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Solid Waste Flux in Higher Education Institutions: A Systematic Review on Modeling Approaches

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***Abstract*– With rising environmental concerns, effective Solid Waste Management (SWM) at Higher Education Institutions (HEIs) has emerged as a critical part of global sustainability efforts. These institutions are not only education and research environments, but they are also major generators of specific types of waste, requiring innovative SWM strategies. This review explores current SWM methods, focusing on the role of statistical modeling in helping to improve these strategies, due to their ability to identify trends in waste generation. Utilizing VOSviewer for a detailed bibliometric analysis, the study identifies current scenarios and strategies in this research area. The unique characteristics and resources of HEIs show the importance of designing specialized SWM models. A significant outcome is the importance of social elements; comprehensive surveys that may include demographic and socioeconomic data are important in establishing competent SWM programs. It suggests that these surveys can provide significant data about behavioral patterns that may affect SWM. These models can offer relevant information, allowing HEIs to successfully adjust their programs, making a significant contribution to campus sustainability and broader environmental goals.**

***Keywords*– Bibliometric Analysis, Higher Education Institutions, Literature Review, Solid Waste Management.**

I. Introduction

Given the current scenario, which is characterized by growing environmental awareness and the urgency to implement sustainable practices, Higher Education Institutions (HEIs) spring up as important players in environmental management. These institutions, long regarded as bastions of intellectual capital, are now challenged to be leaders in sustainability, particularly in solid waste management (SWM). This management not only involves belief in the importance of efficient disposal of a variety of waste generated on campus, but it also represents HEIs' sustainability and environmental responsibility[1]

HEIs generate a significant amount and variety of waste, HEIs generate a significant amount and variety of waste, that may range from organic waste in dining areas to chemical and electronic waste generated in laboratories and administrative areas [1]. This level of intricacy adds another layer of difficulty to waste management, where it is not only about getting rid of waste efficiently while also supporting long-term sustainability goals. In this context, budgetary limitations often provide extra difficulties when attempting to take priority resource integration [2].

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Given its capacity to generate precise and rigorous data on waste composition patterns, waste modeling is considered a leading method within the current waste management framework. By using statistical modeling, HEIs may anticipate and get better prepared for future scenarios, in addition to assessing their waste generation patterns as they still occur [3]. Such foresight is required for successful resource allocation and the implementation of management methods that are both efficient and sustainable.

Advanced waste management analysis covers a wide range of topics, from basic waste classification to estimation methods [4]. These models are useful for several tasks, including categorizing and quantifying waste as well as finding ways to improve solid waste management. However, the level of community awareness and education determine how successful any waste management strategy will be [5]. This reveals how necessary it is to integrate waste management tools into society and HEIs' routine procedures to instill a positive attitude in students, academic advisors, and administration.

As part of this study, a detailed evaluation of waste management techniques are conducted out, with an emphasis on the component of waste flux modeling. The focus of this study is to provide a deeper overview of the present frameworks, trends, and difficulties in this area and to pave the way for future studies and specific uses in sustainable waste management.

A general view of HEI's operations and the many ways in which waste may be produced is given in Fig. 1. Finding the waste sources, it is important to help addressing waste management issues, by tracking down intervention areas and putting in place appropriate waste management strategies for each kind of waste that is produced[6].

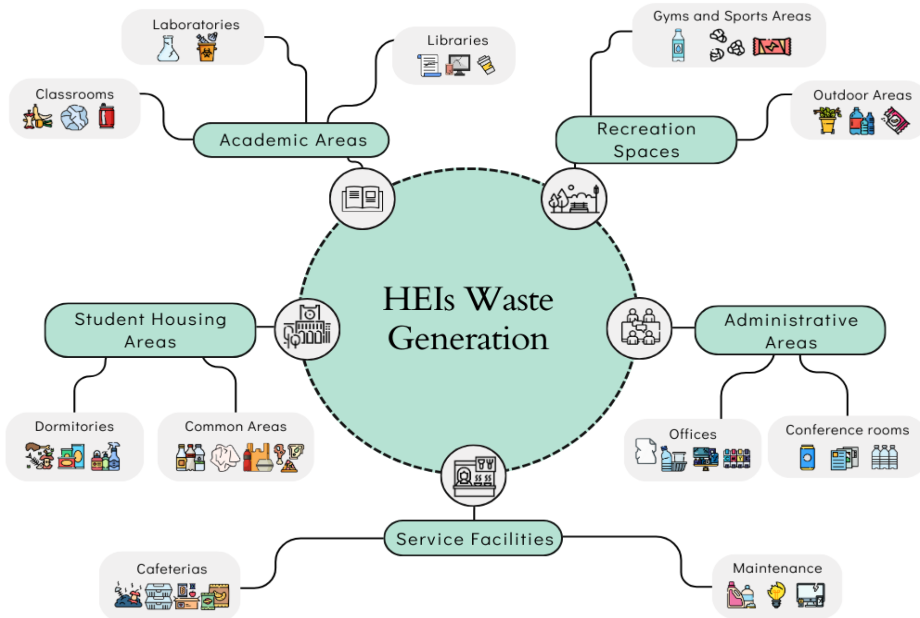

Fig. 1: HEIs Waste Generation [1], [6], [7], [8], [9] [10], [11].

As the central point of the Fig. 1 indicates, the HEI is the intersection of all operational activities that produce waste. The interactions between various maintenance, administrative, instructional, student, and recreational activities are reflected in this core. The need for an integrated and varied waste management strategy is shown by the fact that each of these methods considerably raises the institution's overall waste profile.

Academic settings, including labs, classrooms, and libraries, generate a large amount of wastes chemical and hazardous waste become more prevalent in laboratories, there may be difficulties because proper waste disposal procedures and environmental compliance and safety standards must be followed [7]. However, most of the waste coming from classrooms and libraries is made up of paper plastic bottles, cans and in some cases electronic materials, which seems to indicate that these areas use a lot of materials, technology, and educational resources[1].

A wide variety of waste could be found in student living areas such as dorm rooms and shared spaces. These areas reflect student consumption habits, producing anything from organic waste to food packaging and personal hygiene products [8]. Efficient waste management might be a problem in terms of empowering origin separation, recycling, and reuse practices among the student population.

Service facilities, which may include cafeterias and maintenance rooms, significantly contribute to waste generation. Cafeterias are renowned for producing organic waste and a wide range of packaging, which provides chances for composting and recycling solutions [9].

Maintenance areas generate specialized waste, such as cleaning supplies and disposable items[10]. Offices and other administrative sections of HEIs produce a significant amount of paper and electronic waste [6]. Paper reduction and recycling programs are important, so these areas—where administrative responsibilities are performed—produce a considerable quantity of paper. Electronic waste may accumulate in different areas due to the rapid obsolescence of technological equipment. Effective management of this waste is necessary, like Precious Metal Recycling and Battery, and Cell Management, to reduce its negative effect on the environment [6].

The recreation spaces are frequently used for student gatherings and activities, resulting in a wide range of waste that may include food, beverage containers, plastic, cans, and decorative and promotional items [11]. Waste management in these locations must consider the need to encourage community participation especially during festivals and meetings.

The comprehension of the diversity on waste generation in HEI's it emphasizes the importance of managing each area with unique and adapted strategies, as well as the importance of promoting a culture of sustainability and environmental responsibility throughout the institution.

II. METHODOLOGY

This section presents the study's approach in detail. It consists of two parts: Bibliometric Analysis and the Literature Search Approach. The attention is on current studies on solid waste management and sustainability. A comprehensive evaluation of the area of study is presented by the Bibliometric Analysis, which gives a comprehensive analysis of the key concepts and ideas enclosed in the academic research.

A. Literature Search Approach

The variety of papers published on this matter reflects the significant attention that the joint of modeling, sustainability, and solid waste management has received in latest research. In addition to learning more about this area, a thorough review of the scientific literature was accomplished on Google Scholar and ScienceDirect, two databases that were selected for their reliability and relevance in the science and technology domains. The following keywords were applied as initial criteria to find relevant studies: "Modeling" OR "Simulation") AND "Solid waste management" AND "University" OR "Universities" OR "Higher Education Institutions" OR "HEI" AND "Sustainability".

It was indispensable to narrow down and refine the search to make it more manageable and targeted given the wide range of research that was accessible. To stay focused on the most important components, this activity required rewriting and streamlining the search keywords oriented on relevant features connected to modeling in waste management.

The year of publication was another factor used for the selection of the articles. To guarantee the accuracy and consistency of the data, the giving priority was for research that was published during the previous decade, from 2013 to 2023. The initial assessment was based mostly on the article titles and abstracts, which were used to determine which of them were most relevant to the core study subject by a critical synopsis review based on the objectives of the study.

The chosen publications were classified according with the level of analysis and relevance to the study goals. High, medium, and low relevance categories were used to get a more subtle understanding of the major trends and discoveries in the research area. By providing information that was directly useful to the research, the highly relevant and important papers established the link between methodology and waste management sustainable strategies. To correctly form the state of the art and guarantee a detailed and critical conceptual understanding of the most current trends and results in the line of work, this selection and classification process was fundamental.

As such, the research included complementary search methods referred to as "Bibliographic search" and "Citation tracking" [12], as complementary techniques. This exhaustive manual search was done as part of the study across sources, including books, newspaper articles, legislative documents, and gray literature. This presented a wider knowledge and understanding of the field's practical and historical dimensions. Fig. 2 shows how the search framework is laid out.

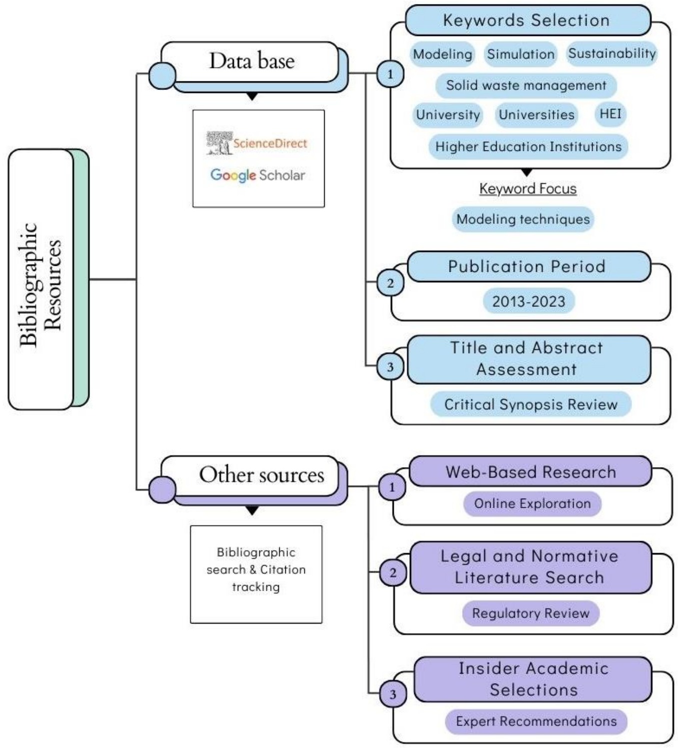

Fig. 2: Literature search process.

B. Bibliometric analysis

The bibliometric analysis was designed with the software VOSviewer, which graphically represents the interactions between key phrases and concepts in academic papers. The setup used to collect terms from abstracts and article titles was binary counting. Also, a phrase had to meet the minimum criterion of four occurrences to be considered in the analysis. Among the initial set of 2339 terms identified, 124 met the relevance criterion, demonstrating their relevance in the solid waste domain.

III. RESULTS ANALYSIS AND DISCUSSION

The result of the research is discussed and analyzed in this section. The interpretation of keywords and concepts that are noteworthy to find the connection between the data collected and the inferences that may be made from it.

A. Present scenario and trends

The shift in color from deep blue to yellow in the VOSviewer visualization Fig. 3 demonstrates a chronological advancement in solid waste management research. The darker blue tones suggest the early emphasis on waste characterization. Preliminary investigations primarily focused on the characteristics and makeup of waste, supporting the foundation for subsequent management approaches.

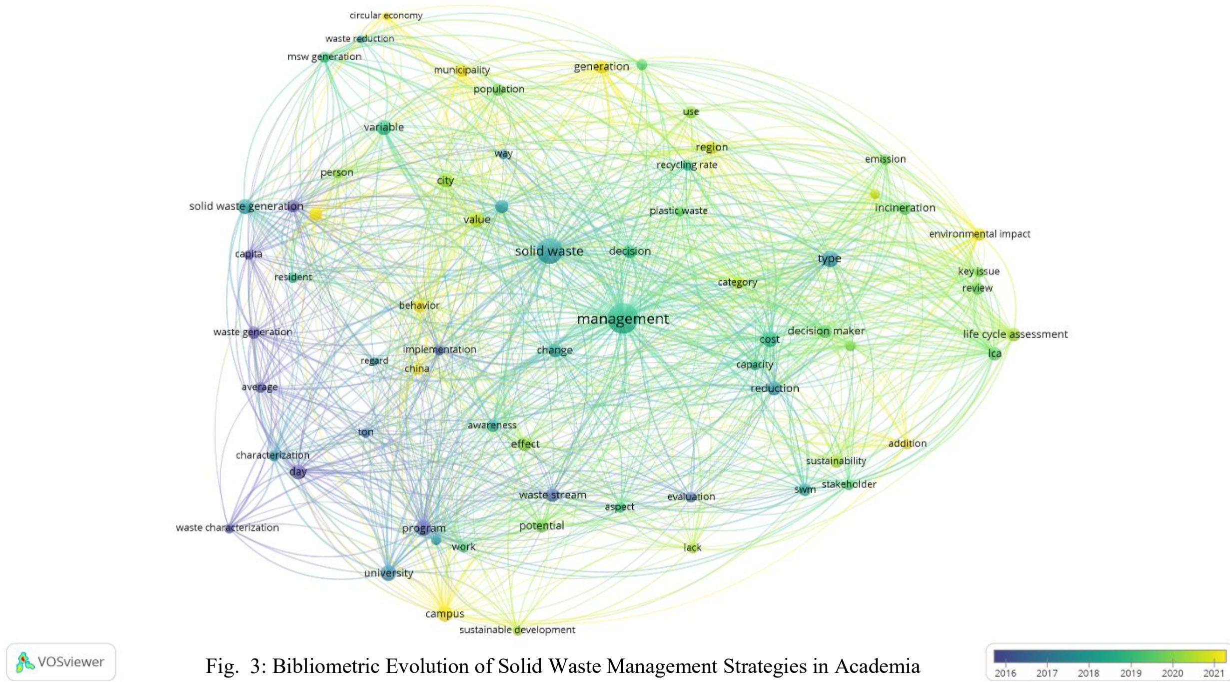

Fig. 3: Bibliometric Evolution of Solid Waste Management Strategies in Academia

The literature is expanding as the spectrum goes toward lighter colors, with words like "management" and "sustainability" becoming much more prevalent. This marks to a transition in scientific work toward the expansion and improvement of waste management techniques. The addition of sustainability into these procedures illustrates a response to the growing demand for environmentally concerned tactics.

Progressing on to the yellow tonalities that are warmer, the analysis shows that there has been a recent exponential increase in interactions about "environmental impact" and "circular economy." This treads a progressive approach for which research seeks to recognize and lessen the long-term ecological effects of waste related handling practices in addition to addressing the problems nowadays.

The visualization's color gradient correlates directly to a narrative found in the discussion, which follows the path from comprehending the attributes of waste to having to put transformative management into practice to, at the end, closely examining the wider ecological implications. This transformation in the academic setting affirms the significance of research and work, such as the creation of statistical models to predicted waste generation patterns, which are aligned with the newest developments in environmentally friendly waste management techniques.

Expanding upon this framework, the following segments will examine the key elements previously denoted. These concepts, important for the formation of sustainable practices, will be carefully analyzed in terms of their potential application, relevance, and impact on how waste management is structured going forward.

B. Solid Waste

Different research techniques are necessary for solid waste, an important environmental concern. Solid waste is studied from different perspectives, such as its composition, generation, impacts on people and the environment. A detailed understanding of the mechanisms of the characteristics of waste and the socioeconomic factors that influence its generation and management to handle seems to be essential for this field [5].

Solid waste research is the main driver behind changing research methodologies because it requires thorough data collection, analytical methods, and a multidisciplinary approach. This is demonstrated in a study by the University of Johannesburg[13] which compares various waste types and percentages using the Waste Category Proportion (WCP) formula as in (1). While large sample hypothesis testing frequently employs procedures like the Chi-square test, in this case, its use is concentrated on examining the association between users demographic attributes and waste generation patterns. To establish sustainable management methods, a greater knowledge of the variables impacting waste generation is facilitated by the examination of these interactions. As seen in the literature analysis, Table 1 provides a visual depiction of the development and prevailing patterns in statistical approaches. It is significant to perform this test to see if there is a significant correlation between the categorical variables, as this could point to a connection between the characteristics of users and how they produce waste. Table 1 gives a visual representation of the advancements and predominant trends in statistical techniques as observed in the literature review.

Ref	Year	Statistical Method	Equation	N°	Variables	Applicability
[13]	2023	WCP	$WCP = \frac{Waste\ Category\ Amount(WCA)}{Total\ Generated\ Waste(TGW)}$	(1)	WCA: share of a specific waste type (e.g., plastics) in total waste. TGW: total waste collected over a set period	Calculate and compare percentages of different waste types.
[13]	2023	Chi-square test	$\chi^2 = \sum \left(\frac{(O-E)^2}{E} \right)$	(2)	O: waste frequencies by demographic (e.g., teachers plastic waste) E: frequencies if no variable relation exists. χ^2: connection between demographics and waste patterns.	Calculate the relationship between users' demographic characteristics and types of waste generated.
[15]	2021	DEA				Analysis of the influence mechanism in waste separation within the community in Municipal Solid Waste (MSW).
[17]	2021					Measure the relative efficiency of decision-making units (DMUs) Municipal Solid Waste Management (MSWM).
[14]	2019					Assess waste management effectiveness in Latin America.
[16]	2018	MLR	$y = \beta_0 + \beta_1 x1 + \beta_2 x2 + \cdots + \beta_n xn + \varepsilon$	(3)	y: dependent variable (e.g., amount of waste generated). β_0: intercept (e.g., amount of waste expected if there were no students). β_1: slope (e.g., average increase in waste generation for each additional student). x: independent variable (e.g., number of students). ε: random error (difference between the actual value and the value predicted by the model).	Data collection instrument, MSW audit, and development of a model with cross-validation.
[18]	2022					Prediction of solid waste generation in MSW.
[19]	2016					Improvement of waste flow prediction and management.
[20]	2023	ABM				Simulate the impact on the household participation rate in the community recycling program – MSW

Table 1: Applicability of Statistical Method

Statistical approaches are needed to the assessment and improvement of waste management techniques. Data Envelopment Analysis (DEA), as covered in [14], becomes fundamental in this scenario for assess the efficacy of waste management systems.

DEA is a performance measurement analytical model that focuses on the operational effectiveness of different entities, or decision-making units (DMUs). With this strategy, the process by which these units transform resources (inputs) into compared to goals (outputs) is carefully examined, providing a good grasp of their operational efficiency.

Likewise, the research in [15], [16], [17] point out the importance of the statistical analysis. These studies clarify efficiency gains that can be reached by assimilating structural modeling, DEA, and statistical analysis. When combined, these approaches offer a solid foundation for understanding the complexities of waste management and trying to locate areas for optimization. Reference [17] places emphasis on the effectiveness of DEA-assisted waste management services in Italian municipalities by contrasting available waste with expected result like composting and recycling.

In addition to using a variety of statistical techniques, the study in reference [15] discusses waste separation behaviors. It identifies important waste trends, separation patterns, and implements factor analysis and structural model analysis using IBM SPSS Statistics.

Substantial progress has been made in the statistical modeling of solid waste, as demonstrated by reference [16], which employs a Multiple Linear Regression (MLR) model. By using the MLR equation (3), this model examines the complex link between certain factors and the production of municipal solid waste (MSW).

Reference [19] goes one step further in using these strategies by integrating socioeconomic and demographic variables like Gross Domestic Product GDP and education, demonstrating a broad range of advanced methodologies in solid waste management research. The author put emphasis on how crucial predictive modeling is to the development and assessment of environmentally friendly waste management techniques.

In addition, [20] presents a sophisticated agent-based model (ABM) that replicates citizen involvement in Beijing's recycling initiatives. This model, which is based on the Theory of Planned Behavior and is bolstered by household surveys, offers essential information for estimating waste output and assessing the effectiveness of environmentally friendly waste management techniques.

C. Management

The word "management" has taken to define an analytical method as well as a comprehensive one. A vital factor in this development is "modeling," that also offers an established, measurable way of managing the difficulties of waste management. This change toward using modeling techniques signifies a substantial movement toward data-driven, techniques, strategic planning. By employing diverse mathematical frameworks, waste management transcends waste disposal and instead adopts an assertive, anticipatory method [21].

A specialized optimization method called Mixed-Integer Linear Programming (MILP) manages to combine linear programming with integer limitations. It is great for trying to address demanding situations that included both discrete and continuous variables [21]. Because of its flexibility, this method is especially well enough for strategic and operational planning in the waste management industry.

MILP was used in the research [22], to strengthen the routes for collecting waste. To increase waste collection efficiency, the model's goal function decided to seek to reduce the overall distances between collection stations. This MILP application stands out because it prioritizes waste management optimization.

Reference [23], decided to make use of this method to concurrently solve diverse important waste management goals. These included cutting greenhouse gas emissions, decreasing the visual effect, and lowering both fixed and operating expenses. Their approach was more expansive, taking cost-effectiveness and environmental factors into account. The optimization objective's inclusion of greenhouse gas emissions illustrates how waste management systems are beginning to place increased focus on environmental responsibility.

Besides that, [24], and [25] work further illustrate the adaptability of MILP. The former discussed the inherent uncertainties in waste amount and recyclable material costs by developing a two-stage MILP model in line with supply chain management and circular economy concepts. Bender's decomposition approach was used to control the complexity of this model, demonstrating MILP's capacity to address complicated waste management issues [25].

The study by reference [26], also applying MILP, stressed the necessity to combine economic efficiency with environmental effect. This is consistent with a more general trend in the industry, where cost reduction is increasingly seen in conjunction with making the most use of the financial resources available for efficient waste management.

A major development in the discipline is the use of advanced mathematical techniques into waste management models. For example, the study [27] estimates the durability of electrical gadgets using the Weibull Distribution (4). Predicting when these gadgets will become rubbish is a particularly useful capability when it comes to organizing Ireland's electronic waste management. The size of (λ) and shape (k) parameters of the Weibull Distribution allow it to be adjusted to a variety of data distribution patterns, allowing it a robust tool for modeling time-to-event data.

$$f(t;\lambda,k)=\frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1}e^{-\left(\frac{t}{\lambda}\right)^{k}} \quad (4)$$

In another example, reference [28] discusses the problem of multicollinearity in waste management studies. The way to align predictor variables in a regression model are a statistical phenomenon that has the potential to skew or invalidate the model's conclusions. The research evaluates and reduces the effect of multicollinearity utilizing methods such as the Variance Inflation Factor (VIF) and the Pearson correlation coefficient. This strategy was important to precisely comprehending how socioeconomic and demographic aspects impact Prespa Park's waste recycling practices. This specific case offers helpful information about the challenges of waste management in protected natural areas, where is of utmost importance.

The use of neural networks to describe intricate and erratic patterns in MSW formation is demonstrated in the work of reference [29]. Neural networks can assess complex and non-linear correlations within vast datasets because they are inspired by the structure and function of the human brain. Their application in waste management modeling allows for a more analysis of waste generation patterns, vital for developing effective waste management strategies [29].

Additionally, the work of [30] displays the employment of crisp and fuzzy optimization models in solid waste management. The crisp model offers precise, measurable goals and on reducing expenses and greenhouse gas emissions. As opposed to this, the fuzzy model manages ambiguous or unclear facts and goals, which is fundamental in situations with unpredictability like waste production. This dual model ensures complete waste management methods by addressing both the flexibility of fuzzy systems and the precision of crisp modeling.

Dynamic systems its pivotal to waste management modeling because it provides a thorough advancement in understanding and forecasting on how waste management systems change over time, [31]. By using a waste generation formula, dynamic models are especially good at mimicking the alterations and advancements in waste management systems over time:

$$W_t = W_0 \times (1+r)^t \quad (5)$$

Where W_t represents the amount of waste at time t, W_0 is the initial amount of waste, and r is the annual growth rate.

A notable feature of these works is the Multiobjective Optimization. This method looks for solutions that strike a compromise between goals, including environmental sustainability and economic efficiency [29]. Diverse goals may be integrated thanks to Multiobjective optimization, which guarantees that waste management techniques are both ecologically and financially sound [32]. It is also well known that genetic algorithms may mimic real-world evolutionary processes. On the other hand, System dynamics is a valuable methodology for simulating interactions and feedback within complex systems [33]. For instance, reference [32] applied system dynamics to model solid waste management in Campania, Italy. This approach helps to understand collaborative dynamics and respond to different components of a waste management system over time with various conditions and policies. The proposed model is divided into interconnected components, which represent various aspects of waste management.

The interaction between Mathematical Methods, MILP, and Dynamic Systems as a varied approach to solid waste modeling is captured by the Venn diagram in Fig. 4. The field of Mathematical Methods and MILP relates to the optimization of intricate decision-making procedures. Its focus is on improving problem-solving skills through the application of mathematical methods. Both MILP and Dynamic Systems are systematic problem-solving systems, which means that they use systematic, orderly methods to solve problems that could become more complex over time. An analytical and multidimensional modeling approach arises when mathematical methods and dynamic systems collide, showing how mathematical methods and dynamical systems can be combined and thoroughly examined. comprehensively. The ability of these disciplines to work together to create complex solid waste management models is reflected in these intersections.

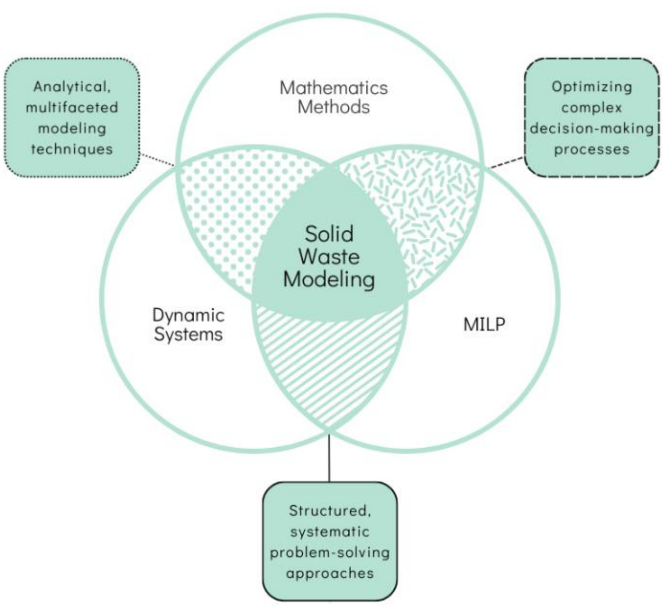

Fig. 4: Solid Waste Modeling

D. Solid Waste Generation

Solid Waste Generation refers to all the waste produced by an activity, and the management of which is pivotal for environmental sustainability. The key to this is 'Characterization,' that is a detailed analysis which identifies the types, origin, and amount of waste. These efforts are important for waste management and guide the development of strategies to reduce the volume of waste and improve resource recovery. By understanding the waste composition, HEIs can adjust waste disposal practices, improve recycling, and plan for waste disposal. Data from these studies are vital for developing models that predict waste patterns and helps institutions manage waste more effectively and reduce their environmental impacts [34].

According to the literature consulted in this analysis, the most studies emphasize the value of elaborating waste characterization using historical databases[34]. These databases are usefulness for developing predictive models, as they provide a spatial representation of MSW generation patters[35]. Studies focusing on HEIs [36] use the ASTM-D 5231-92 standards for measurement methodologies.

ASTM-D 5231-92, titled "Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste," describes a set of methods for measuring solid waste by selecting manual selection and pointer urban solid waste through the collection and distribution of samples. This includes procedures for obtaining samples, manual identification of different waste types, data recording and presentation of results [37].

In case such as the study conducted in reference [38], the selected methodologies were designed according to specific requirements of the research setting, since there are not direct standards for such specialized environments. This indicates a gap in the standardization of waste characterization methods, and it is an opportunity to develop for the development of bespoke protocols that can meet the unique waste management requirements of HEIs.

On the other hand, the studied articles show the integral role of Life Cycle Assessment (LCA) using the collected data. This method, which assesses the environmental impacts of products or processes from inception to end-of-life, has been especially useful in current research aimed to improving waste management strategies [39].

As in reference [18], this methodology emphasizes the necessity for accurate and quantifiable data and absolute quality control of data collection to consistently assess solid waste generation and treatment. LCA for MSWM focuses on the impact of waste generation and treatment technologies on LCA outcomes, considering each step [40].

The study [39] extends the analysis of LCA and Multi-Criteria Decision Making (MCDM) to assess current waste management practices and models, and show aspects of sustainability, cost effectiveness and strategic planning as key tools for solve problems as primary tools to solve environmental, social, and economic problems in the waste management process.

Reference [41] focuses on the application of LCA to assess the environmental impacts of different management strategies in New South Wales (NSW), Australia. This study explores a range of practices from incineration to waste-to-energy by comparing six operational scenarios, including land use as a baseline. Also examines adverse effects on human health and the ecosystem, indicating that waste management strategies that focus on prevention and resource recovery demonstrate the effectiveness of LCA as a critical approach to developing sustainable and efficient waste management practices.

E. Program

In the context of solid waste management, program represents a comprehensive framework aimed at rationalizing and improving waste disposal practices. But the effectiveness of these programs lies in social conditions. This includes the human factors (attitudes, behaviors, cultural norms) that play a key role in shaping the success of a waste management strategy. Programs that directly integrate these social sectors promote community participation, encourage sustainable waste practices, and create environmental protection practices [42].

Surveys are necessary, especially in solid waste management of HEIs. Their importance lies in gathering quantitative data and in capturing the perceptions and attitudes of the community, which are vital for developing comprehensive management strategies. Surveys are integrated into research to facilitate analysis and understanding of current waste management practices, behaviors, and challenges [28]. The data obtained from surveys are important variables in statistical models, improving the accuracy and relevance of predictive analysis.

Surveys also provides stakeholder views, allowing researchers to measure, the level of awareness and commitment to sustainable waste practices[20]. It also plays an influential role in assessing the understanding of the model and helping the developed strategies to focus on the needs and motivations of the industry [43].

IV. CONCLUSIONS

This study, which focuses on bringing attention to an important aspect of environmental sustainability that is frequently disregarded, has been possible to identify the distinctive difficulties and issues that these HEIs. Major points are listed in the following conclusions, which enhance how pertinent it is to adjust waste management practices and models to fit the needs of educational establishments.

- Literature review highlights:

Despite the focus on HEIs, the literature review yielded articles related to MSWM that shows the differences between methods used in research focusing on the aspects of each system and methods. These differences can be attributed to the complexity of the research, the reliance on historical data and the amount of work which is not completely comparable to HEIs previous studies focus on MSW have overlooked the unique dynamics of universities, indicating that the HEI models remain underexplored. In addition, most studies are relied on previously published information on waste characterization, which adequately suited for HEIs. Although studies use ASTM standards for waste identification, these are not ideal, especially in university settings where resource limitations hinder the adoption of these standards.

- HEI-Specific models:

Upon knowing these facts, it is important to create systems and modeling methodologies that are aimed for HEIs. Statistical methods are useful to establish different modelling methods that allow an in-depth research of waste generation trends, contributing to a better understanding of current difficulties and defining future strategies for effective and sustainable waste management, thereby contributing to the campus's overall well-being and sustainability.

- Role of social factors:

Also, it is important to emphasize into the significant role of social factors in solid waste management. Studies acclaim the requirement for structured surveys to gather perspective on waste generation and recycling behaviors and attitudes. The used of comprehensive surveys is a critical step in collecting data on how socioeconomic and demographic factors influence waste management practices. This deeper understanding is key to pinpointing improvement areas and opportunities for implementing more effective waste management strategies.

The data collected from these surveys will be a solid groundwork for establishing waste management models tailored to HEIs. Such models can specifically address the waste life cycles and the interaction of users with the current management systems. This regard will enhance the efficiency and sustainability of waste management practices in HEIs and align them with sustainable development goals and foster a culture of environmental responsibility in academia. The collection and development of waste sampling methods is an effective way to move towards sustainable waste management and understanding of HEIs. These efforts pave the way for the universities to establish a model for adopting innovative and effective environmental practices.

- Recommendations:

To enhance waste management in HEIs, it will be recommended to explore the establishment of regular training programs that emphasize the value of waste reduction at the source using reusable and biodegradable materials. It is necessary to educate staff and students on sustainable practices. Obtaining environmental certifications may demonstrate an organization's dedication to sustainability and set standards for ongoing development. Furthermore, regular environmental impact assessments of waste management procedures will support future improvement efforts by providing documentation of their efficacy.

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