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Review on techniques of automatic solid waste separation in domestic applications

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ABSTRACT

The accelerated modern day urban development is accompanied by an increasing production of solid waste. While managing solid waste on an industrial scale presents different technological challenges, managing household waste requires decentralized solutions dealing with the associated logistic and technical difficulties. In this review, we identify the research trends on household waste recycling by providing a brief description of the main technologies, and the traditional formats commonly used for solid waste (SW) separation. We identify two main threads: the SW management systems within a smart city framework and the design of domestic waste classification systems based on intelligent mechanisms tailored to user psychology. Among the main conclusions, we verify a growing interest in the subject of SW separation in domestic applications, mainly through solutions based on automation and internet of things (IoT). Also, we detected a increasing interest in the analysis of psychological aspects and in citizen education in relation to the importance of recycling, since without this notion the success of proposed solutions might be limited.

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1. INTRODUCTION

Due to economic growth and urbanization, more polymer waste is generated in industry and households nowadays [1]. In literature, there is a noticeable spike in scientific works aiming at introducing new solutions for recycling processes since 2003 [2]. Recycling of household wastes has been widely considered as a key factor for reducing the pollution caused by municipal solid waste and promoting sustainable development [3]. Solid waste (SW) separation techniques refer to modifying a body, suppressing local consistency, and allowing the selection of its unique components [4]. Such processes play an important role in various fields, especially in industry and in the reuse of SW.

The selection and classification of waste are some of the main challenges [5]. Manual sorting is considered expensive and inefficient when large amounts of SW are involved. Literature reports automatic SW separation approaches based on techniques such as dense separation [1], column flotation [6], image recognition [7], magnetic separation [8], Foucault streams [9], sensors [10], robotics, and artificial intelligence [11], [12]. Automatic separation techniques are also applied in different industries for recycling processes in solid waste deposits [13]. However, the implementation of this type of separation in the domestic context is not recurrent. If implemented, it would represent a great advance in terms of waste use by decentralizing the whole recycling process [14]. To the best of our knowledge, an up-to-date systematic

review of the domestic SW management techniques has yet to be done. This work identifies, reviews, and compares recent SW separation techniques currently implemented for domestic applications.

The remaining of this paper is organized as: section 2 describes the methodology used to perform the review. This includes the search strategy used, the searched databases, and the inclusion and exclusion criteria. Results are presented afterwards in section 3, revealing the main study trends, the institutions with the highest number of publications, and the countries with the largest participation in the generation of literature in this field. Finally, in section 4 we present the conclusions, highlighting elements of the current state-of-the-art research in this topic.

2. RESEARCH METHOD

2.1. Review structure

In this section we describe the basic elements of our review process, whose goal is identifying trends and fields of research related to SW separation techniques and their application at the domestic level. We used the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines to structure this review [15]. We selected several specialized databases on engineering and electronic applications. Articles published between 1968 and July 30th, 2021, were included from the Elsevier (SCOPUS), and IEEE databases. Our seach strategy consisted in querying the respective databases by creating a search equation through the following search strings applied to the title, abstract and keywords fields: "SW separation", "automatic SW techniques", "domestic SW", "separation and waste domestic".

2.1. Data collection

The following inclusion criteria were defined: i) papers published in peer-reviewed journals and ii) written in English, as shown in Figure 1.

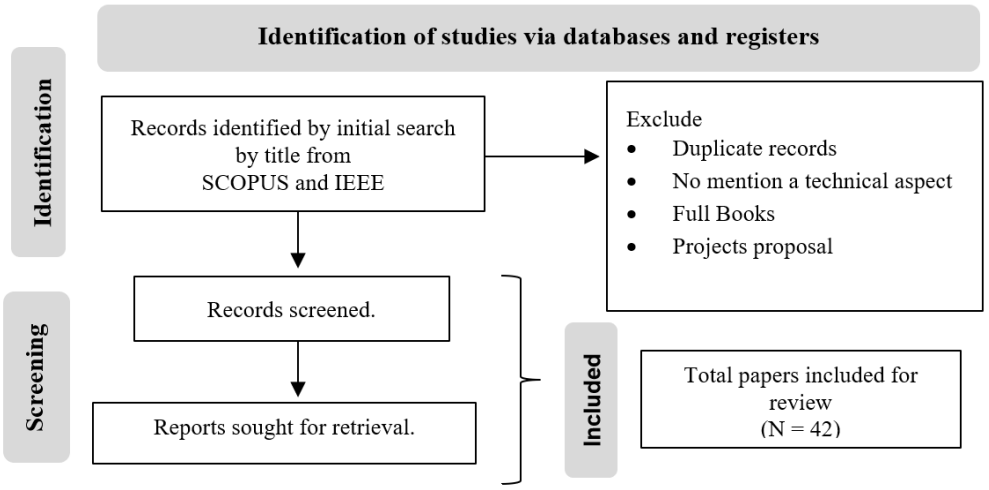

Figure 1. PRISMA diagram for paper screening [15]

3. RESULTS AND DISCUSSION

3.1. Current state of scientific production in the area

In 1968, scientific production on the subject of waste separation began. Figures 2 and 3 show the number of publications by country, which has increased significantly since 2003. Table 1 lists papers that have either developed theoretical models or have provided research examples for the later studies on SW domestic applications. Solutions reported in the literature are mainly focused on automatic SW models and applications seeking to optimize the classification processes, and the development at the level of transport and monitoring of collection processes.

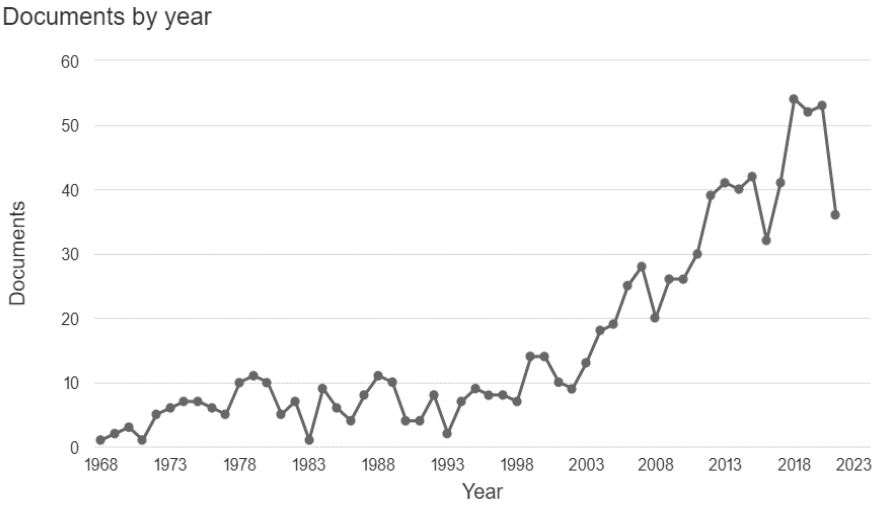

Figure 2. Scientific production on SCOPUS for waste separation

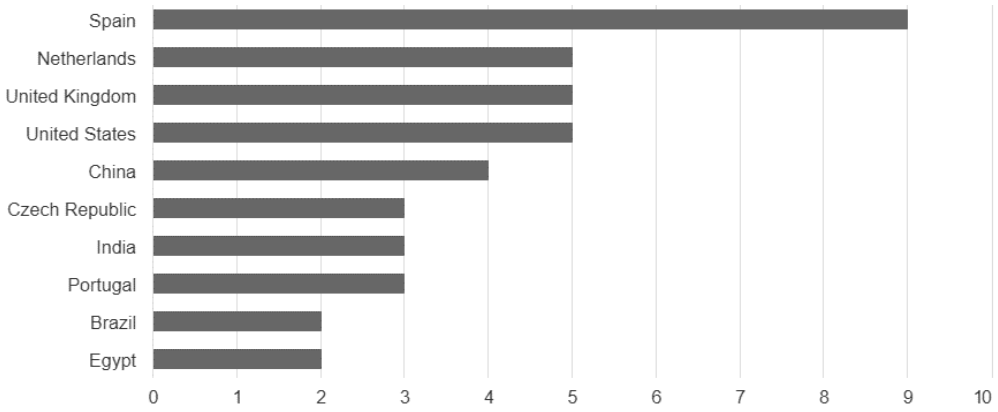

Figure 3. Scientific production by country

Table 1. Included studies: SW domestic applications by category

Authors	Category	Description
Zhang *et al.*, (2021) [3] Wichniarek *et al.*, (2018) [16] Zeng *et al.*, (2020) [17] Li *et al.*, (2021) [18]	Optimization and automatic separation	The category explores automatic separation models and applications. There are numerous works aimed at optimizing the processes.
Cruz *et al.*, (2015) [19] Siddappaji *et al.*, (2016) [20] Chun-lin *et al.*, (2019) [21] Das *et al.*, (2021) [22]	- Waste collection and monitoring - Transportation applications	Solutions are proposed based on IoT, automation and adaptation of containers for use at the domestic level. These are oriented to waste collection, monitoring, and transport systems.
Sivakumar *et al.*, (2016) [23]	- System based on mobile devices	Explores the implementation of supported systems on mobile devices highlighting the possibility of grouping, classifying, and monitoring waste in real time.
Liu *et al.*, (2020) [24] Hassan *et al.*, (2018) [25] Rajkamal *et al.*, (2014) [26]	Domestic waste classification	Improves the initial conditions of SW domestically, and consequently optimizes the successive processes: collection, transport, classification, and use.

3.2. Main studies

Literature reported that the main problem faced by waste sorting is the lack of a suitable garbage collection device that can reasonably classify and recycle waste [24]. Some authors have suggested the solutions; i) multi-stage separation processes based on cyclones for waste plastic films using downward spiral motion, also known as external swirling airflow. Particulate impurities are propelled to the outer wall by the centrifugal force generated by the airflow, and then lose inertia due to gravity [27]; ii) automatic methods

based on systems with eco-design applications. These approaches to product quality assessment integrate environmental aspects as they focus on complying with ecological standards at an early stage of design, enabling recycling of items after their useful life [16]; iii) multi classification categorial algorithms. The proposed algorithms identify four major categories and 10 subclasses of domestic garbage. These two classification tasks are related to each other; implemented joint loss function is helpful to improve the accuracy of garbage recognition [17].

Other solutions explore problems from collection to classification through mixed integer optimization models to collect recyclable waste [19]. Techniques employed include RFID and smart systems (GSM and GIS) [20], garbage collection and transportation network systems based on Voronoi graph theory [21], grouped and classified garbage maintenance systems for mobile devices [23], automatic detection and classification systems based on multi-model cascaded convolutional neural networks [25], monitoring system driven by internet of things (IoT) [25], [28], and IoT-based SW segregation based on relative humidity values [22].

3.3. Trends

SW management systems within a smart city framework. In literature, automation models are proposed for the classification of SW, finding an element in common corresponding to the intention of developing integral management systems [22], [29], [30]. Application design tailored to user psychology. This trend relates to the behavior and psychology of users. Several authors stressed the need to adopt good environmental practices by raising scientific awareness and normalizing habits of waste classification [31]. In Figure 4, the authors' keywords are grouped into one major cluster (185 items) and two relatively minor clusters (181 and 180 items) representing household waste research, wastewater treatment, and the separation phase respectively.

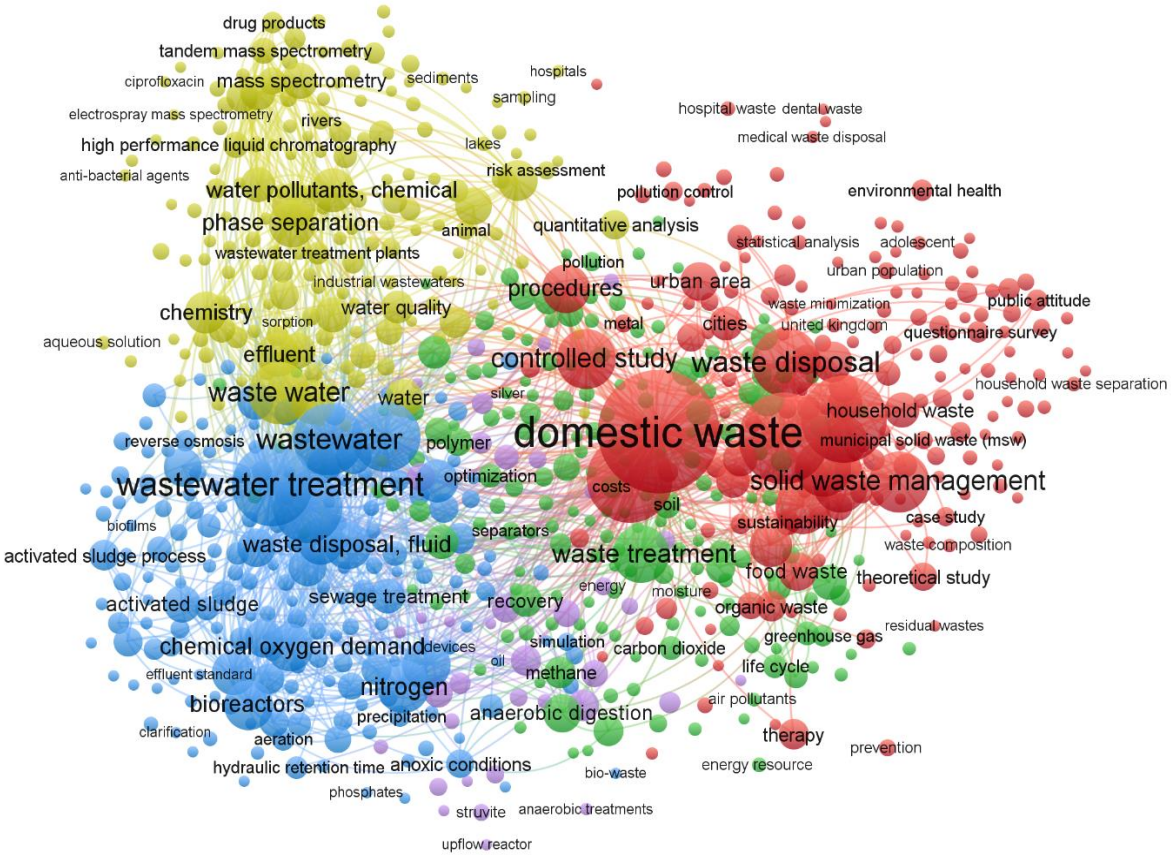

Figure 4. Cluster analysis of the authors' keywords

4. CONCLUSION

This work aimed at providing a review of the techniques of automatic separation of solid waste in domestic applications. The analysis of scientific productivity shows the research field of automatic solid waste separation techniques in domestic applications is still growing as the annual production from 2014 to 2020 has

yet to slow down. We could see a growing interest in the topic of SW separation in domestic applications, mainly through solutions based on automation and IoT. This was mentioned by Garcés-Gómez and colleagues back in 2013, as they highlighted the use of IoT in environmental applications. Research guided by user psychology has been gaining prominence. As the mental processes of an individual are related to their social and behavioral aspects, this could have a great impact to encourage recycling on the domestic level.

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