Towards Artificial Intelligence in Urban Waste Management: an early prospect for Latin America

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Abstract. The expectations about the increase of solid waste generation are a global concern in order to mitigate the negative impacts caused by this scenario. Recent experiences show advantages in applying Artificial Intelligence (AI) in Urban Solid Waste (USW) management. Although, developing countries face many structural and governance barriers that limit the real potential of applying these technologies. This study presents a worldwide outlook about the application of AI in USW management and identifies the reality of Latin America countries in this new context. It is especially important to improve monitoring and to create data management platforms. Also, this study collaborates on the minimization of possible technological boundaries posed to Latin America region and besides, it can be considered a reference study for countries in similar conditions.

Keywords: urban solid waste, artificial intelligence, machine learning, waste management.

1. Introduction
The mitigation of negative impacts of solid waste generation is an important challenge for developing countries, since they faced a fast population growth, non-controlled urbanization and a lack of financial resources to keep a capable management system (Guerrero et al., 2013; Caruso; Gattone, 2019). Latin America countries deal with this reality, since they face difficulties to set adequate final disposition, struggling to eradicate open dumps and to disseminate the use of sanitary landfills (Margallo et al., 2019). The countries of Latin America and Caribbean (LAC) region count 8.42% of world population. In addition to that, the rate of urban solid waste generation is 1.09 kg/capita/day. When compared to the world average of 0.74 kg/capita/day it is considered a high value. About 50% of the generated waste is disposed in sanitary landfills. Even though, that is a significant volume being inadequately discarded. (Kaza et al., 2018)
The improvement of urban waste management is urgent since the high volume and vast composition generated in this region allows the use of different techniques for treatment. Technology has a significant potential to support the improvements and advances in the waste sector. Nowadays, Artificial Intelligence (AI) is considered a vast field of knowledge with a huge potential to establish methods and tools for promoting assertive decisions by analysing data, forecasting quantities, automating process to obtain sustainable and efficient practices. These benefits made AI to play a significant role to promote social good and the usage of AI have been emphasized for minimizing inequalities in LAC region.
The LAC countries are in an early stage of defining the basis and policies to use AI and the mainly fields of interests are health, education, agriculture and finance sectors (Panduro & Roman, 2020, Carrillo-Larco et al., 2020). The emerging expectation of using AI promoted an increase in published studies in the field. Cechinel et al. (2020) investigated the increase of publications in Learning Analytics in Latin America from 2011 to 2019. The authors analysed 282 papers based on applied techniques, goal, ethical issues, to cite some. It was demonstrated an enhanced interest to research and to apply AI to set solutions in Latin America region leaded by Brazil and Ecuador in number of publications.

Despite the efforts and advances to constitute AI as a tool for decision-making in many sectors, there are no considerable discussions on literature about the improvement specifically in the sanitation field through AI in Latin America context. The vast majority of the published cases and reviews of AI applications in waste management refers to developed countries (Abdallah et al., 2020; ISWA, 2019). Thus, to investigate the impacts of applying AI on the waste management of Latin American countries is a relevant task, since these developing countries present limitations related to financial and structural aspects (Leal Filho et al., 2016) that limits an efficient management. To overcome that and consolidate technology as a useful tool, it’s necessary to adapt AI based technologies to local reality, as cited by De-Arteaga et al. (2018).

This paper aims to present an initiatory discussion about the perspectives of Latin America to establish AI based solutions in USW management while it indicates a concise outlook of the worldwide applications in the waste sector.

2. Materials and Methods
The methodology of this study comprised a search on bibliography databases as Web of Science and Google Scholar. The key-words investigated was “solid waste management”, “artificial intelligence”, “waste management”, “machine learning”, “urban waste management”, “urban waste” for the period corresponding of years 2000 to 2021. In addition, many articles were found by consulting cited references.

3. An overview about recent trends of AI usage in USW management
Artificial Intelligence (AI) can be understood as a set of techniques and tools that enable a system to accomplish tasks that initially were exclusive for the human being capacity. AI is composed by the representation of knowledge allied to data manipulation, creativity, capacity of auto correction, ability to perceive and respond to external stimulus (Harkut et al., 2016; Garcia et al., 2018).

Garcia et al. (2018) cite that the intelligence of machines can be classified in levels or kinds. Thus, the classes of AI are comprised in computer vision, robotics, automated reasoning, natural language processing (NLP) and machine learning. This last class is especially important because it deals with the proposition of learning algorithms that guide the decision-making process through analysing inferences, complex associations, predictions and data trends. Machine Learning enables a system to learn and adapting to new conditions by combining rules of computing, statistics and optimization (Garcia et al., 2018).

The several benefits provided by AI poses it as an essential tool to attain the reduction of environmental impacts, development of tools and actions to improve lifespan of equipment, recycle of components and improve the circularity of materials and energy in USW management. Then, this field of sanitation is a potential target to improvements by AI.

3.1. Machine Learning for prediction of USW generation
The increase on solid waste generation is an environmental challenge that affects later steps of the process: storage, collection, transportation, treatment, recycle and final disposition in adequate form (Khan & Samadder, 2014). In this sense, the use of Machine Learning techniques is an efficient way to extract patterns and understanding factors that influences waste generation and the expected composition. It enables to predict the volume generated or the composition expected, developing a numerical or categorical based approach. Based on bibliographic searches, these applications major apply the methods Cluster Analysis, Artificial Neural Networks, Support Vector Machine (SVM), Tree Based Methods and K-Nearest Neighbours (KNN).
The most cited features to investigate the USW generation profile are climatic variables (average temperature, precipitation rate, wind velocity), demographic variables (population density, age range, family size) and socioeconomic variables as income level, educational level, employment rate (Dias et al., 2012). In addition, variables related to the waste collection (collection volume, weight, composition) are essential to analysis and georeferenced data can improve the prediction based on locations (Johnson et al., 2017, Kontokosta et al., 2018, Liu et al., 2019, Kannangara et al., 2018).

3.2. Collection improvements: estimation of bin level and route optimization
Some challenges faced in this stage of management are the high spend of fuel, atmospheric emissions, need for estimation the ideal time for collection and the estimation of the ideal level of waste bins. These difficulties justify the collection stage to concentrate about 70% of operational costs as cited by Ferrer e Alba (2019). In Table 01 are described some applications for the development of smart bins. Another approaches (Khan e Samadder, 2016; Kim et al., 2006) proves advantages on the route optimization through the use of GIS tools (geographic information system). Although, the limitations to optimize many observations (Sulemana et al., 2018) is a reason for associate GIS tools with Machine Learning (ML). This association allows improvements on spatial analysis by applying image processing techniques and also, allows the perception of urban area in a social and structure perspective. Besides, integration of the two tools, reduces analysis time (Tohidi and Rustamov, 2020).

Optimizing routes allows to reduce distance travelled and quantity of vehicles in circulation, which causes improvements on traffic and reduction on emissions of pollutants (Kontokosta et al., 2018). This corroborates that modelling is a powerful tool for the decision-making and the generation of insights for planning and implementing sustainable and efficient actions.

3.3. Automatic sorting
The automatic sorting is considered a technology to approximates the USW management to sustainable practices and optimization of recycling process (Costa et al., 2019). In this stage of the process, the use of image detection enables the automatic classification of the waste. This is advantageous since it enhances the potential to an adequate segregation of components for reuse or recycle.

Costa et al. (2019), Arayakandy et al. (2019) and Bansal et al. (2019) successful applied Machine Learning to automatic classification of waste composition by images, as described in Table 01. These applications confirm that the automatic sorting achieved by AI contributes also for developing equipment, which enhances the benefits. The cited approaches demonstrate the potential of AI to reduce errors on sorting which increases the efficiency of the valorisation process. In addition, AI plays a significant role for reducing the health risks for employees by minimizing the manual contact between them and the solid waste fractions.

| Author | Application | Method |
|--------|-------------|--------|
| Zhao et al. (2017) | Identifies different fill levels of bins by changes in motor vibrations. | Cluster Analysis (K-Means) |
| Aziz et al. (2018) | Classification of the fill level of bins and prediction of reminiscent days for waste collection | SVM for classification and Hidden Markov Model (HMM) for prediction |
| Costa et al. (2019) | Classification of waste images in paper, glass, plastic and metal | Best performance using CNN (Convolutional Neural Network), |
| Arayakandy et al. (2019) | Classification of waste images in plastic, glass, paper, metal, cardboard and non-recyclable | SVM |
4. Perspectives and future challenges

The lack of adequate waste segregation associated to inefficiencies to execute alternatives treatments as composting or anaerobic treatment, causes loss in (I) the reuse and recycling potential, and (II) energy and economic recovery of components. This reflects a remedial vision of the process, which limits the perception about the economic value of the waste and poses the final disposition in sanitary landfills as a treatment stage (Leal Filho et al., 2016).

The difficulties faced to manage the sector are barriers to the modernization, especially related to the application of smart technologies in less economically favored countries. Cultural and economic aspects, legal and infrastructural and technological availability (Leal Filho et al., 2016; Guerrero et al., 2013) poses differences among developing and developed countries. Because of that, when prospecting solutions based on AI, primarily using Machine Learning, it is important to consider the conditions of each country, as mentioned for De-Arteaga et al. (2018).

In the face of this, the following discussion is based on three categories of improvements based on the local conditions.

4.1. Data Management

On a report of Mont et al. (2020) it was indicated that every 12 countries investigated (Argentina, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Mexico, Paraguay, Peru, Trinidad and Tobago, Uruguay) present some kind of policy to consolidate AI as a digital strategy for many sectors. A notable topic of this expectation is the consolidation of data management systems.

The bibliography investigation highlighted the importance of data management to improve the monitoring of collection, treatment and final disposition. In addition, the aggregation of georeferenced data from GIS tools generates a data description level that enables the creation of precise models. In this sense, a data management system plays a leading role in the potential to use AI based systems. The data management and share are considerable challenges, that needs integrated actions on public and private sectors.

Although, LAC countries struggle to establish a data management system and it is common to note low data availability, or little detailed data, outdated records or without standardized labels, also contradictions in records (Deus et al., 2016). It is important to note that these are topics of interest for investigations, given the prominence of the usage of Machine Learning techniques based on scarce data (De-Arteaga et al., 2018) or operations with heterogeneous data (Caruso & Gattone, 2019). Besides, resampling methods and data imputation places a fundamental role to increase the quantity of observations on databases and reduction of bias in models. The integration of data bases from different sources is a relevant topic, particularly when dealing with restrictions to collect new data (Guerrero et al., 2013; Meza et al., 2019).

Relevant efforts to establish the USW management improvement by data systems are verified in public sector of Brazil, Ecuador, Colombia and Argentina with the main aim to adequate monitor waste generation, provide reports for citizens, enhance the reuse or recycle of waste and manage the financial resources of the waste sector.

4.2. Waste collection

The use of GIS tools is a great way of gathering georeferenced data, and poses advantages to the route optimization by the integration of data. Bueno-Delgado et al. (2019), Khan & Samadder (2016) worked on route optimization and ideal allocation of waste bins, achieving success on reducing costs and collection planning.

The access to internet in urban areas allows the utilization of platforms or applications that inform the users the route and time to collection, give instructions about waste segregation and guarantee
transparency on information. The application “I got Garbage” was successfully applied in India, to inform citizens the collection planning and promote instructions to adequate segregation (Kaza et al., 2018). Initiatives based on the interactions with citizens, as mobile applications, are potentially feasible. Although, those kinds of initiatives are not well established in the region and are mainly developed by private sector. It is not common the public sector disseminates that. Latin American countries has a vast potential to use internet as a tool for the communication with citizens and establishment of connectivity-based resources. The penetration rate of the internet on region is 72%, Brazil is the country that presents the majority of internet users. (Statista, 2021) In this sense, to inform citizens the route and schedule of collection trucks, or to allow citizens to use a mobile application to report infractions on waste collection is an option to approximate them of the decision-making process. Although, this effort needs to be complemented by sensibilization to avoid biased information.

4.3. Manufacturing and treatment

The use of technologies on manufacturing process allows the increase of materials reuse, considering the life cycle of components. This can be achieved by the use of software that guides the choose of materials (Kaza et al, 2018). As cited before, manual waste sorting is susceptible to errors and health risks to employees. Because of that, the automatic sorting is an interesting way for the optimization of the sorting process, increase of components recovery and protection of employees. In addition, other interesting application is the monitoring of sanitary landfills by drones. They can be used to verify the capacity of the landfill, to detect gas leak or verifying spaces to allocate equipment, successfully applied in Brazil (Mello et al. 2017; da Silva et al. 2020; da Silva et al., 2018). Figure 01 points the mainly applications and potential impacts in every stage cited.

![Figure 1. Potential impacts of AI based solutions](image-url)

5. Conclusion

This study exposed the conceptual basis of AI, evidencing its importance the establish decision-making tools. It is presented an initial overview about the usage of AI in USW management in three stages: generation, collection and automatic sorting of the solid waste. In view of that, the main challenges and opportunities of applying AI in the UWS management in Latin America is discussed. Despite the limitations on data quality, Latin America countries can benefit on the investigation of Machine Learning topics of interest as data imputation, database integration, among others. Also, it is observed a great potential of the region to benefit of internet-based tools since the spread of internet access are vast and present an increase trend. Thus, data management, waste collection and manufacturing or monitoring are the main opportunities to apply AI and Machine Learning based solutions. It is interesting to note that the consolidation of AI in developing countries is gradual in order to guarantee the sustainability of actions in front of the technological and human resources available. Also, it is a worldwide interest to know how AI based
tools are adapted to less favoured nations. This study briefly shares the potentialities of AI field in USW management and evidences progresses that can be achieved by that.

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