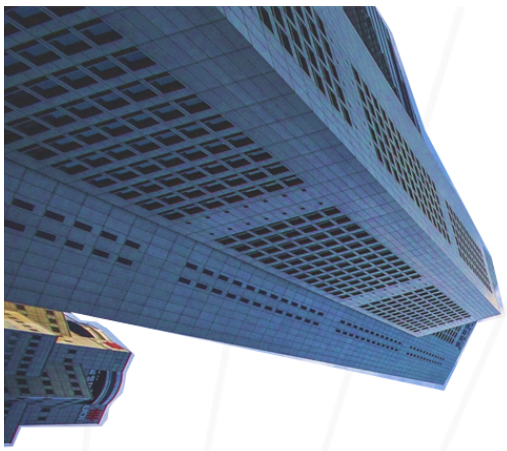

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Pedro Moreno-Bernal
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Municipal Solid waste management systems: application of SWOT methodology to analyze an Argentinean case study

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Abstract. Historically, Municipal Solid Waste (MSW) systems emerged in response to society's needs for managing manufacturing and consumption waste. However, the waste generation in modern cities present several new features that affect the MSW system. These new features include both positive aspects, such as innovative recycling techniques and increased public environmental awareness, as well as challenging aspects, including a rise in the amount of waste generated and in the complexity of waste composition. As a result, MSW systems have to adapt to new opportunities and threats offer by the context by exploiting their strong and weak points. In this line, this article conducts a comprehensive review of contemporary material and waste flows, followed by a revision of the current state of the MSW systems in Argentina and a particular analysis of an Argentinean case study using SWOT (Strengths-Weaknesses-Opportunities-Threats) methodology. The findings of this analysis highlighted the competitiveness of SWOT methodology to formulate strategies to develop more efficient MSW systems.

Keywords: Sustainable cities · Waste management systems · SWOT methodology · Argentinean case study.

1 Introduction

Natural systems are widely recognized for adhering to a self-contained cycle of matter, characterized by the absence of residual product accumulation. Within this inherent framework, structures emerge and dissolve seamlessly, leaving no remnants of accumulable waste. However, human intervention disrupts this innate matter cycle, leading to waste accumulation as a consequence of the pursuit of greater material wealth and ostensibly improved quality of life [4]. Waste is defined as any substance discarded by its creator or possessor, resulting from processes such as production, consumption, or cleansing. The rise in waste accumulation has also spurred the development of waste management policies to address and mitigate the adverse environmental impacts of such refuse.

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Waste management entails a systematic and organized approach to handling, treating, and disposing of various waste materials stemming from human activities [23]. Waste management encompasses a diverse array of practices and strategies aimed at minimizing the negative impact of waste on the environment, public health, and overall well-being while optimizing the potential reuse and recovery of materials. Waste management includes waste collection, transportation, recycling, treatment, and safe disposal. Waste management policies have evolved over time from careless disposal practices to intricate and advanced systems throughout history, following the escalating rate of byproducts generated due to rising consumption rates and population growth.

This article focuses on Municipal Solid Waste (MSW), which includes elements, objects, or substances originating from domestic, commercial, institutional, non-special care activities in urban areas [7]. Among the main contributions of this article there are: a new waste and material flow model within modern cities, an up-to-date overview of the state of MSW systems in Argentina, and a systematic analysis of a specific Argentine case study using SWOT analysis.

This article is organized as follows. Section 2 presents a description of waste and material flow in modern cities and about the waste management systems in Argentina. Section 3 presents the SWOT analysis of the case study. Finally, Section 4 discuss the main outcomes of this work and presents the future lines.

2 Waste management

This section describes the main aspects of waste management, including contemporary dynamics of waste and material flow within modern cities and the specific characteristics of waste management in Argentina, the country of the case study.

2.1 Evolution of waste and material flow: from early cities to current societies

Throughout history, humanity has relied on natural resources to ensure survival and create tools that promote prosperity in challenging environments. In the first sedentary communities, after utilizing these resources, the remnants -primarily originating from food and wood- could be effortlessly integrated into the environment without adverse effects or degradation. As human settlements expanded, they demanded increased extraction and transformation of natural resources, resulting in the accumulation of waste. The disposal of this waste often involved land or water deposition, which contaminated the environment but had limited impact due to the relatively small population and land's absorptive capacity [27].

As population grew and industrial techniques developed, societies faced challenges in managing the waste they produced, leading to the emergence of early landfills. During the Middle Ages, waste disposal within urban areas created issues with rodents and fleas, vectors for disease [29]. However, it was not until the 18th century that state measures were introduced to regulate waste disposal due

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to hygiene concerns, including the development rudimentary sewage networks. The state regulations marked a shift of waste management from individual private initiatives to a public regulated system.

As the urban growth continue to rise, societies organized around cities catering to production and consumption demands. Objects of utility were considered commodities with little thought to their environmental impact. Initial waste management policies involved haphazard accumulation in makeshift containers and basic household collection, followed by transportation to landfills or uncontrolled incineration [13]. By then, the composition of MSW had changed, with reduced organic waste and increased glass, cardboard, and plastic reflecting contemporary consumerism [29].

Notably, it wasn't until the 1960s that a significant portion of society recognized the discord between industrial practices and environmental preservation. The rise in social awareness led to demands for accountability from industrial activities that had a significant impact on the environment [1]. The last decades have seen the proliferation of numerous sustainability-driven initiatives within modern societies. Consequently, the flow of materials in cities and the subsequent waste generation have evolved since the model initially proposed by [27]. In this work, we propose the incorporation of several new features to the flow of materials and waste in modern cities, as it is illustrated in Fig. 1. The key changes include:

- *Raw materials used directly by to consumers.* A growing number of consumers have started to design and even produce their own products. This trend extended beyond cultivating agricultural produce to include more intricate items like clothing, cleaning products, and personal hygiene items. This trend fosters a sense of self-sufficiency among consumers and is expected to continue expanding [2].
- *Reutilization of products by consumers.* Consumers have also ushered in a substantial shift through product reutilization. The reutilization of products can serve a similar purpose as their original use or an entirely different one. A notable example of this shift is the reutilization of refillable packaging systems, where companies provide durable containers, and consumers are responsible for cleaning and refilling the packaging [15].
- *Refurbishment and remanufacturing of products.* Refurbishment and remanufacturing of products have gained prominence in the economic activities of the cities. While there are some differences between refurbishment and remanufacturing [10], both processes involve extending product life cycles through actions resembling and manufacturing processes, contributing to reduce the demand for new resources in the manufacturing sector.

2.2 MSW management in Argentina

In 2004, the enactment of National Law No. 25916 by the Argentine National Congress [7] aimed to promote the recovery of household waste. The objective is

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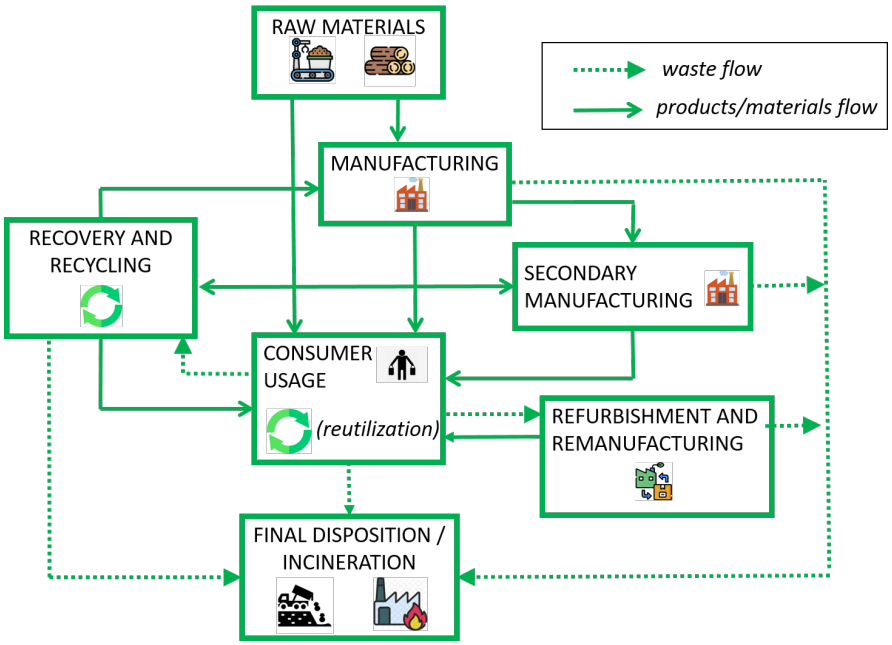

Fig. 1. Waste and material flow in current societies.

to employ suitable methods and processes, thereby reducing the amount of waste destined for final disposal and minimizing its adverse environmental impacts.

In Argentina, the management of MSW falls within the jurisdiction of municipal authorities. Argentina's municipal system is diverse, with different types of municipalities defined by provincial constitutions Municipalities responded to the enactment of National Law No. 25916 by improving their existing MSW systems [3], including the close of open dumps, constructing new sanitary landfills, migrating from door-to-door collection to community bins-based collection networks, implementing segregated waste collection for recyclable and non-recyclable materials, and installing MSW treatment facilities. However, the extent of improvement in the MSW system varied depending on the initial state of the system and the allocation of resources, which were not uniform across municipalities. Consequently, while some municipalities experienced significant progress, others continued to grapple with inefficient MSW management practices [14].

As aforementioned, MSW management comprehends several different aspects. In the following paragraphs, the main aspects of MSW management in Argentina are described.

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Waste generation and composition. An estimated 54,800 tons of MSW were generated daily in Argentina, and this quantity is projected to remain stable or even increase due to the country's expected population growth [16]. However, waste generation is not evenly distributed across all population sectors. The majority of waste is generated by the high and medium-high socioeconomic levels, producing about 42% more waste than the low socioeconomic level [25]. Regarding average waste composition, the largest proportion correspond to food waste (47%) followed by paper/cardboard (17.3%), plastic (13.5%) and glass (6%) [24].

Coverage of the MSW system. The urban population, which comprises 90% of the total population, reports a high coverage of the MSW collection system at 99.8% , with the majority of cities performing daily collection of waste (70%) [17]. Although this percentage of coverage is comparable to those observed in high-income countries, there are some marginalized urban areas and semi-rural municipalities which are still lacking of basic MSW collection [25].

Final destination of MSW. As of 2020, nearly 65% of the generated waste in the country is disposed of in environmentally managed centers with sanitary landfill technology. This indicator has received special attention from authorities and is among the metrics considered within the United Nations' 17 Sustainable Development Goals [8]. The rest of the waste is disposed of in uncontrolled landfills and open-air dumps, which is still a common final waste disposal practice in some municipalities. The presence of almost 5,000 open-air dumps nationwide raises environmental, social, and health concerns, representing a significant challenge for public policies in environmental and social matters [17].

Recovery and recycling. Traditionally, waste collection for recycling in Argentina has been dominated by waste pickers (also referred to as the "cartoneros"). In the city of Buenos Aires alone, it is estimated that the waste pickers recover about the 12% of the waste generated in the city [9]. Regarding particularly paper and cupboard, the recovery rate have risen over the past decade, explaining 50% of the total paper and cupboard consumed by the industry nowadays. Regarding plastic, in 2021 around 286,000 tons of plastics were recycled in Argentina [17], a nearly 25% increment from the year 2017 [11]. Additionally, the substantial presence of organic matter in disposal sites has led to the utilization of biogas from sanitary landfills [17], along with composting when organic waste is properly separated. Since approximately 50% of waste generated in Argentina is organic, these approaches hold potential for reducing landfill volumes, particularly in densely populated cities with limited available space [19].

3 SWOT analysis of a MSW management system: the case study of Bahía Blanca

In this Section, the SWOT analysis of the MSW system of the Argentine city of Bahía Blanca is presented as a case study. In particular, this Section includes a

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succinct description of the MSW system of the city, the main Strengths, Weaknesses, Opportunities and Threats (SWOT) of the system identified by a group of experts, and the outline of the strategies derived from SWOT analysis to improve the system.

3.1 Description of the case study

The city of Bahía Blanca lies on the southern shores of the Bahía Blanca estuary and is a vital hub for commerce, industry, and maritime activity. The city boasts a mix of modern infrastructure and historical architecture, along with educational institutions, cultural venues, and recreational spaces. With a population of around 330,000 inhabitants, Bahía Blanca plays a significant economic role in the region and serves as a gateway to the Patagonia region.

Regarding the MSW system of the city, the budgetary expense in the system for the whole 2023 is expected to be around 35 million US$, representing 14% of the municipal budget [21], which is larger than the national average of 9% [6]. Since the enactment of National Law No. 25916 [7], the city has implemented numerous initiatives to improve the system, such as, eradication of municipal open-air dumps, construction of a sanitary landfill, installation of a recyclable MSW separation and recycling plant, installation of clean points (recyclable differentiated MSW containers), and various programmes that promote source separation and recovery of MSW. Although, the recovery programmes register a great response from the population, recent field studies have identified that strong information campaigns are needed to extend source classification and recycling among population [26].

The waste produced in the city has two major destinations. These are the Recycling Plant located in the separated neighborhood of General Cerri (15km far from the downtown), which receives the material from almost all the recovery programs and clean points in the city, and the landfill located outside the city (around 12km from the downtown), which receives unclassified mixed waste for final disposition. The landfill, due to its intensive use and the semiarid climate of the area -that hinders waste biodegradation-, is almost at the limit of its capacity [22]. Moreover, the payment that the municipality performs to the company that handles the landfill is one of the most expensive contract managed by the municipality [5] (around 12.40 US$ per ton of waste that is sent to the landfill [20]). Currently, in the city of Bahía Blanca there is a door-to-door waste collection, with a frequency of six times per week. The waste collection is divided in 32 collection sectors for managerial reasons [18]. The sectors were determined based on the historical experience of the managers [4]. The city has no transfer station and, thus, the collection vehicles transport the waste directly from the neighborhoods to the landfill or the Recycling Plant [18].

A few months ago the municipality started to implement a program to perform source classified waste collection in several neighborhoods. The program consists of reserving one of the six days in which collection is performed only for recyclable materials (e.g., paper, cupboard, plastics, etc.). The amount of recovered material sent to the Recovery Plant was 130.55 tons in 2021, 155 tons

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in 2022 (it has to be considered that from January to June the plant was out of service due to major maintenance) and 85 tons in the term Jan-April 2023. Regarding the landfill, it received around 138 tons in 2021, 170.9 tons in 2022 and 73 tons in the term Jan-April 2023 [21]. The quantity of material sent to the Recovery Plant is remarkably large considering that the amount of recyclable waste produced in the city is estimated in only one third of the total waste [5]. Similarly to national average, around 50% of the waste is organic which is mostly generated in neighborhoods with low socioeconomic level [28]. The city occasionally witnesses the emergence of uncontrolled open-air dumps; however, the local government is dedicated to mitigating their appearance and promptly addressing them when they do occur.

3.2 SWOT analysis

This Section includes the description of the SWOT factors of the MSW system of Bahía Blanca proposed by a group of experts, the rating of each factor proposed by the authors and finally the strategies to improve the MSW system.

SWOT factors SWOT methodology is a strategic planning framework used by businesses and organizations to assess their internal and external environments. The acronym "SWOT" stands for Strengths, Weaknesses, Opportunities, and Threats. By evaluating the interplay of these four factors, organizations can develop strategies to leverage their strengths, address their weaknesses, seize their opportunities, and mitigate their threats. This evaluation serves as a foundation for informed decision-making and strategic planning across various aspects of the organization [12].

The SWOT methodology starts with research questions. The primary research questions that were developed for the case study are presented and explained below. These questions were designed with the aim of collecting information about the situation and the perspectives of the waste management system in Bahía Blanca. The questions were replied by several experts, including decision makers of the municipality, personnel of the companies in charge of waste collection and landfill management, and members of the local academic community whose research field is related to waste management. In the following sections we present for each factor the research question and the main outcomes.

Q1: What are the strengths (S) of the current municipal solid waste management system of Bahía Blanca?

The aim of this question is to examine the internal strengths of the MSW system to provide a service of decent quality to the citizens while also diminishing the negative impact of waste generation over the local environment. The identified strengths (S) by the group are:

(S1) Current door-to-door collection and final disposal system is working correctly with a low level of complaints from the citizens.

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(S2) One day of the door-to-door collection is dedicated to gather recyclable waste in some neighborhoods.
(S3) A series of implemented projects and programmes for increasing the amount of source classified waste and raising environmental awareness in the community.
(S4) Personnel from the waste collection company has a vast experience in the subject.
(S5) Waste pickers are well organized in cooperatives and have experience in collection and handling of recyclable material.
(S6) Existence of a municipal web portal of updated open access basic data about the MSW system.
(S7) Willingness of the decision makers to improve the MSW system in order to increase its economical, social and environmental sustainability.

Q2: What are the weaknesses (W) of the current state of the waste management system of Bahía Blanca?

The aim of this question is to understand the internal weak points of the MSW system that make it difficult to provide an economic and sustainable service of high quality. The identified weaknesses (W) are:

(W1) Little dissemination of information campaigns and programs for community awareness.
(W2) Outdated technology (equipment and systems).
(W3) Little continuity of senior managers within both the municipality and the predominantly state-owned waste collection company due to political instability, which hinders the establishment of a consistent and long-term MSW management policies.
(W4) Percentage of municipal budget dedicated to waste management is high compared to the national average.
(W5) Several neighborhoods in which source classified collection has not been applied.

Q3: What are the opportunities (O) for the waste management system of Bahía Blanca to become more efficient and sustainable considering the outcome in economic, social and environmental aspects?

The third question examines the aspects from the context outside the current MSW system that can be used for improving the system. The identified opportunities (O) are:

(O1) Possibility of reducing the environmental impact through the increment in separation and recycling rates of the city.
(O2) Existence of a local academic and professional community involved in the study of waste management and recycling and recovery technologies.
(O3) Existence of a market for the sale of recyclable material.
(O4) Integration of cooperatives of waste pickers into new sources of work due to the possible increment in the volume of material destined for recycling.

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(O5) Successful experience of community-bins based collection system in other Argentine cities.
(O6) Successful experience of biogas and composting plants in other Argentine cities.

Q4: What are the threats (T) for the waste management system of Bahía Blanca to become more efficient and sustainable considering the outcome in economic, social and environmental aspects?

The fourth question examines the aspects from the context outside the current MSW system that can negatively affect the system. The identified threats (T) are:

(T1) Lack of motivation and commitment from the population, due to the discontinued application of previous waste differentiation campaigns.
(T2) Economic fluctuations in the country that affect public budgets and the lifestyle of waste pickers.
(T3) Regular emergence of uncontrolled open-air dumps in outskirts of the city.

Rates of factors In SWOT analysis, a useful addition is to rate the factors according to two main aspects: the degree in which they are under/outside the control of the system and their impact in the efficiency of the system [12]. Regarding the control that the MSW system has over the factor, the factors were ranked in a scale from -5 to 5, in which -5 represents that the factor is completely outside the control of the MSW system while 5 represents the opposite, i.e., the factor is completely under the control of the system. Regarding their impact on the efficiency of the system, the factors were ranked in a scale from -5 to 5, in which -5 represents that the factor is a major inhibitor of the MSW system while 5 represents that the factor is a major enhancer of the system. Treating these rates as coordinates, they are presented in a two-dimensional grid in Figure 2. This grid provides a visual representation of how each factor is positioned in terms of its control and its impact on the performance of the MSW system.

Strategies Considering the replies to the research questions, the following strategies were developed by combining the different factors. These combinations led to four groups of strategies that are presented in Table 1.

The strategies outlined in Table 1 vary in their execution horizon. For example, a short-term strategy like (W4.T3) can be promptly implemented to improve the efficiency of the MSW system with the following actions: monitoring the collection sectors of the city, making adjustments to minimize truck travel distances, and collaborating with drivers to enhance driving skills and reduce fuel consumption. An example of a medium-term strategy is (W3.O2) which focuses on ensuring greater job stability for senior managers. Currently, the waste collection company is predominantly state-owned. However, implementing local regulations could assure managers that their positions will extend beyond the tenure of political authorities. Finally, an example of long-term strategy is (W4.O7), which demands meticulous consideration. The installation of a

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Table 1. Strategies of the SWOT analysis for improving the system.

	Strategies Strength-Opportunities
(S3.O3)	Deepen the dissemination of programs to increase the volume of material to be recycled.
(S4.O2)	Design, plan and put into operation a new waste collection, separation and final disposal system, using previous studies and models developed by the local academic community and taking advantage of experienced personnel.
(S5.O4)	Evaluate the quality and quantity of new jobs for waste pickers based on the projected volume of waste to be recycled.
(S6.O2)	Encourage new mechanisms that allow speeding up the information upload processes in the municipal portal so that they can be used for studies and analysis by the local academic community.
(S7.O5)	Study the implementation of community-bins based system in highly-populated parts of the city to improve collection efficiency.
(S7.O6)	Study the implementation of biogas and composting plants taking advantage of the large amount of organic waste produce in the city.
	Strategies Strength-Threats
(S3.T1)	Use ongoing programs to raise awareness among the population about the consequences of the indiscriminate disposal of waste in the city, and encourage them to collaborate in social and environmental improvement.
(S7.T2)	Contribute to improve the labor stability of the waste pickers, formalizing their activity in order to have a greater degree of social coverage, e.g., incorporating them in the current Recycling Plant or in the potential biogas or composting plants.
	Strategies Weaknesses-Opportunities
(W1.O3)	Use the experiences in other cities as a motivating element to raise awareness among citizens.
(W2.O2)	Incorporate highly qualified staff to implement new technologies in the system.
(W3.O2)	Improve the selection process for senior managers in waste management and provide greater job stability for these positions.
(W4.O5)	Study the impact of community bins-based system to the collection cost of the system.
(W4.O6)	Study the implementation of biogas and composting plants to reduce the amount of waste sent to the landfill which is expensive for the city.
(W5.O1)	Expand the one day door-to-door collection of recyclable material to the rest of the neighborhoods.
	Strategies Weaknesses-Threats
(W3.T1)	Enunciate local laws that make it possible to ensure the continuity of the system policies regardless of the managers in charge of the decisions.
(W4.T3)	Enhance the cost-effectiveness of waste management expenditure.

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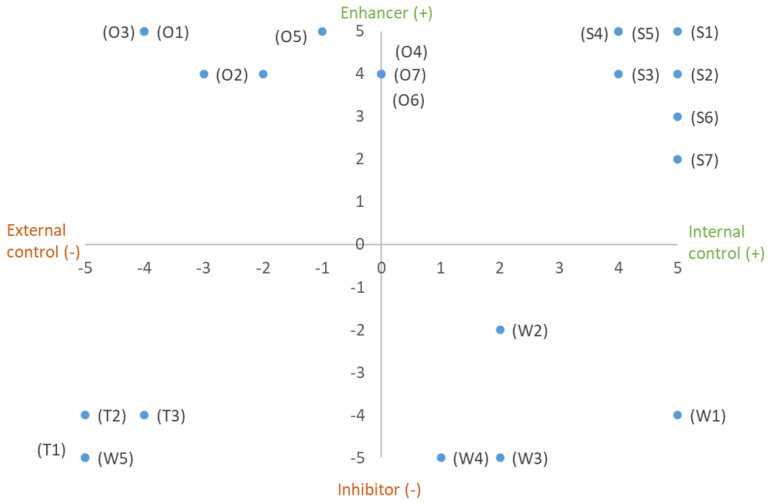

Fig. 2. Rates assigned to each factor.

biogas and composting facility requires a thorough feasibility study, and if the outcome of the feasibility study is positive, a substantial investment for building the facility.

4 Discussion and future work

Municipal Solid Waste (MSW) management systems play a pivotal role in building sustainable urban environments. Not only they allow to process waste with minimal environmental and social impact but also they gather recyclable material that can be used to reduce the amount of raw materials used by modern cities. This article conducted a comprehensive evaluation of material and waste flows in contemporary cities, followed by an in-depth analysis of MSW management practices in Argentina. As a case study, the MSW system in a specific Argentinean city was scrutinized using the SWOT methodology, revealing the efficacy of this approach in devising strategies for enhancing MSW systems. Future research lines include employing the SWOT methodology to analyze the MSW systems of other cities for comparative purposes. This expansion of research will hopefully further enrich the understanding of effective waste management strategies.

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