Senior

REMATE

Liceo Scientifico “E. Amaldi” Bitetto

ITALY

Don’t waste your time

Robotic **e**cological **m**ulti-waste **a**utomatic **t**rashcan **e**

Remate is a smart bin that has the task of recognizing and sorting waste. Unlike all other products on the market, it is able to work with multiple waste instead of one at a time.

Table of contents

Team presentation

The team is composed by three senior year students from the “Edoardo **Amaldi**” Scientific High School in **Bitetto**, in the south of Italy: **Andrea** Tarasca, who attends Applied Sciences scientific course, **Giulio** Gismondi and **Paolo** Vairo, who attend the traditional scientific course. Our journey into robotics began a few years ago, thanks to school initiatives which led us to become passionate about computer science, mechanics and electronics.
In the last three years we have taken part in several national and international Computer Science and Robotics competitions, including the Italian Robotics Championship, which we won in 2024, and the Maker Faire Rome 2023. We are now an established team and this year we have decided to participate in the WRO.

Figures 1, 2, 3, 4. The team at WRO National qualifiers 2024, Maker Faire Rome 2023 and Italian Robotics Championships 2023 and 2024

Giulio served as **project manager**. He was responsible for organizing and managing the resources at our disposal, whether economic or human. Finally, he was responsible for writing the Python code and training the **Artificial Intelligence** model on which the project is based.

Andrea took care of the **mechanical design** of the prototype, 3D printing, video editing and everything related to the communication of our project.

Paolo designed and built the **Hardware** and **Software** components. He designed the hardware component, built the project, and wrote the algorithms that allow the project to run in the Arduino language.

Summary of the project idea

According to the "What a Waste 2.0" [1] World Bank report, by **2050** the amount of municipal **waste** will **increase** by 70 percent, from the current 2.01 billion tons to 3.14 billion tons. This increase is caused by population growth, expanding cities and increasing economic activities.

The problem of waste is one of the most worrying for our planet. It is essential to find innovative solutions to address the environmental and economic problems associated with waste disposal. Analyzing the solutions already available, we realized some **gaps** and thought we would have a try at solving them.

One effective method to reduce the environmental impact of waste is **separate collection**, which involves separating trash according to the material of which it is made. This facilitates recycling and allows more waste to be reused. Thus, the goal is to increase the number of waste sorted so as to **reduce** the use of **landfills** and incineration plants, and to achieve an environmental and economic return.

Smart bins are devices that can automatically recognize and sort waste. Typically, these devices take photos of waste and recognize it through Artificial Intelligence models. In order to capture the environmental and economic benefits, a device that solves the largest problem of existing smart bins is needed: in fact, all smart bins on the market process a **single waste** at a time.

In other words, users are not free to throw a whole bag of waste inside the bin, but must take one piece of waste at a time, place it inside the bin, and wait for the bin to sort and differentiate it; the process takes several seconds for each piece of waste.
This problem makes large-scale implementation of such devices **impossible**. It is essential to provide the users with the ability to throw away whatever they want whenever they want, leaving all the work to the machine. And that is what Remate sets out to be: a smart dumpster that can handle **multiple** pieces of **waste** at once. We strongly believe that autonomous solutions like Remate are the future of waste separation.

Our current prototype is able to autonomously sort plastic bottles and metal cans; due to its materials (which were chosen in order to disassemble and travel by airplanes and trains) it isn't at the stage of a finished project. However, we are currently working on iterating on the mechanical design to create value in **real life situations** by building a sorter of this kind.
In order to get some **early feedback**, we plan to dispose these sorters in waste collection centers, where operators would otherwise sort waste by hand.

The **long term goal** is to place multi-waste autonomous smart bins in public places in population centers, where they can give out the best value and actively reduce the number of unsorted waste.

Robotic solution

The idea

As soon as we discovered the theme of the competition, we immediately thought of the problem of waste. During the **brainstorming** phase, we got curious about bins able to autonomously sort waste, and we understood that it was a feasible project for our skills and knowledge. We were aware of the large number of such devices on the market; therefore, we initially thought of designing an **open source** bin with the intention of lowering costs and facilitating the diffusion of these devices.

We later analyzed **competitors** on the market and scientific research on the subject, and realized that none of them had yet made an industrialized device or even a prototype capable of handling a waste stream comparable to that of a trash can or street dumpster, in which users put multiple waste items at the same time.

The company that was perhaps the first to launch a trash can that can recognize waste autonomously is **Bin-e** [2]. Their device has a great strength: it is incredibly accurate at recognizing waste. In fact, it has an accuracy of 92 percent. However, like all smart bins on the market, it recognizes and sorts a single waste at a time, and is for this reason extremely slow. Contrary to what one might think, the Convolutional Neural Networks that are used to classify images are actually quite fast: on embedded systems running the model locally, the inference time can be estimated to be under 100 ms. Yet, to these timescales additional time must be taken in consideration: time it takes to take the picture, the time it takes to insert the waste into the bin, and the time it takes to mechanically sort the waste. Taking these additional times into account, an even fairly optimistic estimate of the time required to sort a single waste is 2 seconds. To sort for example **100 pieces** of waste, it would take almost **3½ minutes**.

Figure 5. Bin-e smart bin

All existing devices are used in **controlled settings** such as offices, hospitals and schools, where single waste smart bins can be used without too many problems. So we reevaluated our idea and decided to build a prototype that was on the way to solving this problem.

Finally we **validated** our idea by talking to several engineers, including Giuseppe Falagario, Talent and Innovation Manager from SITAEL [3], an italian tech company, and mechanical engineer Mario Gismondi, from Sidercamma [4], an italian company that specializes on waste management facilities.

With the aim of realizing a device capable of handling multiple waste items at the same time, we designed a **mechanical separation** system, which is in charge of dividing the waste that is placed by the user inside the device.
To cover the case where the separation system was unable to properly divide two or more waste items, we trained on a custom dataset an **Artificial Intelligence** model capable of recognizing multiple objects in a single image, unlike Image Classification models implemented by competitors and researchers.

General workflow of the prototype

The prototype workflow begins with the **placement** of the waste inside the loading hopper. In this section, the waste is pushed down by a rotating **paddle**, which drops it onto a surface.
A **camera** captures the surface and records frames in real time. The frames are fed into an **AI**, which recognizes the waste and informs the device of its presence. Based on the recognized waste, different motors are activated, and the waste is **dropped** into one of four baskets located below the prototype.

Figures 6 and 7. The plane where waste falls, the camera

Technical overview

Please be aware that some minor changes will be made before the presentation at the WRO Global Final.

The **structure** of the prototype is made of wood, aluminum, and plexiglass. The hardware consists of two **boards**, namely a Raspberry Pi 4 and an Arduino Nano Every. The Arduino Nano controls the **motors** of the mechanical separation system while the Raspberry handles the **camera** and sends and receives data from an external computer that runs the Artificial Intelligence model that recognizes the waste. The software thus consists of three scripts, run by the Raspberry Pi 4, the Arduino Nano and the external computer.

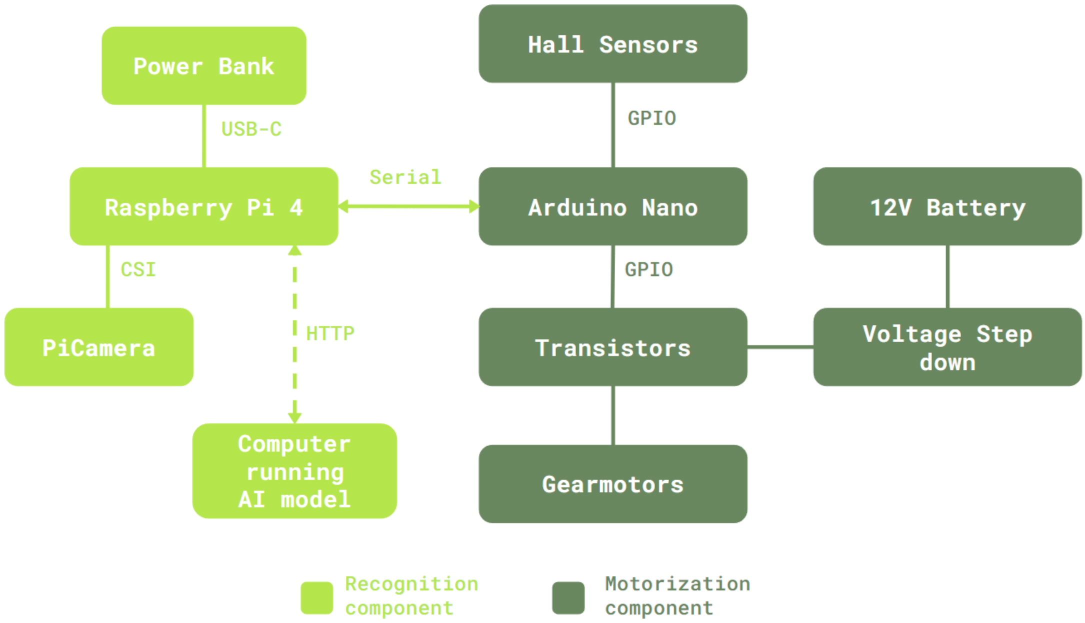


Figure 8. System architecture

Mechanics

The prototype structure is made of laser-cut wooden parts, aluminum uprights recovered from construction material used in our school, and plexiglass, purchased by our school for the Covid 19 pandemic but never used. We designed the structure in 3d with a CAD software. The mechanics is divided into three separate compartments, each with specific functions.

Figures 9 and 10. Prototype structure (without the plexiglass)

Loading hopper

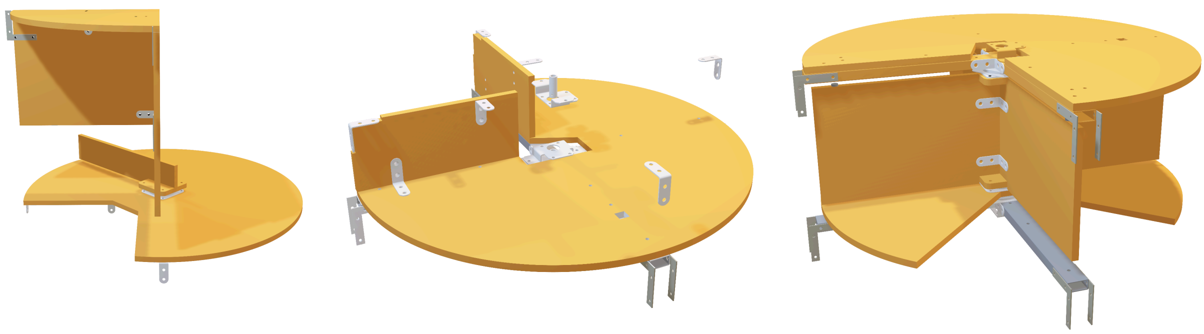
Consists of a fixed circular disk with an empty sector, above which is placed a wooden addition, aimed at preventing the direct fall of waste into the lower compartments. Mounted in the center of the disc is a **rotating paddle** on a fifth wheel, driven by a motor located below the disc, whose function is to gradually drop the waste through the **empty sector**.

Electronics section

Separated by upper and lower fixed circular disks, it contains most of the **electronics** and hardware components. This part is laterally enclosed by two wooden walls, which prevent accidental entry of waste. This section also stores two of the three motors used in the prototype.

Sorting section

Consists of two rotating elements: a **disk** with a **hollow sector** and separators arranged to form a cross. The **separators** are able to rotate thanks to a motor located above, while the disk motor is located below it. Both motors are aided by slewing rings to make the movements smoother. These mechanical components are designed to sort the recognized waste by **dropping** it, through the **empty sector**, into the appropriate bins, which are placed below the disk.



Figures 11, 12 and 13. Loading hopper, electronics section and sorting section

Electronics

The motors are powered by a 12V lead-acid battery reduced to 6V by a voltage regulator. The boards and all other components are instead powered at 5V by a power bank. To move the rotating parts of the prototype we use 3 gearmotors of 12 and 20 RPM. The 12 RPM motor is used for the paddle and is driven by the Arduino Nano through a transistor. The two 20 RPM gearmotors are used for the separators and the rotating disk; 8 transistors allow us to manage the motors and move them in either direction. The prototype also uses hall sensors and magnets to find the position of the rotating parts.

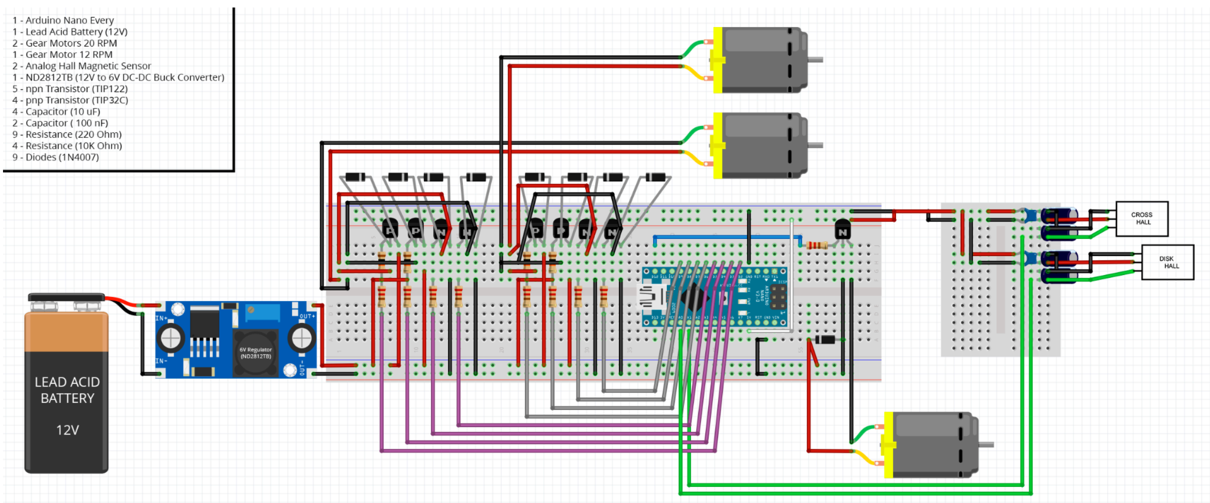


Figure 14. Schematics of the project

Software

The software is divided into code run on the **Raspberry Pi 4,** code run on the **Arduino Nano**, and code of the external **computer** running the AI model, which is (in our case) a laptop with an Nvidia 4080 GPU.

Raspberry Pi 4 code

The code executed by the Raspberry is written in **Python** and is responsible for taking images from the camera in **live stream** and acting as a bridge between the server and the Arduino Nano, which makes the motors move. Therefore it handles at the same time an **http** communication with the computer running the AI model and a **serial** communication with the Arduino.

To summarize, the Python code workflow of the Raspberry Pi 4 is this:

1. Opens serial communication with the Arduino Nano
2. Opens the camera and starts writing data to the buffer
3. Opens http communication with the Computer
4. Looping:
    a. Sends a frame
    b. Gets the prediction of the AI model
    c. Sends the prediction to the Arduino Nano via serial communication

AI Server code

The AI Server code is also written in **Python**. It takes care of getting the frames from the camera live stream with a **GET request**, performing model **inference**, filtering the results, and sending the predicted class to the Raspberry Pi 4 with a **POST request**.

To summarize, the Python code workflow of the AI Server is this:

1. Sends the GET request to the Raspberry Pi 4
2. Looping:
    a. Extracts the single frame from the buffer
    b. Executes the model on the single frame
    c. Extracts the predicted class
    d. Sends the prediction to the Raspberry Pi 4 via a POST request

Arduino Nano code

The code executed by the Arduino Nano is responsible for managing all the motors based on data received from the Raspberry Pi 4 via serial communication. To achieve this, it utilizes PNP and NPN transistors configured as an H-bridge for both the cross and disk motors, as well as a single NPN transistor to control the paddle motor. Finally, to ensure that the motors stop in the correct position, it reads analog data from two Hall magnetic sensors.

To summarize, the workflow of the Arduino code is this:

1. Initializes serial communication for data exchange with the Raspberry Pi 4
2. Configures input and output pins for managing the Hall sensors and the transistors
3. Looping:
   a. Manages the paddle's movement, pausing every 200 milliseconds
   b. Monitors for incoming data from the Raspberry Pi 4
   c. When the Raspberry Pi detects a waste, the paddle is stopped and the waste is in the corresponding bin
   d. Sends feedback to the Raspberry Pi and resumes the paddle's movement

Artificial Intelligence

As anticipated earlier, our approach employs a model that is able to detect multiple items simultaneously. In particular, the model we use is an **Object Detection** model.
Object Detection models classify objects and locate them based on four points, i.e., the coordinates of the vertices of a rectangle enclosing the recognized object.

Figure 15. Object detection output

Dataset

We built a **custom** dataset consisting of images belonging to two classes, namely “Plastic Bottle” and “Can.” The images were acquired using a Raspberry Pi Camera and annotated through the Roboflow platform. Looking forward, additional datasets, such as TACO[5], NUNIWaste[6], TrashCan[7] e MJU-Waste[8], are planned to be integrated with the goal of making the model effectively usable in the **real world**.

Model

The model used is a **YOLOv8**, which was chosen for its excellent performance/light weight ratio. We started with a pre-trained model and did transfer learning using our custom dataset. To train the model, we converted the labels of the dataset to the appropriate format and ran the training with the Python ultralytics library on an Nvidia 4080 GPU.

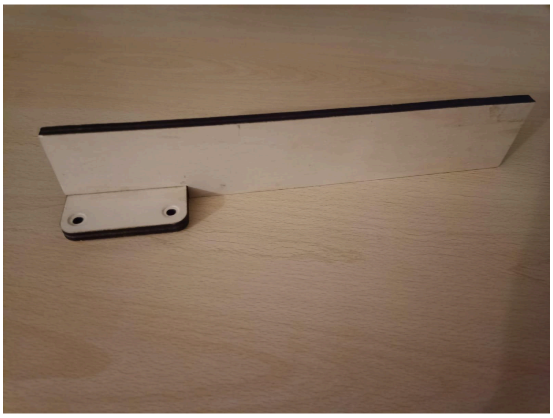
Challenges faced

The biggest challenges we faced are inherent in the most innovative components of our prototype.

By far the biggest problem we faced was that of **waste separation**. We immediately realized the difficulties that our first version of the separation system had in getting one waste to separate from the other. Even at the design stage we realized that this would be the biggest challenge, so we quickly realized the need to make the paddle move in steps, so as to give the model time to recognize one waste before pushing down another.

The original separation system worked with a 12V battery, and as a result the paddle motor moved more quickly but roughly, causing more waste to fall at once. Moreover, the dustpan had a simple but non-functional design. Over the months, we adopted mechanical, electronic and software solutions to solve this problem.

To begin with, we modified the design of the **paddle** to make it more **functional**. We also added plexiglass **curtains** similar to those on conveyor belts, which reduce the risk of more waste falling at once. Next, we used a voltage regulator to reduce the speed of movement. Finally, we significantly reduced the time it takes for the device to stop the paddle (and consequently prevent other waste from falling) once it recognizes an object.




Figures 16 and 17. Old and new paddle design

Social impact and innovation

Social impact

To live, we human beings produce waste. This is a reality we cannot change. What can be changed is what we do with this waste: do we exploit it as a resource or do we waste it, causing great harm to our planet?

The first step in exploiting it as a resource is separate collection. In general, sorting waste means **facilitating** processes that reduce its environmental impact, such as recycling and composting. It is much more complicated to reduce the impact of unsorted waste.

Italy produced 29 million tons of municipal waste in 2020[9]. Of this 63% is sorted waste and 37% is unsorted. Overall, 30% of municipal waste is recycled and 26% goes through composting processes. The waste recovered through these two management processes is mostly the sorted waste. However, the municipal waste that is not sorted, or 37%, causes a great environmental and economic impact. In fact, 23 percent of municipal waste is incinerated or sent to landfill, and 21 percent is burned to generate energy.[10].

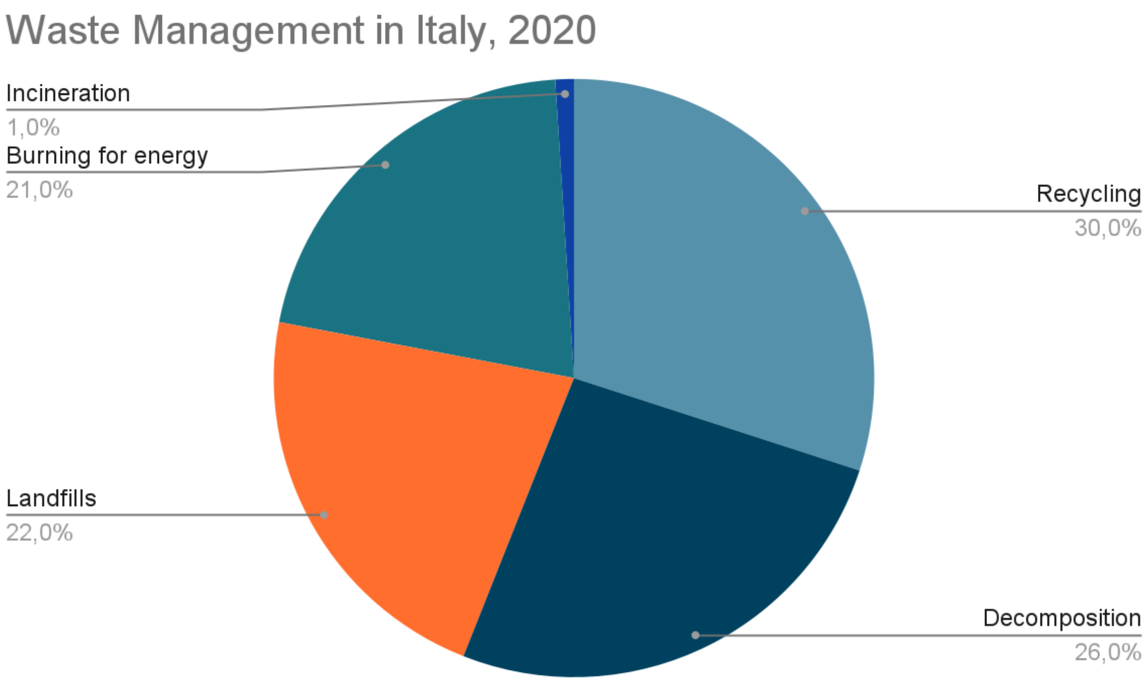


Figure 18. Waste management in Italy in 2020

The target of our device are the population centers of **middle/high income** nations. In contexts where deployment of Remate-like devices is possible, they can lead to environmental and economic benefits.
From an environmental point of view, Remate would allow more **accurate sorting** and, replacing mixed waste bins, a **reduction** in the amount of **unsorted waste**.

Increasing the accuracy of waste collection means facilitating the separation work that is done in large industrial plants. In this way, much less waste is produced as waste and released into landfills. Improving sorting in terms of **quality** and **quantity** results in less waste being landfilled, incinerated, or burned to recover energy.

On the other hand, from an economic point of view, waste segregation leads to its increase in value. Entities that purchase waste from local municipalities pay more for separated waste because it is easier to obtain recyclable material from it and thus make a profit. Increasing the value of waste means **increasing the profit** of the government agencies that manage it and consequently increasing funds and services for the community.

The context in which Remate can have the greatest impact is in **large cities**, where waste management is very complex. For example, waste management in Rome is ineffective: it causes constant inconvenience to citizens, has a significant environmental impact, and results in a loss in the municipality's profit in selling waste to third-party entities.

Figure 19. Dustbins in Rome

In **Rome** in 2022 [11], only 45 percent of the municipal waste produced was sorted. All unsorted waste is naturally more difficult to recycle; therefore, it is an environmental and economic loss. Unsorted waste is mostly collected from the streets, where huge dumpsters are placed.

Although the bins are separated, citizens often disregard the signs, resulting in poor collection accuracy and less sorted waste.

Replacing the bins with Remate would make citizens' work easier, improve collection accuracy, and enable the city of Rome to gain economic gain and lower its environmental impact.
Exactly like Rome, dozens of other large cities around the world have poor waste management. Remate can help cities improve the **quality of life** for citizens, reduce their **environmental impact**, and increase **revenue** from waste sales.

Entrepreneurship aspects

Innovation

No smart bin currently on the market is capable of working with more than one waste at a time. The real innovative component of the prototype is the **division** system. This is the beating heart of the design, around which all other technical components revolve and on which the accuracy of segregating waste depends.

Resources study

While we have successfully utilized technical expertise to achieve the current level of functionality, advancing towards a fully market-ready product introduces **new demands** that extend beyond technical capabilities alone. As financial considerations become increasingly significant in this phase, it is essential to make a comprehensive analysis of required resources to inform and facilitate strategic planning for the next steps.

The hard skills needed for project development in the coming months are:
- Management skills
- ML development
- Embedded software development
- Industrialized electronics design
- Industrialized mechanical design

Recognizing the importance of these skills, we see a clear need to strengthen the team with someone who brings advanced **managerial expertise**. Moreover, given the complexity of individual waste separation, we have determined that a senior professional with a strong background in **industrial design** would be invaluable.

In addition, we would also need economic resources to support the process of prototype iteration and subsequent development of the actual industrial product.

Next steps

The very next step is definitely to expand the team to include someone with economic and project **management** skills. Furthermore we believe in the imminent need to lean on a startup **accelerator**/incubator to have support in the early stages of fundraising and prototyping at the industrial level. During the next 6 months the goal is to **iterate** as quickly as possible and get feedback. In particular we plan to get feedback in a more controlled scenario: waste collection centers. In our local collection centers, operators sort waste by hand: this is therefore the perfect context to test and evaluate our ideas.

At the end of the 6 months we would like to have a working prototype in the **real world**, even if in a limited context such as waste collection centers, in order to have more credibility in the eyes of investors and get funding.

In the year following the next 6 months, we plan to design and build, with the help of a highly experienced mechanical engineer, an actually **saleable** and usable device.

References

[1] https://www.worldbank.org/en/news/infographic/2018/09/20/what-a-waste-20-a-global-snap shot-of-solid-waste-management-to-2050
[2] https://bine.world/
[3] https://www.sitael.com/
[4] https://www.sidercamma.it/
[5] https://arxiv.org/abs/2003.06975
[6] https://link.springer.com/article/10.1007/s11042-024-18265-1
[7] https://arxiv.org/abs/2007.08097
[8] https://arxiv.org/abs/2007.04259
[9] https://www.catasto-rifiuti.isprambiente.it/index.php?pg=nazione&aa=2020
[10] https://www.isprambiente.gov.it/files2022/pubblicazioni/rapporti/rapportorifiutiurbani_ed-2022_n-380_agg-23_12_2022.pdf
[11] https://www.catasto-rifiuti.isprambiente.it/index.php?pg=detComune&aa=2022&regidb=12&nomereg=Lazio&providb=058&nomeprov=Roma&regid=12058091&nomecom=Roma&cerca=cerca&&p=1&advice=si