Service Design of Garbage Classification Driven by AI

Subjects: Environmental Sciences
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Keywords: AI ; municipal solid waste classification ; garbage classification ; service design

1. Introduction

Since 2019, Chinese provinces and prefecture-level cities have advocated solving problems of “garbage siege” and carrying out the environmental protection policies like the “Ban on Free Plastic bags”, both of which have put forward the overall requirements of “reduce, reuse, and recycle” for municipal waste classification [1][2]. Compared with other countries, there are big differences in the treatment modes and actual results of garbage classification due to different economic strengths, resource demands, technical levels, and legal policies. With the reuse, superimposition, and crossover collaboration of “Internet plus”, “AI plus”, big data, Internet of Things, and other technologies in recent years, the exploration of the technology and service changes in garbage classification, a systematic project, is particularly prominent and important in the round of the comprehensive management of garbage classification in major cities of China [3]. At the same time, it introduces the case of the ZRR2 waste classification robot used in the waste classification processing plant in Barcelona [4]. By comparing the two cases, it more prominently highlights the huge potential of AI in waste management strategies.

2. Research on Service Design of Garbage Classification Driven by Artificial Intelligence

Municipal solid waste (MSW) classification management comprises the activities associated with the collection, transfer, treatment, recycling, resource recovery, and disposal of solid waste generated within urban locales [5]. The process extends from the point of waste generation to its ultimate disposal, with efficiency and productivity being critical considerations. Artificial intelligence (AI) technology has emerged as a promising tool in bolstering the efficiency and precision of MSW classification. Artificial intelligence-based technologies like smart garbage bins, garbage sorting robots, predictive models for waste production, and optimizing the performance of waste processing facilities. The details are shown in (**Table 1**). Notably, Finland, Japan, and the United States have pioneered the R&D of automatic garbage-sorting robots. ZenRobotics Recycle system (ZRR) from Finland, the first garbage classification robot globally, can efficiently differentiate mixed waste, useful, and non-useful waste within MSW. Japan’s FANUC garbage sorting robots utilize the AI vision analysis system to analyze wood quality and discriminate polymer from plastic. The Computer Science and AI Laboratory at the Massachusetts Institute of Technology has developed ‘Rocycle’, a garbage recycling and sorting robot that can distinguish paper, metal, and plastic by touch [4].

The application of AI in waste management transcends waste classification. AI modeling methods can accurately predict waste generation quantities, facilitating the design and operation of effective waste management systems [6]. AI has also been instrumental in forecasting waste generation, managing construction waste, and optimizing landfill site selection [7]. Other studies have employed non-parametric models to track the temporal productivity changes in waste management services, considering both economic and environmental aspects [8].

In essence, AI technology, in conjunction with the Internet of Things (IoT), plays a vital role in the classification and management of MSW. These technologies enable precise waste classification, waste collection and transportation optimization, and the establishment of efficient waste management systems. AI modeling and DEA-based models are employed to measure productivity from various perspectives, thus providing comprehensive insights into the performance of waste management services in terms of productivity and eco-productivity [8].

In China, the government initiated a new MSW classification strategy in 2017, with Hangzhou being one of the first pilot cities. The policy aims to ensure effective MSW classification implementation via measures like AI- and computer vision (CV)-based approaches [9]. The implementation of IoT technology in MSW classification and management can enhance the classification level and optimize waste collection and transportation, thereby reducing costs and environmental pollution. The COVID-19 pandemic has amplified the challenges of MSW management due to the surge in medical and household waste [10]. This scenario has highlighted the criticality of waste collection, recycling, treatment, and disposal services. Concurrently, the pandemic has exposed the complexities of waste management, emphasizing the importance of efficiency, health considerations, and customer satisfaction. In this context, factors such as waste collection frequency, age, educational status, and family size play a crucial role in customer satisfaction [11].

Table 1. The main application of artificial intelligence to waste management [12].

Type of AI Technology	Types of Waste	Measures of AI	Key Information	Results/Benefits	References
Smart garbage bin	Solid waste	Sensor network	1. Garbage bin monitoring 2. Collect data 3. Analyze information	Used to collect municipal waste	Khan et al. (2021) [13]; Ghahramani et al. (2022) [14]
	Solid waste	Ultrasonic sensors	1. Garbage will not overflow 2. The lid will open automatically 3. Automatic detection of garbage	Digital garbage bin	Wijaya et al. (2017) [15]; Praveen et al. (2020a) [16]
	Solid waste	Ultrasonic sensors Red external sensor	1. Identify garbage 2. tracking the vehicle and IR sensors 3. Garbage level monitoring	Instantly detection of the status of Bins: Filled or Empty	Pawar et al. (2018); [17]
Garbage-sorting robot	Reusable garbage	Computer vision Robotic framework	1. Gripping 2. Motion control 3. Material categorization	Success rates: glass: 79% plastic: 91%	Wilts et al. (2021) [6]; Kshirsagar et al. (2022) [18]
	Solid waste	Computer vision simultaneous localization and mapping	1. Automatic navigation 2. Garbage recognition 3. Pick up automatically	Recognition accuracy is 94%, even without path planning	Bai et al. (2018) [19]; Lee, K.-F. (2023) [4]
	Seven types of garbage	Skin-Inspired Tactile Sensor	1. Quadruple tactile sensing 2. Object recognition 3. Garbage classification	Recognizing 7 types of garbage, accuracy of 94%	Li et al. (2020) [20]; Lee, K.-F. (2023) [4]
Predictive model for waste production	Hazardous waste, construction site waste	Genetic algorithm-adaptive neuro-fuzzy inference system	1. Defining targets for waste production 2. Optimizing resources 3. Reporting and conducting inspections 4. Compared with different AI prediction models	Raised proposed measures for waste reduction prediction	Haque, M.S. et al. (2021) [10]; Bang et al. (2022) [8]
	Solid waste	Proximate analysis	1. Generation rate and waste composition 2. Quantified, characterized, and evaluated energy potential and nutrient value of solid waste	Reduce tons of carbon dioxide equivalent greenhouse gas emissions.	Fetene et al. (2018) [11]
	Solid waste	Eco-Productivity Analysis	1. DEA-based models 2. Sampling and characterization 3. Carbon emissions evaluation of MSW disposal system	Decline of daily carbon emission in MSW disposal system after waste sorting.	Lo Storto, C. (2017) [7] Wang, Y. et al. (2021) [9]

Therefore, it is imperative to conduct further research to unravel the multiple roles of AI technology or AI agents in waste classification management systems. These technologies function not only as technical components of the service system but also as collaborative agents alongside human operators [21]. The aim is to explore how AI influences service design and management practices for MSW from different perspectives. This investigation would provide constructive insights for future service ecosystem innovation, preparing us to better handle unforeseen events and navigate the multifaceted challenges of our evolving social environment.

Service design models the social, material, and relational elements that support the customer experience [22][23], integrating the various silos of the organization into a coordinated service offering [24]. It applies human-centered and collaborative methods to explore the experiences of different stakeholders. This ability to integrate stakeholders enables service design to develop solutions that are relevant to customers while considering the structural context of the organization [25][26]. However, the relationship between artificial intelligence and service systems is a complex and evolving new one [27]. Some believe a key aspect of the relationship between AI and service systems is that AI has the potential to complement rather than completely replace human labor [28]. While AI can automate certain tasks, it also amplifies the comparative advantages of human workers in areas such as problem solving, adaptability, and creativity. To fully leverage the potential of AI in service systems, it is crucial to study and implement strategic frameworks [29]. This framework should consider the nature of service activities, service processes, and other specifics [30].

Consistent with all service-dominant logic premises, the AI-driven service system guides the description of the situation at three levels: Value constellation, whole picture view of the system, service activities, and other specifics. According to Alter [30], there are three frameworks for service systems, namely the Work System Framework, the Service Value Chain Framework, and the Service Lifecycle Framework. The Work System Framework provides a systematic perspective for understanding and analyzing any system that performs work within or between organizations. The Service Value Chain Framework extends the Work System Framework by introducing functions that are particularly relevant to services. The Service Lifecycle Framework emphasizes the evolution of service systems, including the creation, operation, and planned and unplanned changes to services. Therefore, AI technologies or AI agents are set to become vital focal points in the construction of new service systems, interactive experiences, and value co-creation [30][31].

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