The Smart Trash Can

Final report Engineering Design (4WBB0)

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1. Group effectiveness

The fact that the project was developed with group members in different majors, having different interests and backgrounds, of course leads to a specific way of working and a well thought out task distribution. This group effectiveness is of great importance in the project. The reason for this is that it determines almost completely crucial aspects in the project such as complexity of the prototype, sufficient workload, a good atmosphere, a smooth transition between the seven phases and hence at the end a neat product. Therefore, we, as a team took the principle of group effectiveness very seriously from the beginning and thus applied strengths of each group member as effectively as possible. This means we also had to deal with certain weaknesses and preferences of different members. This will all be discussed in the paragraphs below.

First of all, which different general fields would be required for our product. We defined these fields in four technical and five non-technical categories. The four technical categories were defined as follows: electronic/electrical components, programming and server hosting, physical appearance and user interface. The latter one includes a light touch of all three categories named in front of it. These can all be seen in figure 1, together with the non-technical skills which will be discussed later. This categorization is of course extremely rough and in practice cannot be taking this literally. An example for this is a display that shows our users some basic information on our product. We defined it to be in the last-mentioned category. However, it demands talents from all four expertise's combined and thus is not that clear cut. The five non-technical categories, or with a better name, skills, where the following: cooperation, communication, writing, time management and creativity. These skills are certainly as important as the skills in the technical categories as they are essential when it comes to cooperation in a group project and to document its results. Because it was clear from the beginning that we were quite profound in all the technical skills as a complete team, we put the focus on these non-technical skills. We researched them and then discussed as a team which were the most important or prominent in our project (Indeed Tutorial Team, 2021).

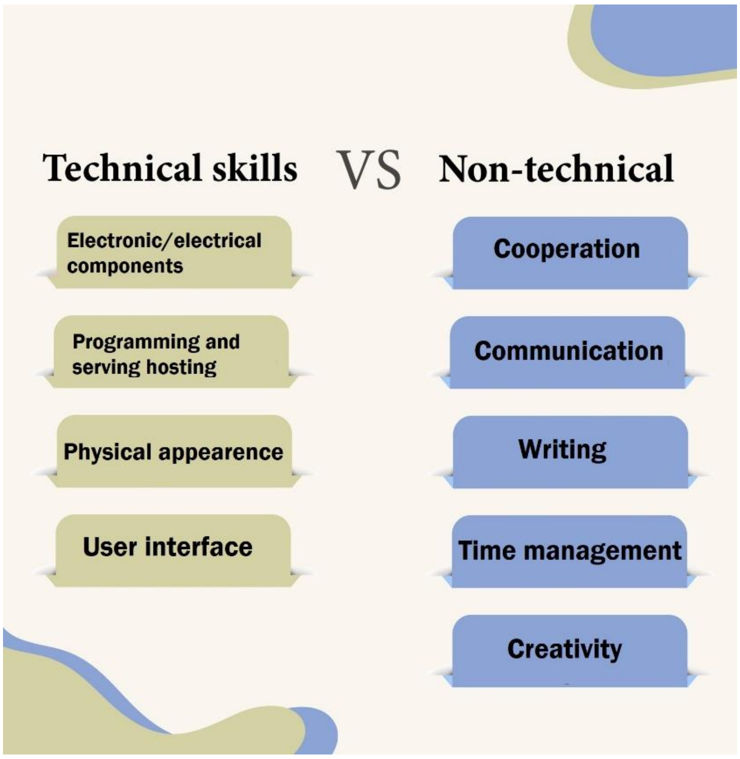


Figure 1, The technical and non-technical skills necessary to the group project

After we had made this categorization, we could start and divide individuals and their strengths according to the best and most efficient fit possible. When doing this, we did not only take into account each major. This means that blindly giving an Electrical Engineering student all of the wiring tasks or giving an Industrial Design student the task of designing the physical format was a no go. We used a couple of criteria to do this. These included someone's knowledge (which happened to roughly coincide with each major), new learning goals, hobbies and preferences. The total effect resulting from this categorization, step by step task distribution and applied personal criteria was that we already had an exquisite group effectiveness from the start. However, to keep the principle of improvement open we decided to always be open to switch team members to other fields or tasks if needed. This would then be discussed in the group meetings and then approved or disapproved.

Next up was our method of dealing with potential weaknesses of team members. It is of course good and all to try to use strengths of each member as effectively as possible, but it is also crucial to deal with weaknesses appropriately. As explained before, the first and most important thing was to not expose those weaknesses at all by looking at specific personal criteria. Nevertheless, it is almost impossible to completely reduce the possibility of dealing with weaknesses to zero. This is why we used a couple of solutions to fix these situations where inadequacies had to be suppressed.

The first method was presenting in the group that someone was stuck at a specific task or casus. He would then present his way of thinking and what the problem encompassed. Group members could then give tips and tops or possible solutions to solve the faced problem. Other times two members would team up and help one another. When this method would not give any advancements after a given amount of days, we would switch tasks between members and thus let someone with more knowledge and experience in the field try to solve the issue.

The second way of resolving possible weaknesses of members (or even remedy them for good) was the procedure to look for CBL modules that specifically addressed the problem that was faced. We however have not needed this last resort option, luckily. This option also included asking professionals such as experienced people in soldering or programmers for help.

Before concluding our group effectiveness, the most prominent developments in our group will be mentioned. In the beginning of the project, some of the meetings were quite static as not everyone talked as much or gave input. This was in many situations the result of shyness or others talking more than average. This however quickly changed and meetings started to get much more dynamic and therefore more interesting. Also, the Self Study Assignments were in the beginning sometimes not that elaborated. The research done at home was very deepening and effective for the project, but the accent was therefore not on writing it down in the report for the others. This was smoothly addressed when we talked about the importance of this information for the group as a whole in the meetings.

To conclude, the group effectiveness was already highly valuated from the beginning and thus researched very thoroughly at the start. The whole group was familiar with working in a Design Based Learning project and therefore knew that having a strong foundation to start from is important. Doing this strengths-weaknesses analysis and finding each team member's skills in the first meeting is always extremely valuable and does not take too much time. This then leads to not encountering many obstacles or weaknesses in the first place. As also explained before, to nevertheless keep improving the group effectiveness we had certain methods to tackle occurring problems by asking for help at other team members, working with two persons on one task, switching from tasks or even ask professionals for a possible solution.

2. Design goal

Litter on the street and in nature is still a big problem in society (Dijk, 2022). People throw away trash on the street every day. Trash thrown away on the street has a massive impact. The trash will end up on land and in water. This has large negative consequences for the environment and the livability of humans and animals (Milieu Centraal, 2022). A big example of a consequence of littering nature is plastic soups. 80 percent of all the trash that ends up in the ocean in a plastic soup comes from the land (Cho, 2011). The trash in the plastic soups last immensely long, because it often takes a long time before this litter is broken down. For example, plastic bags break down in 10 to 20 years, while bottles break down in 450 years and there even are some plastic items that will last for 1000 years (LeBlanc, 2015). This has a massive negative consequence for the livability of sea animals, they will ingest plastic rubbish thinking it is food or they can become entangled in, for example, plastic bags (Reddy, 2018). Furthermore, it also has a massive negative consequence for the livability of animals on land, and eventually for the entire ecosystem because in nature everything is closely related and so it has consequences for everything that goes with it and people are part of that too (Reddy, 2018).

Our focal area is of course the whole world, since throwing away litter in nature or on the street is bad for the environment all over the globe. But we focus on the Netherlands and especially the big cities like Eindhoven. Furthermore, we focus especially on young people aged between 16 and 25, because we still have a lot of progress to make within this group. For example, most beverage cans litter is caused by people between the ages of 16 and 25. Moreover, people under 30 are more likely to change their behavior because they are more impressionable than people aged over 30 (Oosterveer, 2012).

For the problem of litter being thrown onto the streets and in nature society already has a solution, namely a trash can. However, we believe that just a trash can does not motivate and encourage people enough to stop throwing their trash on the street instead of in the trash can, since there is still too much litter on the street instead of in a trash can. Therefore, we want to improve the concept of a trash can, since we do believe that the solution to reduce litter on the street and in nature is some sort of trash can, but with some sort of motivation added to the design of a trash can. The concept of trash cans is already known to people, and we believe that an improved trash can would be easy to implement in today's society. We will come back to how we envision our idea into society in a further paragraph.

In order to understand how we can have an impact on the behavior of our target group, we need to know what the best way of motivating them is. We can create motivation in two different ways, by punishing and rewarding people (Potts, 2012). We tend to think that punishment helps people from preventing bad behavior. However, this already has been put into reality, because it already happens with fines for throwing waste in public space. And it appears not to be enough of a motivation for people. Of course, we know that several factors play a role here, such as that catching it in the act is very hard. So, we needed to find another way.

In contrast to punishment as a way of motivating people, it seems to be more effective to reward good behavior, because when a reward is given relatively immediately after the task in question, it strengthens the association between its activity for the task and what the goal of the task in question was. This strong association makes people give a feeling as if the activity of the task itself is rewarding, regardless of the reward (Kelley, 2018). This has to do with the increase of the positive experience of the task by receiving the important outcomes for the motivation and the persistency.

In other words, throwing away trash on the street is in this case the bad behavior. And throwing away the trash in a trash can is the task that needs to be rewarded in order to prevent the large negative consequences for the environment and the livability of humans and animals that littering nature and littering the streets cause.

Therefore, we came up with a smart trash can that gives you money that you paid for extra when buying a product at the supermarket. Motivation through stimulation and not punishing is effective, especially with money as a reward for throwing away the trash at the right place. Eventually, throwing away trash in trash cans will be an association with doing something rewarding, which is exactly what we want. We already have a system in supermarkets where you can hand in empty bottles at supermarkets and get so-called 'statiegeld' as a reward for the activity. In this way, supermarkets can recycle the empty bottles and reuse them, which prevents them from making new bottles, needing a garbage dump somewhere else and prevents municipalities from having high cleaning costs of cleaning up litter and emptying public bins. This 'statiegeld' system has been proven to work, since it is already implemented in supermarkets in for example the Netherlands, Germany and Norway (Buurman, z.d.). For Dutch municipalities alone, the savings from this system can be up to 80 million euros annually (Buurman, z.d.). Furthermore, in Germany and in Norway, after they have been introduced to this deposit system, recycling rates have reached up to 90 percent (Buurman, z.d.).

So, what we want to achieve is that we implement this process, which is already known to people and is proven to work, into the trash can itself that we will be placing in public space outside. A difference to the 'statiegeld' system is, however, is that we don't want only glass and plastic bottles to be able to be thrown away into our trash can, we want our trash can to receive all kinds of litter. We are talking about waste from banana peels to plastic bottles, because our main goal is to keep the trash of the street out of nature. In order to achieve this, we want to work together with the government and supermarkets to be able to realize this on a large scale. For the government, this should be really appealing, because as we said, it will prevent municipalities from having high cleaning costs of cleaning up litter and emptying public bins. For Dutch municipalities alone, the savings from this system can lead up to 80 million euros per year (Buurman, z.d.).

For us as a group to try and realize a prototype of our concept fits perfectly with our backgrounds, strengths and weaknesses. As most of this is already discussed in section one of this report, we could divide tasks on the realization part really well. Some of us are really good at electronics, some of us are well known with doing good research, some of us are good at coding and others are experienced with physical prototyping. All this together, we believed that it would lead us to a desirable and innovative product as our smart trash is meant to be.

3. Functional design and solutions

The most significant consideration was that the device meets its purpose as a trash can that lowers the amount of rubbish discarded outside of trash cans. Therefore, it requires some functional characteristics to make waste disposal easier or more fulfilling for the user.

The most obvious requirement for a trashcan is that waste can be discarded without difficulty.

To make it possible for consumers to reduce waste, we must make it easy for them to dispose of rubbish in the first place. We identified the steps that must be taken to make it possible for individuals to dispose of trash without difficulty:

1) The trash can's height must be appropriate. It must be easy for everyone to utilize the garbage can. However, this is problematic because people vary in height. We cannot position the entrance too high, as it would be inconvenient for short people and vice versa.

Because there is no such thing as an ideal height that is convenient for everyone, we had to be creative. Therefore, if the entrance is neither too low nor too high for anyone, the remedy would be to enlarge it. In such a situation, everyone will be able to dispose of rubbish without difficulty. The larger hole is also advantageous because it will allow for the disposal of larger objects. The height of the trashcan's opening would be inserting the height here>. This ensures that both short and tall individuals may access the garbage can without difficulty.

2) The placement of the garbage cans is also one of the most crucial factors to consider. Many individuals are unwilling to transport waste to the trashcan if they must walk or drive a considerable distance. It would be ideal if garbage cans could be placed wherever on the street. However, that would be too expensive. Therefore, we must carefully consider where to place the garbage can. Supermarkets would be an ideal location for placing garbage cans. Since consumers are already bringing their bottles to the grocery store, it would need no effort for them to also bring their garbage containing deposit.

3) The garbage can must also be simple to use. As a result, we have chosen not to produce a garbage can that requires its users to separate their rubbish. This would deter consumers from placing their trash in the trashcan since it would be too cumbersome to separate the waste. We may have been able to develop a trashcan capable of segregating waste on its own, but we lacked the resources and time to do it.

In addition to these three factors, there should be a factor that compels consumers to throw away their rubbish. Several factors can encourage people to utilize the problem. One of these is the color of the garbage container. When the garbage can is grey, it does not stick out and people will link the hue with being dull or outdated. Therefore, if the objective is to encourage people to utilize the trashcan, a different color must be used. There are certain hues that subconsciously urge individuals to discard waste. Yellow is one of the colors we may employ. According to research, yellow trashcans have a favorable effect on the amount of trash that is deposited in them. Green is also a hue that encourages individuals to go to the beach. Because people link the color green with money, users will be encouraged to dispose of their rubbish in order to collect the deposit on their trash. Red may also have a good effect on the number of those who wish to use the trashcan. Red is said to urge folks to approach without their conscious awareness. Therefore, individuals may elect to discard their rubbish earlier.

Money is also a powerful incentive for people to dispose of their rubbish. Therefore, if we are able to collaborate with retailers and/or the government, we can actualize something similar to what occurs with our bottles and, in the near future, cans in the Netherlands. People will receive a tiny amount of money that they overpaid for groceries.

To make this principle a reality, it is required to equip our trashcans with the ability to recognize what is discarded, who discarded it, and to return the deposit to the customer.

4. Concept designs

A major concern in this current time period includes littering and improper disposal of waste products. An average individual produces trash at a rate of 4.4 pounds per person per day, which contributes to about 3.5 million tons of plastic and other solid waste a day (Picarazzi, L. (2019, 10 januari)). littering Is highly detrimental to the environment as degradation of litter release chemicals and microparticles. These toxins can make their way into the soil and freshwater sources. While 19.9% litter on land comes from unsecured items in the back of trucks or trash receptacles, most of the litter originates intentionally. Thus, in order to reduce littering, we must understand as to why people litter intentionally. A few reasons can be laziness or carelessness, lack of access to trash receptables and lenient law enforcement (Texas Disposal Systems, (2022, 3 augustus)). Other reasons to litter are largely based on environmental cues (or what people see around them). For instance, if an area is highly littered, people are most likely to add more waste, while the cleaner an area already is, the less likely people are to disrupt the area by littering. Thus, we must come up with a solution to create an environment where people feel less discouraged and are less likely to litter. As a result, we created a set of exploratory prototypes to reach our goal.

Concept design:

The main objective of our project is to expand the idea of an already existing system “statiegeld”, imposed by the Dutch government . Here plastic bottles have an added deposit of 15 or 25 cent depending on the size of the bottle. On returning the bottle to a nearby supermarket the individual will get the deposit back. Our aim is to create a trashcan that returns a deposit back to an individual on throwing an item, with a deposit on every package bought by them. This in return will help to maintain a cleaner environment and encourage citizens to throw out garbage in trash cans.

Prototype 1:

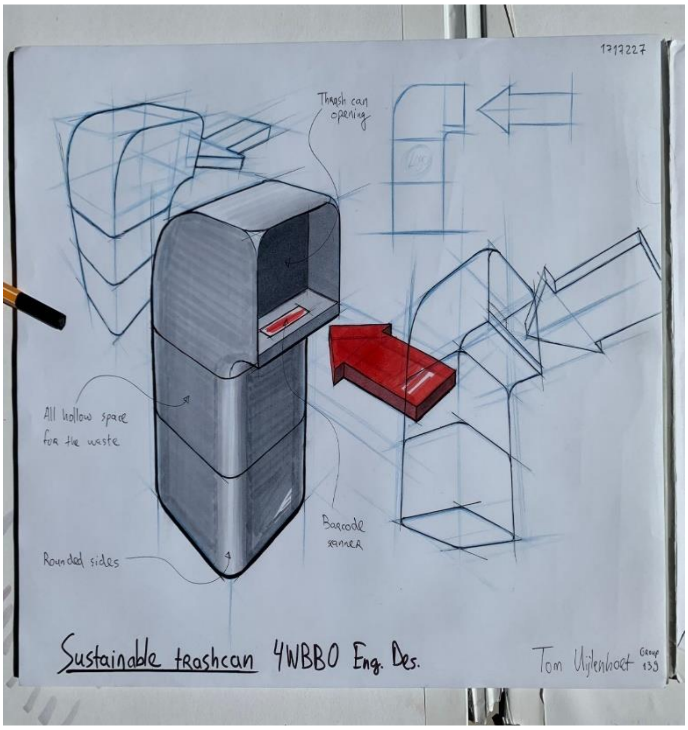


Figure 2, Initial sketch of the prototype

The initial sketch of the concept design includes creating a trashcan with a custom QR scanner, LCD display and NFC/RFID scanner. Here the main idea is that every packaging will have a certain deposit added to it. The package will then have a barcode assigned and that item will be saved to a database which keeps track of barcodes valid for a refund. The consumer will have a NFC tag which contains data regarding the package and the deposit allocated to the item. When the consumer disposes the trash into the trashcan, the scanner scans the barcode present on the packaging. On scanning the NFC tag onto the NFC scanner, the consumer receives the deposit back, which was designated to the packaging. The display then displays the amount compensated back to the individual, thereby indicating a verification. In order to make a connection between the NFC, LCD display and scanner we make use of the Arduino microcontroller. The Arduino microcontroller will be embedded with the devices in order to control the actions and features of the combined product. In order to make the prototype itself, the team made use of wood to make a general base of the trashcan, along with white sheets

Prototype 2:

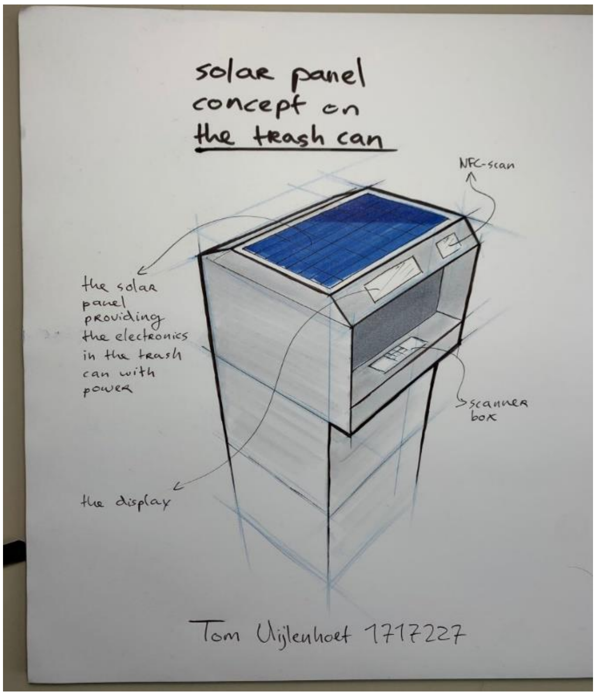


Figure 3, Sketch of prototype with solar panel

In order to make the prototype more sustainable, the team came up with the possibility of attaching a solar panel onto the trashcan which will supply power to the Arduino, thereby providing power to the entire system (NFC, display and scanner). The LCD display and scanner require 5V of power, whereas the NFC tag requires 3.3 V of power. The Arduino itself already consists of a 5V and 3V pin, which will provide energy to the display and NFC, after they are embedded with the microcontroller. The Arduino itself requires about 5 volts of power. One way of solar powering the Arduino is by using DFRobot Solar Power Manager 5V. The battery must be connected to the solar power manager. The solar terminal needs to be located on the solar power manager and this must be connected to the Arduino via the USB port. This will power the entire Arduino, which in return will power the entire system, when placed outside in direct sunlight. However, adding a solar panel to the final product is out of budget and will be an additional amount of work. Along with the possibility that people might fidget with the solar panels which might hinder the functionality of the solar panels. Also solar panels contain toxic materials like lead that can leach out as they breakdown, resulting in the creation of solar e-waste , which in turn creates new environmental hazards.

Prototype 3:

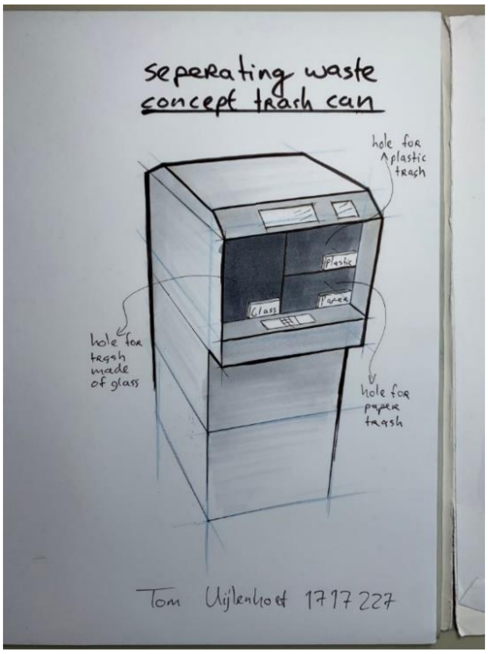


Figure 4, Sketch of prototype with recycling system

The main intension of our project is to encourage individuals to throw out trash and prevent littering. However, in order to create a more sustainable environment, the team must encourage recycling. A possible idea was to create a trashcan that could segregate recyclable and non-recyclable trash. This could be done by attaching separate tubes to the trashcan itself and programming the Arduino in such a way that that it can detect and separate the trash. However, there are some issues with recycling plastic and other waste. Plastics are made of several different polymers, thereby making it almost impossible to recycle different plastic waste together as they melt at different temperatures. As a result, before plastics can be recycled properly, they need to be separated, which is time consuming and costly. Thus, this system won't be added to the protype due to lack of resources and technology.

Prototype 4:

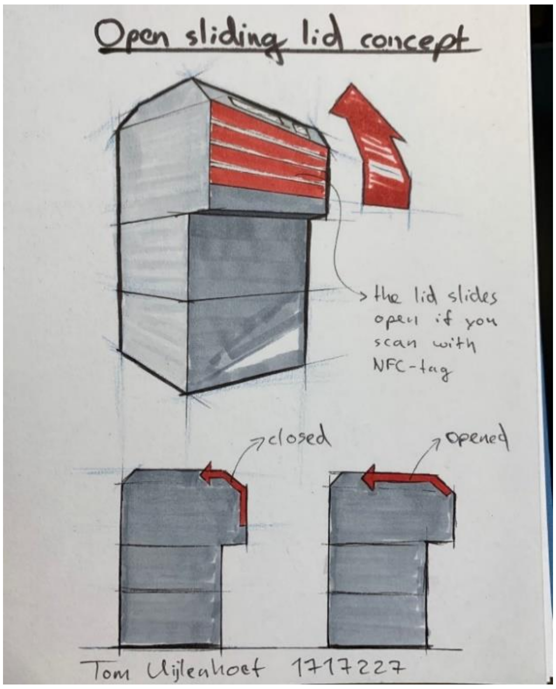


Figure 5, sketch of prototype with mechanical lid

Another proposal the team was skeptical about, was including a lid on the smart trashcan itself. Including a lid to the bin will prevent invasion by pest, insects and reduce odor. Covered bins also protect the bin opening from filling up with rainwater which can cause overflow if exposed to rain for long period of time. However, since our goal is to encourage individuals to throw out garbage, a trashcan without a lid will be much more convenient as it will be quick and easy to dispose trash. Not having to open a lid makes disposing trash more easy, convenient and hygienic. Adding a mechanical lid also requires extra maintenance which adds to the cost. Since we want to make the trashcan accessible to the entire public, adding a lid will be an extra burden as it restricts access to only those individuals who have a NFC tag which is linked to the trashcan, used to open the lid.

5. Final concept design

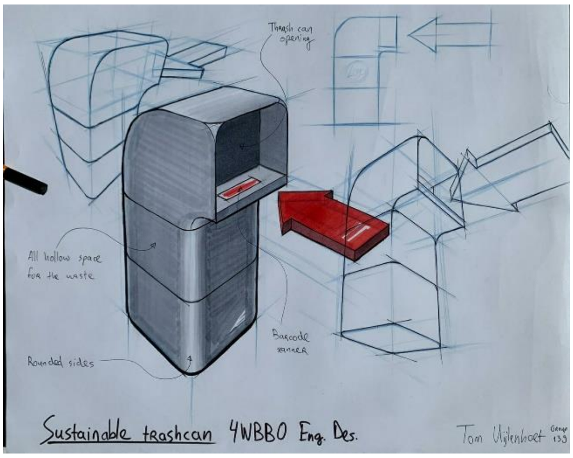


Figure 6, initial concept design.

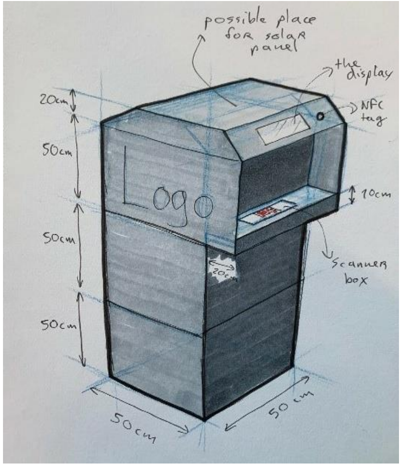


Figure 7, final concept design with updates in height and shape

Based off the various exploratory prototypes mentioned in the concept design, the final concept design is shown above. The absence of the lid makes it attainable to the local public situated near a specific area, along with individuals wanting to attain a refund back on their disposed trash. The height is perfectly made, such that it's easily accessible to all the general public. The screen is placed at an angle that makes the screen easily visible and clear. The system does not consist of a recycling system, as it will force individuals to segregate their trash and throw it away separately. It is applicable for any sort of trash, making it more user friendly.

This smart trash can enable individuals to throw garbage, and on doing so he/she will get the deposit back that was assigned to the packaging of the trashcan. The trashcan consists of a scanner, NFC, and display. The scanner, placed at the bottom of the lid is used to scan the barcode placed on the packaging. The NFC scanner placed on top of the trashcan is used to scan the NFC tag. On tapping the NFC tag on the scanner and throwing away the scanned trash, the total amount of returned deposit is stored in a separate database. The display also shows the total amount refunded back to the individual. Login out happens automatically or is done by tapping the NFC tag again. This system is sustainable yet user friendly, as it's accessible to the entire public. This means that throwing away trash without a barcode is also possible. The supposed color of the trashcan is meant to be green, since it implies that individuals will get money on disposing of waste. This is one way to captivate and motivate people to throw away waste.

6. Technical specification

Based on our MOSCOW prioritization:

- Our product must be equipped to do the required processing, by establishing connection between different sensors and the onboard Arduino. This processing encompasses scanning a barcode, determine the user via the NFC reader, sending and receiving data to the database via a server and showing instructions on a display.
- Our product should have sensors which provide an interactive interface with the customers.

- Our product could use solar panels as a power source; however, it wasn't feasible within our budget. If our product is launched through large scale production, it might lower our product cost, thus help us in including solar panels for power.
- Our product, however, will not have sensors to help segregate waste depending on its type (plastic, metal, etc.) due to space limitations, time & budgetary restrictions . Also our project's main initiative is to inculcate sustainable behavior among people by throwing waste into a trash can.

The technical elements needed for the product's functioning are as follows:

- Microcontroller: A physical programmable circuit board, used to connect and run sensors. Based on the requirement of digital and analog pins & power, the Arduino Mega seemed to be the perfect fit. The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. This provides support for different types of components and sensors.

- QR/Barcode reader: The scanner uses infrared LEDs and phototransistors to distinguish white and black surfaces on the barcode. A model circuit is shown in figure 8 below. Once connection is established with the microcontroller, it will pass a discreet voltage difference between detecting much infrared light (white objects such as white paper) and a low intensity of infrared light (black ink). The difference will be around 2.5V when the phototransistor in the upper left corner detects infrared light, and 0V when it detects no infrared light (black patches absorb all of the light and thus do not reflect any of it back into the phototransistor). This voltage difference can then be used by the microcontroller to tell this color difference. A basic 3x3 QR (used as the barcode) can then already have 512 possibilities. Only 140 of these possibilities can be implemented in a real world situation as we had to remove some to make the remaining 140 QR-codes rotating resistance. This means that rotating the package with 90 degrees does not change your QR/barcode (figure 1a). The number 140 was obtained using a computer program (figure 3a) that removed any duplicates. Also, a proven formula was used to end up in the same answer of 140 (figure 2a). The specifications of the scanner circuit are as follows. For R1, a plane potentiometer is used. It is a resistor which can vary its resistance between its three pins (for example, it can divide its total 50kOhm as 20-30kOhm, or 10-40kOhm). The Op-amp (the triangle component) is of the type LM324N. It is a quad package that contains four individual operational amplifiers in one compact format. Three of them are used, as the QR code/barcode will have 9 different regions to scan. R2 and R3 have been chosen appropriately. R3 is 100ohm as it is only used to limit the current through the LED. R4 is 84Kohm which gave the right amount of sensitivity. The LED is a plane red one, as it will only be used for checking if the output is correct. The 5V power that is also visible in figure 8 is supplied by 6 1.5V AA batteries in series. This means their total voltage will be 9V. This means that the 9V should be transformed down into 5V. This has been done by a static voltage regulator, meaning that it can take a range of input voltages and transforms this to a static 5V. Research was done in the datasheet of the regulator (type LM7805C) to find this range and it turned out be a 5 to 18V. A circuit diagram can be seen below, together with the physical component (figure 9).

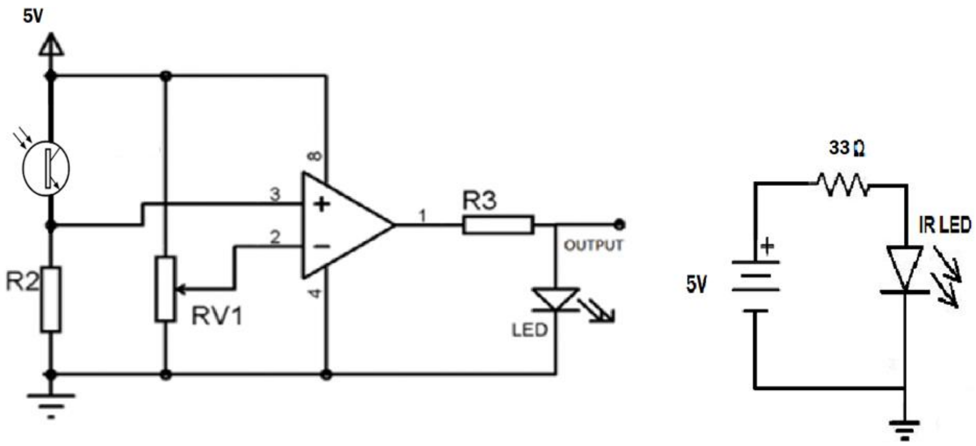


Figure 8, the circuit of one scanner module. This was built 9 times, for each patch on the QR-code.

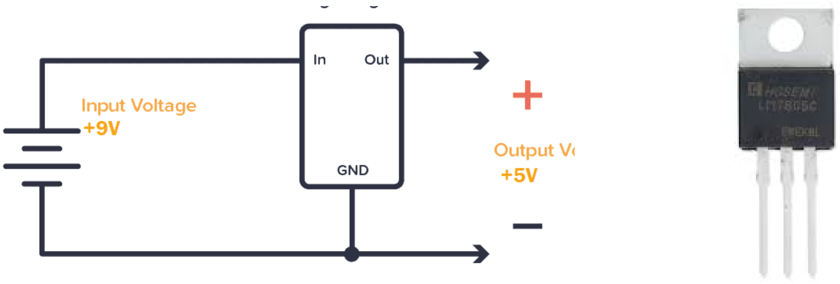


Figure 9, The circuit diagram of the power supply of the scanner, together with the physical component

- System for suitable user interface:
    - Display: The prototype's display is an LCD with a resolution of 20*4. The first 5 pins of the 16-pin LCD include the general conditions. It features a GND (ground pin), a VCC (which connects to the Arduino board's 5 volts), a Vo (to which we can attach a potentiometer to change the display's contrast), an RS (used to send commands to the LCD), an R/W pin to read or write to the LCD, an e pin to enable writing to the LCD, a D0-D7 (for sending 8 bits of data), and a pair of pins It has the ability to print text messages, texts, and a list of symbols.
    - NFC/RFID reader: The architecture of an NFC reader is standard: it consists of an antenna, a matching circuit, the NFC IC, the host controller, and, optionally, a contact reader and a SAM module. Based on compatibility with the microcontroller, the MFRC522 reader was chosen as a suitable sensor. MFRC522 is a highly integrated RFID reader/writer IC for contactless communication at 13.56 MHz. The MFRC522 reader supports ISO/IEC 14443 A/MIFARE and NTAG. The operating voltage of the RC522 module is 2.5V – 3.3V. Even though the maximum supply voltage is 3.3V the communication pins are 5V tolerant. So, we can connect the module directly to an Arduino without any Level-Shifters. The NFC tags have 1024 bytes of data storage divided into 16 sectors and each sector is protected by two different keys, A and B. The MFRC522 has both reading and writing capabilities to the NFC tags.

7. Detailing

- Our product uses a financial incentive to help tackle the littering problem. Deposit is charged while buying a package and refund is done at the trashcan upon proper disposal. The necessities needed to fulfill the tasks are an product identifier, user identifier, user interface, server hosting a database and a physical design.
  a. Product identifier: For our product, we have a 3*3 barcode scanner which scans the barcodes that are added to the package. The barcodes are saved onto a database when a product is bought, and the deposit is paid. The scanner was built from scratch by a fellow team member. The scanner uses IR and photoresistors to capture the barcode. Based on code type, there are 512 possible permutations based on the formula shown in figure 2a. However, rotations of the code while scanning could cause errors, therefore eliminating rotation possibility decreases the possible permutations to 140.
  b. User identifier: Our product uses an NFC reader which is placed on an inclined surface. NFC format is widely available in the form of tags, in a smartphone, etc. Any such form can be used, once the user has registered himself with one of them particularly. The database contains user information that can be stored locally or online (based on the scale of production and implementation). The server would have saved valid QR codes, and odes, save user information and have networking capabilities (sending and receiving data).
  c. User interface: An LCD display is integrated into our product at an incline for providing information to the user while also engaging them. It welcomes the user upon scanning an NFC tag and displays the balance credits upon once a package is scanned.

- The 3 main key components for the design are:
  a. Facilitation: The system must provide users with an incentive to use and an ease of using. The product shouldn't be too complex to use, neither should it have reasons to restrict anybody from the target audience. The sensors used in our product follow the shortest algorithm (steps needed to be done by the user for disposal) while retaining user interaction. Providing the user an interface to interact would help engaging them on top of the financial motive. Subtle features like the product height also matter for the user to use the product with ease. The product is designed based on height range attainability for the average man and woman.
  b. Usage: The product would have to be an adaptable size which could be placed at supermarkets/grocery stores/stores. It was ensured while designing, that the size of the product must be adequate to store a decent amount of trash while also being accommodated at the above-mentioned locations. Measurements were done accordingly, and real-life usage was tested to see that the product does satisfy the requirements for an adequate size while also being able to set at any desired location.
  c. Product Cost: Creating a product that solves the littering issue but having a huge toll on production cost would make the project ineffective. The raw materials for our product are a small part of the budget, majority of the budget would be to invest on the microcontroller, barcode scanner, display, the NFC system and addition features such as network chip, database storage, etc. However, we were able to design the product using the required budget by prioritizing the usage of parts that help the product to complete its task. If product demand rises and we can get our product under mass production, our main would decrease and additional parts could be added to the product to increase its overall efficiency.

- The programming is done based on our product algorithm, which is as follows:
    a. The display reads “Scan the NFC tag”.
    b. The user scans his/her tag
    c. The user is greeted by the display reading “Welcome {Username}”
    d. The user scans the trash using the scanner and throws it into the trash. (The system returns to step i. if no trash is scanned for 20 seconds)
    e. Upon scanning the User’s credit balance is displayed on the display. (The system returns to step i. if no trash is scanned for 20 seconds)
    f. Once the User is done throwing the trash, he/she can leave, the system automatically returns to step i. upon inactivity.

- The programming is a root to the working of our product. The working of the sensors isn’t just based on it, but it interconnects them. Due our microcontroller of choice, it allows us to use one file containing the program code to run all the sensors. The Arduino program receives input from the NFC reader, reads data from the scanner upon scanning, provides feedback to the user. For our current product, it helps to host a database for both: the hard coded QR/barcodes and the user information for/from the NFC system.
- With utmost optimization from programming and the calculated design goals, we were able to design our product with perfect optimization.
- The program and code structure are listed as follows: https://github.com/aadershkalyan/ED-139.git

8. Realization

The realization of the three different electronic parts can be divided into a couple of sub-steps. As the complexity varies, not all of them have that many intermediate steps. More explicitly said, the display and NFC reader did have less physical steps, but more steps in the development of their code.

The final scanner is built as shown in the circuit diagram as in figure 8 in section 6. This circuit was build nine times, as mentioned before. This also means that the big complexity of the circuit resulted in many intermediate assembling steps. All the pictures made cannot be shown (as there are many), but the two most important steps can be seen below. At the left figure, the backbone of the circuit is complete. At the right picture, the infrared LED’s and phototransistors (together with their extension cables, which have been insulated and soldered separately) are also installed. The cardboard mall is assembled and the orange cables for the red LED display are installed (visible at the sides of the breadboard). The only thing not installed is the AA battery pack, which is visible in figure 17.

The assembling of the NFC reader, which is our second electronic component, was luckily a little less complicated. It required less analog realization (only for power, information sending and ground), but more coding. The realization of the analog circuit is also visible in figure 17. The circuit design is shown below for extra clarity (figure 12).

Then the display. The display was realized on a breadboard. The circuit diagram is shown in figure 12. Our physical design of it is visible in figure 17. Also here, the wiring is only for power, ground and pins that send information and/or instructions from the Arduino the display.

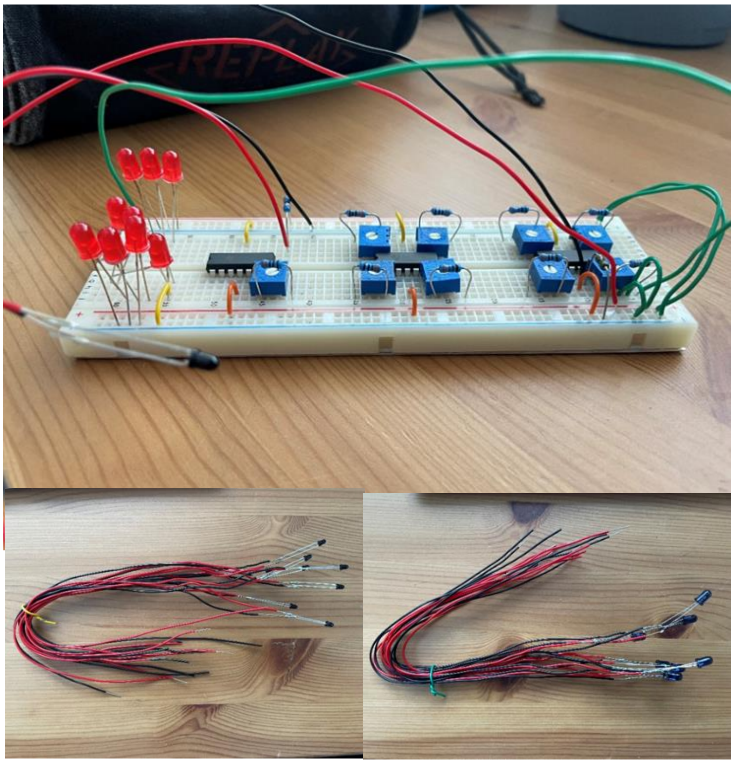


Figure 10, The backbone of the scanner circuit, together with the loose infrared LED’s and phototransistors

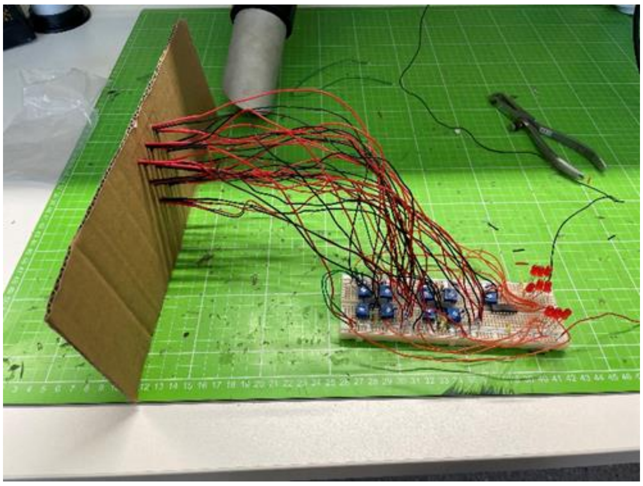


Figure 11, The finished scanner circuit (without battery pack).

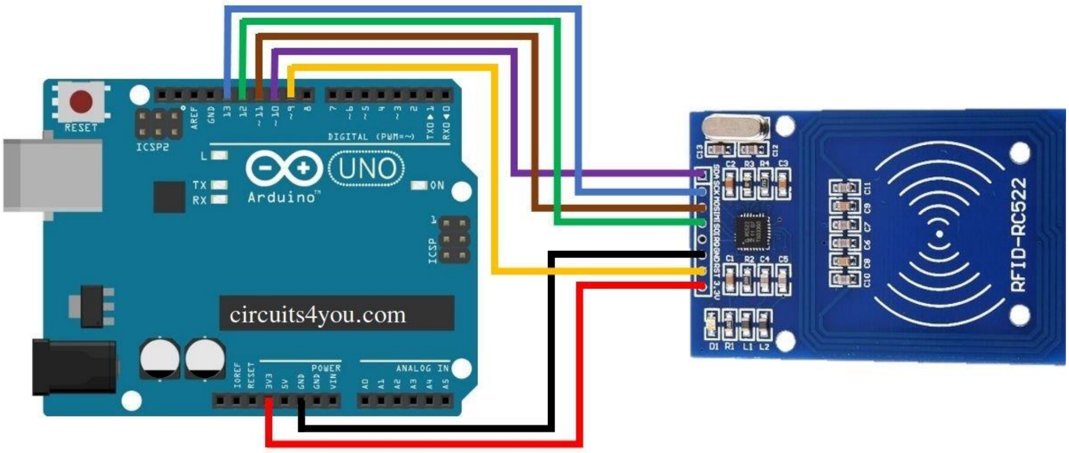


Figure 6, The circuit diagram of the wiring of the NFC reader to the Arduino

We started off by designing the ideal looking trash can, so we could make fast progress in the ideation phase of a design process. After sketching multiple low fidelity sketches for exploration of the shape, we came out with rounded looking trash can with the hole on the side. We did this, because we knew that we wanted some sort of interaction with the customers and it would be the best to put the hole the side so we have multiple options for electronics and interactive devices there. The progress of this communicative sketch is shown below.

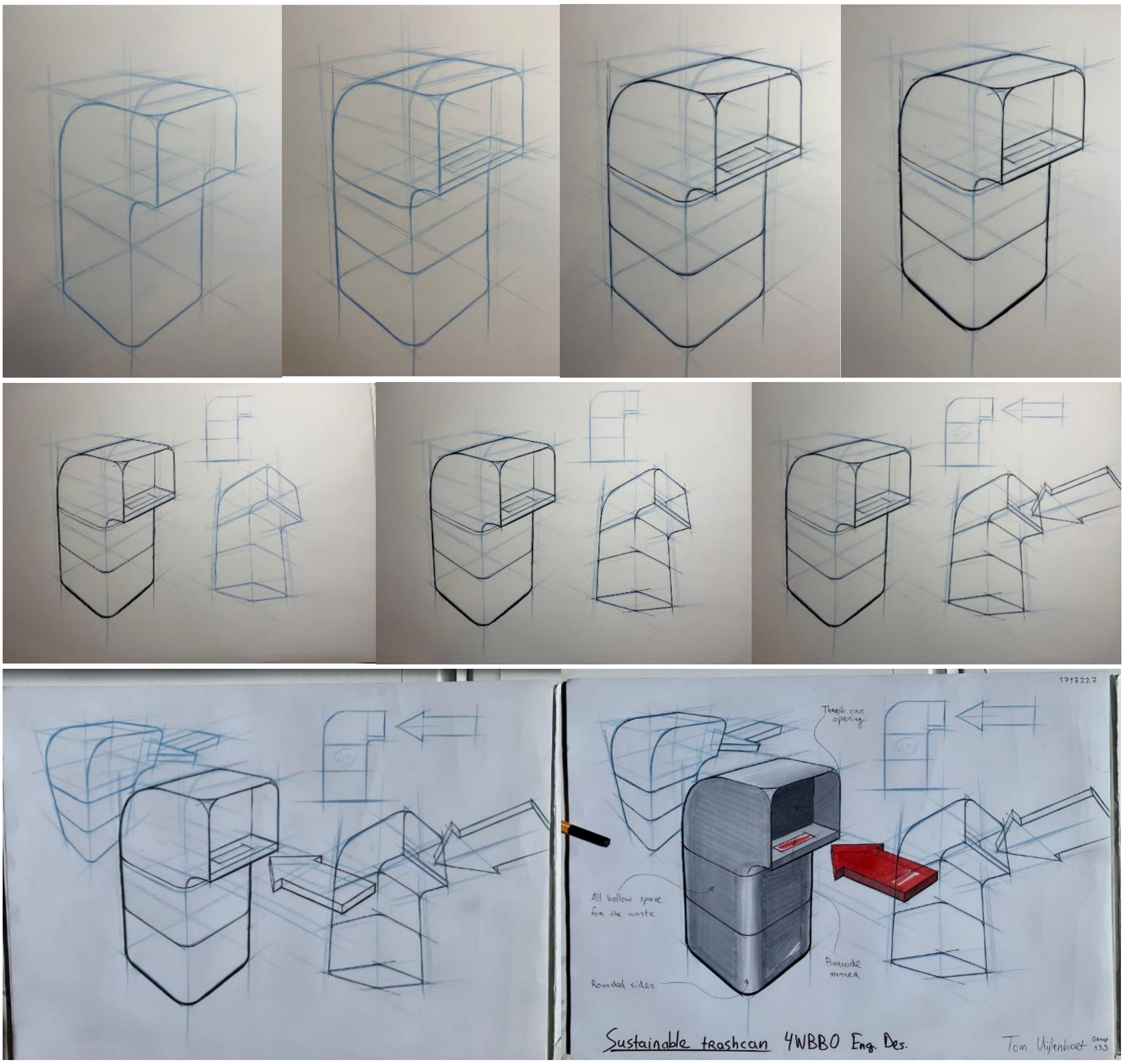


Figure 7, The first concept sketch of our product.

After a long period of brainstorming, doing research and looking of the right electronics, we came to the conclusion of what our design goal was going to be. Therefore, we needed to divide three different electronical components. We wanted some sort of scanner, a NFC-reader and a LCD display. We communicated the measurements and now we could again go on with the design of our product. The sketches below represent the three different components that we wanted to implement into our trash can.

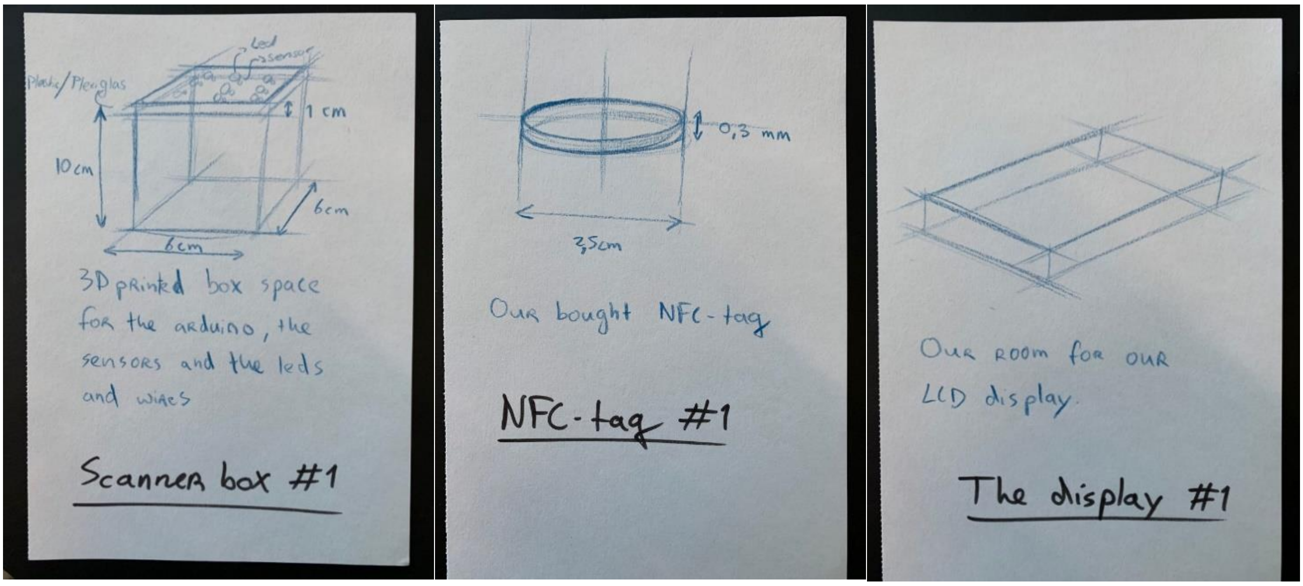


Figure 8, preliminary sketches of each electronic component. The dimension where still subject to change.

After the ideation phase, it was time to make a concrete plan for the physical prototype. After implementing our user-centered design skills, we came to the conclusion that we wanted our trash can to be as user friendly as possible so we made a new sketch with dimensions for it. This time, the sketch looks really sharp in contrast to the rounded version at the start of our project. We did this because it was easier to realize and more convenient for mass production.

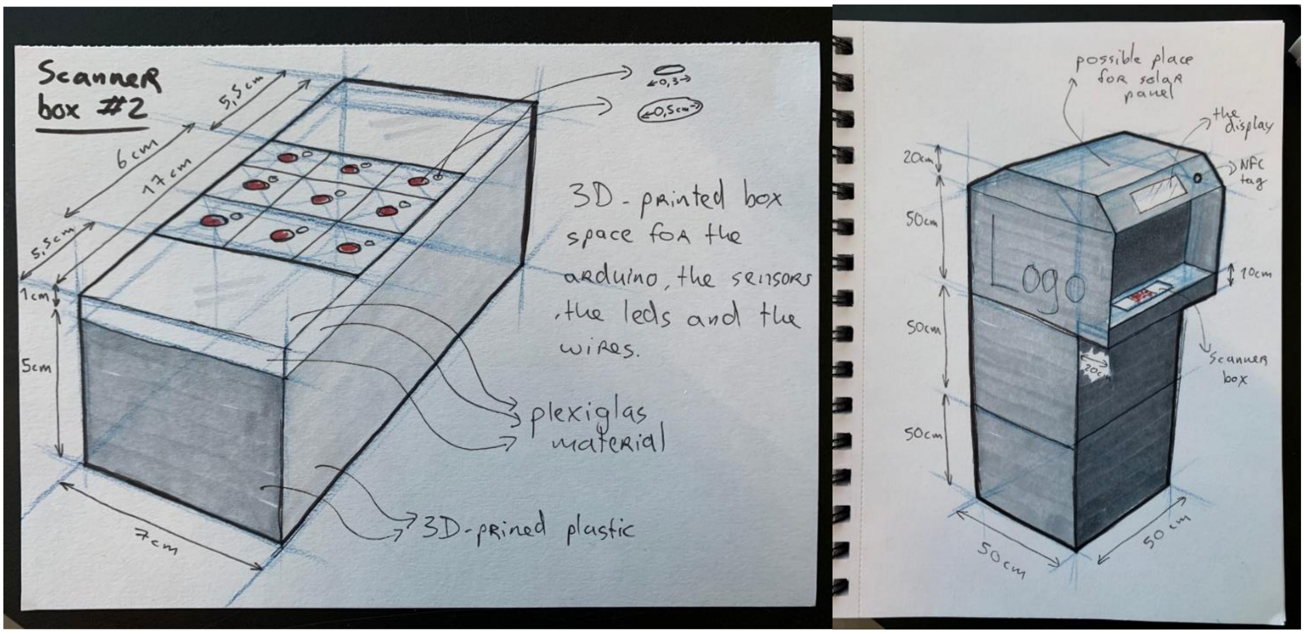


Figure 9, Sketches of the scanner box and the ultimate concept of our smart trash can.

After these final sketches, shown in the pictures above, for the physical prototype, we changed some of the dimensions. The difference is the height, our final prototype is less tall than the sketch above indicates. So we could start buying our electronics, build the electronical components together, make codes and databases for them and build the actual physical prototype where all components would come together. The pictures of the progress of this prototype can be seen in the pictures below.

Figure 10, The preliminary design steps of the physical trash can.

We build the framework of wooden planks and we screwed them together with screws. After that we sawed thinner planks in the right dimensions and put them on the right place on the frame with a staple gun for wooden materials. We left the preserved spots open for the electronics as can be seen. The place where the display and the NFC-reader will be placed on the inclined part is open. And the box for the scanner is still open.

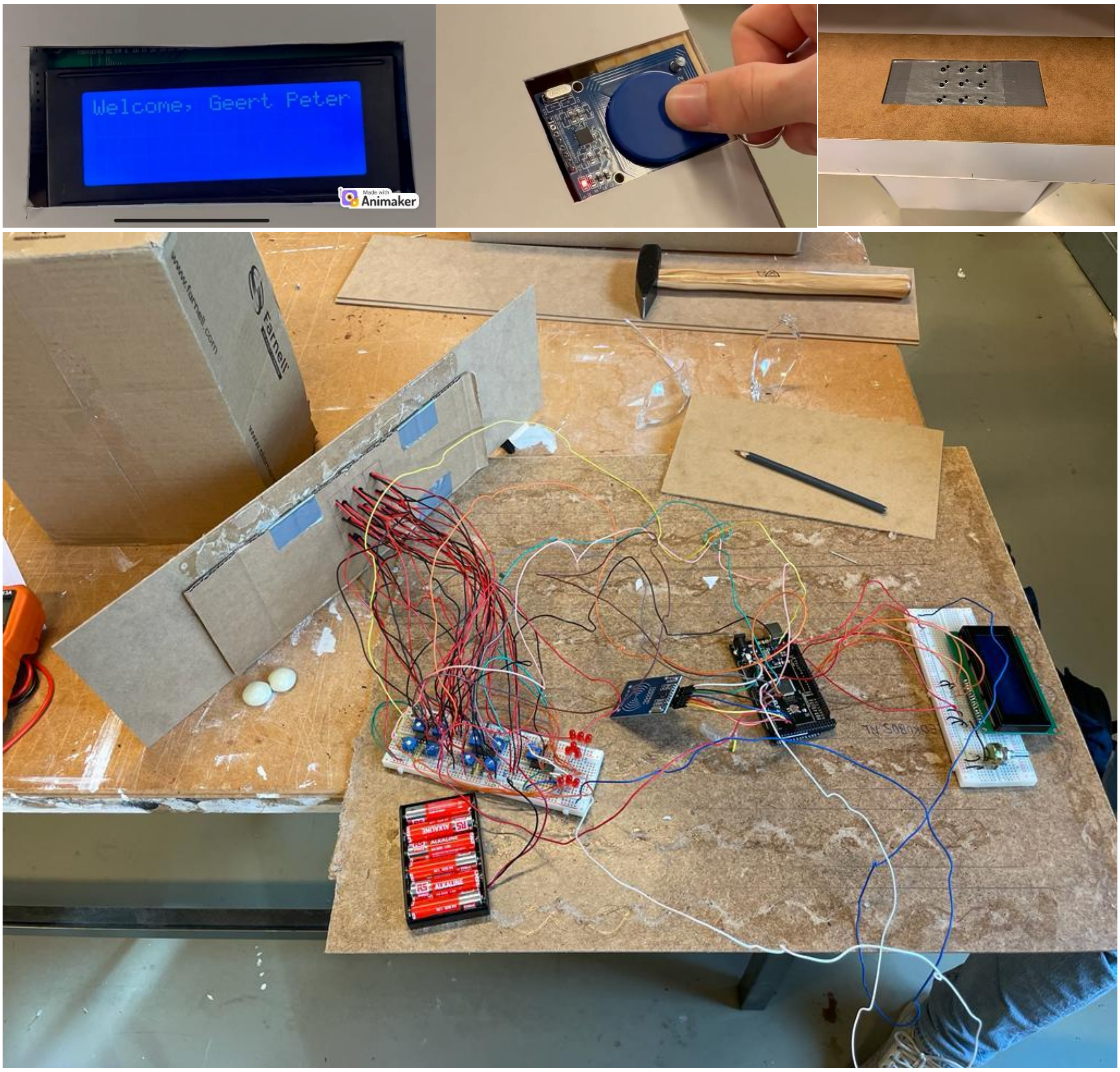


Figure 11, The working display at the top left, the active NFC reader with tag in the top middle, the integrated scanner in the trashcan in the top right and lastly all of the electronic subparts interconnected before the big integration in the trashcan.

The pictures above show our three different electrical components combined into one power circuit. When this was done, we combined all the electronical parts into the preserved places on the trash can. Our final prototype is shown in the pictures below at two different angles.

In total, this was our plan of production. It took us quite some time, but we made it work, because we divided our tasks really well as has been told in section 1 and 2.

	Product	Link	Price	Paid by	Total
2	Arduino Max	https://www.amazon.nl/gp/product/B01MA5BLQI/ref=ppx_od_dt_b_asin_title_s00?ie=UTF8&psc=1	20.48	Tycho	67.63
3	Breadboard	https://www.tinytronics.nl/shop/nl/gereedschap-en-montage/prototyping-toebehoren/breadboards/breadboard-830-points	4	Tycho	
4	LCD Display	https://www.tinytronics.nl/shop/nl/displays/lcd/lcd-display-20*4-karakters-met-witte-tekst-en-blauwe-backlight	7	Tycho	
5	NFC Reader	https://www.tinytronics.nl/shop/en/communication-and-signals/wireless/rfid/rfid-kit-mfrc522-s50-mifare-with-card-and-key-	5.5	Aadersh	
6	Battery Pack	https://www.tinytronics.nl/shop/nl/power/batterijhouders-en-clips/aa/6x-aa-batterij-houder-met-losse-draden	1.5	Micha	
7	Breadboard 2	https://www.tinytronics.nl/shop/nl/gereedschap-en-montage/prototyping-toebehoren/breadboards/breadboard-830-points	4	Aadersh	
8	Voltage Regulator	https://www.tinytronics.nl/shop/nl/componenten/spanningsregelaars/l7805cv-5v-spanningsregelaar	0.5	Aadersh	
9	Physical resources	Planks, screws, nails etc.	15.4	Tom	
10	Divers Electronic compc	Phototransistors, LED's, wires, resistors, Op-amp	9.25	Micha	

This picture above shows our bill of materials. We came out a little bit below 70 euros, however, we did not take all the small purchases we had to make for making the prototype into account. For example, we bought a Stanley knife, duct tape and wood glue. But we did not write that down there, because it is not part of the final prototype itself.

9. Test plan

When different subparts of the final prototype completed the phase of manufacturing, it was very crucial to first test them individually before integrating them into the whole final prototype. Many of us also appreciated this fact in other Design Based Learning courses, as doing the integration before the testing leads to a lot of possible fault situation. This means that when isolating each different subpart for testing result in a huge reduction in places where things can go wrong. Detecting this fault is then much more easy then when you have to search for it in five distinct elements. These parts could be concretely divided into the following subparts: the scanner, the display, the NFC reader, the Arduino together with the database and server and finally the physical appearance of the trash can itself. Before describing the individual test plans, it is important to mention that we also executed tests while the manufacturing process was still taking place. This is for the same reason as mentioned above namely, doing these intermediate tests rules a lot of possible errors out so they can be skipped during the final testing if something goes wrong.

First of all, the scanner circuit. Because this was the biggest circuit in the project by a long extent, the intermediate testing while manufacturing together with the final individual test when the circuit was ready, was of great importance. Some of them were much more significant and bigger than others, so the most crucial of them will be described. One of the smaller test was to check if the 9 infrared LED's were indeed illuminating the black and white squares on the tree by tree QR/barcodes. When the scanner would not give any output, and the LED's were not checked, this could of course waste a lot of time searching for the problem. As your eyes cannot detect this light, a special camera was used to check if they were on. A bigger test was to see if each of the 9 scanner modules (one pair of LED, phototransistor and the corresponding circuit part as visible in figure 8) could detect the difference between a white and black patch. This could be checked via a small LED display that was built into the circuit. This display can been seen as the 9 red LED's in the bottom of picture 3, in the pattern of the tree by tree QR/barcode. In this picture you can also see quite nicely that the circuit really is just figure 8 replicated 9 times for each patch on the QR code. Then finally, the last two tests. One of them was the final individual test, where a specific QR/barcode was hold in front of the sensing part (figure 18) and the output was read of the red-LED display (figure 20). As can be seen in figure 19, the white z-block and the individual white square in the corner are correctly shown on the display. Lastly, The circuit was made wirelessly by replacing the 5V power supply (also visible in the circuit diagram of figure 8) by six 1.5V AA batteries in series (so the total voltage will be 6x1.5V=9V). As explained before in paragraph 6, this was done using a voltage regulator that converts the 9V from the battery to 5V for the circuit.
This test can be seen in figure 21.

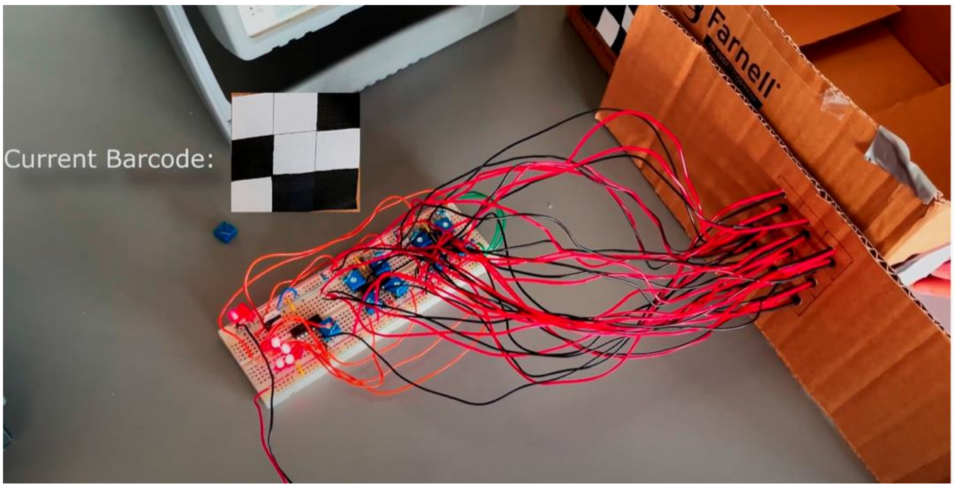


Figure 13, the final test where a specific QR code was held in front of the scanner and the output could be read from the LED display.

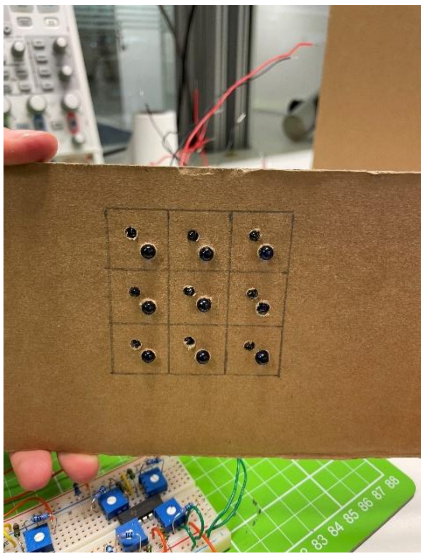
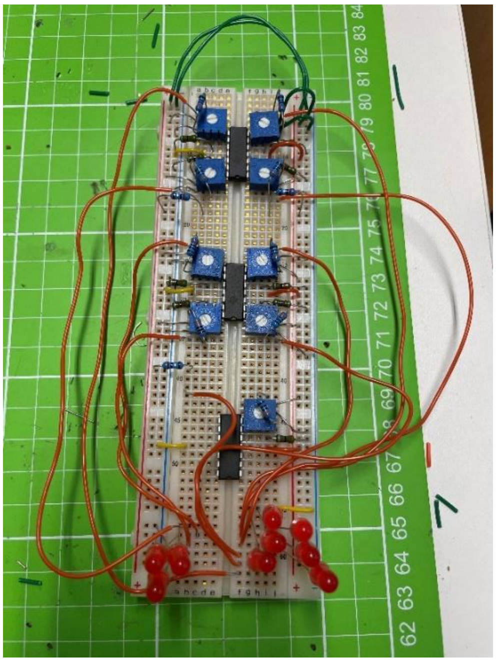


Figure 12, the sensing part of the scanner; a phototransistor (small) combined with an infrared LED (big).



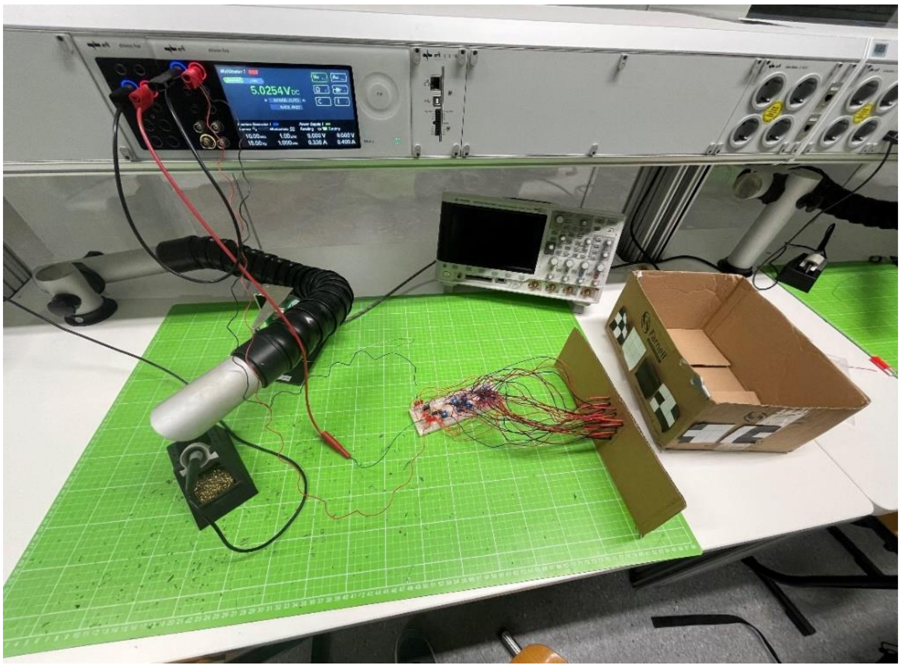


Figure 14, the 3 by 3 LED display at the bottom.

Figure 15, measuring the output of the voltage regulator which transforms 9V DC to 5V DC.

Next up, the display. The display used was a 20*4 LCD display. This resolution is high enough to interface with the user and show useful information. In order to make a connection between the Arduino (the brain of the trash can) and the display, a breadboard along with a 20 kilo ohm potentiometer and some wires were used. The testing procedure here was pretty simple. The circuit was build and checked after completion (figure 22). To fully check it, a digital connection was made with the Arduino. Here, an example code was used in order to test the display. On connecting the Arduino to the power supply (PC) and uploading the code onto the Arduino this display lit up and projected 'HELLO WORLD', which was a sign that the display works and functional.

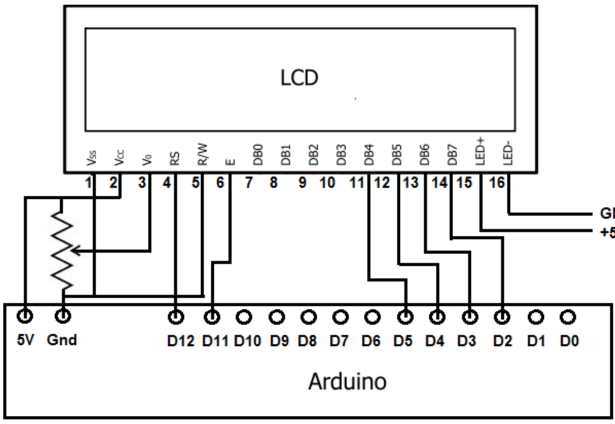


Figure 16, circuit diagram of the connection between the display and Arduino

Then the database and server, which processes all of the information (scanned QR-codes, clocked in users and balances). The database is an Apache HTTP web server hosted on a raspberry pi and coded in PHP and SQL languages with MariaDB as the database. The system made works on webhooks, so to test it sample data was manually added to the database. Then the webhooks with that data was used the same way as the program on the Arduino will use it. Lastly, it was checked if the correct actions in the database were executed with this sample data.

Testing the NFC reader was mostly checking the capabilities of the reader itself and the interconnection method with different parts of the prototype such as the sensor and the display. For the capabilities, it was checked if and how the NFC reader differentiates between tags. Via the serial monitor on a laptop it could be seen that different UID (unique identifier) were used for this. Next up was the research to the data storage capabilities of the reader itself. This checked and ended up to be 1024 bytes. Some information could be stored here, but because our server will process all of the data, we decided to not use the storage on the reader but rather save it in the database on the server. Then, tests were conducted to determine if a static or loop code would be used for the reader. The only time when the reader should respond is when someone taps a card onto it. So a static code seems logical. However, after both the static and the loop code were tested, it became clear that a loop code is still handier as it does not depend on other sensors for detecting a card.

Lastly, the tests for the physical design. The trash can was mildly tested for correct placements. This includes a comfortable angle at which the display is positioned towards the user. Also, the opening in the trashcan for the litter itself was specifically placed at a certain height so that the average person can throw in their trash without too much effort.

10. Design evaluation

Our design definitely fulfills the design goal, the system we made actively pushes people to behave in a sustainable manner. There are however a few points which we could have done better. We for instance did not end up actively including a sustainable power source in the design, even though we did consider implementing a solar panel we ended up cutting the idea because it took up too much budget and time, we ended up just using batteries for the prototype.

Another potential flaw of the design is the ambitiousness of the government cooperation required for our idea to function widespread. People wont pick up the system if the trashcans aren’t readily available and if not a lot of products work with it. This is why there would ideally be a new law comparable to the law on plastic bottles which forces manufacturers of packaging to adopt the system.

For the sake of budget and simplicity we designed and made our own 2d code scanner but in a follow-up design this would definitely need to be replaced. Our scanner is limited to under 200 unique barcodes due to rotational symmetry and actually scanning something is a bit finicky (even though an unexperienced tester did manage it first try). Thus an aftermarket digital scanner would fit the project better with increased speed, acceptable codes and convenience, although this would increase the price of the project quite a bit.

To make prototyping a lot easier we made all the electronics with wires on breadboards but this also makes everything quite fragile so in further designs these would probably have to be made on pcb’s.

The materials for the body of the trashcan would also be changed in further design cycles as wood is definitely not durable enough for the outside environment where the trashcan would be placed.

Another thing which could be improved by further design is the actual storage of the trash, for this project we just went with a simple trash bag design but the system could easily be implemented with bigger underground storage compartments.

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12. Appendices

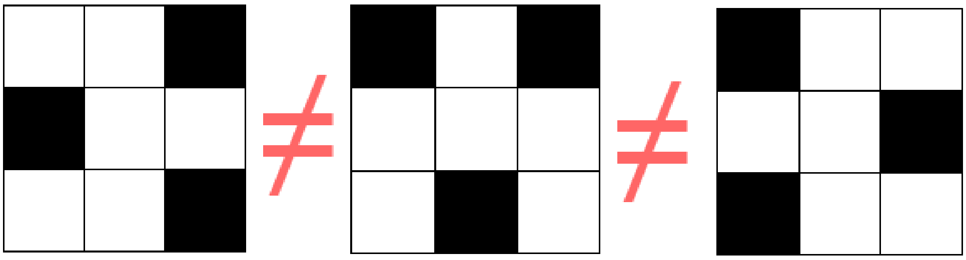

Figure 1a. Rotation symmetries in a 3 by 3 QR code.

$$N= \frac{1}{4}(k^{n^2} + k^{\lceil n^2/2 \rceil} + 2k^{\lceil n^2/4 \rceil})$$

Figure 2a. Formula to calculate the amount of rotation-unique n by n QR codes where the patches can have k states (=colors). In this project, n=3 and k=2.

```
def dec_to_bin(num):
    binary_num = "{0:#b}".format(num)[2:]
    while len(binary_num) < 9:
        binary_num = '{}{}'.format(0, binary_num)
    return binary_num

# rotate every string 90 degrees to the right
def rotate(string):
    indexes = [*string]
    nindexes = [''] * 9
    # too lazy to name indexes accordingly :)
    nindexes[1-1] = indexes[7-1]
    nindexes[2-1] = indexes[4-1]
    nindexes[3-1] = indexes[1-1]
    nindexes[4-1] = indexes[8-1]
    nindexes[5-1] = indexes[5-1] # == middle, thus the same
    nindexes[6-1] = indexes[2-1]
    nindexes[7-1] = indexes[9-1]
    nindexes[8-1] = indexes[6-1]
    nindexes[9-1] = indexes[3-1]
    item = ''.join(nindexes)
    return item


checked = 0
list_of_uniques = []
```

```python
while checked < 512:
    new_check = dec_to_bin(checked)
    r1 = rotate(new_check)
    r2 = rotate(r1)
    r3 = rotate(r2)
    if r1 not in list_of_uniques and r2 not in list_of_uniques and r3 not in
list_of_uniques:
        print('{} is a unique number!'.format(checked))
        list_of_uniques.append(new_check)
    checked += 1


for item in list_of_uniques:
    print('{}\n{}\n{}\n'.format(item[0:3],item[3:6],item[6:9]))

print(len(list_of_uniques))
```

Figure 3a. Python code that removes rotation duplicates. The final total QR-codes is the same as with the formula above.