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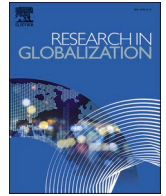
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A novel framework for waste management in smart city transformation with industry 4.0 technologies

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ABSTRACT

Most of the developed and developing nations focus on the transformation of city livelihood through the development of smart cities. Waste management in smart cities is a critical concern for policymakers and smart city administration. The fourth industrial transformation (hereafter Industry 4.0) helps to improve waste management practices in smart cities to improve the sustainability of the city. This paper tries to develop a roadmap for industry 4.0 technologies relevant to managing waste in smart cities. This paper proposes a novel framework for analyzing the deployment enablers of Industry 4.0 technologies, implementation barriers, current best practices, and opportunities for digital technologies (EBPO) for smart city transformation. The proposed EBPO conceptual framework is analyzed in the context of studies conducted in developed and developing countries. The EBPO presents the unique linkages among the technological advancements for managing waste in smart cities. The present research is an early attempt to explore the relevance of industry 4.0 technologies in the smart waste management context for improving environmental sustainability. The keyword and theme mapping analysis proposes *three* major waste management clusters in smart cities. This paper provides insight for improving EBPO elements for smart cities' waste management. The policy and theoretical implications are presented for smart city stakeholders. The paper also highlights the different dimensions of the EBPO framework.

Introduction

In the last *twenty-five* years, the smart city concept has gained recognition in global policies and academic studies because cities considerably impact global social, economic and environmental well-being (Mori & Christodoulou, 2012). According to the United Nations (UN), by 2050, two-thirds of the world's population will live in urban spaces, which necessitates the improvement of infrastructure, energy, health, and waste management services for the upcoming urban level of population (Baltac, 2019; Espinoza-Arias et al., 2018; Jagtap & Rahimifard, 2019; Marques et al., 2019). UN marked the year 2008 as crossing 50 % of the population living in cities globally; by the same year, Europe had crossed 75 % of the population (Albino et al., 2015). Cities are prime consumers of important natural resources and are pivotal in any nation's economic activity. Cities alone consume nearly 80 % of energy production globally (Albino et al., 2015), and there is a relation between urban density and electricity consumption, i.e., increased urban density decreases electricity consumption. This is because CO₂ per capita will be reduced by more density (Hammer et al., 2011). From the perspective of the metabolism of cities, input goes to

cities and consists of electricity, goods, and other resources. Outputs from cities consist of waste and many adverse environmental effects. Cities are important consumers of natural resources; cities are key areas to promote sustainability with urban metabolism through social and economic activities (Berardi, 2013a; b; Turcu, 2013). With the increasing city population, waste management is a serious concern in urban spaces and requires a sustainable ecosystem for an urban population for efficient city life (Baltac, 2019; Jagtap & Rahimifard, 2019; Jatinkumar Shah et al., 2018; Valenzuela-Levi, 2019). Waste generation in cities will double every decade, with an increasing population of 3–5 % every year. It imposes severe pressure on waste collection and waste processing activities (Chatterjee & Kar, 2018). With the increasing challenges, cities are in the surge to find solutions so that urban spaces can be enabled with quality services, shared resource capabilities, and efficient public transportation to improve connectivity, employment, transportation, and waste management practices and facilities (Baltac, 2019; Bibri, 2018; Lowe, 2021). Some of the potential solutions to improve connectivity and empower decision-making capabilities include integrating information and communication technologies (ICT) and envisaging what "smart cities" concept of an intelligent city has

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critical implications on the social, economic, and environmental performances of city and specifically not limited by the usage of digital technologies (Chatterjee & Kar, 2018; Lowe, 2021), and the word smart city has proliferated into many different sectors due to its promising benefits (Albino et al., 2015).

For developing countries, smart city development is a potential solution for problems arising from the growing urbanisation process. Future prospects of smart cities and their potential to attract investments support the city's and nation's financial requirements (Sharma et al., 2020).

Many authors from past studies have tried to define a smart city. A common thread of discussion from all these authors is that a smart city is a multifaceted concept to make cities sustainable with an increasing urban population and have the ability to attract investments and improve quality of life (Adapa, 2018; Albino et al., 2015; Zanello et al., 2014). In achieving a sustainable ecosystem, smart city actions integrate various digital technologies and ICT into different operational areas of urban space, such as health care, transportation, governance, etc. (Alavi et al., 2018; Marques et al., 2019). A smart city is the intersection area of technology, ecology, society, and economy with key actors of citizens, government, urban planners, and policymakers (Espinoza-Arias et al., 2018; Simonofski et al., 2021). Globally, among various digital technologies, the internet of Things (IoT) plays an important role in executing smart city activities. IoT-oriented ecosystem is a friendly ecosystem to transform urban space into an efficient, livable space with better waste management practices, mobility options, workplaces, and a happy environment (Patel, 2019; Paulchamy et al., 2019). IoT-enabled urban space ought to deliver advanced services, and by reorganizing current practices, IoT-enabled smart space is equipped with different aspects of internet technologies such as association with end-users, network, coverage, scalability, and heterogeneity (Hoang et al., 2019). According to the UN, from ongoing urban population, by 2050 two, two-thirds of the global population will settle in cities, and this creates serious concerns about waste management and providing basic municipal services. Many smart city researchers insisted on the need for cities to prepare for building a sustainable ecosystem for the growing urban population is an important global concern, and it can be accommodated by developing smart cities (Baltac, 2019; Jagtap & Rahimifard, 2019; Valenzuela-Levi, 2019). Developing and developed countries have chosen digital paths to achieve sustainability (Macke et al., 2019; Reyna et al., 2018). Although many paths are possible to incorporate digital technologies in city operations, smart cities emerged as a feasible approach to fulfil citizens' needs and attract economic development (Mohanty et al., 2016; Neirotti et al., 2014). Developed countries have advantages in developing smart cities over developing countries because developed countries have more funds, efficient frameworks, and cases from existing smart cities to take action and seek guidance (Gaffney & Robertson, 2018). This case for developing countries is different, and developing countries face difficulties from existing financial and technical capabilities to ramp up digital improvement programmes. In a country like India, the smart city initiative is very important to improve the living standards of people (MoUD, 2015). The implementation of IoT technology in developing countries is different in terms of following structural frameworks from developed countries; structural frameworks must be changed for work procedures to ramp into an IoT-enabled environment smoothly (Adapa, 2018). In previous studies, some authors pointed out the need to analyse the factors that affect smart cities separately in developing countries (Muvuna et al., 2019).

For the emerging complex scenario with population, IoT application became a discussion with an obligatory mandate because IoT connects with many different devices and communicates with humans more intelligently (Delgado et al., 2020; Kunst et al., 2018). Many services can be made possible with IoT applications; among all, waste management services are more relevant to smart city applications. IoT framework for waste management can facilitate innovative platforms to organise waste management activities such as waste collection, storage and processing;

this innovative environment can not be achieved by previously used technologies such as routing scheduling, geographical information system (GIS) and other (Alcayaga et al., 2019; Ghose et al., 2006; Hannan et al., 2015). Much of the research on IoT applications for smart city waste management (SCWM) does not consider an integrative perspective by including different stakeholders such as policymakers, municipality administration, and town planners, etc., and considered IoT as for single stakeholder interest (Evans et al., 2019; Kumar et al., 2009; Shekdar, 2009). Sharma et al. (2020) considered the integrative perspective by considering different stakeholders in the IoT-based SCWM process and analysed barriers for IoT applications in smart cities. IoT-enabled smart cities are a potential solution to ramping up urbanisation with its benefitting solutions to optimising management of city operations such as waste management, transportation, health care, etc., and IoT can make communities smart communities with better communication and social networks (Monostori et al., 2016). Along with a smart way of managing city operations, it has some additional benefits such as virtualisation, transparency, adaption, and flexibility (Mineraud et al., 2016). On the other side of benefits, IoT faces numerous implementation challenges, such as government regulatory issues, scalability, architecture, and heterogeneity (Atlam et al., 2018; Ben Yahia et al., 2021; Reyna et al., 2018). Research on waste management with IoT applications is minimal, and most of the available studies focus on the optimisation and design of IoT tools for waste collection methods (Keerthika et al., 2018). In addition to a collection of waste, IoT applications are required to incorporate in other stages of SCWM and also for factors that affect SCWM practices (Jim et al., 2019). Based on the previous studies, this paper will answer the following questions,

RQ1. What are the key challenges and driving forces for managing smart cities with industry 4.0 technologies?

RQ2. How are industry 4.0 technologies used to manage waste in smart cities?

RQ3. What are the linkages among the enablers, barriers, practices, and outcomes (EBPO) for improving the deployment of industry 4.0 technologies in a smart city context?

Many smart city services can be made possible with IoT applications, and all waste management services are more relevant to smart city applications. IoT framework for waste management can facilitate innovative platforms to organize waste management activities such as waste collection, storage and processing, this innovative environment can not be achieved by previously used technologies such as routing scheduling, geographical information system (GIS) and other (Alcayaga et al., 2019; Ghose et al., 2006; Hannan et al., 2015). Much of the research on IoT applications for smart city waste management (SCWM) are not consider an integrative perspective by including different stakeholders such as policy makers, municipality administration, and town planners etc., and considered IoT as for single stakeholder interest (Evans et al., 2019; Kumar et al., 2009; Shekdar, 2009). Along with a smart way of managing city operations, it has additional benefits such as virtualization, transparency, adaption, and flexibility (Mineraud et al., 2016). On the other side of benefits, IoT faces numerous implementation challenges, such as government regulatory issues, scalability, architecture, and heterogeneity (Atlam et al., 2018; Ben Yahia et al., 2021; Reyna et al., 2018). Research on waste management with IoT applications is minimal, and most available studies focus on optimising and designing IoT tools for waste collection methods (Keerthika et al., 2018).

Research gaps identification

This paper presents a unique perspective of a literature review-based framework for analyzing the application of industry 4.0 technologies in SWM in smart cities. The key literature review papers are analyzed to identify the role of industry 4.0 technologies in SWM. Table 1 highlights the presented research's concept, method, and application novelty.

The remainder of the paper is arranged in the following order: Section 2 presents the literature review protocol and research gaps. Section

Table 1
Relevance of the present study.

Author(s)	Type of literature review	proposed framework	Contribution to Smart City SWM
Sankar Cheela and Dubey (2019)	Review of methods and tools used in smart city SWM	System engineering approaches in the development of Integrated SWM in smart city	Consideration of sustainable development goals based SWM in smart city.
Zhao et al. (2019)	Bibliometric and Scientometric Analysis	Knowledge mapping of smart city research	The paper presents the concept of an intelligent smart city and its development strategy research.
Zheng et al. (2020)	Bibliometric review	From digital to sustainable: A scientometric review of smart city literature between 1990 and 2019	The paper highlights ten core sub-research topics and proposes a roadmap for smart city transformation.
Shukla and Hait (2022)	Systematic literature review	Current practices and future directions	Smart waste management framework based on integration of tools like IoT, AI, cloud computing, and intelligent transportation system
Sosunova and Porras (2022)	Systematic literature review	IoT-enabled smart waste management	Identified main approaches and services that help to improve SWM in smart city
Szpilko et al. (2023)	Systematic literature review	Current practices and future directions	Barriers to technological advancement and impact assessment
Kannan et al. (2024)	Systematic review	Introducing SWM4.0 for smart cities	Analyzing the role of Industry 4.0 technologies with 5 R strategies
Present study	Systematic and bibliometric literature review	Proposing a novel Enabler, Barrier, Practices, and Opportunities (EBPO) for analyzing SWM in smart cities	The comprehensive framework helps policymakers and smart city stakeholders to assess the maturity level of industry 4.0 technologies in SWM.

3 presents a detailed EBPO framework and a conclusion and future scope in Section 4.

Literature review

This section presents the literature about smart city development in a developing nation context and solid waste management (SWM) practices in smart cities. The paper uses the structural literature review to explore the contributions of digital technologies to improving SWM practices in smart cities (Esmailian et al., 2018). The literature review of any subject offers a way to identify issues, patterns and themes, which assists in theory conceptualization (Lahane et al., 2020). This paper uses different review questions to explore the need for literature review. The literature review is focused on smart cities' definitions, used methods, and tools for improving SWM in smart cities, industry 4.0 technologies for SWM in smart cities, and proposed solutions for improving SWM in smart cities (Gracias et al., 2023). The following literature review questions are kept in mind before framing the literature search.

- How are smart cities defined in the case of developed and developing nations?
- What is the current status of SWM in smart cities around the globe?
- What type of Industry 4.0 technologies are applicable to smart cities?

- How are Industry 4.0 technologies helping stakeholders to manage waste in cities?
- What metrics are used to prioritize and analyse industry 4.0 technologies interventions in smart cities SWM?
- What are the positive and negative impacts of Industry 4.0 technologies on smart cities SWM?
- What kind of policy and managerial frameworks are available to assess SWM in smart cities?
- What are the key management strategies and solutions that smart cities have to adopt to improve the deployment of Industry 4.0 technologies in smart city SWM initiatives?

After carefully considering the above literature review questions, the author explored the Scopus database to explore the scientific literature on industry 4.0 technologies for SWM in smart cities. The following search string is framed.

Search String: (TITLE ("Industrie 4.0") OR TITLE ("Industry 4.0") OR TITLE ("Fourth industrial revolution") OR TITLE ("Smart technologies") OR TITLE ("digital technologies") AND TITLE-ABS-KEY ("smart city") OR TITLE-ABS-KEY ("Digital cities") OR TITLE-ABS-KEY ("Intelligent city") AND TITLE-ABS-KEY ("waste management") OR TITLE-ABS-KEY ("solid waste management") OR TITLE-ABS-KEY ("garbage management")). Fig. 1 presents the flow chart of the literature review process used in this paper. This study considered 332 articles for analysis.

Concept of a smart city

The based on previous studies on smart city development and their alignment with modern technologies are discussed in this section. The California Institute for Smart Communities was one of the initial bodies that emphasised how cities can be designed to implement ICT and make communities be smart (Alawadhi et al., 2012). After a few years of this institute's propositions on smart cities, the centre of governance at the University of Ottawa criticised excessive technical orientation and strongly stated that it should be promoted with themes of network among urban communities, social capital, and a strong governance approach (Hollands, 2020). The concept of a smart city is confused by its different definitions; many definitions are proposed by replacing the word "smart" with adjectives like intelligent, digital, etc. (O'Grady & O'Hare, 2012). Nam and Pardo (2011) discussed possible meanings of the word "smart" in a marketing context, "smartness" is a user-friendly term compared to "intelligent", and "intelligent" is an elite term compared to "smartness", which only refers to the quick thought process and provide responsive feedback. According to an IBM corporate document on smart cities, a smart city is a city that has three qualities. *First* is "instrumented", with capabilities of capturing real-world data from personal devices, sensors, and appliances, *second* is "inter-connected", which means with the help of computing platforms collected data communicated to various city services, and *third* is "intelligent" which implies use of analytic tools for optimisation of operational activities (Harrison et al., 2010). According to Ballas (2013), in urban planning, a "smart city" is treated as an ideological option to make its citizens happy by embracing smartness in policies for sustainable growth by improving economic well-being and quality of life. There are multiple definitions for smart city, and there is much confusion about the different names that were given to the smart city; no general conclusion has been drawn on this term (Neirotti et al., 2014). The smart city consists of two contrasting domains. One consists of hard domains like roads, water systems, mobility, power grids, waste management, and logistic services, among others. Soft domains include culture, governance, social practices, policy, and education. Smart tools and ICT play a decisive role in hard domains, whereas they do not play a decisive role in soft domains (Neirotti et al., 2014). ICT diffusion is an important aspect in smart cities; the way technology diffusion takes place is critical; ICT diffusion has to be included in each subsystem of city operations to improve citizens' quality of life (Batty et al., 2012). Nam and

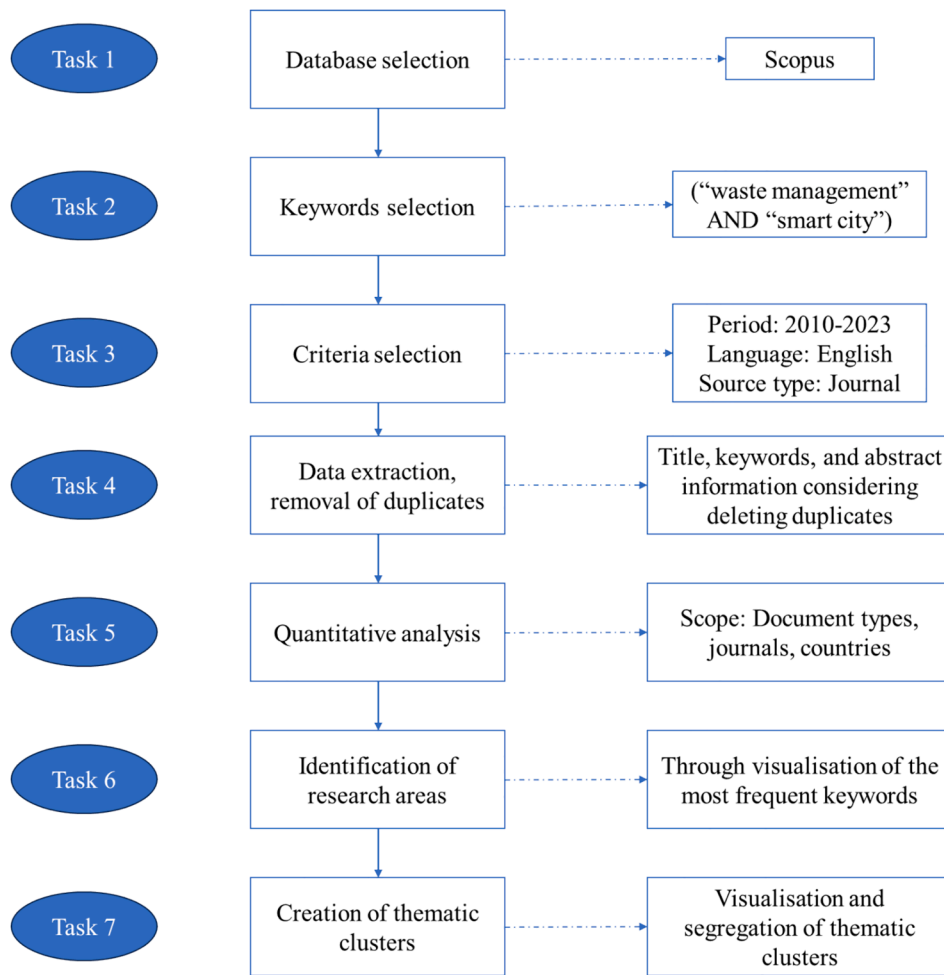


Fig. 1. Process map for the literature review.

Pardo (2011) discussed differences among different words used for smart city, such as virtual city, ubiquitous city, intelligent city, and digital city with community, people, and technological perspectives. Concerning technology, a smart city has a significant ICT presence in infrastructure and city services (Washburn, 2010). ICT enables machines with thinking capabilities and artificial intelligence (Klein & Kaefer, 2008). Globally, much of the smart city-related research focuses on the implementation of smart space-related technologies on a city scale; these include miniaturisation techniques of systems, information sharing, wireless technologies, sensor node technologies, etc. (Liu & Peng, 2014). Corporate organisations such as Siemens AG, IBM, and Cisco Systems have given high priority to sound technological features in their smart city concept for optimising operations. Many authors criticised technology usage; Greenfield (2013) opposed the emphasis on technological aspects in smart cities with his book *Against the Smart City*, which includes explanations of complexity, natural calamities, shared uses of city spaces, etc. Some authors discussed on the importance of implementing technology that prioritises citizens first and incorporates the needs of citizens with technology implementation and must not be in a surge to make human lives adapt to technical advancements (Cugurullo, 2013; Kitchin, 2014; Vanolo, 2014).

2.2. Dimensions of the smart city

Integration of different city systems in an organic manner is significantly important for a smart city. These systems include infrastructure, energy, food, safe neighbourhoods, health care, education, and water management. In complex and densely populated areas like cities, it is

impossible to work with each individual system in isolation; interconnection and interdependency between systems is an unavoidable scenario (Dirks, Gurdgiev, & Keeling, 2010). Based on the work of Komninos (2011; 2013), the dimensions of a smart city are segregated into four types from the features of a smart city. The first dimension explains how ICT and other digital technologies can make cities cyber and informational. The second dimension discusses the use of real-time data to make sustainable and happy human lives and workspaces, the third is about installing ICT technologies in urban infrastructure, and the last and most important fourth dimension emphasises the integration of humans and digital technologies to establish an ecosystem for the promoting knowledge development and innovation.

Giffinger (2007) recognised four basic components of a smart city: education, social participation, industry, and ICT infrastructure. These components were further extended by later findings in research and proposed components by the Vienna University of Technology as six components. These are smart governance, smart economy, smart people, smart environment, smart living, and smart mobility. These components are organised based on social participation, human capital, social capital, transportation facilities, economics with ICT installation, natural resources, competitiveness, and "quality of life" (Giffinger & Gudrun, 2010). Here, it specifically included "quality of life" as an aspect in analysing smart cities to insist on the definition of smart cities because a smart city is a city that enhances the quality of life of its residents (Giffinger, 2007). However, some authors argue that it is not required to discuss especially quality of life as a specific part aspect or function of a smart city because actions taken in all components of a smart city are done with the aim of improving the quality of citizens' life of a city

(Shapiro, 2006).

In regard to ICT tools in a smart city, smart is mainly about the organic integration of different systems and facilities in a city to develop an innovative environment, collaborative work spaces and multi-sectorial networks with carefully balanced ICT networks, institutions and policy-promoted innovation (Komninos, 2011). Because excessive pushing of ICT with a more corporate approach in achieving a smart city may pose a risk for government and independence from institutions, smart city execution needs a subtle understanding of differences between providing security and quality of life with safe usage of city information with data protection and government control (Paskaleva, 2011).

Smart cities are means of social development and human human-oriented rather than a pack of ICT tools and technologies (Hollands, 2008; Shapiro, 2006). Leadership and education are two important factors in a smart city, providing equal entrepreneurship opportunities to all citizens and reducing language, ethnicity, and culture barriers to maintaining equality. A smart city comprises smart people, people with cosmopolitanism, a lifetime learning attitude, diversity in social groups, and open-mindedness (Nam & Pardo, 2011). The smart city also has smart people who can find solutions to problems that arise in urban areas with their education, creativity, and social connections (Baron, 2012). Some of the other studies discussed about dimensions of a smart city include Barrionuevo et al. (2012); Kourtiti and Nijkamp (2012); Mahizhnan (1999). All these studies, which mentioned the dimensions of a smart city, pointed out four important aspects these are,

1. Smart cities should improve political ease, social stability, and culture.
2. Enhance urban growth through creative activities and business growth.
3. Social connections among city residents and maintaining social capital for sustainable urban growth.
4. Preserving the natural environment as a strategic means for future generations.

2.3. Evolution of smart city from its conception to now and future perspectives

This section discussed evolutions in the smart city ecosystem from 2000 to 2020, with four periods discussing evolutions from 2020 to now and providing important future perspectives. And continued discussions on smart city's infrastructure, data, devices and services.

The evolution of smart cities is divided into four segments with a five-year period: the first is from 2000 to 2005, the second is from 2006 to 2010, the third is from 2011 to 2015, and the *fourth* is from 2016 to 2020. In *first* segment i.e., from 2000 to 2005, discussed a smart city as a ubiquitous city or U-city, and this segment is mainly about IT; *second* segment discusses the construction of infrastructure for IT applications, the *third* segment is concerned with the application of IT for specified urban areas, and finally, *fourth* segment focuses on entire city-wide applications with a complete smart city perspective and focuses for solving problems arise in urban spaces. In the first segment, as an initial concept, a smart city started as a ubiquitous city or U-city; the word ubiquitous is derived from the Latin word ubiquitous, which means being everywhere or existing. It symbolizes solving problems anywhere, at any time in urban areas, by using IT (Katagiri et al., 2004). This means IT implies solving urban problems for a U-city concept (Galloway, 2003; Katagiri et al., 2004). In the period of 2006 to 2010, i.e., in the second segment, the U-city concept evolved into a smart city concept (Lee et al., 2008). The U-city concept uses IT to resolve problems arising from urban spaces, whereas in a smart city, IT technologies are matched to the problems of urban residents (Kim, Kim, Moon, & Bae, 2009). Many countries started providing smart city-specific solutions in this period from the second segment; for example, in this period, the government of South Korea came up with legislation to provide smart city services. Based on this legislation, U-city collects information from major

functional areas of the city, such as disaster prevention, administration, welfare, mobility and management of the natural environment (Kim, 2022). In a smart way to extract information in U-city, the information is linked to people and based on this information, city-level U-city applications can be prepared. In a U-city, IT is applied to problems that come to residents, and in a smart city, IT matches problems (Kim, Kim, Moon, & Bae, 2009; Kwon et al., 2008). Because of this, large-scale developments are taking place in IT infrastructure on a city level (Jang & Suh, 2010; Kim, 2010; Lee & Oh, 2008). In the period from 2006 to 2010, smart city research mainly focused on the development of IT infrastructure and their installation and concentrated very minimal on understanding urban problems (Kim, 2022).

In the period from 2011 to 2015, early trials of services from smart cities are operationalised, to scale up smart city services, it is required to define types of problems that arise in urban spaces and execute smart city services in a trial basis with a designated and specified area first, before going to provide smart city services on a city level. For example, South Korea initially selected cities for smart city applications, and with a trial and error method verified utility of smart technologies for providing services to citizens (Lee & Lee, 2014; Leem et al., 2019). Accordingly, research focused in this period on building smart city infrastructure for urban services, but these services are not able to run for the long term due to a lack of verification of the profitability of services provided. In the fourth segment for a period of 2016 to 2020, prevented services of smart city of which are not profitable, from being completely operational. Only promoted and operationalised services can make profits and be realistic to execute (Anthopoulos, 2017). Only in South Korea, three hundred smart city services, initiated from 2011 to 2015, are analysed and classified and reduced into fifty-six profitable and practically executable smart city services (Kim, 2022). City residents quite often use these fifty-six smart city services and are profitable to smart city authorities. Based on this type of analysis, South Korea selected Pusan and Sejong as cities to develop smart city infrastructure and provide services for a pilot project of smart cities (Kim, 2022). In the United States of America, with a smart city challenge project, the problems of residents were defined before, and based on the problems, an execution framework was suggested, and services were developed to resolve problems (Kim, 2022). From 2016 to 2020, research on smart cities implied maturity in smart city services, moving from a more administrative and authoritative approach to a human-centric and practical approach. Research during this period has done a proactive investigation to identify problems faced by urban residents and categorise these problems.

2.4. Smart (solid) waste management practices

IoT is an ecosystem in which numerous digitally enabled devices communicate with each other using the internet (Ferrari et al., 2020). The communicative devices are called smart devices, which are dispersed in buildings, vehicles, and the workplace (Bruneo et al., 2019). The current state of IoT has evolved through several stages, and the IoT concept is about the capacity to establish a connection among different objectives in an environment and not limited to computers alone (Atlam et al., 2018). The architecture of IoT consists of three layers: the first layer is the sensing layer or personal layer, the second layer is the network layer, and the third layer is the application layer, which is supported by the data processing layer (Botta et al., 2016; Khan & Salah, 2018). The first layer consists of communicative devices that can receive data, able to recognise and perceive objects and information from objects, and exchange collected information with other devices (Talari et al., 2017). Some of the most common communicative devices include GPS, RFID, and sensors. The second layer receives data from the first layer, that is, to the application layer (Kamble et al., 2019). According to IoT, the entire system is connected with many elements, and all elements are competent enough to communicate with each other. This connectivity among elements forms a digital world; in the digital world, smart

applications are utilised to build a smart community with the help of internet technologies. Currently, emerging internet technologies like mobile technologies, cloud computing, and IoT are gaining traction in developing sustainable urban places for smart cities (Atlam et al., 2018; Mehmood et al., 2017).

Attain efficient waste management practices is a key concern for India due to increasing waste generation, landfills, incinerators and other waste disposal procedures (Das et al., 2019; Marques et al., 2019). In recent times it can be seen that increasing scholarly works for the improvement of IoT-enabled waste management models with three-stage activities, i.e., waste collection-recycle-recovery (Jatinkumar Shah et al., 2018; Kang et al., 2020; Silva et al., 2018). Various types of devices are used to communicate waste management information, such as near-field communications (NFC), wireless sensor networks (WSN), sensors, actuators, and RFID tags. Sensors are specifically useful for measuring atmospheric information such as pressure, temperature, and humidity. And details of commodity such as weight and capacity, whereas NFC and WSN are utilised for data sharing (Nižetić et al., 2019). Sensors are placed in a way that can make wireless communication, and actuators are placed for bin movement (Francis & Chichebe, 2019). Different technologies are used in waste collection, such as intelligent waste collection bins, which can optimise vehicle routes and the weight of the bins. This information helps in reducing costs and resources. Information regarding the level of waste in bins transferred to the server will be helpful in optimising waste collection in broader cities (Sowndharya, Savitha, & Rani, 2019). Ghose et al. (2006) used the optimal route by GIS with information regarding waste generation, waste collection trucks, population density, road network, etc., to calculate the lowest possible transportation cost per mile for taking waste to processing units and landfills. Radio communication technique LoRa utilised to notify vehicle collection partners when the bins are full (Andrade & Yoo, 2019; Fataniya et al., 2019). Smart waste collection practices are needed and require prioritisation for installation in cities to make cities smart and improve waste collection efficiency (Delgado et al., 2020).

2.5. Smart waste management practices for a city

The literature shows that many articles concentrated on city-scale smart waste management (SWM) practices, services, technologies, systems, and approaches. Anagnostopoulos et al. (2017) analysed city-level actions and services with the required architecture for SWM systems. It includes dynamic scheduling, DSS, dynamic routing, GIS, experimental data, and social context. When discussing systems in this article, two particular characteristics are considered. These characteristics are, physical infrastructure and software analytics. In physical infrastructure, the following aspects are considered: pneumatic pipes, dumps, trucks, depots, and recycling processing plants. For software analytics, the following features are considered: social context, dynamic routing, dynamic scheduling, geographic information system (GIS), and decision support system. This article focuses on IoT applications and their benefits for energy efficiency. And aimed to provide a wide variety of useful models for waste management applications. Special mention is given to garbage collection and disposal. This article shows the requirement for defining an efficient waste collection model with IoT applications; the model will include heavy-capacity waste collection vehicles as mobile warehouses and develop a framework by incorporating locations of waste collection bins to provide maximum comfort to city residents. Sankar Cheela and Dubey (2019) conducted a review of systems engineering applications for developing waste management practices with an integrated perspective for a smart city scenario. Three systems engineering methods are reviewed: life cycle analysis (LCA), GIS, and multi-criteria decision-making for waste management applications.

Authors from Vitorino de Souza Melaré et al. (2017) systematically reviewed operations research tools and ICT technologies used in SWM. It also reviewed processes to manage solid waste for countries that were

finding waste management solutions in the period from 2010 to 2013. Adriyanti et al. (2018) provided a review of models for waste management. A total of *nine* models are reviewed for waste management practices and to select a potential model used to transition Indonesia villages to make sustainable development from an urban perspective. Based on a systematic review of processes conducted by Vitorino de Souza Melaré et al. (2017) for waste management practices in various countries. Based on the analysis, the authors conclude that China came out as a country that offers the most diverse variety of applications; Malaysia is a country that utilised more heuristics and ICT integration. Among all operational tools, GIS is the most frequent method, and this is used in combination with various other methods. In the period from 2010 to 2013, the most frequently used operations research tools are multi-criteria decision analysis (MCDA), optimisation techniques, and heuristic approaches (Vitorino de Souza Melaré et al., 2017). Vitorino de Souza Melaré et al. (2017) also concluded the significance of the social aspects in city waste management, which explains the need for research on citizens. That is awareness of the natural ecosystem and analysis of citizens' behaviours towards waste management.

Vitorino de Souza Melaré et al. (2017), usage of business intelligence applications and techniques like multivariate analysis and data mining for transforming raw data from sensors and other devices to convert useful information could be a novel approach to learning about ICT applications for waste management decision-making. Esmaeilian et al. (2018) conducted an unstructured but fairly detailed review of IoT technologies used in waste management practices in clusters of 1. Management of waste, 2. Qualification of waste, and 3. Characterisation of waste. Also, the existing shortcomings of IoT applications in waste management are highlighted, and a centralised framework for garbage collection and management systems is proposed. Some studies focused on smart garbage bins (SGB) and related technologies, services, and approaches implying different actuators, sensors, and IoT communication devices. Soni and Kandasamy (2018) analysed different types of SGBs by a categorisation of cloud technologies, web technologies, GPS, and sensors. Analysed a total of eighteen different SGB systems and proposed a novel framework based on the requirements and shortcomings of existing SGB technologies. Anagnostopoulos et al. (2017) provided a detailed discussion and structured analysis of the topics of SGB and SWM in IoT-enabled ecosystems or smart cities. They have analysed different types of sensors (for recognising temperature, capacity, humidity, weight, pressure, and chemicals) used in SWM applications, such as GPS, RFIDs, cameras, and WSNs.

Dhyani and Patel (2019) explained different available waste management stages, i.e., garbage collection, segregation, and waste collection mechanisms in a smart way. A total of twenty-eight SWM mechanisms were analysed according to the IoT technologies, sensors, and other devices they used. Topaloglu et al. (2018) made a comparison analysis among Wi-Fi, Li-Fi, drones, and cellular systems for SWM, with an aim to propose evaluation methodologies by type-2 fuzzy enabled multi-criteria approach for prioritising alternative waste collection mechanisms. According to their results, Li-Fi and drone-based approaches are appropriate choices of waste management in the conducted study field. These technologies can be used for communication in managing solid waste in a smart city context, and the prepared priority weights are robust to changes in priority order. The methodology demonstrated in this work can solve solid waste management problems facing other regions and cities. Chaudhari et al. (2019) gave an overview of IoT-enabled waste management practices for smart cities, with a description that prioritised the advantages of systems, important characteristics, and functional aspects of smart cities. The contribution of this study proposed a novel and their own framework for SWM. This review has no shortcomings; additionally, pivot tables cannot be used to compare waste management systems. An important conclusion of this work is that there is insufficient research on using genetic algorithms to optimise waste management applications.

The above-discussed studies in this section of SWM practices for

smart city context have many layers, available from top management to the bottom level of management with a clear overview of elements for implementing SWM practices. The top level usually consists of stakeholders and their waste management roles. And the lower level consists of data collection and transformation from SGBs and IoT devices to support individuals making informed decisions with real-time data (Sosunova & Porras, 2022). Table 2 shows the type of waste in cities.

2.6. Technologies used for municipal solid waste in smart city

A scenario of SWM in a developing nation demonstrates the different available techniques and methods for waste management and disposal. Modern and intelligent technology-based tools are used to manage waste in smart cities. These tools also help to maintain the quality of the raw materials for recycling. Many technological advancements exist, from conventional techniques such as composting or landfilling to advanced digital technology solutions.

Several developed countries, including Austria, Germany, New Zealand, the USA, the UK, Japan, Singapore, Switzerland, South Korea, and Canada, have already begun to adopt artificial intelligence technologies to maximize resource utilization, efficiency, and recycling opportunities throughout the solid waste management cycle (Soni et al., 2019). Therefore, artificial intelligence is critical in developing sustainable waste management models, particularly for transitioning to a “zero waste circular economy” while considering social, economic, and environmental factors. By leveraging artificial intelligence, municipalities bins reduce costs, improve safety, and reduce environmental

Table 2
Types of solid waste in cities.

S. No	Type of waste	Description	Reference
1	Green waste	The types of waste included in this category include edible waste, leaves, wood waste, and branches of a tree. Green waste can be incorporated in the preparation of compost and in the production of organic fertilizers.	(Krzywoszynska, 2012)
2	Recyclable waste	Green waste can specifically be accommodated in the manufacturing of various other raw material preparation processes, and the disposal issue of this type of waste can be managed easily due to its requirement in other processes.	(Seyring et al., 2016)
3	Industrial waste	Industrial waste comes out of industries as a form of residues used in raw materials and from the manufacturing process of different goods.	(Zobel, 2015)
4	Hospital waste	Hospital waste poses potential risks to people’s health; this waste is generated from hospitals, clinics, and medical camps. Hospital waste poses risks to civilians because of its transmission potential to spread diseases.	(Ali et al., 2017)
5	Electronic waste	Electronic waste is generated out of electronic goods, and this waste is managed in two ways. One is to recycle electronic waste and the second is to dispose of it in a scientific procedure to reduce its impact on the natural ecosystem	(Hussain and Hait, 2022)
6	Commercial waste	Commercial waste is generated from appliance stores, garment industries, clothing, and suiting and shirting shops.	(Pardini et al., 2019)
7	Organic waste	Organic waste is generated from eateries, residential complexes, restaurants, and food industries.	(Kawai and Huong, 2017)

impacts associated with waste management. Conventional garbage bins solely collect waste, and sanitation workers must carry out manual inspections to assess the trash level in the bins. This approach is not efficient for routine waste disposal inspections. Moreover, due to the frequent filling of the containers, disease-causing organisms and insects tend to breed on them. Therefore, designing intelligent garbage bin monitoring systems to manage garbage is essential in constructing smart cities.

Numerous research studies on intelligent garbage bins have focused on two key functions: automatic waste classification and monitoring. The AI can perform tasks that typically require human intelligence and visual perception, speech recognition, decision-making based on huge data, computer vision, and language translation. The other side of AI and its integration with robots would help to improve the waste collection process with limited human interventions. Robots can easily detect types of waste based on their visual characteristics. It will help in the waste sorting process at the recycling facility or conveyor belt during waste processing. Integrating AI and computer vision helps automate the waste collection process faster and more effectively. The Finnish company ZenRobotics developed a technology for automated waste sorting using AI and robotics named Heavy Picker and Fast Picker (<https://www.terex.com/zenrobotics/waste-types/municipal-solid-waste>). The Robots integrated with computers will help to sort recyclable and non-recyclable materials. AI algorithms can distinguish different types of plastic to reduce the chances of mixing. Another application of AI will help to optimize waste collection and routing.

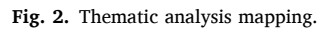
Robotics is a useful technology in materials recovery facilities (MRFs), typically processing a wide range of mixed materials. Before materials can be recycled, they need to be separated and sorted into distinct groups. Instead of relying on manual pickers to process and sort materials, robotic sorting solutions are used to automate these tasks. Using AI computer vision, Recycle Vision scans the co-mingled waste materials before Recycle Robotics picks and places materials in designated locations. Effectively replacing or supplementing the work of human pickers, robotics sorting solutions operate with high efficiency and accuracy rates, thus minimizing errors and maximizing productivity. Fig. 2 presents the thematic analysis of major smart city waste management decisions with industry 4.0 technologies. The thematic model development is presented in Fig. 3.

2.7. Performance measures of smart city

Various performance indices are developed based on the perceived meaning of smart cities in past studies. Systematic quantitative rating mechanism grasping attention from smart city management and policymakers, this type of rating mechanism is instrumental in evaluating smart city and directs city administration towards meaningful ways of utilising resources and investments, and also useful to communicate with citizens, visitors and investors with supportive information for stimulating smart city investments (Berardi, 2013a; 2013b). The critical implications of performance measures include providing comparison “metrics” and reducing the chances of self-declaration as a smart city. This section will discuss proposed rating mechanisms and indicators in previous literature.

The University of Vienna proposed a metric model to rate medium-sized 70 European cities; in this approach uses indicators in each dimension of all six dimensions (Giffinger, 2007). For example, indicators for smart mobility include local connectivity, international connectivity, implementation of ICT in transportation, and maintaining safety and sustainability aspects in mobility. Another rating mechanism proposed by the Intelligent Community Forum (ICF), this forum annually presents city awards as *Smart 21 Communities*. ICF rating is based on five factors: internet connectivity, innovation, skilled workforce, digital platforms, and ease of legal clearance and marketing opportunities for businesses.

Zygiaris (2013) developed rating metric based six layers of a smart



in sharing information, communicating content and data etc, *application layer* applicable for using real time data to mirror responsive operations, and last layer is *innovation layer* which insists on smart cities has to act as a supportive platform for innovation and entrepreneurship. [Lazaroiu and Roscia \(2012\)](#) proposed a smart city index to assess, but the indicators used in [Lazaroiu and Roscia \(2012\)](#) index are not homogenous and are not considered equal in the assessment process. Additionally, these indicators need large information. The ability to obtain large amounts of information and compute weights for indicators are typical

limitations of this index, and this index was used to distribute European funds in the 2020 strategic plan. This procedure for computing the index uses a fuzzy approach. The fuzzy approach allows for defining a set of values suitable for indicators, combining effects from all indicators through the creative importance of indicators for the smart city concept.

A more systematic and sophisticated rating mechanism was proposed by Lombardi et al. (2012) to assess the smartness of a smart city; this assessment is based on a modified form of the triple helix model. In this assessment, the triple helix model is used to evaluate knowledge-based innovations in accordance with three main knowledge-creation agencies: industry, universities, and government (Leydesdorff & Deakin, 2011). Lombardi et al. (2012) used the four helices approach, including the fourth helix as civil society. The authors of this work proposed indicators of these *four* knowledge drivers from *five* clusters. Carli et al. (2013) focused on how indicators measure smart city dimensions and revealed new indicators for assessing citizens' quality of life and well-being through real-time data sensing through communications in social networks. Different rating mechanisms assess the smartness of a smart city by comparing indicators in the dimensions of smart cities. *Japanese Institute for global strategies*, corresponding "The Global Power City Index" evaluates the smartness of a city with observed data and complemented with various stakeholders' perceptions. According to this index, rankings are given to cities based on their weaknesses and strengths, accompanied by extensive comparative analysis based on the city's socioeconomic status in attracting smart people and investments (Albino et al., 2015).

Research framework development based on literature review

Past literature on different digital technologies and their interaction for transforming smart city waste management is discussed in terms of framing enablers, barriers, practices, and opportunities (EBPO). The EBPO framework comprehensively analyses digital technology applications for smart city waste management. (Chauhan et al., 2021) proposed an integrated decision framework that links circular economy practices with industry 4.0-enabled smart city for hospital waste management. Chauhan et al. identified that GPS and GIS tracking of waste collection vehicles helps improve waste collection procedures in smart cities. The literature review by Esmaeilian et al. (2018) discussed the different practices in waste management in smart cities and their possible future development for managing smart city operations based on 220 research articles based on IoT-enabled waste management practices. One of the important findings of their study is that the use of tracking and data-sharing technologies to identify e-waste paths will help to improve the waste collection process. The EBPO is a novel framework that presents the interlinking among different contexts of technology implementation. This paper presents the different industry 4.0 technologies enablers for improving smart city operations, which are presented in Table 3.

Based on the literature survey, many of the studies explored the industry 4.0 technology challenges/barriers to implementing digital technologies in waste management in smart cities. Zhang et al. (2019) various barriers and their interaction in smart waste management in China. The lack of environmental education and a culture of environmental protection are key barriers to implementing smart solutions for waste management in cities. (Fuss et al., 2018) developed a sustainability-oriented framework for managing solid waste management in the Brazilian context. Sharma et al. (2020) discussed barriers to IoT adoption in the context of smart cities in India. Therefore, a comprehensive analysis of the barriers needs to be presented in Table 4.

The current practices of digital technologies are discussed for transforming the smart city waste management process. Fatimah et al. (2020) developed a practical framework based on IoT practices in smart waste management in Indonesian cities. They provide a practical multi-dimensional approach that determines the maturity level of waste management with a suitable smart waste management strategy.

Table 3

Industry 4.0 technologies enablers for smart cities.

S. No	Industry 4.0 technologies enablers	Technology explanation	Source (s)
1	Smart grid	A smart electric grid is a sophisticated and modern electric grid that utilizes ICT to manage consumer and utility information automatically.	Basharat et al., 2015; Ejaz and Anpalagan, 2019)
2	Public Wi-Fi	Public Wi-Fi is the foundation for a smart city environment; it enables citizens to connect any device to the network. In addition, it supports city residents in availing a wide variety of citywide services via the network	(CLOUD4WI, 2023; Ejaz and Anpalagan, 2019)
3	Smart meters	A smart meter is a communication-enabled electronic device between a consumer and a utility and can be incorporated for a broad number of applications. Some of the potential applications include real-time pricing, anti-theft, and load management.	(Ejaz et al., 2017; Ejaz and Anpalagan, 2019)
4	Supporting communication technologies for smart buildings	Efficient communication technologies are available to connect devices at home. ZigBee and Wi-Fi are two commonly used wireless networks for connecting devices in a building.	(Jia et al., 2019; Tanasiev et al., 2021)
5	Supporting communication technologies for smart grids	Different communication technologies are available for managing smart grids; some of these technologies include general packet radio service (GPRS), power line communication (PLC), and global systems for mobile communication (GSM), WiMAX, ZigBee, etc.	(Ejaz et al., 2017; Gungor et al., 2012)
6	Smart appliances	Smart appliances include computers, laptops, air conditioning, heating, and lighting.	(Ejaz and Anpalagan, 2019; Hashem et al., 2016)
7	Smart energy management of buildings	Smart energy management is a system for buildings and house energy management through an intelligent way.	Observed during the discussion with smart city officials
8	Smart people management	Smart city investments have immense potential to transform the socioeconomic status of cities and attract smart people, and smart cities have facilities to provide education and training programs on ICT tools for citizens' personal growth.	(Albino et al., 2015)
9	IoT-enabled waste management	IoT frameworks are able to manage waste in high-priority locations and reduce adverse negative effects caused by waste by considering the	Observed during the discussion with smart city officials

(continued on next page)

Table 3 (continued)

S. No	Industry 4.0 technologies enablers	Technology explanation	Source (s)
10	Wireless sensor networks	environment simultaneously Wireless sensor networks have the capability to reform daily life activities from the everyday functions of a smart city. In wireless sensor networks, numerous opportunities are available to incorporate sensors.	(Anagnostopoulos et al., 2017)
11	Shared resource capabilities	The IoT supports shared resource capabilities in an environment where challenges are increasing in accommodating urban spaces, efficient public transportation, and improved connectivity.	(Baltac, 2019; Bibri, 2018c; Lowe, 2021)
12	Scalability and heterogeneity	Urban spaces with IoT-enabled environments can facilitate end-user association, coverage, scalability, and heterogeneity, by which urban spaces can deliver advanced services by reorganising existing practices.	(Hoang et al., 2019)
13	Smart communication and social connect	IoT-enabled urban spaces are a potential solution to growing urbanization, managing communities with smart communication, improving social connections and helping in managing city operations	(Monostori et al., 2016)
14	Accountability of services	In an IoT-enabled ecosystem, it is feasible to manage the transparency and ambiguity challenges occurring in services and remove the risk of isolation from people's personal lives, ultimately helping promote accountability for services.	(Evans et al., 2019; Rana et al., 2019)
15	Data Harvesting and big data analytics	IoT-enabled smart cities are sources of the digital environment with IoT devices for harvesting urban data, and these data can be incorporated with big data analytics for the acquisition of knowledge from harvested data from the urban environment.	(Rathore et al., 2018)

Viswanathan and Telukdarie (2022) discussed the role of industry 4.0 technologies in improving city waste management practices. The bibliometric analysis shows that Industry 4.0 technologies will help to improve sustainable waste management practices and shows a close association between waste management and Industry 4.0. Szpilko et al. (2023) presented a literature review on waste management in smart cities and the linking of current practices and future directions. Based on multiple studies, this paper presents the practices of industry 4.0 technologies for improving waste management in smart cities, as presented in Table 5.

Table 4

Barriers to digital technology implementation in smart cities.

S. No	Industry 4.0 technologies barrier	Barrier explanation	Source (s)
1	High operational costs	Operate digital technologies using various devices and tools such as actuators and sensors.	(Ejaz & Anpalagan, 2019; Fataniya et al., 2019)
2	Long payback periods	The payback period is an important factor in deciding on an investment. In technology applications, the payback period is longer and more uncertain.	(Adapa, 2018; Ejaz & Anpalagan, 2019)
3	Transparency and traceability issues	Transparency is a serious concern when operationalizing smart city initiatives.	During discussions with city residents
4	Lack of skilled workforce	Based on the Labour Bureau report (2014), it is evident that India lacks a skilled workforce.	(Ani et al., 2019; Umachandran et al., 2019)
5	High energy requirements	IoT networks and smart city devices consume more energy than individuals currently spend.	(Bibri, 2018c; Ejaz & Anpalagan, 2019)
6	Lack of common network system	To obtain transparency from an end-to-end network, facing difficulty in the lack of common network systems.	Ani et al., 2019; Ismagilova et al., 2019; Kamble et al., 2019)
7	Lack of a digital infrastructure	To accompany smart city initiatives, the required information and digital technology infrastructure is available in most Indian cities.	(Barbierato et al., 2019)
8	Difficulties in standardization	Frequent changes in standardization make the instrumentation of smart city initiatives.	(Rana et al., 2019; Silva et al., 2018)
9	Lack of a smart vehicle movement of the MSW	Many times, IoT or GPS-enabled vehicles are not available for bin pickup.	During discussions with city residents
10	Nonuniform internet connectivity	Across the country, internet connectivity is not uniform, and it is difficult to incorporate IoT applications.	(Bruneo et al., 2019; Zeb et al., 2019)
11	System failures	System failure related to various devices and digital technologies must be verified.	(Ahanger and Aljumah, 2019; Zeb et al., 2019)
12	Integration issues among digital technologies enabled networks	Enabling IoT systems in cities requires the convergence of different IT networks.	(Kamble et al., 2019)
13	Difficulties from policies and regulations regarding smart bin deployment for MSW	To prepare for smart city initiatives, difficulties faced from lack of data and appropriate scalable procedures	During discussions with city residents
14	Lack of availability of data	Lack of past data on uses and impact on technology deployment for smart waste management	Observed during a discussion with smart city officials
15	Lack of smart bins-related knowledge with developers and Real estate planners	The required level of technical knowledge related to smart bins and waste management is available to town planners and developers.	Observed during discussions with smart city officials

Table 5
Digital technologies practices for smart cities.

S. No	Industry 4.0 technology practices	Digital technology practice explanation	Source (s)
1	Smart bin system	A smart bin system can recognize the fullness and emptiness of waste collection bins, and this helps to minimize the transportation required to collect waste.	(Folianto et al., 2015)
2	Smart waste management	In an IoT ecosystem, waste can be managed using real-time data, DSS, dynamic routing routing GIS, and many operations research MCDM techniques with the inclusion of the social context.	(Anagnostopoulos et al., 2017)
3	Spatial technologies for MSW	Geographic information systems (GIS) and global positioning systems (GPS) are two important spatial technologies used in IoT-enabled waste management practices.	Observed during discussions with smart city officials
4	Resource identification techniques	Among various identification technologies, radio frequency identification (RFID) tags and bar codes are the two most commonly used in smart city waste management.	(Hussain and Hait, 2022; Zhang et al., 2012)
5	Data acquisition devices	Acquire data related to atmospheric parameters and related waste information, such as temperature sensors, proximity sensors, actuators, and many imaging devices that use waste management practices.	Observed during discussions with smart city officials
6	Communication network among smart waste management	Bluetooth, Wi-Fi, Zigbee, and global system for mobile communications (GSM) are commonly used in smart city ecosystems for data communication.	Observed during discussions with smart city officials
7	Smart waste collection	Smart waste collection practices are needed and must be prioritized for installation in cities to make cities smart and improve waste collection efficiency	(Delgado et al., 2020)
8	Mobile phones and IoT devices	Different IoT devices and mobile applications used by city residents act as important sources of data. The data is also collected from various organizations through these devices. Here, the integration of stakeholders into the data is an important task. for city administration	(Esmailian et al., 2018)
9	Waste management schemes	Developing countries, particularly India, have initiated many waste management schemes, such as waste to wealth, to improve MSW practices	Observed during the discussion with smart city officials

The implementation of digital technologies in smart city waste management opens many opportunities for new businesses, individuals, and governments to improve the smartness of cities. Chatzopoulos et al. (2017) suggested that mobile augmented reality will help to improve technology understanding among city residents. The IoT and digital technologies can also open avenues for organizations and individuals to move forward with entrepreneurship opportunities (Barns, 2018; Ben Yahia et al., 2021). Digital technologies also bring more diversity in the usage of technologies not only for waste management but also for other allied disciplines (Chatterjee et al., 2018; Nam & Pardo, 2011; Sánchez-Teba and Bermúdez- González, 2019; Sankar Cheela & Dubey, 2019). Data management is one of the major opportunities for technologists to develop a solution for improving data management in the Industry 4.0 era (Raptis et al., 2019). Saad et al. (2020) discussed the opportunities of transforming autonomous vehicles for city mobility in the 6G era. They also discussed the challenges related to the deployment of 6G technologies for smart city operations. Table 6 presents the future opportunities of industry 4.0 technologies for smart city transformation.

3.1. Implications of the EBPO framework

This study proposes a novel EBPO framework that has a few key implications for policymakers and smart city stakeholders.

Policy and managerial implications

- The implementation of digital technologies in SWM in smart cities will be improved with the consideration of adequate investment incentives, development regulatory frameworks, capacity-building programs, and public-private partnerships. Many developing nations can consider the above measurement for improving SWM in smart cities.
- Policymakers also need to address concerns related to smart cities' waste management data governance, privacy, and security to build trust in city residents.
- The framework also helps policymakers consider encouraging digital technologies for SWM in other cities through knowledge-sharing platforms and best practices and supports the expansion of proven solutions.
- The proposed framework also helps to develop a roadmap for improving the current practices used in SWM in smart cities in terms of improved data-driven decision-making, real-time waste monitoring, and city residents' public engagement.
- The digital technologies used for SWM in smart cities can be improved with collaboration and partnerships with service providers, academic institutions, and community organizations.
- The opportunities exploration of the presented framework helps the smart city SWM team to optics collection routes, smart waste shorting, predictive maintenance of the technological infrastructure, data analytics, and promote circular economy practices in cities.

Theoretical implication

- The proposed research opens a scope for future researchers to consider the EBPO framework for their interdependence.
- The proposed model can be validated with developed and developing nations' smart city waste management practices and maturity levels.
- This study proposes an EBPO framework that can be validated with other industry contexts.

Conclusion, limitation, and future scope

Smart cities are transforming city life in developing and developed nations. Many developed nations use Industry 4.0 technologies for managing SWM in smart cities to improve the city environment, good health, and more systematic management of waste for improved collection, transfer, and recycling of waste. The past studies discuss the

Table 6

Opportunities for digital technology implementation in smart city waste management.

S. No	IoT opportunities	Description	Source(s)
1	Leadership and Education for Developing Smart Community	Smart cities are designed to empower citizens by equipping them with education, policy support, and efficient leadership.	(Noori et al., 2020)
2	Mobile augmented reality (MAR)	Mobile augmented reality applications are discussed in education, training, tourism, and navigation. The MAR would help to integrate the different information systems.	(Chatzopoulos et al., 2017)
3	Entrepreneurship opportunities	Through electronic democracy, people-centric decisions can be made, and equal opportunities to grow for all citizens in the city have the same approach.	(Barns, 2018; Ben Yahia et al., 2021)
4	Cosmopolitanism	A smart ecosystem and equal opportunities can reduce ethnicity, language, and culture barriers, and promote equality in urban ecosystems and cosmopolitanism in smart cities.	(Noori et al., 2020)
5	Diversity in Social Groups	Smart cities encourage entrepreneurship and equal opportunities and are able to attract diverse social groups. Additionally, the IoT-enabled ecosystem stimulates and simplifies interconnection for socialization among these diverse social groups.	(Chatterjee et al., 2018; Nam and Pardo, 2011; Sánchez-Teba and Bermúdez-González, 2019; Sankar Cheela and Dubey, 2019)
6	Smart waste mobility and traffic management	Through analysis, mobility connected with logistic services and digital technologies can gain information about busy and alternate transportation routes and reduce traffic problems.	Observed during discussions with smart city officials
7	Smart City Governance System	Smart governance is about attaining electronic democracy with the help of interactive ICT tools to convey people's opinions, make decisions, and implement solutions in a citizen-centric, transparent manner.	Observed during discussions with smart city officials
8	Data management in industry 4.0 transformation	The excellent application of industry 4.0 technologies for transforming the manufacturing and service industry provides the integration of the automation pyramid into the data management system.	(Raptis et al., 2019)
9	Smart City Waste Management Transport	With the rapid development of ICT infrastructure and other communication technologies, important vehicle–infrastructure–pedestrian communication is possible at a commonplace, i.e., vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), and pedestrian-to-Infrastructure (P2I)	Observed during discussions with smart city officials
10	Smart environment	The smart environment involves the use of ICT tools and technologies to manage the natural environment, promote sustainability and manage solid waste	(Kim, 2022; Vitorino de Souza Melaré et al., 2017)
11	Smart living	Smart living confirms security and safety measures. The utilization of ICT tools in cities ultimately improves the quality of life.	(Giffinger & Gudrun, 2010)

Table 6 (continued)

S. No	IoT opportunities	Description	Source(s)
12	Smart infrastructure	Infrastructure plays a key role in improving the “quality of life” of people. Smart infrastructure helps municipalities and cities ensure that infrastructure is in shape and usable condition using accelerometer sensors and smart meters.	(Kononov et al., 2018; Syed et al., 2021)
13	6G wireless system	The 6G wireless system can truly help to integrate various applications ranging from autonomous systems to extended reality.	(Saad et al., 2020)
14	Smart city services	Smart city services include sustaining the city's population, including water management, environmental monitoring, and waste management through a connected environment to ensure water quality, efficient waste management, and the maintenance of a sustainable natural ecosystem.	Observed during discussions with smart city officials/residents
15	Smart home	The smart home is a central component of the smart city, which is at the core of the life of city citizens. In a smart home, sensing devices are installed throughout the home environment.	(Syed et al., 2021)

positive and negative impact of industry 4.0 technologies on SWM in the smart city, but the literature is silent about a combined framework that considers industry 4.0 technologies enabling factors, barriers, current practices, and future opportunities for improving SWM in smart cities. To fill the above research and policy mechanism gap, this study explored past studies and conducted and focused on a literature review on industry 4.0 technologies' relevance for managing SWM in a smart city. The proposed study developed a novel EBPO framework based on the literature review. The paper considered a thematic review of 332 articles that were published between 1990 and 2020. The further analysis of each element of the framework is again explored and discussed with select stakeholders for validation and inclusion of any new dimension in the EBPO element. The thematic analysis of the reviewed literature highlighted the lack of linkages between industry 4.0 technologies and smart city waste management practices. The thematic analysis presents three main clusters for further analysis: sustainable solid waste management, smart waste management, and transportation planning and decision-making. The degree of linkage among these themes clearly shows that industry 4.0 technologies are helping to manage smart city waste management. The proposed EBPO is an early attempt to comprehensively analyse the intervention of industry 4.0 technologies for smart city management. The study also presents multiple new dimensions for industry 4.0 technology barriers, such as transparency and traceability issues, lack of smart vehicles, and lack of smart bins-related knowledge. The study also included waste management schemes for improving technological maturity.

Like all studies, this study also has limitations, such as the validation of the proposed EBPO framework and its maturity stage in any country's context. Another limitation is that the proposed framework only considered the technological interventions for SWM; in the future, behavioural and stakeholder perspectives can be explored. Also, future researchers can model the interlinkages among the EBPO elements and their causal degree. The EBPO is also validated with the other socio-technical perspectives and relevance with management theories.

CRedit authorship contribution statement

Aalok Kumar: Visualization, Supervision, Methodology,

Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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