IoT-Based Smart Solid Waste Management System A Systematic Literature Review

Nor Azman Ismail, Nurul Aiman Ab Majid, Shukur Abu Hassan

Abstract*: With the increasing number of world population and the rapidly expanding globalization of the world, waste is one of the main issues that concerns many parties. The World Bank estimates that in 2025, the population of the world's urban population will reach 4.3 billion and the rate of waste production is about 1.42 kg per day for every resident.Based on World Bank reports, there is a positive relationship in which waste generated is directly proportional to the level of economic prosperity and the level of industrial growth achieved. Today a smart solid waste management system uses Internet-of-Things (IoT) technology in order to automate several traditional waste management processes. It is proven in several smart cities such as Nottingham, England and Hamburg, Germany that implementation of this system in the right way gives many benefits. In this paper, a systematic literature review methods is used to collect and analyse related works on smart solid waste management systems.Literature has been compiled based on five major databases including, IEEE Xplore, Google Scholar, Springer, Web of Science (WoS) and ACM Digital Library.Literatures were searched based on several relevant keywords and the ones selected were the ones that satisfy selection criteria defined. A total of 25 literature met the requirements set, and 12 of them are reviewed in this paper. Research gaps from an existing works have been concluded, based on the results of the study.

***Index Terms*: Systematic Literature Review; Smart Solid Waste Management System; Internet-of-Things; Smart City.**

I. INTRODUCTION

Solid waste management (SWM) is the process of collecting, handling, and disposing of no longer in use solid objects that are discarded[1]. In today’s world, typical solid waste management includes large outdoor waste bins, waste pickup trucks, and scheduled pickup routine by the related party. Manaf et al. [2] explain that solid waste is categorized into three categories, each is handled by different authorities. Table 1 shows the categories of solid waste and the related party that's responsible for handling the waste.

Table 1: Category of Solid Waste and Related Authorities [2]

Category	Related Authorities
Municipal solid waste	Ministry of Housing and Local Government
Hazardous waste	Department of Environment
Clinical waste	Ministry of Health

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Nor Azman Ismail, School of Computing, Universiti Teknologi Malaysia (UTM), Johor Bahru, Johor, Malaysia.

Nurul Aiman Ab Majid, School of Computing, Universiti Teknologi Malaysia (UTM), Johor Bahru, Johor, Malaysia..

Shukur Abu Hassan, School of Mechanical Engineering Universiti Teknologi Malaysia (UTM), Johor Bahru, Johor, Malaysia.

In London, solid waste collection is carried out based on selective collection requirements. Different color of garbage bags and/or garbage bins are used for different categories of solid waste. The examples of this color categorization are the yellow container for hospital waste, the red container for toxic waste and black container for household waste [3]. Pardini et al.[4] also came out with waste categorization as shown in Table 2 below.

Table 2: Waste Categorization and Description [4]

Category	Description
Commercial Waste	Waste originated from commercial establishments such as toys and clothes [5].
Electronic Waste	Disposed electronic gadgets due to no longer being used or already malfunctioning [6].
Hospital Waste	Waste originated from medical clinics or hospitals that may be contaminated as a medium of disease transmission [7].
Industrial Waste	Waste generated by industries, usually in the form of solid waste [8].
Nuclear Waste	Hazardous radioactive waste produced by nuclear plants and should be treated under strict procedures [9].
Organic Waste	Biodegradable waste from organic matter, usually foods [10].
Recyclable Waste	Waste that can be processed into other product(s) for different usage [11].

On the other hand, smart solid waste management system (SSWMS) is a smart system that links smart waste bins (as smart objects) to web-based and/or mobile-based application through cloud servers using Internet-of-Things (IoT) technologies [12]. IoT allows traditional, physical objects to communicate among each other by transforming them into “smart objects” using several essential technologies such as embedded devices, sensor networks, and Internet protocols [13]. The overall concept of IoT is depicted in Figure 1 which shows an example of domains suitable for IoT services.

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Figure 1: Overview of IoT Implementation[13]

In a SSWMS, the smart waste bins are integrated with several sensors (e.g., proximity sensor, weight sensor, temperature sensor, etc.). Example of working smart waste bin is produced by ZAN Compute Inc. called Smart Garbage Bin, as patented by Shahabdeen[14]. These sensors then collect related real-time data regarding the solid waste inside the bin before the microcontroller embedded on each bin transfer the data to Cloud servers. Next, the Cloud servers communicate with specially developed mobile-based and/or web-based applications for monitoring and management purposes.This SSWMS is important as its efficiency is proven to be better than the traditional waste management procedures. The aim of this system is to assist the waste management team to carry out their work more efficient in terms of (but not limited to) monitoring, scheduling and cutting operational cost. For example, the implementation of Bigbelly Solar Waste &Recycling System (BSWRS) in smart cities such as Hamburg and New York City has managed to help these cities reducing their number of waste pickups up to 80% while also reducing the waste collection costs around 75% [15].There is no universal solution on how SSWMS should be planned and implemented as it is a complex task. Therefore, several factors and aspects need to be considered and analyzed. The main purpose of this paper is to gather more relatable information about SSWMS. Next, Section II elaborates related works regarding SSWMS while Section III explains the review process. Result and discussion are reported in Section IV. Finally, Section V concludes the study and states its future work.

II. RELATED WORKS

IoT is an integral part of any development and implementation of SSWMS. According to Dorsemaine et al.,[16]Internet-of-Things (IoT) is a group of infrastructures interconnecting linked objects and permitting their management, data mining and access to the information they generate. The interconnection between objects is realized by having an Internet connection and/or cloud server as its gateway. To understand the IoT concept further, it is divided into six components as shown in Table 3[13].

Table 3: Components of IoT

Component	Examples
IoT Identification	Object ID, object's address
IoT Sensing	Smart actuators, sensors, wearable sensing devices
IoT Communication	6LOWPAN
IoT Computation	Fog Computing
IoT Semantics	Extraction of knowledge wisely by different systems
IoT Services	Identity-related services, collaborative-aware services, ubiquitous services, information aggregation services

SSWMS is one of many services that any Smart City can implement in order to provide an environment that is more sustainable. According to Priano& Guerra[17], Smart City can be defined as a future-looking and well performing city based six characteristics (i.e., Smart Economy, Smart People, Smart Living, Smart Governance, Smart Mobility and Smart Environment), built on the abilities combination and activities of independent, self-decisive and conscious citizens.Several SLRs can be found regarding IoT and Smart City which are both highly related to SSWMS as mentioned earlier in this paper. These SLR investigates on issues regarding IoT and/or Smart City but with different focuses. In [18], a SLR has been carried out to find out potential indicators in implementing Smart City. In the SLR, the author manages to list out twelve main indicators that can be used as the main factors in making the decision regarding Smart City Development which includes environmental sustainability.

Next, Trindade et al. [19] discuss environmental sustainability and smart city concept. The SLR focuses on theoretical basis concepts of both sustainability and smart city, their relationships, issues, proposed works and strength and weaknesses of related works. Besides, Mijac et al. [20] conducted an investigation on proposed Smart City services driven by IoT by using SLR. The SLR gathered literature regarding applications of IoT in the development of Smart City services before dividing them into categories of proposed or described services. One of the dominant categories of Smart City services driven by IoT that the SLR recognized is waste management. Therefore, this paper aims to gather information regarding proposed and existing solutions of SSWMS.

III. REVIEW PROCESS

In this section, a review process is conducted using the SLR method. This method consists of four steps which are establishing research question, search process, inclusion and exclusion criteria, and quality evaluation[21][22]. These steps are divided into each subsection respectively as follows.

A. Research Question In this study the following research question is as follows:

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RQ1: What are the current solutions of proposed and current solutions in Smart Solid Waste Management System?The research question was constructed based on three criterias, namely; population, intervention and context as shown in Table 4.

Table 4: Research Questions Structure

Criteria	Scope
Population	Papers that propose solutions (e.g., design/ architecture/ implementation) related to SSWMS
Intervention	Methodology /tool/ technology/ procedure used in development of SSWMS
Context	Municipal areas/ smart cities/ smarter campuses

B. Search Process

The main objective of this section's research is to find the existing works on SSWMS. The first step of the research is conducting the preliminary search process using keywords of relevant terms extracted from research questionsconstructed. The keywords chosen are shown in Table 5.

Table 5: Search Keywords

Code	Detail Keywords	Similar keywords
C1	Smart	Intelligent
C2	Waste	Garbage, Rubbish
C3	Management System	Monitoring System, Collection System
C4	Implementation	Design, Development
C5	Internet-of-Things	IoT, Internet of Things

The possible queries generated based on keywords in Table 4 are:

- ("Smart" OR "Intelligent") AND ("waste" OR "garbage" OR "rubbish") AND ("management system" OR "monitoring system" OR "collection system") AND ("implementation" OR "design" OR "development") AND ("internet-of-things" OR "IoT" OR "internet of things")
- ("Smart" OR "Intelligent") AND ("waste" OR "garbage" OR "rubbish") AND ("management system" OR "monitoring system" OR "collection system") AND ("implementation" OR "design" OR "development")
- ("Smart" OR "Intelligent") AND ("waste" OR "garbage" OR "rubbish") AND ("management system" OR "monitoring system" OR "collection system") AND ("internet-of-things" OR "IoT" OR "internet of things")
- ("Smart" OR "Intelligent") AND ("waste" OR garbage" OR "rubbish") AND ("management system" OR "monitoring system" OR "collection system")

C. Inclusion and Exclusion Criteria

To carry out a SLR, papers found were sorted based on type and sources e.g. journals and proceedings. Computer science and software engineering are chosen as domains of this study. Table 6 shows inclusion and exclusion criteria selected for this study.

Table 6: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
All papers are written in English	Papers are written in other than English
Papers that highlight the studies in implementation of SSWMS	Papers that do not highlight the studies in implementation of SSWMS
All papers published from 2013-2018	All papers published before the year 2013

This study reviewed the literature that focuses on proposing works in SSWMS implementation. The literature selected are the ones written in English as the majority of journals and proceedings are published in this language. Next, papers that did not highlight the implementation of SSWMS is the main exclusion criterion besides papers that are published before the year 2013 also are excluded in this research. Figure 2 shows a summary of the review process conducted in this paper.

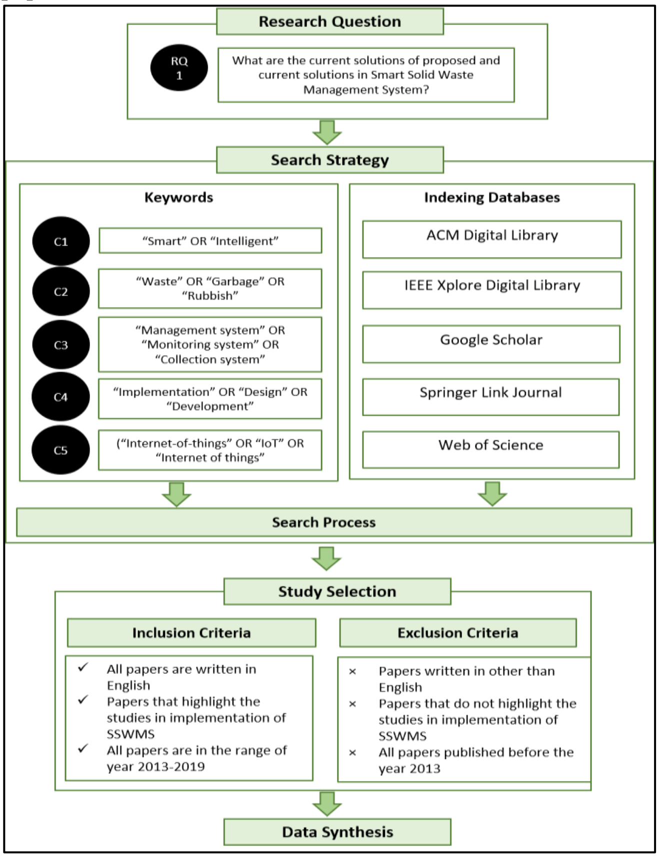

Figure 2: Summary of Review Process Conducted

D. Quality Evaluation

Quality checklist has been outlined in this research to ensure the quality of chosen papers.

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This checklist is constructed that fit the highlighted research question. Table 7 shows the of research question structures selected in this study. Literature that did not have a clear focus on SSWMS implementation are excluded from this study as they are not research-compatible.

Table 7: Research Question Structure

Items	Answer
Does the literature discuss the design of proposed and current solutions in SSWMS?	Yes/No/Partially

IV. RESULTS AND DISCUSSION

The results of this SLR are based on the major indexing databases that are ACM Digital Library, IEEE Xplore Digital Library, Google Scholar, Springer Link Journal and Web of Science. Around 100 literature are found that are related to SSWMS, however, only 25 met the selection criteria as described in Table 6. The search process flow of related studies is shown in Figure 3. The trends of articles related to SSWMS from the year 2013 until 2018. The highest number of published related literature found is in the year 2017 with a total of nine papers while the least number of papers published is in the year 2013.

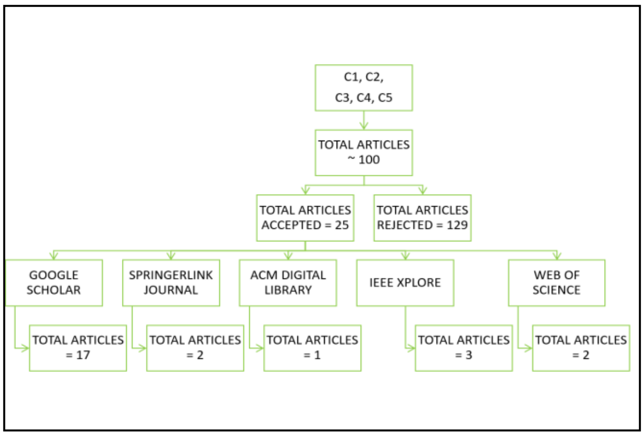

Figure 3: The Search Process

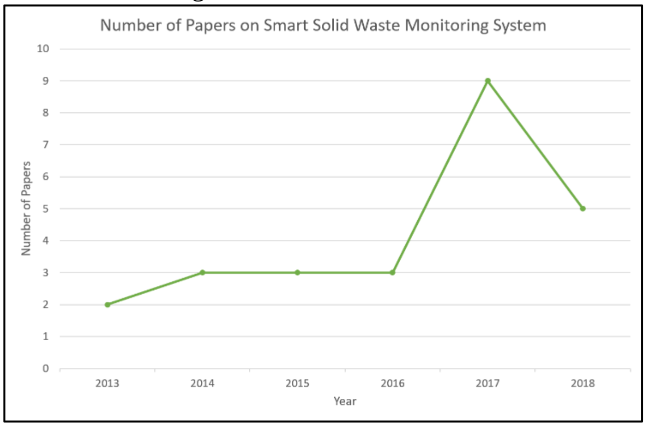

Figure 4: Number of Papers on SSWMS within the Range of the Year 2013-2018

Table 8 shows the timeline of literature chosen to answer the Research Question RQ1 is drawn. Based on the timeline, it can be seen that papers chosen for this SLR are from the year 2014, 2016 and 2017. A total of twelve papers is chosen, which two are from the year 2014, three from the year 2015, five for the year 2017 and two from the year 2018.

Table 8: Timeline of Literatures

Year	Title
2014	i. Effective Waste Collection with Shortest Path Semi-Static and Dynamic Routing [23] ii. An approach for monitoring and smart planning of urban solid waste management using smart-M3 platform [24]
2016	iii. The Big Bucket: An IoT Cloud Solution for Smart Waste Management in Smart Cities [25] iv. Smart City Service Monitoring and Waste Collection [26] v. Implementation of spatial smart waste management system in Malaysia [27]
2017	vi. A Smart Waste Management System using IoT and Blockchain Technology [28] vii. A Smart-bin Prototype for in-house Waste Management [29] viii. Multi-Agent based IoT Smart Waste Monitoring and Collection Architecture [30] ix. IGOE IoT Framework for Waste Collection Optimization [31] x. Smart Bin: Internet-of-Things Garbage Monitoring System [32]
2018	xi. A Low Power IoT Sensor Node Architecture for Waste Management Within Smart Cities Context [33] xii. IoT-Enabled Smart City Waste Management using Machine Learning Analytics [34]

Based on the 25 papers that passed the quality evaluation criteria, several papers are chosen to answer the research question RQ1.The summary of the proposed and current design of SSWMS is depicted in Table 9.

Table 9: Summary of SSWMS Proposed Designs

Proposed Work	Summary
Effective Waste Collection with Shortest Path Semi-Static and Dynamic Routing [23]	Introduced two routing models to achieve effective waste collection driven by IoT
A Smart Waste Management System uses IoT and Blockchain Technology [28]	Proposed a smart waste management system using IoT, plus Blockchain technology as the

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	technology as the more secure payment method
A Smart-bin Prototype for in-house Waste Management [29]	Created a smart waste bin prototype specifically for in-house waste management
An Approach for Monitoring and Smart Planning of Urban Solid Waste Management using the Smart-M3 Platform [24]	Proposed an approach in monitoring urban solid waste management based on Smart-M3 platform
Multi-Agent based IoT Smart Waste Monitoring and Collection Architecture [30]	Proposed a multi-agent based IoT smart waste monitoring and collection architecture using Netlogo platform
IGOE IoT Framework for Waste Collection Optimization [31]	Designed an IoT framework called IGOE framework for waste collection optimization
The Big Bucket: An IoT Cloud Solution for Smart Waste Management in Smart Cities [25]	Proposed "The Big Bucket" solution, an IoT cloud solution for smart waste management in the smart cities
Smart City Service Monitoring and Waste Collection [26]	Designed a low-cost and open source technology-based for monitoring and waste collection as a smart city service
Implementation of Spatial Smart Waste Management System in Malaysia [27]	Proposed to the local authority the implementation of smart waste management in Malaysia improve the city management and to provide better services
Smart Bin: Internet-of-Things Garbage Monitoring System [32]	Introduced the design and development of the smart green environment of the garbage monitoring
	system by measuring the garbage level in real time
A Low Power IoT Sensor Node Architecture for Waste Management Within Smart Cities Context [33]	Proposed a minimal network architecture based on the LoRa LPWAN (Low Power Wide Area Network) technology to promote energy-saving.
IoT-Enabled Smart City Waste Management using Machine Learning Analytics [34]	Integrated a back-end data analytics algorithm with an off-the-shelf smart waste management system in order to increase the efficiency of waste collection.

Anagnostopoulos &Zaslavsky[23] proposed an effective shortest path selection with the shortest path semi-static and dynamic routing. The effective solid waste collection is proposed to be achieved by both routing models introduced, as they are complemented with sensing abilities through objects connected to the Internet. Semi-static routing is proposed to be implemented when there is no network segment disruption, in contrast, if the disruption of a network segment happens, the dynamic routing model is proposed. Both models are evaluated by the effective threshold, which is time spent, distance covered, fuel consumption and solid waste capacity.A smart waste management system using IoT and blockchain technology called "Thrift and Green" (TAG) is proposed by Lamichhane[28]. The blockchain technology is proposed to be used as a payment channel using custom cryptocurrency due to its nature of high-security measures and lowering massive overhead cost of traditional payment method. Author present the idea of the client paying waste collection service based on the amount of waste disposes instead of paying a fixed price assigned by the service provider. On the other hand, Mware[29] took another approach by proposing a smartbin prototype, specialized for in-house waste management. The smart-bin prototype proposed takes gas emission levels and waste current level inside the smart-bin as the parameters over a period. These data are then used to notify users the right time to attend the waste bin besides reporting the average of waste disposal of a household.Next, Catania & Ventura [24] simulated the real-time waste collection by using an open-source platform called Smart M-3. The Smart M-3 platform has the features to virtualizea real environment, therefore the authors used this platform to simulate the real-time waste collection by implementing weight and proximity sensors, Raspberry PI and Xbee module using the Python language into the platform. Alternative simulation platform, Netlogo, is used by Likotiko et al. [30] to propose a multi-agent based IoT smart waste monitoring and collection architecture. Netlogo is a multi-agent programmable modeling environment, or in other word, a platform for simulating processes that use a multi-agent model. In the authors' proposed solution, the waste current level in waste bins and waste pickup process by trucks are abstracted to a multi-agent model. The citizens are involved by paying the waste collection services, while a decision algorithm is used to determine the pickup truck optimal route for waste collection using waste data level collected. An IoT framework for waste collection optimization is introduced by Lokuliyana et al. [31]. The name given in the framework is the IGOE IoT framework, whereas IGOE stands for input, guidance, output and enables which are the outcome of the proposed framework. The framework is divided into three layers which are Data Gathering Layer (DGL), Data Processing Layer (DPL) and Optimization Layer (OL). Furthermore, this framework's scope takes into consideration solid waste disposed at authorized and unauthorized disposal areas, which, for the unauthorized disposal areas, it depends on inputs from the local community. Another proposed solution is given by Giacobbe et al.[25] that is called The Big Bucket. In the authors' proposed solution, IoT and cloud technologies

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are implemented for smart waste management in the smart cities. Authors emphasized on implementing the smartwaste bin, named as "The Big Bucket" using economical sensors and convenient, open source hardware, software, and tools. The open source IoT platform proposed is Stack4Things platform, an OpenStack extension which it features include managing sensing and actuation resources, controlling nodes remotely while virtualizing their tasks and generating network overlays among them. A similar solution is proposed by Hassan [26], by proposing a smart city service for monitoring and waste collection using low-cost and open source technologies. The proposed system is further divided into five subsystems which are Smart Waste System, Local Station, Smart Monitoring and Controlling, Smart Truck System and Smart Monitoring and Controlling Interface.

Omar et al. [27] also proposed a smart waste management system by utilizing IoT. This system brings together local citizen, waste pickup contractor and local authorities into one system. This system pilot case study has been conducted in Sepang and Kuala Langat, Malaysia in collaboration with local municipal authorities. In their proposed solution, the GSM module is used for communication between smart bins and the system.Furthermore, Mustafa and Ku Azir[32] proposed garbage monitoring system whereas each type of bins (paper, glass, plastic, and waste) are embedded with ultrasonic sensors respectively. These sensors will communicate with ThingSpeak platform in real-time for data storage and analysis.Cerchecci et al. [33] proposed an IoT-based Waste Management System architecture using low-powered sensors as its nodes. This architecture design uses LoRa LPWAN (Low Power Wide Area Network) technology in order to reduce energy consumption thus extending the nodes' battery lifespan. The low power architecture is achieved by implementing no electrical grid connection in the smart bin side, instead, the nodes are expected to be running on batteries or energy storing cells such as solar panels.The effectiveness of this proposed architecture is proven in a laboratory environment. However, it is not yet validated in the real-life scenario as the implementation will be dependent on local authorities' and local waste management companies' policies.Finally, Bakhshi and Ahmed [34] introduced a back-end data analytics algorithm to be integrated with the off-the-shelf smart waste management system. This algorithm is intended to increase the efficiency of waste collection process by identifying current best waste collection scheduling while at the same time predicting its future schedule. The effectiveness of this algorithm is proven through the validation test conducted which managed to save almost half of the fuel consumption and reduced the waste collection time by approximately one-fifth from normal time spent. Therefore, it is noted that this data analytics algorithm is more beneficial than the fixed scheduling of waste collection.

V. CONCLUSION AND FUTURE WORK

Waste management is indeed a crucial element for any city in order to practice good sustainability, enhancing urban mobility and at the same time maintaining natural resources. These goals should be targeted by any city that intended to become a smart city. Therefore, an IoT-based SSWMS is usefulin many ways such as monitoring garbage level in real-time, tracking the location of garbage bins, optimizing waste collection route using an algorithm or even as a communication medium between residents and local authorities for better waste disposal and management practice. In this paper, selected works related to thedesign of SSWMS is reported. Specifically, this paper focus on reviewing proposed/current designs of SSWMS, that can be used in designing or improving the SSWMS. These findings can be found in Section IV of this paper. For future work purposes, a better solution of SSWMS can be proposed with enhanced features by taking into consideration the gap in the current solution. Besides, this SLR can be further improved by considering including several other major indexing databases such as ProQuest and ScienceDirect to get a more through SLR that may be missed by this paper.

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REFERENCES

1. J. A. Nathanson, "Solid-waste management | Britannica.com." [Online]. Available: https://www.britannica.com/technology/solid-waste-management. [Accessed: 21-Apr-2019].
2. L. A. Manaf, M. A. A. Samah, and N. I. M. Zukki, "Municipal solid waste management in Malaysia: Practices and challenges," *Waste Manag.*, vol. 29, no. 11, pp. 2902–2906, Nov. 2009.
3. L. Mi, N. Liu, and B. Zhou, "Disposal Methods for Municipal Solid Wastes and Its Development Trend," in *2010 4th International Conference on Bioinformatics and Biomedical Engineering*, 2010, pp. 1–4.
4. K. Pardini, J. Rodrigues, S. Kozlov, N. Kumar, and V. Furtado, "IoT-Based Solid Waste Management Solutions: A Survey," *J. Sens. Actuator Networks*, vol. 8, no. 1, p. 5, 2019.
5. H. Bacot, B. McCoy, and J. Plagman-Galvin, "Municipal Commercial Recycling," *Am. Rev. Public Adm.*, vol. 32, no. 2, pp. 145–165, Jun. 2002.
6. B. R. Balakrishnan Ramesh Babu, A. K. Anand Kuber Parande, and C. A. Chiya Ahmed Basha, "Electrical and electronic waste: a global environmental problem," *Waste Manag. Res.*, vol. 25, no. 4, pp. 307–318, Aug. 2007.
7. M. Ali, W. Wang, N. Chaudhry, and Y. Geng, "Hospital waste management in developing countries: A mini review," *Waste Manag. Res.*, vol. 35, no. 6, pp. 581–592, Jun. 2017.
8. T. Zobel, "ISO 14001 adoption and industrial waste generation: The case of Swedish manufacturing firms," *Waste Manag. Res.*, vol. 33, no. 2, pp. 107–113, Feb. 2015.
9. L. Gan and S. Yang, "Legal context of high level radioactive waste disposal in China and its further improvement," *Energy Environ.*, vol. 28, no. 4, pp. 484–498, Jun. 2017.
10. K. Kawai and L. T. M. Huong, "Key parameters for behaviour related to source separation of household organic waste: A case study in Hanoi, Vietnam," *Waste Manag. Res.*, vol. 35, no. 3, pp. 246–252, Mar. 2017.
11. N. Seyring, M. Dollhofer, J. Weißenbacher, I. Bakas, and D. McKinnon, "Assessment of collection schemes for packaging and other recyclable waste in European Union-28 Member States and capital cities," *Waste Manag. Res.*, vol. 34, no. 9, pp. 947–956, Sep. 2016.
12. S. Sharmin and S. T. Al-Amin, "A Cloud-based Dynamic Waste Management System for Smart Cities," in *Proceedings of the 7th Annual Symposium on Computing for Development - ACM DEV '16*, 2016, pp. 1–4.

13. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Commun. Surv. Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.
14. J. A. SHAHABDEEN, "SMART GARBAGE BIN," 24-Jun-2016.
15. "Bigbelly - Smart Solutions for Cities // World Leader in Smart Waste." [Online]. Available: http://bigbelly.com/. [Accessed: 21-Apr-2019].
16. B. Dorsemaine, J. P. Gaulier, J. P. Wary, N. Kheir, and P. Urien, "Internet of Things: A Definition and Taxonomy," *Proc. - NGMAST 2015 9th Int. Conf. Next Gener. Mob. Appl. Serv. Technol.*, no. September, pp. 72–77, 2016.
17. F. H. Priano and C. F. Guerra, "A framework for measuring smart cities," in *Proceedings of the 15th Annual International Conference on Digital Government Research - dg.o '14*, 2014, pp. 44–54.
18. F. Purnomo, . Meyliana, and H. Prabowo, "Smart City Indicators: A Systematic Literature Review," *J. Telecommun. Electron. Comput. Eng.*, vol. 8, no. 3, pp. 161–164, 2016.
19. E. P. Trindade, M. P. F. Hinnig, E. M. da Costa, J. S. Marques, R. C. Bastos, and T. Yigitcanlar, "Sustainable development of smart cities: A systematic review of the literature," *J. Open Innov. Technol. Mark. Complex.*, vol. 3, no. 3, 2017.
20. M. Mijac, D. Androcec, and R. Picek, "Smart City Services Driven By Iot: a Systematic Review," *SMART CITY Serv. DRIVEN BY IOT A Syst. Rev. J. Econ. Soc. Dev.*, vol. 4, no. 2, 2017.
21. B. Kitchenham and S. Charters, "Guidelines for performing Systematic Literature Reviews in Software Engineering," Elsevier Inc., Durham, UK, 2007.
22. N. A. Shamat, S. Sulaiman, and J. S. Sinpang, "A Systematic Literature Review on User Interface Design for Web Applications," *J. Telecommun. Electron. Comput. Eng.*, vol. 9, no. 3–4 Special Issue, pp. 57–61, 2017.
23. [23] T. V. Anagnostopoulos and A. Zaslavsky, "Effective waste collection with shortest path semi-static and dynamic routing," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 8638 LNCS, pp. 95–105, 2014.
24. [24] V. Catania and D. Ventura, "An approch for monitoring and smart planning of urban solid waste management using smart-M3 platform," *Conf. Open Innov. Assoc. Fruct*, no. July, pp. 24–31, 2014.
25. [25] M. Giacobbe, C. Puliafito, and M. Scarpa, "The big bucket: An IoT cloud solution for smart waste management in smart cities," *Commun. Comput. Inf. Sci.*, vol. 707, pp. 43–58, 2018.
26. [26] S. A. Hassan, "SMART CITY SERVICE MONITORING AND WASTE COLLECTION," Near East University, 2016.
27. [27] 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, no. 1, 2016.
28. [28] M. Lamichhane, "A Smart Waste Management System using IOT and Blockchain Technology," pp. 1–60, 2017.
29. [29] E. M. Mware, "A Smart-bin management prototype for waste A Smart-Bin Prototype for In-House Waste Management," pp. 1–75, 2017.
30. [30] E. D. Likotiko, D. Nyambo, and J. Mwangoka, "Multi-Agent Based IoT Smart Waste Monitoring and Collection Architecture," *Int. J. Comput. Sci. Eng. Inf. Technol.*, vol. 7, no. 5, pp. 01-14, 2017.
31. [31] S. Lokuliyana, J. A. D. C. A. Jayakody, L. Rupasinghe, and S. Kandawala, "IGOE IoT framework for waste collection optimization," in *2017 6th National Conference on Technology and Management (NCTM)*, 2017, pp. 12–16.
32. [32] M. . Mustafa and K. N. . Ku Azir, "Smart Bin: Internet-of-Things Garbage Monitoring System," *MATEC Web Conf.*, vol. 140, p. 01030, 2017.
33. [33] 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.
34. [34] T. Bakhshi and M. Ahmed, "IoT-Enabled Smart City Waste Management using Machine Learning Analytics," in *2018 2nd International Conference on Energy Conservation and Efficiency (ICECE)*, 2018, pp. 66–71.

AUTHORS PROFILE

Dr. Nor Azman Ismailis an Associate Professor and Head of Virtual, Vision and Visualization (VicubeLab) research group. He received BSc (Hons) in Computer Science with Education from UniversitiTeknologi Malaysia, MIT in Information Science and Multimedia from National University of Malaysia and PhD in Human Computer Interaction from Loughborough University, United Kingdom. His current research interest includes Multimodal Interaction, Usability/UX study, Social Media Analytic, Webometric and Web Mining.

Nurul Aiman Ab Majidis currently a final year degree student of School of Computing, UniversitiTeknologi Malaysia. She is taking Bachelor of Computer Science (Software Engineering) and is a Sony EMCS Sdn. Bhd. scholar.Her current research interest includes IoT and Usability/UX study.

Dr. Shukur Abu Hassan is an Associate Professor at the School of Mechanical Engineering, UTM and also the Director for Centre of Advanced Composites Material (CACM). He received Bachelor of Mechanical Engineering from UniversitiTeknologi Malaysia (UTM), M.Sc in Manufacturing Systems Engineering from University of Warwick and PhD in Composite Structure from UTM. His research interest revolves around composites structure durability, recycling of composites, biomimetics design, composites testing, natural fibre composites, hybrid composites, composites bonding and polymer mortar composites.