Ecological Innovation in Sports Venues: A Robotic Revolution for Sustainable Waste Management in Sports Stadiums

Rishi Patel

Massachusetts Academy of Math and Science at WPI

Worcester, MA 01605

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Executive Summary

Sports stadiums and facilities historically have had a detrimental impact on the environment, causing issues such as waste management, energy consumption, and air pollution, with sports fans creating carbon footprints much higher than day-to-day activities (Wilkes, 2021). Specifically, waste management operations in sports stadiums have become a pressing environmental concern due to the significant amount of waste generated during events (Costello et al., 2017). Current disposal methods lack sustainability, posing threats to ecosystems. To address this, a robotic waste disposal system was designed for sorting fan-generated waste into recyclables, compost, and trash bins. The system streamlines the collection, enhances sorting efficiency, and reduces landfill waste, consequently lowering CO_2 emissions. To classify scanned images of different types of waste and correctly identify the waste category, the CLIP zero shot model was finetuned. Using the zero-shot model, a robotic waste disposal system was built to dispose of waste in its respective waste bin: recyclable, compost, or trash. The CLIP model was 83.0 % accurate in sorting the waste items and the robotic waste disposal system sorted ___ items every minute. Analyzing recycled and composted data allows for calculating the landfill diversion percentage by assessing waste volume/weight and categorizing prevented contributions. Additionally, evaluating diverted waste enables calculating reduced CO_2 emissions, including avoided emissions from waste decomposition and transportation. In the future, the waste disposal system could handle multiple items simultaneously and become autonomous, reducing the need for numerous robots around the stadium.

Keywords: sports venues, waste, robotic system, sustainable waste management, CLIP zero-shot model, waste classification, Raspberry Pi, CO_2 emissions, zero waste

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Academic research on greening sporting events has grown but lacks a detailed exploration of technical aspects, waste management, and operational issues. Therefore, stadiums need a device to mitigate the environmental issues caused by the lack of waste management. The goal of this project is to design and engineer a robotic waste disposal system that collects trash from fans and sorts the trash into bins for the respective waste.

Historical Impact of Sports Stadiums on the Environment

Sports stadiums and facilities historically have had a detrimental impact on the environment, causing issues such as waste management, energy consumption, and air pollution, with fans of major sports games creating carbon footprints much higher than day-to-day activities (Wilkes, 2021). For example, regarding the energy consumption in the larger stadiums in the world, the largest stadium in the NFL and home to the Dallas Cowboys can use up to 10 megawatts of electricity on a game day, which is enough energy to power roughly 3,600 homes (Wilkes, 2021). The disposal of waste resulting from these events, including packaging materials, food remnants, and other discarded items, often ends up in landfills, contributing to environmental degradation (Costello et al., 2017). Moreover, the infrastructure and facilities of sports stadiums consume considerable amounts of energy and resources. For instance, the lighting, heating, cooling systems, and transportation to and from these venues contribute to high energy consumption, resulting in increased greenhouse gas emissions (Ke, 2021). Additionally, the transportation emissions generated by fans traveling to and from stadiums have a notable impact on air quality and local ecosystems (Costello et al., 2017).

However, many sports stadiums, such as AT&T and Mercedes-Benz Stadiums, have recently created eco-friendly stadiums through their additions of renewable energy, LEED certifications, rainwater collection, and LED lighting to reduce their carbon footprint and promote the idea of saving our environment (Wilkes, 2021). Even though this process is in its early stages, greening sports has gained traction due to the efforts to gather information on energy, waste, and water usage from various sports arenas (Wharton School, 2013). Despite the fact that sporting events have a relatively minor environmental impact in comparison to big polluters like coal power plants, the movement is a small step in the right direction that aids in increasing public awareness, influencing fan behavior, and spreading environmentally conscious messages to a wider audience (Wharton School, 2013).

Environmental Concerns and Waste Generation

The waste management operations in sports stadiums have become a pressing environmental concern due to the significant amount of waste generated during events (Costello et al., 2017).

In a study done by Christine Costello, with expertise in life cycle analysis~~,~~ they collected data on the landfill-destined waste generated at the University of Missouri football stadium in 2014. According to Figure 1 an estimated 47.3 metric tons (mt) of waste was generated. The majority (29.6 mt) came from off-site, pre-game food preparation activities; over 96% was pre-consumer and unsold food waste. The remaining 17.7 mt originated from inside the stadium, with recyclable materials accounting for 43%, followed by food waste, 24% (Costello et al., 2017). Given these numbers, there is a clear necessity for an efficient waste classification and disposal system. Additionally, the large amount of pre-consumer and unsold food waste emphasizes the importance of a system that can efficiently categorize and manage such types of waste, meaning that the system will need to manage compost waste. Lastly, the fact that much of the waste produced in the stadium is recyclable materials and food waste, along with majority of the other waste being regular trash, there is also a need for a waste management solution that can effectively distinguish between different waste categories.

Table 1. Total waste estimated corresponding to football game days.

Game and Game Date	Pre-Consumer and Unsold Waste (mt) [1]	Post-Consumer Waste (mt) [2]	Game Day Attendance
South Dakota 30 August 2014	6.73	2.72	60,589
Central Florida 13 September 2014	3.41	1.90	60,348
Indiana 20 September 2014	2.86	2.31	66,455
Georgia 11 October 2014	4.16	2.64	71,168
Vanderbilt 25 October 2014	3.13	3.27	65,264
Kentucky 1 November 2014	8.45	2.14	62,004
Arkansas 28 November 2014	0.84	2.67	71,168
TOTAL	29.58	17.65	

Notes: [1] These totals are derived from waste audits associated with the food preparation and post-game disposal that occurs at the Mizzou Arena; [2] These totals are derived from waste audits associated with waste occurring on game day that is generated within the Stadium.

Figure 1: Table of total waste estimated for football games at the University of Missouri in 2014 (Costello et al., 2017)

Zero-Waste

Since it has been established that there is a need for a waste management solution that can effectively distinguish between different waste categories, the concept of zero-waste emerges as a guiding principle. The notion of zero-waste has existed for decades and challenges humans to close material loops during the production or consumption of any product or service

(Costello et al., 2017). This concept is intended to give rise to innovative and creative ideas that can achieve the zero-waste goal, ultimately creating a significant positive environmental impact. To define it in terms of the Zero Waste International Alliance, zero waste is preserving all resources through careful manufacturing, usage, recycling, and retrieval of items, packaging, and materials, while avoiding any combustion and preventing any releases into land, water, or air that could harm the environment or human well-being ("Zero Waste Definition," 2018).

The concept of zero-waste, grounded in ecological theory, aims to eliminate waste generation almost entirely during production and consumption. This goal is typically achieved by following the zero-waste hierarchy pictured in Figure 2. Most organizations aim to recycle or compost 90% of the waste stream, considering it the most sustainable option (Costello et al., 2017). However, the solutions to achieving 90% waste diversion involve complex changes in supply chains, coordination, and investment in waste infrastructure.

Figure 2: The zero-waste hierarchy

("What Is Zero Waste," 2021)

Shortcomings of Current Waste Disposal Methods

Current disposal methods often lack sustainability and cause harm to the environment, posing a threat to the surrounding ecosystems. For example, in the 2014 World Cup, an average of about 5 tons of garbage was scattered in and around the stadiums after each game. The host country, Brazil, had to employ around 850 workers to manage hygiene in the 12 World Cup stadiums (Duc Thanh, 2019). Additionally, a 2006 study in California revealed that, on average, each event attendee generated about 2.44 pounds of waste per day. Various stadiums in the US, like Beaver Stadium in Park University Campus, collected approximately 40 tons of waste after each game (Duc Thanh, 2019).

There is a clear problem with the current sports venue waste management system due to the massive amounts of waste generated at games (Wergeland & Hognestad, 2021). For this reason, addressing this issue is vital to mitigate the environmental footprint of sports stadiums and promote a more sustainable future.

Section II: Specific Aims

This proposal's objective is to provide a detailed and clear description of the project, including its goals, objectives, methodology, and expected outcomes. Additionally, this proposal should demonstrate the specific need the project addresses and why the need is crucial to focus on. In order to demonstrate the importance of this project, relevant data, statistics, and evidence will be presented.

Our long-term goal is to mitigate the environmental impact of sports stadiums by implementing a comprehensive recycling and composting program facilitated by a waste disposal system that can identify, sort, and dispose of waste into its respective waste bin. By developing this technology, the project seeks to incorporate robotic automation in the waste collection process and efficiently sort the waste into appropriate bins for recycling, composting, and trash. The central hypothesis of this proposal is that implementing such a robot in sports venues will significantly reduce waste sent to landfills, ultimately leading to a reduction in CO_2 emissions into the atmosphere (Buzby, 2022).

Specific Aim #1: Develop an image classification system which can correctly identify the waste's category: recyclable, compost, or trash. With the image classification system, the goal is to build a camera that uses the system's algorithm to scan any waste placed in a tray and correctly identify the waste's category.

Specific Aim #2: Build a waste system that will dispose of waste into its respective waste bin: recycling, composting, or trash. This system will be equipped with a tray where the waste will be placed by the user, a camera that identifies the waste category, an Arduino that controls the motors' function based on the relayed information from the camera, and motors that will move the tray above the respective waste bin for disposal.

Specific Aim #3: To determine the effectiveness of the robotic waste disposal system, it will be vital to calculate the impact the device has on CO_2 emissions.

The expected outcome of this work is a high-tech functioning waste disposal system that can sort waste based on its scanned image and then dispose of it into one of three possible bins: recycling, composting, or trash. This process will ultimately relieve the user of identifying their waste's category when disposing of it. Also, and most importantly, this waste disposal system will decrease the portion of waste sent to landfills, ultimately decreasing carbon emissions.

Section III: Project Goals and Methodology

Relevance/Significance

Historically, during big sports games in stadiums, the fans are known for inaccurately disposing of their waste–throwing all their waste in the trash bins–which contributes to environmental degradation (CleanRobotics, 2022). The project's relevance stems from its commitment to addressing these issues innovatively through introducing a waste collection system that minimizes the work needed to be done by fans in the waste disposal process. The methodology aims to revolutionize traditional waste management practices in stadiums, offering a solution that aligns with the zero-waste concept ("Zero Waste Definition", 2018). The project's goals extend beyond waste reduction, directly impacting the carbon footprint of sports events by lowering CO_2 emissions associated with waste disposal (Buzby, 2022). Additionally, the project serves as a real-world example of sustainable practices in the sports industry. It demonstrates the practicality and advantages of incorporating technology-driven solutions for environmental improvement. Ultimately, the project's methodology will not only enhance the overall fan experience by simplifying waste disposal but also set a standard for replicable sustainability measures in sports venues, contributing to the broader implementation of environmentally viable practices. While waste classification model developed in this project cannot be used outside of a sport's venue, with more finetuning with waste data sets that comprise of all types of waste, this system could be applied to areas outside of sport's venues.

Innovation

This project stands out through its innovative integration of advanced image classification, specifically the finetuned CLIP zero-shot model, for sustainable waste management in sports stadiums (Radford et al., 2021). The approach showcases a unique and non-traditional solution that relies on sophisticated algorithms and a waste-scanning camera system. This departure from conventional robotics-based waste management initiatives emphasizes efficiency, cost-effectiveness, and ease of implementation, making this project a distinctive and inventive contribution to sustainable practices in large-scale event venues.

Methodology

Technique 1: Finetuning CLIP Zero-Shot Classification Model

First and foremost, the CLIP model is put through a finetuning process using a meticulously prepared waste dataset. This involves the implementation of transfer learning techniques to specifically tailor the model for the task at hand – classifying waste items into recyclable, compost, or trash categories.

Technique 2: Integration with Camera System

Moving on to the second step, the integration with the camera system becomes a pivotal focus. The camera system used was a Raspberry Pi camera. Here, the objective is to either develop a waste-scanning camera system with the capability to capture images of waste items arranged in a tray. The next crucial sub-step involves seamlessly integrating the finetuned CLIP model into this camera system. This integration aims to create a unified and functional solution that enables real-time waste classification.

Technique 3: Classification Process Testing and Validation

The third step in the process revolves around testing and validation. Extensive testing is conducted to rigorously evaluate the accuracy and performance of the integrated camera system and CLIP model. To ensure robustness, a diverse array of waste items is utilized to assess the model's proficiency in correctly classifying different categories.

Technique 4: Optimization and Iterative Refinement of the Model

Following the testing phase, the optimization and iterative refinement step takes center stage. Results from testing are thoroughly analyzed to pinpoint areas for improvement. Subsequently, an iterative refinement process ensues, involving adjustments to hyperparameters or the incorporation of additional data. The overarching goal is to enhance the model's classification accuracy.

Technique 5: Build the Robotic Waste Disposal System

The fifth step involves the actualization of the Robotic Waste Disposal System. This entails the design and construction of the waste bin disposal system using an Arduino and motors. Crucially, the waste-scanning camera system is seamlessly integrated into this robotic system, allowing for efficient scanning of the waste.

Technique 6: Analysis and Reporting on the Robotic Waste Disposal System

In the final step, an in-depth analysis and reporting phase ensues. The collected data is meticulously examined to assess the success of the waste disposal system. Detailed reports are then generated, shedding light on the environmental impact, the reduction in waste sent to landfills, and the overall efficiency of the implemented system.

Specific Aim #1: **Develop an image classification system which can correctly identify the waste's category: recyclable, compost, or trash. With the image classification system, the goal is to build a camera that uses the system's algorithm to scan any waste placed in a tray and correctly identify the waste's category.**

Justification and Feasibility. The methods outlined in the methodology directly address Specific Aim 1, focusing on finetuning the CLIP zero-shot model for waste classification and building a camera system for real-time waste identification. By finetuning the CLIP model with a prepared waste dataset, the algorithm becomes adept at recognizing distinct features of recyclable, compostable, and general waste items. Integrating this finetuned model with a waste-scanning camera system creates a unified solution, allowing the camera to accurately identify waste categories when items are placed in the tray. Extensive testing, including diverse waste items, ensures the reliability of the system, validating the CLIP model's real-world performance. Iterative refinement further enhances the model's accuracy, and the subsequent development of a robotic waste disposal system with Arduino and motors ensures the practical application of the project's goals in a functional manner.

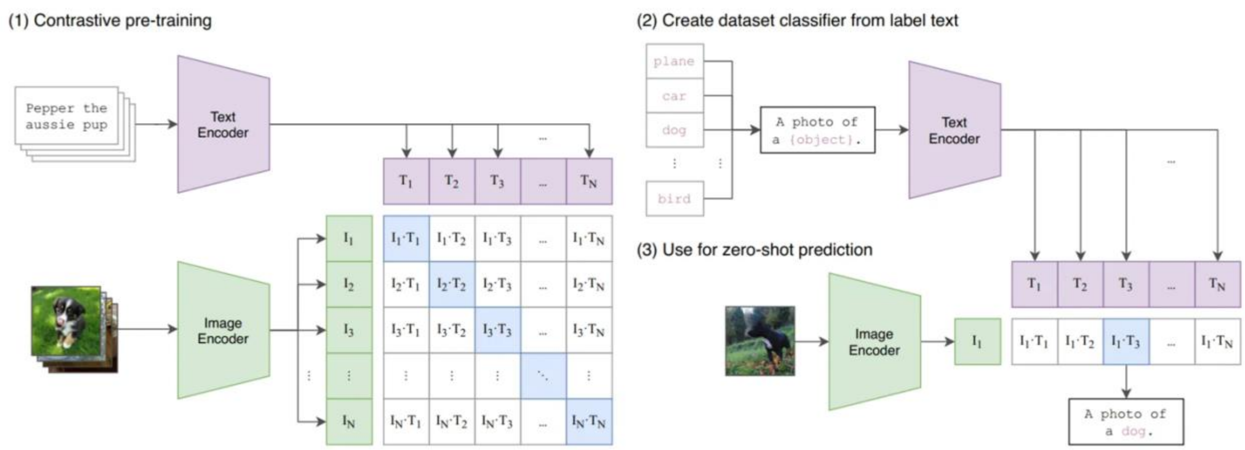


Figure 3: Flowchart diagram for CLIP model

(Shariatnia, 2021)

Expected Outcomes. The overall outcome of this aim is to develop a high-level functioning CLIP model that can accurately identify the category of unique waste items and to integrate this algorithm into a camera system that will execute the function of the model. This knowledge will be used for the entire robotic waste disposal system, allowing it to accurately sort waste into its respective bin.

Potential Pitfalls and Alternative Strategies. We expect the potential pitfalls to include challenges related to the representativity of the prepared waste dataset, the risk of overfitting during CLIP model finetuning, and complexities in distinguishing visually similar waste categories. Alternative strategies used to mitigate these challenges include diversifying the dataset to encompass a broader range of waste items, implementing regularization techniques to prevent overfitting during model finetuning, and exploring hierarchical classification for more nuanced identification. Addressing these considerations will enhance the reliability and efficiency of the waste management system in sports stadiums.

Specific Aim #2: **Build a waste system that will dispose of waste into its respective waste bin: recycling, composting, or trash. This system will be equipped with a tray where the waste will be placed by the user, a camera that identifies the waste category, an Arduino that controls the motors' function based on the relayed information from the camera, and motors that will move the tray above the respective waste bin for disposal.**

Justification and Feasibility. The methods outlined for Specific Aim #2 directly address the goal of building an effective waste disposal system. The tray system provides a user-friendly interface for waste placement, while the camera system captures and identifies waste categories using the finetuned CLIP model. The integration of an Arduino control unit processes information from the camera, directing motors to move the tray above the respective waste bins. The motors, under Arduino control, execute the final step, ensuring accurate waste sorting into recycling, composting, or trash bins. This integration of user interaction, computer vision, and mechanical functionality forms an efficient waste management system made to achieve the objectives of Specific Aim #2.

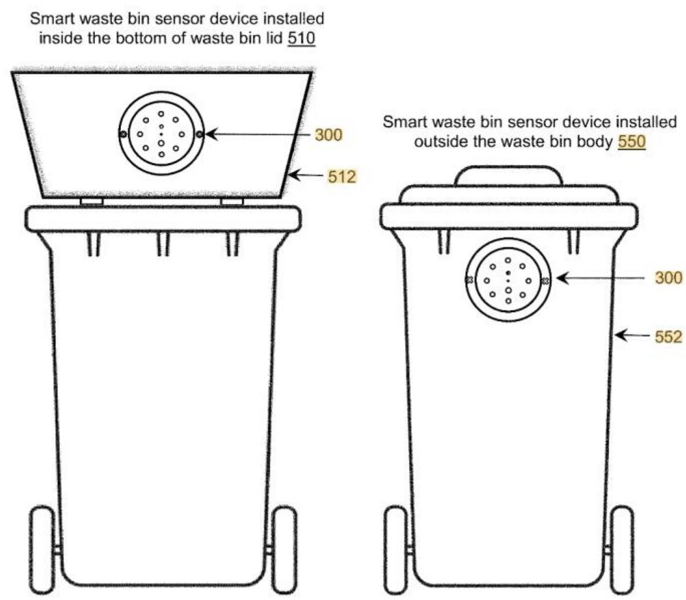


Figure 4: Diagram of waste disposal system from patent US11702280B2

(Kurani, Hetal and Kurani, Hemal, 2023)

Expected Outcomes. The overall outcome of this aim is to design and build a functional robotic waste disposal system that integrates the camera system technology.

Potential Pitfalls and Alternative Strategies. We expect to face potential challenges such as inaccuracies in waste recognition by the camera system, communication delays between the camera and Arduino, motor malfunctions affecting tray positioning, and potential user interface issues. Alternative strategies could include implementing redundant camera systems for enhanced accuracy, employing advanced communication protocols to reduce reaction time, incorporating motor redundancy and regular calibration to ensure precise movements, and integrating user guidance technologies to assist users in correctly placing waste items on the tray.

Specific Aim #3: **To determine the effectiveness of the robotic waste disposal system, it will be vital to calculate the impact the device has on CO_2 emissions.**

Justification and Feasibility. The methods outlined play a vital role in evaluating the effectiveness of the robotic waste disposal system in reducing CO_2 emissions. Through data collection during system deployment and continuous monitoring of performance during sports events, the project gathers data on waste diverted from landfills. The subsequent analysis of this data assesses the system's success in reducing CO_2 emissions by diverting waste from landfills. Additionally, the environmental impact assessment provides a comprehensive understanding of the waste disposal system's contribution to reducing its carbon footprint. The generation of reports consolidates findings, offering a clear overview of the system's environmental benefits and impact on CO_2 emissions.

Material	1	2a	2b	3 *	4 *	5a		5b		5c		5d *		5e *	
						E	I	E	I	E	I	E	I	E	I
	Percent of total weight														
Aluminum Cans	1.2	1.2	1.2	1.2		1.2		1.2		1.2		1.2			
Glass	2.8	2.8	2.8	2.8		2.8		2.8		2.8		2.8			
LDPE	4.0	4.0	4.0			4.0		4.0		4.0					
PP	4.0	4.0	4.0			4.0		4.0		4.0					
PS	4.0	4.0	4.0			4.0		4.0		4.0					
Corrugated Containers	7.9	7.9		7.9		7.9		7.9				7.9			
Food Waste (non-meat)	5.1	5.1	5.1	5.1	5.1	5.1		5.1		5.1		5.1		5.1	
Beef	5.7	5.7	5.7	5.7	5.7	5.7		5.7		5.7		5.7		5.7	
Poultry/Pork	10.3	10.3	10.3	10.3	10.3	10.3		10.3		10.3		10.3		10.3	
Bread	13.4	13.4	13.4	13.4	13.4	13.4		13.4		13.4		13.4		13.4	
Fruits and Vegetables	30.7	30.7	30.7	30.7	30.7	15.5	15.1	15.5	15.1	15.5	15.1	15.5	15.1	15.5	15.1
Dairy Products	4.2	4.2	4.2	4.2	4.2	4.2		4.2		4.2		4.2		4.2	
Mixed Paper (general)	4.3	4.3		4.3		4.3		4.3				4.3			
Mixed Plastics	2.4	2.4	2.4	2.4		2.4		2.4		2.4		2.4			
Mixed Organic			12.1		12.1					12.1				12.1	
PLA				12.0	18.4							12.0		18.4	
Waste management category key:						landfill		recycle		compost		source reduction			

Notes: * Indicates that the scenario would achieve > 90% diversion of waste from the landfill. "E" is an abbreviation for edible. "I" is an abbreviation for inedible. Sums of percentages may not equal 100% due to rounding.

Figure 6: Summary of waste management scenarios, represented by percent weight of materials generated over the 2014 football season at the University of Missouri.

(Costello et al., 2017)

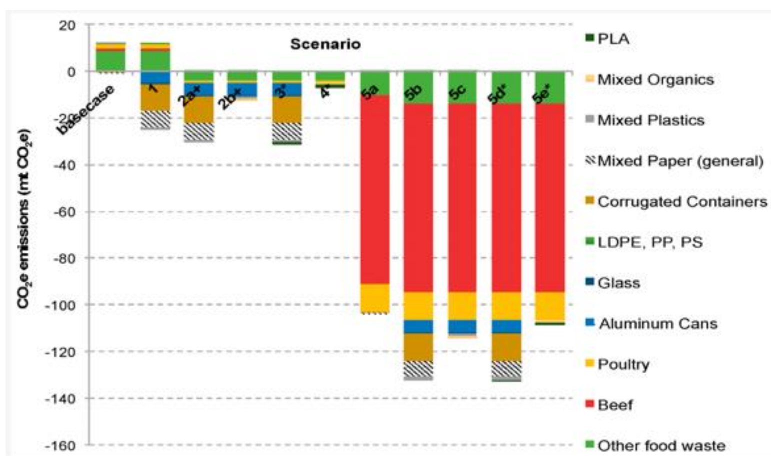


Figure 5: Greenhouse gas emissions estimated for each waste management scenario modeled in Waste Reduction Model (WARM).

(Costello et al., 2017)

In the study done by Christine Costello and others, as referenced earlier, they calculate the impact of each waste disposal strategy discussed in the paper (see Fig.5) on greenhouse gas emissions (Costello et al., 2017). They utilize a bar chart in Figure 6 to show how each waste disposal strategy affects greenhouse gas emissions.

Expected Outcomes. The overall outcome of this aim is to assess the environmental impact of the waste disposal system, specifically looking at the greenhouse gas and carbon emissions. The expected outcome is that the disposal system will decrease the carbon emissions, proving an environmentally sustainable waste system.

Potential Pitfalls and Alternative Strategies. We expect potential pitfalls for evaluating the system's impact on CO_2 emissions to include incomplete or inaccurate data collection and limited analysis of collected data. These pitfalls may compromise the accuracy and reliability of the assessment. Implementing advanced data collection technologies for more accurate and comprehensive data capture should be considered. An example would be image data augmentation or image cleansing to increase the clarity of the images in the dataset. Additionally, extending the assessment period allows for a more thorough evaluation of the robotic waste disposal system's long-term impact on CO_2 emissions. These alternative strategies aim to improve the overall reliability of the environmental impact assessment.

Section IV: Resources/Equipment

- CLIP zero-shot object classification model
- Google Colab
- GitHub

- Kaggle
- Waste categories datasets via Kaggle
- Raspberry Pi 5
- Raspberry Pi Camera
- Motors
- Waste bins
- Stainless-steel tray

Section V: Ethical Considerations

This project does not involve humans or animals in the designing, building, or testing phases.

However, one potential safety concern is the possibility of technical failures or malfunctions in the robot's electrical systems or mechanical components. Such failure could cause electrical hazards, potentially causing a dangerous incident with an individual. Implementing strict protocols for regular maintenance and safety checks can ensure the robot's mechanical and electrical systems are functioning properly. To ensure safety at all times, the precautions would include routine inspections and following the safety guidelines. If any safety guideline is failed by the robot during a routine inspection, that would mean that the system be shut off instantly and taken to be fixed for future use.

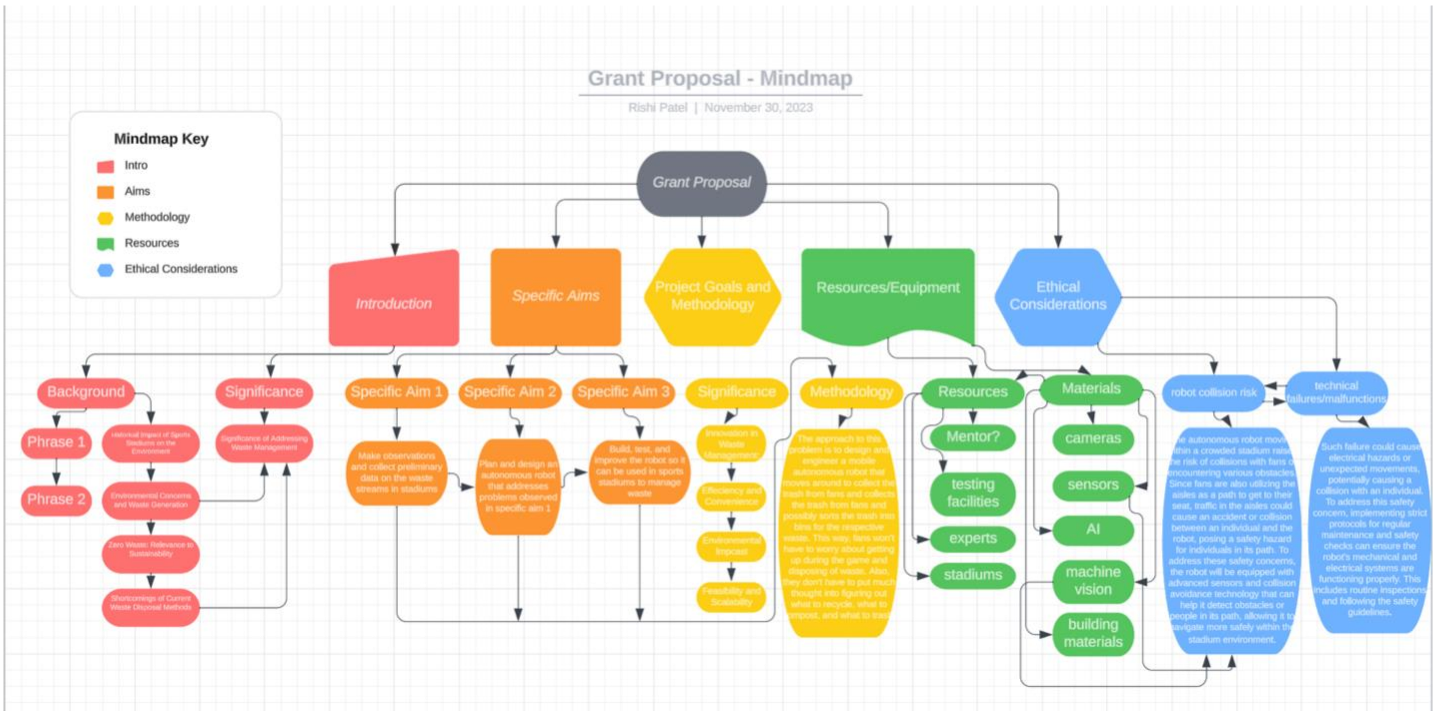
Section VI: Timeline

- 11/1 - 11/19 Phase 1: Research
  - Developing an engineering need
  - Determining how to fulfill the engineering need
  - Determining materials, resources, and professionals needed to complete the project
- 11/20 - 12/3 Phase 2: Design

    - Develop a strategy to design the prototype
    - Develop a strategy to make the prototype autonomous
- 12/4 - 12/12 Phase 3: Procedure and Improve Design
    - Learn how to program autonomous machines
    - Design the prototype and test the feasibility
    - Figure out the materials needed to build a prototype
- 12/13 - 1/14 Phase 4: Building and Testing
    - Start building the prototype
    - Integrate autonomy into the prototype
    - Test prototype

Section VII: Appendix

Appendix 1: Mind Map of the Grant Proposal



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