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Robotics in solid waste handling: From science fiction to reality

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It is currently estimated that approximately 55% of the world population lives in urban centers (World Bank, 2020). This is partly caused by phenomena such as the migration of people from rural areas toward cities. A direct consequence of this situation is the increase in solid waste (SW) generation.

In 2018, the World Bank stated the amount of waste generated annually is approximately 2 trillion tons (World Bank, 2018). Particularly, in low-income countries, 90% of waste is not appropriately handled. Without proper SW handling, the environment becomes polluted, causing a global problem. In support of these arguments, we can assert that adequately recovering SW has become a serious and widespread problem in urban areas. Therefore, an appropriate treatment of SW is necessary to reduce the environmental impact generated by this kind of residual.

There are different processes associated with the task of SW handling, as shown in Fig. 1. As evidenced in the scientific literature, authors have approached SW handling from different perspectives, especially to improve the processes associated with the recycling chain. These approaches have included the use of techniques

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from different areas, such as robotic methods [mechanical arms for waste handling in recycling plants (Chen et al., 2019)], machine learning [for the separation and categorization of materials located on the ground (Liao et al., 2019)], deep learning [for the recognition of construction waste located in work areas (Ku et al., 2021)], and neural networks [for the separation of recyclable items from landfill trash objects (Sultana et al., 2020)], among others. This article examines how diverse techniques provided through science fiction (sci-fi) some decades ago have inspired the development of

solutions applied to procedures for SW handling in the real world, notably, for recovery; separation; and classification, transit, and storage operations.

Robotics in sci-fi

The most ancient references to artificial entities capable of performing tasks are most likely found in Greek mythology, in works such as Homer's *Iliad*, where automata of pure gold appear. These automata are equipped with intelligence and verbal abilities. In the 16th century, the philosopher and rabbi Judah Loew created Golem, a giant creature of clay, which, through combinations of letters, gained life and movement; it could perform all kinds of jobs entrusted to it.

Sci-fi literature has grown in popularity, particularly during the last century. The term *robot* is attributed to the writer Karel Capek in his work *Rossum's Universal Robots*, which was published in the 20th century. In his work, robots are humanoid creatures that perform forced labor so that humans do not have to. The robots rebel and destroy humanity at the end of the story.

Frankenstein by Mary Shelley, one of the most popular literary works mentioning artificial robot-like creatures, appeared in the middle of the

FIG1 The processes associated with SW handling.

19th century. In this story, a creature is built from human corpses and configured as a machine. Due to its attributes, the main character of Shelley's work is regarded as one of the first robots described in literature.

Later in the 20th century, Isaac Asimov began publishing works of sci-fi. In them are the Three Laws of Robotics, which are thought to have influenced the establishment of the first conceptual principles of robotics, eventually evolving into the primary referential framework for defining the behavior of autonomous robots. Asimov's masterpiece corresponds to the *Foundation* collection, a set of books presenting a future history— that is, a technosociological fantasy in which technological artifacts, primarily robots, shape contemporary social organization.

SW management fictional processes

As mentioned, sci-fi has contributed significantly to the conceptualization of robots. In the case of SW handling, real developments in the field of robotics have been performed to simplify the daily life of society while accomplishing works or activities considered dangerous for human beings. Additionally, these developments have driven improvements in the traditional methods of SW handling processes, which are currently performed manually.

Focusing on the first robots oriented to the development of cleaning or waste recovery jobs, the writer and scientist Arthur C. Clarke published, in 1973, *Rendezvous With Rama*, in which he introduces robots in charge of cleaning activities (Clarke, 1973). These robots are called *crabs* and are arthropod bio robots that instinctively carry inanimate objects to the garbage pits on Rama (an artificial asteroid created by an alien race). The novel tells the story of the crab robot first encountered by humans when cosmonaut Jimmy Pak lands in a personal glider vehicle. The vehicle is recognized as foreign debris to be recycled. This novel by Clarke can be considered as a futuristic reference and one that

has influenced the development of robotics and artificial technology in modernity.

In cinematography, robotics is a recurring topic within the genre of sci-fi. For example, the movie *Space Sweepers*, released in 2021, describes a scenario in which Earth has become inhospitable, and only a small percentage of the population can live in its orbit. The story is set in 2092 and follows the adventures of the crew of the ship *Victory*, which cleans up space debris, such as obsolete satellites, abandoned ships, and other materials floating through space. The collected materials are transported by means of the hooks and clamps equipped on the space vehicle. Inside the crew, there is a humanoid robot helping to secure the material on the spacecraft.

Another example of a film describing the incorporation of robots performing SW storage activity is *Wall-E*. The story of this movie occurs in the 29th century, when humans have been evacuated from Earth due to large amounts of SW, which severely contaminate the planet. The story follows a small robot tasked with compacting garbage to clean up the environment.

In sci-fi literature, robots appear as entities that work autonomously without the need of human interaction to address SW handling tasks, either due to their repetitive nature or the potentially dangerous implications of dealing with toxic wastes. However, one unfavorable message that can be derived from these references is the treatment of SW handling as a task unrelated to humans. That is, sci-fi approaches designate SW handling as a task that could be considered an external responsibility to humans.

Developments in the recycling chain

Figure 2 shows approximations of robotics applied to the recycling chain. Most of them resemble human beings or some part of their bodies. These robots use some of th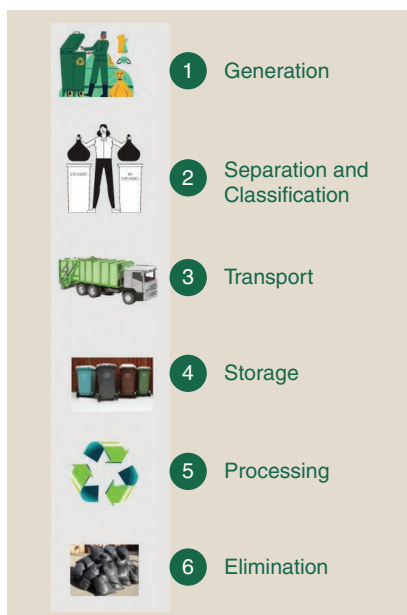e techniques mentioned at the beginning of the article.