. 455–460, doi: 10.1109/ICGCIoT.2018.8753060.

[66] T. Bakhshi and M. Ahmed, ''IoT-enabled smart city waste management using machine learning analytics,'' in *Proc. 2nd Int. Conf. Energy Conservation Efficiency (ICECE)*, Oct. 2018, pp. 66–71, doi: 10.1109/ECE.2018.8554985.

[67] E. Al-Masri, I. Diabate, R. Jain, M. H. Lam, and S. R. Nathala, ''Recycle.io: An IoT-enabled framework for urban waste management,'' in *Proc. IEEE Int. Conf. Big Data (Big Data)*, Dec. 2018, pp. 5285–5287, doi: 10.1109/BigData.2018.8622117.

[68] J.-W. Lu, N.-B. Chang, F. Zhu, J. Hai, and L. Liao, ''Smart and green urban solid waste collection system for differentiated collection with integrated sensor networks,'' in *Proc. IEEE 15th Int. Conf. Netw., Sens. Control (ICNSC)*, Mar. 2018, pp. 1–5, doi: 10.1109/ICNSC.2018.8361307.

[69] G. S. Rohit, M. B. Chandra, S. Saha, and D. Das, ''Smart dual dustbin model for waste management in smart cities,'' in *Proc. 3rd Int. Conf. Converg. Technol. (I2CT)*, Apr. 2018, pp. 1–5, doi: 10.1109/I2CT.2018.8529600.

[70] P. Jajoo, A. Mishra, S. Mehta, and V. Solvande, ''Smart garbage management system,'' in *Proc. Int. Conf. Smart City Emerg. Technol. (ICSCET)*, Jan. 2018, pp. 1–6.

[71] K. Pardini, J. J. P. C. Rodrigues, S. A. Hassan, N. Kumar, and V. Furtado, ''Smart waste bin: A new approach for waste management in large urban centers,'' in *Proc. IEEE 88th Veh. Technol. Conf. (VTC-Fall)*, Aug. 2018, pp. 1–8, doi: 10.1109/VTCFall.2018.8690984.

[72] M. Talha, A. Upadhyay, R. Shamim, and M. S. Beg, ''A cloud integrated wireless garbage management system for smart cities,'' in *Proc. Int. Conf. Multimedia, Signal Process. Commun. Technol. (IMPACT)*, Nov. 2017, pp. 175–179, doi: 10.1109/MSPCT.2017.8363999.

[73] D. D. Vu and G. Kaddoum, ''A waste city management system for smart cities applications,'' in *Proc. Adv. Wireless Opt. Commun. (RTUWO)*, Nov. 2017, pp. 225–229, doi: 10.1109/RTUWO.2017.8228538.

[74] A. S. Wijaya, Z. Zainuddin, and M. Niswar, ''Design a smart waste bin for smart waste management,'' in *Proc. 5th Int. Conf. Instrum., Control, Autom. (ICA)*, Aug. 2017, pp. 62–66, doi: 10.1109/ICA.2017.8068414.

[75] H. Poddar, R. Paul, S. Mukherjee, and B. Bhattacharyya, ''Design of smart bin for smarter cities,'' in *Proc. Innov. Power Adv. Comput. Technol. (i-PACT)*, Apr. 2017, pp. 1–6, doi: 10.1109/IPACT.2017.8245162.

[76] F. I. Khan and A. Gawade, ''Dynamic routing for waste management using IoT for cost-efficient service,'' in *Proc. Int. Conf. Current Trends Comput., Electr., Electron. Commun. (CTCEEC)*, Sep. 2017, pp. 222–230, doi: 10.1109/CTCEEC.2017.8455167.

[77] P. Haribabu, S. R. Kassa, J. Nagaraju, R. Karthik, N. Shirisha, and M. Anila, ''Implementation of an smart waste management system using IoT,'' in *Proc. Int. Conf. Intell. Sustain. Syst. (ICISS)*, Dec. 2017, pp. 1155–1156, doi: 10.1109/ISS1.2017.8389367.

[78] A. Sathish, M. Prakash, S. A. K. Jainulabudeen, and R. Sathishkumar, ''Intellectual trash management using Internet of Things,'' in *Proc. Int. Conf. Comput. Power, Energy Inf. Commun. (ICCPEIC)*, Mar. 2017, pp. 53–57, doi: 10.1109/ICCPEIC.2017.8290338.

[79] B. Keerthana, S. M. Raghavendran, S. Kalyani, P. Suja, and V. K. G. Kalaiselvi, ''Internet of Bins: Trash management in India,'' in *Proc. 2nd Int. Conf. Comput. Commun. Technol. (ICCCT)*, Feb. 2017, pp. 248–251, doi: 10.1109/ICCCT2.2017.7972277.

[80] K. Nirde, P. S. Mulay, and U. M. Chaskar, ''IoT based solid waste management system for smart city,'' in *Proc. Int. Conf. Intell. Comput. Control Syst. (ICICCS)*, Jun. 2017, pp. 666–669, doi: 10.1109/ICCONS.2017.8250546.

[81] B. S. Malapur and V. R. Pattanshetti, ''IoT based waste management: An application to smart city,'' in *Proc. Int. Conf. Energy, Commun., Data Anal. Soft Comput. (ICECDS)*, Aug. 2017, pp. 2476–2486, doi: 10.1109/ICECDS.2017.8389897.

[82] L. Manqele, R. Adeogun, M. Dlodlo, and L. Coetzee, ''Multi-objective decision-making framework for effective waste collection in smart cities,'' in *Proc. Global Wireless Summit (GWS)*, Oct. 2017, pp. 155–159, doi: 10.1109/GWS.2017.8300475.

[83] A. B. Melo, A. M. Oliveira, D. S. De Souza, and M. J. da Cunha, ''Optimization of garbage collection using genetic algorithm,'' in *Proc. IEEE 14th Int. Conf. Mobile Ad Hoc Sensor Syst. (MASS)*, Oct. 2017, pp. 672–677, doi: 10.1109/MASS.2017.57.

[84] S. Ravi and T. Jawahar, ''Smart city solid waste management leveraging semantic based collaboration,'' in *Proc. Int. Conf. Comput. Intell. Data Sci. (ICCIDS)*, Jun. 2017, pp. 1–4, doi: 10.1109/ICCIDS.2017.8272627.

[85] G. K. Shyam, S. S. Manvi, and P. Bharti, ''Smart waste management using Internet-of-Things (IoT),'' in *Proc. 2nd Int. Conf. Comput. Commun. Technol. (ICCCT)*, Feb. 2017, pp. 199–203, doi: 10.1109/ICCCT2.2017.7972276.

[86] M. Marchiori, ''The smart cheap city: Efficient waste management on a budget,'' in *Proc. IEEE 19th Int. Conf. High Perform. Comput. Commun., IEEE 15th Int. Conf. Smart City, IEEE 3rd Int. Conf. Data Sci. Syst. (HPCC/SmartCity/DSS)*, Dec. 2017, pp. 192–199, doi: 10.1109/HPCC-SmartCity-DSS.2017.25.

[87] M. A. Ramalho, R. J. F. Rossetti, and N. Cacho, ''Towards an architecture for smart garbage collection in urban settings,'' in *Proc. Int. Smart Cities Conf. (ISC2)*, Sep. 2017, pp. 1–6, doi: 10.1109/ISC2.2017.8090833.

[88] C. Tiwari and K. Nagarathna, ''Waste management using solar smart bin,'' in *Proc. Int. Conf. Energy, Commun., Data Anal. Soft Comput. (ICECDS)*, Aug. 2017, pp. 1123–1126.

[89] L. Abbatecola, M. P. Fanti, A. M. Mangini, and W. Ukovich, ''A decision support approach for postal delivery and waste collection services,'' *IEEE Trans. Autom. Sci. Eng.*, vol. 13, no. 4, pp. 1458–1470, Oct. 2016, doi: 10.1109/TASE.2016.2570121.

[90] D. Karadimas, A. Papalambrou, J. Gialelis, and S. Koubias, ''An integrated node for smart-city applications based on active RFID tags; use case on waste-bins,'' in *Proc. IEEE 21st Int. Conf. Emerg. Technol. Factory Autom. (ETFA)*, Sep. 2016, pp. 1–7, doi: 10.1109/ETFA.2016.7733532.

[91] M. Aazam, M. St-Hilaire, C.-H. Lung, and I. Lambadaris, ''Cloud-based smart waste management for smart cities,'' in *Proc. IEEE 21st Int. Workshop Comput. Aided Modeling Design Commun. Links Netw. (CAMAD)*, Oct. 2016, pp. 188–193, doi: 10.1109/CAMAD.2016.7790356.

[92] V. Jain, ''eBin: An automated food wastage tracking system for dormitory student's mess,'' in *Proc. Int. Conf. Internet Things Appl. (IOTA)*, Jan. 2016, pp. 52–56, doi: 10.1109/IOTA.2016.7562694.

[93] A. S. Bharadwaj, R. Rego, and A. Chowdhury, ''IoT based solid waste management system: A conceptual approach with an architectural solution as a smart city application,'' in *Proc. IEEE Annu. India Conf. (INDICON)*, Dec. 2016, pp. 1–6, doi: 10.1109/INDICON.2016.7839147.

[94] J. O. Adeyemo, O. O. Olugbara, and E. Adetiba, ''Smart city technology based architecture for refuse disposal management,'' in *Proc. IST-Africa Week Conf.*, May 2016, pp. 1–8, doi: 10.1109/ISTAFRICA.2016.7530704.

[95] S. Idwan, J. A. Zubairi, and I. Mahmood, ''Smart solutions for smart cities: Using wireless sensor network for smart dumpster management,'' in *Proc. Int. Conf. Collaboration Technol. Syst. (CTS)*, Oct. 2016, pp. 493–497, doi: 10.1109/CTS.2016.0092.

[96] R. Fujdiak, P. Masek, P. Mlynek, J. Misurec, and E. Olshannikova, ''Using genetic algorithm for advanced municipal waste collection in smart city,'' in *Proc. 10th Int. Symp. Commun. Syst., Netw. Digit. Signal Process. (CSNDSP)*, Jul. 2016, pp. 1–6, doi: 10.1109/CSNDSP.2016.7574016.

[97] D. Bonino, M. T. D. Alizo, C. Pastrone, and M. Spirito, ''WasteApp: Smarter waste recycling for smart citizens,'' in *Proc. Int. Multidisciplinary Conf. Comput. Energy Sci. (SpliTech)*, Jul. 2016, pp. 1–6, doi: 10.1109/SpliTech.2016.7555951.

[98] A. Papalambrou, D. Karadimas, J. Gialelis, and A. G. Voyiatzis, ''A versatile scalable smart waste-bin system based on resource-limited embedded devices,'' in *Proc. 20th Conf. Emerg. Technol. Factory Automat. (ETFA)*, Sep. 2015, pp. 1–8, doi: 10.1109/ETFA.2015.7301466.

[99] T. Anagnostopoulos, A. Zaslavsky, and A. Medvedev, ''Robust waste collection exploiting cost efficiency of IoT potentiality in smart cities,'' in *Proc. Int. Conf. Recent Adv. Internet Things (RIoT)*, Apr. 2015, pp. 1–6, doi: 10.1109/RIOT.2015.7104901.

[100] F. Folianto, Y. S. Low, and W. L. Yeow, ''Smartbin: Smart waste management system,'' in *Proc. IEEE 10th Int. Conf. Intell. Sensors, Sensor Netw. Inf. Process. (ISSNIP)*, Apr. 2015, pp. 1–2.

[101] T. Anagnostopoulos, A. Zaslavsy, A. Medvedev, and S. Khoruzhnicov, ''Top—*k* query based dynamic scheduling for IoT-enabled smart city waste collection,'' in *Proc. 16th IEEE Int. Conf. Mobile Data Manage.*, Jun. 2015, pp. 50–55, doi: 10.1109/MDM.2015.25.

[102] A. G. Voyiatzis, J. Gialelis, and D. Karadimas, ''Dynamic cargo routing on-the-go: The case of urban solid waste collection,'' in *Proc. IEEE 10th Int. Conf. Wireless Mobile Comput., Netw. Commun. (WiMob)*, Oct. 2014, pp. 58–65.

[103] P. Reis, R. Pitarma, C. Goncalves, and F. Caetano, ''Intelligent system for valorizing solid urban waste,'' in *Proc. 9th Iberian Conf. Inf. Syst. Technol. (CISTI)*, Jun. 2014, pp. 1–6, doi: 10.1109/CISTI.2014.6876904.

[104] J. Chin and V. Callaghan, ''Recyclable, eco-friendly, on-demand bin (ReDBin),'' in *Proc. Int. Conf. Intell. Environments*, Jun. 2014, pp. 222–225, doi: 10.1109/IE.2014.42.

[105] A. Medehal, A. Annaluru, S. Bandyopadhyay, and T. S. Chandar, ''Automated smart garbage monitoring system with optimal route generation for collection,'' in *Proc. IEEE Int. Smart Cities Conf. (ISC2)*, Sep. 2020, pp. 1–7, doi: 10.1109/ISC251055.2020.9239002.

[106] K. Jaikumar, T. Brindha, T. K. Deepalakshmi, and S. Gomathi, ''IoT assisted MQTT for segregation and monitoring of waste for smart cities,'' in *Proc. 6th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, Mar. 2020, pp. 887–891, doi: 10.1109/ICACCS48705.2020.9074399.

[107] J. R. Raj, B. I. P. Rajula, R. Tamilbharathi, and S. Srinivasulu, ''AN IoT based waste segreggator for recycling biodegradable and non-biodegradable waste,'' in *Proc. 6th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, Mar. 2020, pp. 928–930, doi: 10.1109/ICACCS48705.2020.9074251.

[108] L. Pelonero, A. Fornaia, and E. Tramontana, ''From smart city to smart citizen: Rewarding waste recycle by designing a data-centric IoT based garbage collection service,'' in *Proc. IEEE Int. Conf. Smart Comput. (SMARTCOMP)*, Sep. 2020, pp. 380–385, doi: 10.1109/SMARTCOMP50058.2020.00081.

[109] K. Thibuy, S. Thokrairak, and P. Jitngernmadan, ''Holistic solution design and implementation for smart city recycle waste management case study: Saensuk city,'' in *Proc. 5th Int. Conf. Inf. Technol. (InCIT)*, Oct. 2020, pp. 233–237, doi: 10.1109/InCIT50588.2020.9310948.

[110] N. Baras, D. Ziouzios, M. Dasygenis, and C. Tsanaktsidis, ''A cloud based smart recycling bin for waste classification,'' in *Proc. 9th Int. Conf. Mod. Circuits Syst. Technol. (MOCAST)*, Sep. 2020, pp. 1–4, doi: 10.1109/MOCAST49295.2020.9200283.

[111] S. Jagtap, A. Gandhi, R. Bochare, A. Patil, and A. Shitole, ''Waste management improvement in cities using IoT,'' in *Proc. Int. Conf. Power Electron. IoT Appl. Renew. Energy Control (PARC)*, Feb. 2020, pp. 382–385, doi: 10.1109/PARC49193.2020.236631.

[112] S. Sarker, M. S. Rahman, M. J. Islam, D. Sikder, and A. Alam, ''Energy saving smart waste segregation and notification system,'' in *Proc. IEEE Region 10 Symp. (TENSYMP)*, Jun. 2020, pp. 275–278, doi: 10.1109/TENSYMP50017.2020.9230949.

[113] A. Hassani, A. Medvedev, A. Zaslavsky, and A. Saravanan, ''IoT-enabled smart waste disposal system: A use case for the context management platform,'' in *Proc. Global Internet Things Summit (GIoTS)*, Jun. 2020, pp. 1–6, doi: 10.1109/GIOTS49054.2020.9119592.

[114] V. Kalyuzhnyy, M. Costa, P. Silva, and J. Santos, "Smart city IoT system—CollectMyWaste," in *Proc. 4th Int. Symp. Multidisciplinary Stud. Innov. Technol. (ISMSIT)*, Oct. 2020, pp. 1–5, doi: 10.1109/ISMSIT50672.2020.9255271.

[115] A. Jadli and M. Hain, "Toward a deep smart waste management system based on pattern recognition and transfer learning," in *Proc. 3rd Int. Conf. Adv. Commun. Technol. Netw. (CommNet)*, Sep. 2020, pp. 1–5, doi: 10.1109/CommNet49926.2020.9199615.

[116] G. S. Nair, P. V. Devika, K. Jyothisree, N. Giriraj, and N. B. S. Shibu, "Architecture, concept and algorithm for data analytics based zero touch waste management in smart cities," in *Proc. 2nd Int. Conf. Electron. Sustain. Commun. Syst. (ICESC)*, Aug. 2021, pp. 851–856, doi: 10.1109/ICESC51422.2021.9532723.

[117] S. Chavan, U. Patil, S. S. Koshy, and S. V. Srikanth, "Garbage zero (Garb0): An IoT framework for effective garbage management in smart cities," in *Proc. Int. Conf. Artif. Intell. Smart Syst. (ICAIS)*, Mar. 2021, pp. 1336–1342, doi: 10.1109/ICAIS50930.2021.9395970.

[118] M. Paturi, S. Puvvada, B. S. Ponnuru, M. Simhadri, B. S. Egala, and A. K. Pradhan, "Smart solid waste management system using blockchain and IoT for smart cities," in *Proc. IEEE Int. Symp. Smart Electron. Syst. (iSES)*, Dec. 2021, pp. 456–459, doi: 10.1109/iSES52644.2021.00107.

[119] S. Pargaien, A. V. Pargaien, D. Verma, V. Sah, N. Pandey, and N. Tripathi, "Smart waste collection monitoring system using IoT," in *Proc. 3rd Int. Conf. Inventive Res. Comput. Appl. (ICIRCA)*, Sep. 2021, pp. 11–16, doi: 10.1109/ICIRCA51532.2021.9544982.

[120] P. Leninpugalhanthi, G. Bharanidaran, T. Bahiradhan, E. Abirami, R. Anandh, and R. S. Kumar, "Enhanced smart waste management system with incinerator compartment," in *Proc. 7th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, Mar. 2021, pp. 1313–1317, doi: 10.1109/ICACCS51430.2021.9441785.

[121] M. S. Monteiro, F. L. de Caldas Filho, P. D. O. M. e Souza, V. S. Costa, G. P. C. P. da Luz, L. F. D. O. Carvalho, and R. T. de Sousa, "Solid waste management and monitoring system for smart cities: Development of a low-cost sustainable IoT architecture using GPRS/GSM," in *Proc. Workshop Commun. Netw. Power Syst. (WCNPS)*, Nov. 2021, pp. 1–6, doi: 10.1109/WCNPS53648.2021.9626317.

[122] M. J. C. Samonte, S. H. Baloloy, and C. K. J. Datinguinoo, "e-TapOn: Solar-powered smart bin with path-based robotic garbage collector," in *Proc. IEEE 8th Int. Conf. Ind. Eng. Appl. (ICIEA)*, Apr. 2021, pp. 181–185, doi: 10.1109/ICIEA52957.2021.9436763.

[123] K. Rajesh, B. Rohini, R. Agalya, S. Janani, S. Rajendran, and A. Ramkumar, "Intelligent garbage monitoring system using IoT," in *Proc. 2nd Int. Conf. Electron. Sustain. Commun. Syst. (ICESC)*, Aug. 2021, pp. 717–722, doi: 10.1109/ICESC51422.2021.9532937.

[124] N. C. A. Sallang, M. T. Islam, M. S. Islam, and H. Arshad, "A CNN-based smart waste management system using TensorFlow lite and LoRa-GPS shield in Internet of Things environment," *IEEE Access*, vol. 9, pp. 153560–153574, 2021, doi: 10.1109/ACCESS.2021.3128314.

[125] E. Shanthini, V. Sangeetha, M. Jagadeeswari, B. Shivani, P. Selvapriya, K. Anindita, D. D. Shree, and R. U. Suryanarayanan, "IoT based smart city garbage bin for waste management," in *Proc. 4th Int. Conf. Smart Syst. Inventive Technol. (ICSSIT)*, Jan. 2022, pp. 105–110, doi: 10.1109/ICSSIT53264.2022.9716343.

[126] S. Varudandi, R. Mehta, J. Mahetalia, H. Parmar, and K. Samdani, "A smart waste management and segregation system that uses Internet of Things, machine learning and Android application," in *Proc. 6th Int. Conf. Converg. Technol. (I2CT)*, Apr. 2021, pp. 1–6, doi: 10.1109/I2CT51068.2021.9418125.

[127] S. Akshayaa, R. Evangeline, S. H. Sree, and B. Banuselvasaraswathy, "Smart bin for clean cities using IoT," in *Proc. 7th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, Mar. 2021, pp. 1280–1283, doi: 10.1109/ICACCS51430.2021.9441681.

[128] D. J. Dasari, V. S. Velala, B. Ganbaaatar, and N. Kunicina, "Smart trash bin segregation and identify and create alerts on the level of waste present in the trash bin," in *Proc. IEEE 8th Workshop Adv. Inf., Electron. Electr. Eng. (AIEEE)*, Apr. 2021, pp. 1–6, doi: 10.1109/AIEEE51419.2021.9435755.

[129] P. Hewagamage, A. Mihiranga, D. Perera, R. Fernando, T. Thilakarathna, and D. Kasthurirathna, "Computer-vision enabled waste management system for green environment," in *Proc. 3rd Int. Conf. Advancements Comput. (ICAC)*, Dec. 2021, pp. 276–281, doi: 10.1109/ICAC54203.2021.9671222.

[130] N. Mittal, P. P. Singh, and P. Sharma, "Intelligent waste management for smart cities," in *Proc. Int. Conf. Ind. Electron. Res. Appl. (ICIERA)*, Dec. 2021, pp. 1–7, doi: 10.1109/ICIERA53202.2021.9726729.

[131] A. Kanade and S. P. Warkhade, "Framework of automated robotic dustbin (ARD) for garbage collection in smart cities with priority scheduling approach," in *Proc. 5th Int. Conf. Trends Electron. Informat. (ICOEI)*, Jun. 2021, pp. 295–300, doi: 10.1109/ICOEI51242.2021.9452812.

[132] A. Hojjati, W. Nasar, D. Mishra, S. Alaliyat, and I. A. Hameed, "Cloud-based smart IoT sustainable solution for waste sorting and management," in *Proc. IEEE/SICE Int. Symp. Syst. Integr. (SII)*, Jan. 2022, pp. 218–224, doi: 10.1109/SII52469.2022.9708794.

[133] S. Squire, S. U. Rehman, and M. A. Khan, "Investigating efficient municipal solid waste collection through technology," in *Proc. IEEE Microw. Theory Techn. Wireless Commun. (MTTW)*, Oct. 2021, pp. 211–216, doi: 10.1109/MTTW53539.2021.9607088.

[134] A. Sivasangari, U. R. Polishetty, A. Anandhi, and R. M. Gomathi, "IoT based smart garbage system," in *Proc. 5th Int. Conf. Comput. Methodologies Commun. (ICCMC)*, Apr. 2021, pp. 506–509, doi: 10.1109/ICCMC51019.2021.9418455.

[135] T. Vairam, S. Sarathambekai, and D. Vigneshwaran, "A software-defined networking (SDN) architecture for smart trash can using IoT," in *EAI International Conference on Big Data Innovation for Sustainable Cognitive Computing*. Cham, Switzerland: Springer, 2020, pp. 163–172, doi: 10.1007/978-3-030-19562-5_16.

[136] A. Chitreddy, K. Gogineni, V. Anirudh, P. V. Akhilesh, K. K. Vamsi, and L. P. Swarna, "Application of sensors using IoT for waste management system," in *Proc. Int. Conf. Intell. Comput. Smart Commun.*, 2020, pp. 1565–1575.

[137] S. A. Gopala, C. G. Sarath, and R. N. Srinivasa, "Energy-efficient waste management system using Internet of Things," in *Proc. Int. Conf. Nanoelectron., Circuits Commun. Syst.*, 2020, pp. 7–13.

[138] V. Manchanda, R. Bathla, and D. Gupta, "Implementation of IoT for trash monitoring system," in *Proc. Int. Conf. Comput. Netw., Big Data IoT*, 2020, pp. 988–998.

[139] H. N. Saha, S. Gon, A. Nayak, S. Kundu, and S. Moitra, "IoT based garbage monitoring and clearance alert system," in *Proc. IEEE 9th Annu. Inf. Technol., Electron. Mobile Commun. Conf. (IEMCON)*, Nov. 2018, pp. 204–208, doi: 10.1109/IEMCON.2018.8614840.

[140] S. Idwan, I. Mahmood, J. A. Zubairi, and I. Matar, "Optimal management of solid waste in smart cities using Internet of Things," *Wireless Pers. Commun.*, vol. 110, no. 1, pp. 485–501, Jan. 2020, doi: 10.1007/S11277-019-06738-8.

[141] K. C. Saranya, V. Sujan, B. Abivishaq, and K. N. Kanna, "Smart bin with automated metal segregation and optimal distribution of the bins," in *Emerging Technologies for Agriculture and Environment*. Singapore: Springer, 2020, doi: 10.1007/978-981-13-7968-0_9.

[142] J. N. Kalshetty, A. Anil, H. Jain, S. Beli, and A. K. Singh, "Smart monitoring for waste management using Internet of Things," in *Intelligent Data Communication Technologies and Internet of Things* (Lecture Notes on Data Engineering and Communications Technologies), vol. 38, D. Hemanth, S. Shakya, and Z. Baig, Eds. Cham, Switzerland: Springer, 2020, doi: 10.1007/978-3-030-34080-3_11.

[143] T. S. Vasagade, S. S. Tamboli, and A. D. Shinde, "Smart solid waste collection and management system," in *Techno-Societal 2018*. Cham, Switzerland: Springer, 2020, pp. 663–671.

[144] P. S. A. Mahajan, A. Kokane, A. Shewale, M. Shinde, and S. Ingale, "Smart waste management system using IoT," *Int. J. Adv. Eng. Res. Sci.*, vol. 4, no. 4, pp. 93–95, 2017, doi: 10.22161/IJAERS.4.4.12.

[145] Y. B. Jinila, M. S. Alam, and P. D. Singh, "Cloud-based scheme for household garbage collection in urban areas," in *Advances in Big Data and Cloud Computing*. Singapore: Springer, 2019, doi: 10.1007/978-981-13-1882-5_47.

[146] A. Patel and N. Patel, "Garbage monitoring system using Internet of Things," in *Soft Computing and Signal Processing*. Singapore: Springer, 2019, doi: 10.1007/978-981-13-3600-3_28.

[147] P. S. Saarika and T. Sudha, "IoT based market and waste management system for a smart city," in *Proc. Int. Conf. Intell. Data Commun. Technol. Internet Things (ICICI)*, 2019, pp. 920–926.

[148] N. Abdullah, O. A. Alwesabi, and R. Abdullah, "IoT-based smart waste management system in a smart city," in *Proc. Int. Conf. Reliable Inf. Commun. Technol.*, 2018, pp. 364–371.

[149] R. Kansara, P. Bhojani, and J. Chauhan, ''Smart waste management for segregating different types of wastes,'' in *Data Management, Analytics and Innovation*. Singapore: Springer, 2019, doi: 10.1007/978-981-13-1402-5_3.

[150] T. V. Chandan, R. C. Kumari, R. Tekam, and B. V. Shruti, ''Smart waste monitoring using wireless sensor networks,'' in *Emerging Research in Computing, Information, Communication and Applications*. Singapore: Springer, 2019, pp. 363–369, doi: 10.1007/978-981-13-6001-5_28.

[151] D. Misra, G. Das, T. Chakrabortty, and D. Das, ''An IoT-based waste management system monitored by cloud,'' *J. Mater. Cycles Waste Manage.*, vol. 20, no. 3, pp. 1574–1582, Jul. 2018, doi: 10.1007/S10163-018-0720-y.

[152] N. K. Gattim, M. G. Krishna, B. R. Nadh, N. Madhu, and C. L. Reddy, ''IoT-based green environment for smart cities,'' in *Microelectronics, Electromagnetics and Telecommunications*. Singapore: Springer, 2018, doi: 10.1007/978-981-10-7329-8_27.

[153] S. K. Deka and K. Goswami, ''IoT-based monitoring and smart planning of urban solid waste management,'' in *Advances in Communication, Devices and Networking* (Lecture Notes in Electrical Engineering), vol. 462. Singapore: Springer, 2018, doi: 10.1007/978-981-10-7901-6_96.

[154] P. Argulwar, S. Borse, K. N. Argulwar, and U. S. Gurunathappa, ''IoT-based smart garbage management system,'' in *Proc. Int. Conf. Intell. Comput. Appl.*, in Advances in Intelligent Systems and Computing, vol. 632. Singapore: Springer, 2018, doi: 10.1007/978-981-10-5520-1_23.

[155] D. J. Rosa-Gallardo, G. Ortiz, J. Boubeta-Puig, and A. García-De-Prado, ''Sustainable waste collection (SWAT): One step towards smart and spotless cities,'' in *Proc. Int. Conf. Service-Oriented Comput.*, 2018, pp. 228–239, doi: 10.1007/978-3-319-91764-1_18.

[156] M. Giacobbe, C. Puliafito, and M. Scarpa, ''The big bucket: An IoT cloud solution for smart waste management in smart cities,'' in *Proc. Eur. Conf. Service-Oriented Cloud Comput.*, 2018, pp. 43–58, doi: 10.1007/978-3-319-72125-5_4.

[157] A. G. Briones, P. Chamoso, A. Rivas, S. Rodríguez, F. De La Prieta, J. Prieto, and J. M. Corchado, ''Use of gamification techniques to encourage garbage recycling. A smart city approach,'' in *Proc. Int. Conf. Knowl. Manage. Org.*, 2018, pp. 674–685, doi: 10.1007/978-3-319-95204-8_56.

[158] P. Fedchenkov, A. Zaslavsky, A. Medvedev, T. Anagnostopoulos, and I. Sosunova, ''Supporting data communications in IoT-enabled waste management,'' in *Internet of Things, Smart Spaces, and Next Generation Networks and Systems* (Lecture Notes in Computer Science), vol. 10531. Cham, Switzerland: Springer, 2017.

[159] I. Sosunova, A. Zaslavsky, T. Anagnostopoulos, P. Fedchenkov, O. Sadov, and A. Medvedev, ''SWM-PnR: Ontology-based context-driven knowledge representation for IoT-enabled waste management,'' in *Proc. Int. Workshop Nano-Scale Comput. Commun.*, in Lecture Notes in Computer Science, vol. 10531, 2017, pp. 151–162.

[160] L. Murciego, G. V. González, A. L. Barriuso, D. H. de La Iglesia, J. R. Herrero, and J. F. De Paz Santana, ''Smart waste collection platform based on WSN and route optimization,'' in *Proc. Int. Conf. Practical Appl. Agents Multi-Agent Syst.*, 2016, pp. 135–145, doi: 10.1007/978-3-319-40159-1_11.

[161] T. Anagnostopoulos, A. Zaslavsky, S. Georgiou, and S. Khoruzhnikov, ''High capacity trucks serving as mobile depots for waste collection in IoT-enabled smart cities,'' in *Proc. Int. Conf. Next Gener. Wired/Wireless Netw.*, 2015, pp. 80–94, doi: 10.1007/978-3-319-23126-6_8.

[162] A. Medvedev, P. Fedchenkov, A. Zaslavsky, T. Anagnostopoulos, and S. Khoruzhnikov, ''Waste management as an IoT-enabled service in smart cities,'' in *Proc. Int. Conf. Next Gener. Wired/Wireless Netw.*, 2015, pp. 104–115, doi: 10.1007/978-3-319-23126-6_10.

[163] T. V. Anagnostopoulos and A. Zaslavsky, ''Effective waste collection with shortest path semi-static and dynamic routing,'' in *Proc. Int. Conf. Next Gener. Wired/Wireless Netw.*, 2014, pp. 95–105, doi: 10.1007/978-3-319-10353-2_9.

[164] B. Fataniya, A. Sood, D. Poddar, and D. Shah, ''Implementation of IoT based waste segregation and collection system,'' *Int. J. Electron. Telecommun.*, vol. 65, pp. 1–6, May 2019, doi: 10.24425/IJET.2019.129816.

[165] M.-V. Bueno-Delgado, J.-L. Romero-Gázquez, P. Jiménez, and P. Pavón-Mariño, ''Optimal path planning for selective waste collection in smart cities,'' *Sensors*, vol. 19, no. 9, p. 1973, Apr. 2019, doi: 10.3390/S19091973.

[166] K. Subbulakshmi, ''Smart recycle trash management systems for smart city using IoT,'' *J. Mech. Continua Math. Sci.*, vol. 1, no. 2, pp. 407–410, Aug. 2019, doi: 10.26782/jmcms.spl.2019.08.00050.

[167] M. Cerchecci, F. Luti, A. Mecocci, S. Parrino, G. Peruzzi, and A. Pozzebon, ''A low power IoT sensor node architecture for waste management within smart cities context,'' *Sensors*, vol. 18, no. 4, p. 1282, Apr. 2018, doi: 10.3390/S18041282.

[168] O. Rybnytska, F. Burstein, A. V. Rybin, and A. Zaslavsky, ''Decision support for optimizing waste management,'' *J. Decis. Syst.*, vol. 27, no. 1, pp. 68–78, May 2018, doi: 10.1080/12460125.2018.1464312.

[169] N. Ali, M. Awais, M. Muzammul, and A. Zafar, ''Intelligent system for garbage collection: IoT technology with ultrasonic sensor and Arduino mega,'' *Int. J. Comput. Sci. Netw. Secur.*, vol. 18, pp. 1–6, Sep. 2018.

[170] Á. Lozano, J. Caridad, J. De Paz, G. Villarrubia González, and J. Bajo, ''Smart waste collection system with low consumption LoRaWAN nodes and route optimization,'' *Sensors*, vol. 18, no. 5, p. 1465, May 2018, doi: 10.3390/S18051465.

[171] M. F. Arief and F. L. Gaol, ''Developing and evaluating prototype of waste volume monitoring using Internet of Things,'' *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 215, Jun. 2017, Art. no. 012038, doi: 10.1088/1757-899X/215/1/012038.

[172] Z. Oralhan, B. Oralhan, and Y. Yiğit, ''Smart city application: Internet of Things (IoT) technologies based smart waste collection using data mining approach and ant colony optimization,'' *Int. Arab J. Inf. Technol.*, vol. 14, no. 4, pp. 423–427, Jul. 2017.

[173] C. Popa, G. Carutasu, C. Cotet, N. Carutasu, and T. Dobrescu, ''Smart city platform development for an automated waste collection system,'' *Sustainability*, vol. 9, no. 11, p. 2064, Nov. 2017, doi: 10.3390/SU9112064.

[174] M. F. Omar, A. A. A. Termizi, D. Zainal, N. A. Wahap, N. M. Ismail, and N. Ahmad, ''Implementation of spatial smart waste management system in Malaysia,'' *IOP Conf. Ser., Earth Environ. Sci.*, vol. 37, Jun. 2016, Art. no. 012059, doi: 10.1088/1755-1315/37/1/012059.

[175] C. Unnithan, P. S. Ramkumar, A. Babu, S. Joseph, S. Patil, and A. Joshi, ''Mobile waste management for smart cities: Monitoring sanitation through living labs,'' in *Proc. Int. Conf. ICT Sustain. Develop.*, 2016, pp. 625–633, doi: 10.1007/978-981-10-0129-1_65.

[176] D. E. Popescu, C. Bungau, M. Prada, C. Domuta, S. Bungau, and D. M. Tit, ''Waste management strategy at a public university in smart city context,'' *J. Environ. Protection Ecol.*, vol. 17, no. 3, pp. 1011–1020, 2016.

[177] A. Imteaj, M. Chowdhury, and M. A. Mahamud, ''Dissipation of waste using dynamic perception and alarming system: A smart city application,'' in *Proc. Int. Conf. Electr. Eng. Inf. Commun. Technol. (ICEEICT)*, May 2015, pp. 1–5, doi: 10.1109/ICEEICT.2015.7307410.

[178] P. Reis, F. Caetano, R. Pitarma, and C. Gonçalves, ''iEcoSys—An intelligent waste management system,'' in *New Contributions in Information Systems and Technologies*. Cham, Switzerland: Springer, 2015, doi: 10.1007/978-3-319-16486-1_84.

[179] Á. L. Murciego, G. V. González, A. L. Barriuso, D. H. De La Iglesia, and J. R. Herrero, ''Multi agent gathering waste system,'' *Adv. Distrib. Comput. Artif. Intell. J.*, vol. 4, no. 4, pp. 9–22, Dec. 2015, doi: 10.14201/ADCAIJ201544922.

[180] L. Catarinucci, R. Colella, S. I. Consalvo, L. Patrono, C. Rollo, and I. Sergi, ''IoT-aware waste management system based on cloud services and ultra-low-power RFID sensor-tags,'' *IEEE Sensors J.*, vol. 20, no. 24, pp. 14873–14881, Dec. 2020, doi: 10.1109/JSEN.2020.3010675.

[181] A. Saeidi, S. Aghamohamadi-Bosjin, and M. Rabbani, ''An integrated model for management of hazardous waste in a smart city with a sustainable approach,'' *Environ., Develop. Sustainability*, vol. 23, no. 7, pp. 10093–10118, Jul. 2021, doi: 10.1007/S10668-020-01048-7.

[182] P. Jiang, Y. V. Fan, J. Zhou, M. Zheng, X. Liu, and J. J. Klemeš, ''Data-driven analytical framework for waste-dumping behaviour analysis to facilitate policy regulations,'' *Waste Manage.*, vol. 103, pp. 285–295, Feb. 2020, doi: 10.1016/j.wasman.2019.12.041.

[183] K. Pardini, J. J. P. C. Rodrigues, O. Diallo, A. K. Das, V. H. C. de Albuquerque, and S. A. Kozlov, ''A smart waste management solution geared towards citizens,'' *Sensors*, vol. 20, no. 8, p. 2380, Apr. 2020, doi: 10.3390/S20082380.

[184] T. Ali, M. Irfan, A. S. Alwadie, and A. Glowacz, ''IoT-based smart waste bin monitoring and municipal solid waste management system for smart cities,'' *Arabian J. Sci. Eng.*, vol. 45, no. 12, pp. 10185–10198, 2020, doi: 10.1007/S13369-020-04637-W.

[185] F. Alqahtani, Z. Al-Makhadmeh, A. Tolba, and W. Said, ''Internet of Things-based urban waste management system for smart cities using a cuckoo search algorithm,'' *Cluster Comput.*, vol. 23, no. 3, pp. 1769–1780, Sep. 2020, doi: 10.1007/S10586-020-03126-X.

[186] J. John, M. S. Varkey, R. S. Podder, N. Sensarma, M. Selvi, S. V. N. S. Kumar, and A. Kannan, "Smart prediction and monitoring of waste disposal system using IoT and cloud for IoT based smart cities," *Wireless Pers. Commun.*, vol. 122, no. 1, pp. 243–275, Jan. 2022, doi: 10.1007/S11277-021-08897-Z.

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