# “Designing better waste-collection systems for urban high-rise buildings”

Graduation Project
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# Abstract

This graduation thesis report is about the design of a better method of waste collection for high-rise buildings in Rotterdam. The first part covers the research into the current situation of waste collection, including the specifics of how waste is collected in the city, the policy of the municipality and the factors that drive the recycling behaviour of people in general.

The second part is about finding an ideal future scenario for the city, which can be compared to the current situation to find the factors that a design can improve. This part begins with a definition for the ideal scenario which is as follows: 'In the ideal scenario, the amount of material from the waste stream that is being reused in the production of new consumer goods is as high as possible'.

Next, this part shows the results from researches into the context of a new high-rise district in Rotterdam, followed by an analysis of how the waste collection is more successfully managed in other cities around the world, and on current and future technologies by which the recyclable wastes are sorted.

The research part is concluded in a set of considerations for the municipality of Rotterdam to approach becoming a more circular city, and these considerations are used as design principles for the following design phase.

The design part of the report shows how the design was approached, starting from a map of the different stakeholder concerns over the multiple stages of the context of waste collection. It was followed by ideation and the formation of concept directions. After some iteration, the concept directions culminated in a final concept, which is the Re-Posit system.

The Re-Posit system aims to increase the convenience of separating and disposing of recyclable waste from the moment that a person starts living in one of Rotterdam's new high-rises. It does this by offering the residents a space to collect their waste separately inside their own homes, as well as a system that takes most of their waste through one single receptacle and sorts the waste into the right containers automatically. Additionally, it includes the provision of all the information that the residents need to participate in the recycling efforts, as well as enabling the municipality to offer feedback and/or other incentives for the recycling behaviour.

The design showcase starts with an overview of the Re-Posit system, and shows its daily use by the residents. The next parts goes into the different parts of the system in detail, and shows the considerations that were made during their design.

The final part of the report discusses topics such as how the system relates to the current and future context, how it can be managed and paid for, and an evaluation that was done to verify the desirability of the system.

# Abbreviations

AVAC = Automated Vacuum Collection

AVR = Afvalverwerking Rijnmond, the processor of Rotterdam's municipal residual waste

DIFTAR = Differentiated (waste) Tarrifs

GFT = "Groente, Fruit & Tuinafval", or organic waste

MSW = Municipal Solid Waste

NFC = Near-field Communication, a data transfer technology

NIR = Near-InfraRed

PET = Polyethylene terephthalate, a common type of consumer plastic

PMD = "Plastic, Metaal & Drinkpakken", or Packaging waste consisting of plastics, metals or drink cartons.

RR = Recycling Rate

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# 1. Problem Introduction

The city of Rotterdam is looking to expand within its city limits, building new high-rises to be able to offer more housing for its growing population. Additionally, the city is increasing its ambitions to become circular. In a fully circular city, all of the city's resources are retrieved from the waste that it generates, and used again in the production processes that provide for its needs.
("Rotterdamse woningmarkt naar een nieuw evenwicht", nd.; "Over Rotterdam Circulair", nd.)

Between these two ambitions, there is a big mismatch: high-rise districts are notorious for having the worst recycling rates of any type of district, and Rotterdam's recycling rates are already among the lowest in the country.

This graduation project is about finding a possible solution for this problem, by conducting a thorough analysis of the current and future context of waste management in Rotterdam, and designing a product to fit into and perhaps contribute to bringing about this future context.

## Analysis setup

The analysis consists of 2 parts. First, the current system of waste management in Rotterdam is analysed. It is necessary to first get an understanding of how this system works before being able to understand the requirements for the design, and its implications for the system.

The second part of the analysis is about finding out what the ideal future of waste management might look like, and by extension about defining the future that we want to move towards. After the analysis follows the design phase. This part will be about designing an intervention that will help Rotterdam to move from the current situation to this ideal future.

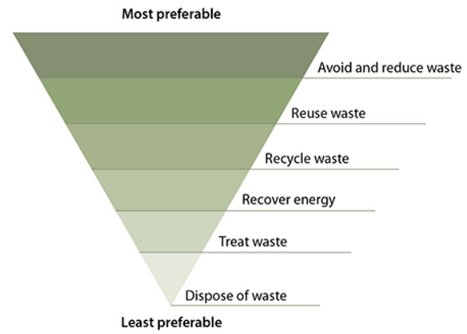



*Figure 1 - Waste Hierarchy*

## Project Scope

The EU's Waste framework directive includes the so-called waste hierarchy: an order of waste management operations in the order of preference from an environmental standpoint.

Although it should be acknowledged that reducing and reusing waste is preferable, this project's scope ranges from the moment something is thrown away and becomes waste to the point that it either finds its destination as a new (recycled) resource or is incinerated or landfilled. In other words, the scope limits itself to the recycle, recover and treat waste layers from the hierarchy in figure 1. This limitation is because the municipality of Rotterdam will have the most influence in this area.

Another matter that should be acknowledged is that the largest percentage of waste that is produced is commercial. In the Netherlands only about 16% of all the waste produced is household waste. However, since the municipality is responsible for the collection of only the household waste, the commercial waste is outside the scope of this project. Be that as it may, something might be said for including certain types of commercial waste together with the municipal collections, which will be elaborated on further in this report.

# Part I
# Research on the Current Situation





The waste in Rotterdam is being managed and processed by a large amount of different stakeholders. The waste is in largest part collected by the municipality, but changes hands to all sorts of different contractors. These companies compete for the licence to process a certain waste fraction from Rotterdam.

## Types of Waste

In Rotterdam, as in most Dutch cities, there are six different main fractions of municipal solid waste that are collected with containers spread over the city. These are paper/cardboard, glass, PMD (plastic, metal and drink cartons), textiles, organic waste (Groente-, Fruit- en Tuinafval (GFT)) and residual waste.

Other kinds of waste, such as the bulky residual waste, and more specific fractions like mattresses, carpeting, and chemical waste are collected at one of the seven 'milieustraten'. These are waste disposal stations that are usually in the form of a drive-through past different containers for each of the fractions.

The infographic on the next page shows the different kinds of waste, their collection methods, and the final results of their processing, alongside their relative weights. The circle graphs for the recyclable fractions include a grey part that signifies the part of the fraction that is in the residual waste. In this way the relative amounts of what the fractions would look like with a 100% recycling rate become visible.

This analysis only includes the municipal solid waste that is being collected by the municipality itself. Streams such as the PET bottles collected in supermarkets and household electronics collected in other shops are not part of the collection services of the municipality, and are instead sold to recyclers directly.

There are also organisations that collect specific waste types in the city, such as Groencollect for bread and MVO for (frying) fat and oils. These organisations are also not included in this analysis.

## Collection and Transport

The collection of residential waste is the responsibility of the municipality. They handle the waste up until it arrives in a transfer station. From here it is handed over to the processing companies, who use their own transports to move it to their facilities.

The different waste fractions are gathered from the collection bins by small garbage trucks that can easily manoeuvre through the city streets. Each fraction is being collected by its own specialised trucks that are made to empty a specific kind of bin, meaning that trucks that empty rolling containers are different from those that empty underground containers.

Once full, the trucks will bring their load to a transfer station in the city. A transfer station will only take a specific waste fraction, and store the waste before it is shipped to the processing plant. From there, heavier transport is used to bring it to its destination. For most fractions, transport is done by large trucks. One exception is the residual waste: this is transported by ship to AVR (Afval Verwerking Rijnmond), which is located in the Rotterdam harbour.

## Processing

The municipality works together with a lot of different companies to process the different kinds of waste from the city. These companies have to win the contracts with the municipality by making the best offer, and therefore the exact companies that process the recyclable fractions are always changing. This also means that the municipality has a certain amount of control over how the waste is processed, which might be helpful towards their ambitions to go circular.

Most recyclable fractions are polluted with waste that is either too low quality or of the wrong kind, and therefore the recycling processes start with filtering these pollutants. These end up in the incinerator at AVR or other residual waste processors.

## Overview Per Fraction:

### Residual waste

Consists of both small and bulky fractions, the latter kind too big for normal collections and therefore collected only at the 'milieustraat' The amount per person collected in 2017 is 326kg, which is 78% of the total weight measured over all waste fractions.

All of the residual waste is brought to AVR, where it is incinerated.

The heat from the incineration process is used to heat water to drive steam turbines, but the hot water itself is also being used to warm buildings in the city. Aditionally, some steam is being used in other industrial processes.

After the waste is incinerated, the leftover ashes are filtered for metals which can be recycled, and for minerals that can be used for example in road building. The remaining part of the residual ash is being landfilled.
(AVR, n.d.)

### Organic waste (GFT)

Consists of GFT (vegetables, fruit and garden waste) and bulky garden waste which is collected in the 'milieustraat'. The amount per person collected in 2017 is 15kg, which is 3,6% of the total weight measured over all waste fractions.

At the time of this analysis, the GFT waste is being processed by two different companies: one for the GFT from the north part of the city, and the other for the south. However, this setup could change at any time as a result of the earlier-mentioned contracting system.

The GFT waste is first filtered for pollutants, and divided by size. A part of the waste undergoes a yeasting process and is turned to biogas that can be used as a fuel or for power generation. The rest is composted and used for soil treatment.
(Attero, n.d.)

### Paper and Cardboard

The paper and cardboard fraction is collected both from public (underground) containers and from private minicontainers (Kliko). The amount per person collected in 2017 is 21kg, which is 5% of the total weight measured over all the waste fractions.

The process of recycling paper starts with sorting. The cardboard and other big kinds of paper are separated from the smaller pieces. The paper is then pulped by adding water and chemicals that dissolve the paper. The pulp is cleaned with soap and more chemicals to remove most of the ink. Next, the pulp is pressed to remove the water and turn it into new paper sheets. After drying the recycled paper is sometimes bleached for use as A4 paper or similar, but might otherwise be used as toilet paper or packaging material.

Paper can only be recycled about 6-7 times, as every time a sheet of paper gets cut the fibres along the cut are shortened. Eventually these paper fibres become too short and unsuitable for the recycling process, since paper made from these fibres would be weak and easy to tear.
(How it's made, 2015)

### PMD (Plastic, Metal, Drink-cartons)

This fraction is collected in underground containers throughout the city. The amount per person collected in 2017 is 2,4 kg, which is only 0,6% of the total weight. Because only 7% of all PMD waste is collected separately, the municipality of Rotterdam is making a transition to the post-separation of this fraction. You can find more about this transition on page 25.

This fraction is a big mix of all kinds of materials, and these have to be sorted first.

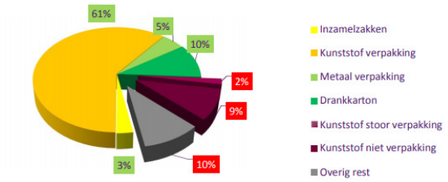
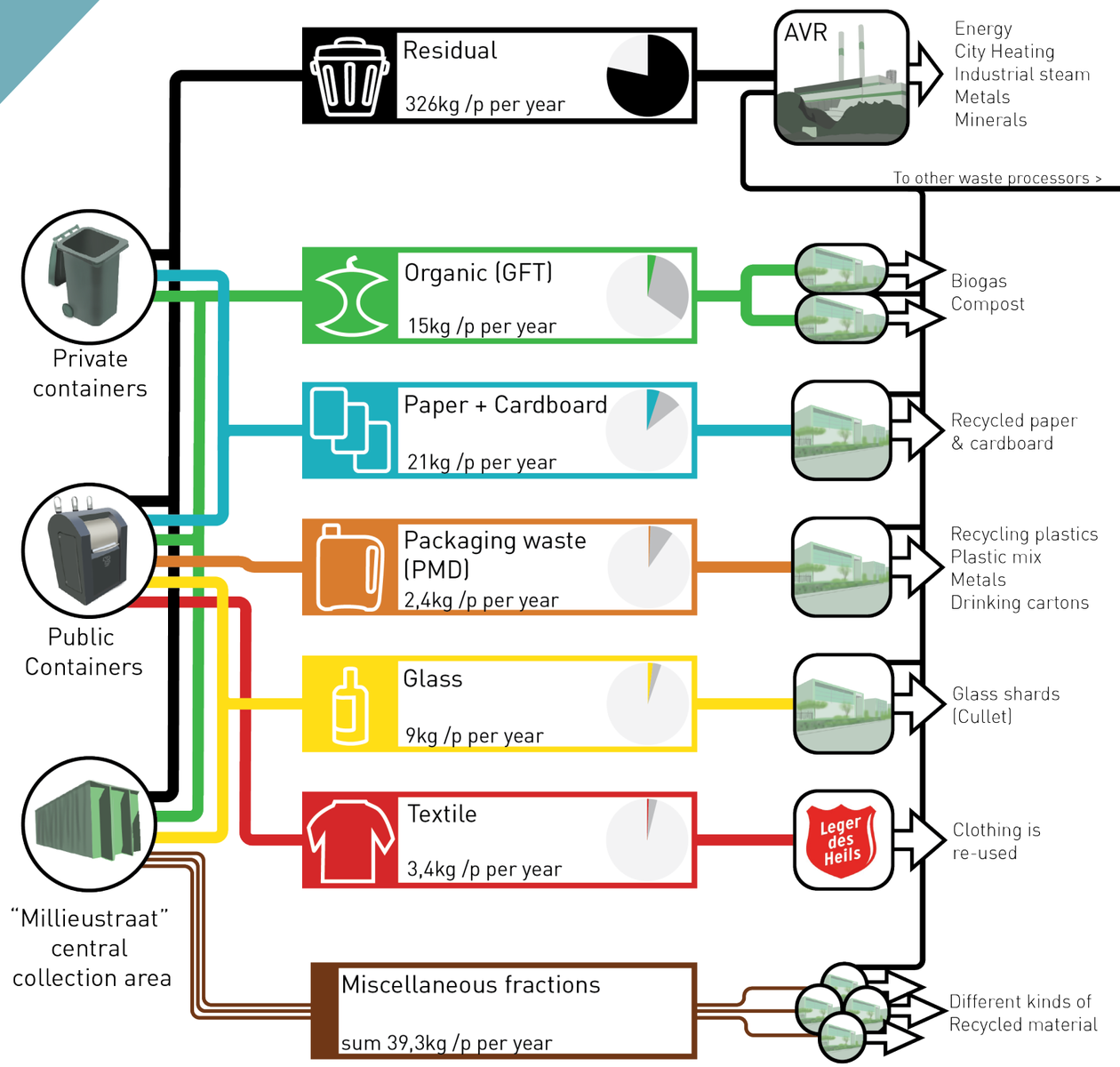



*Figure 2 - Composition of PMD Waste*

Many sorting plants sort by size using rotary drums, by weight using shaking platforms and blowers, and by colour or material by using computer-driven optical sorters. Magnets are used to separate the metals, and the final step of any sorting process is always a manual check by human workers. The sorting process aims to make separate fractions for the different recycling plastics (PET, HDPE, PP), a metal fraction, a drink-carton fraction, and a plastic mix with all the unsorted plastics. A further analysis of these sorting methods was done, and can be found on page 23.

The resulting sub fractions are usually pressed into bales and shipped to other companies that can further process them into usable material.
(Attero, n.d.)




# Rotterdam Waste Cycle

Data taken from 'Afvalmonitor' & Municipality of Rotterdam

### Glass

This fraction consists of hollow glass (bottles and other packaging) and flat glass (window panes), the latter of which is collected at the ‘milieustraat’.

All hollow glass in Rotterdam is collected in underground containers. The different colours of glass are collected in the same bin instead of separating the green, white and amber glasses. The amount per person collected in 2017 is 9kg, which is 2,1% of the total weight measured over all the fractions.

The recycling process starts by breaking the glass into shards. These are put through a filter for pollutants such as plastic or metal bottlecaps and the paper labels, and afterwards through an optical sorter that separates them by colour (clear, green or amber). After this process the glass shards are reduced to the consistency of sand. The shards, also known as ‘cullet’ are then left outside for several weeks to allow bacteria to remove any food residue. Afterwards, they can be used in a smelter to make new glass.
(“Glass Recycling: How Do They Do It?”,n.d.)

### Textile

Textiles are collected in public containers for the Salvation Army. The amount per person collected in 2017 is 3,4kg, which is 0,8% of the total weight measured over all fractions.

The salvation army, which operates in the Netherlands under the company ReShare, takes clothing and other kinds of textiles to redistribute them to those in need. Once the clothes have been sorted according to their quality, they are either sold at low prices or given away in the Netherlands or distributed all over the world, for instance to be given to people in crisis situations.
(ReShare, n.d.)

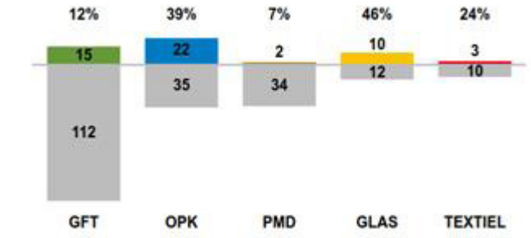



*Figure 3 - Overview of separated and non-separated resources in kilograms per resident per year*

### Miscellaneous fractions

These are the waste fractions that are only collected at the ‘milieustraat’. They are mostly either bulky kinds of waste, or fractions that are too uncommon to warrant public containers.

They consist of the following fractions: electrical appliances (2,7kg), clean debris (15kg), wood (13,6kg), metals (2,3), asbestos (0,1kg), car tires (0,1kg), clean soil (2,7kg), roofing(0,2kg), large plastics (0,6kg), mattresses (0,3kg), gypsum (0,7kg) and the small chemical waste (0,7kg) for a total of 39kg collected per person in 2017, which is 9,4% of the total amount of MSW.

All of these fractions are processed by specialised companies, in a similar way to the other recyclable fractions.

### Further Information

The figures below were received from communications with the waste collection department of the municipality of Rotterdam. They show the comparison between the waste that was separated and not separated in 2018, and the composition of the residual waste in the same year in both weight and volume. This information was used to calculate the data shown in the Rotterdam Waste Cycle infographic on page 8.

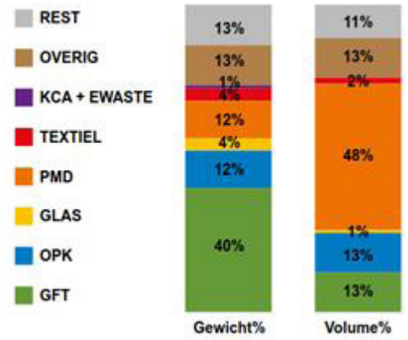



*Figure 4 - Composition of the Rotterdam residual waste in weight and volume percentages*

Gemeente Rotterdam

The current situation in Rotterdam is that the citizens pay a fixed tax for the waste management services in the city to the municipality. By law, the municipality has to use the funds collected in this way exclusively for the collection and treatment of waste. Primarily, these funds are put towards collection equipment, salaries for personnel, and the treatment of the waste. A smaller part of it is spent on cleaning streets and on enforcement of the waste policy. Of course, the municipality is free to spend more of their funds on these.

Several other municipalities in the Netherlands employ a differentiated tariffs (DIFTAR) waste tax. In this system, instead of a base tax, the citizens pay for the collection of their residual waste, either by weight, volume, or amount of collections, or a combination of these factors. This tax system is meant to encourage people to separate their recyclables to lessen their output of residual waste.

Even though this system seems successful towards increasing recycling rates, the municipality of Rotterdam has, after informed deliberation, decided not to enact it in the city in the near future. This decision has mainly been made because the city fears that the illegal dumping of waste will increase, together with an increase of pollutants in the recycling fractions.

# 4. Residents' Willingness to Recycle

The people that have the most influence on the efficiency of the recycling process are those that create the waste in the first place. The city's residents have the opportunity to separate the different waste streams at the source, so that they form the pure streams of material that can be processed easily. More often than not, however, the separation of waste is not done as efficiently as it could be. In 2017, the separation percentage for total amount of household waste in Rotterdam was only 21%, where the average of all the Dutch municipalities was around 65%.
(Rijkswaterstaat, n.d.)

A lot of research has already been done to find the factors that influence if and how residents separate their waste, as well as the barriers that prevent them from doing so. This chapter will present the conclusions made based on the information gathered from this varied body of research.

## Socio-demographic factors

### Age

It seems that age has a significant positive influence on the recycling rates, meaning that older people tend to recycle more. (Sidique, 2010b)

However, most of the data that was used to come to this conclusion was collected before 2005. As a result, it is hard to say whether this still holds up, going by the current trends of environmental awareness among younger people. It does seem logical however that people that have retired have more time to organise and do their recycling. Other than that, age correlates with other factors like home ownership and income, which are discussed later in this chapter as well.

### Income

This is a more controversial factor. It is mostly agreed that a higher income corresponds to the generation of more waste. However, some sources quote a similar or better recycling rate for higher incomes (Timlett & Williams, 2009), while others found the opposite (Sidique, 2010b). Neither sides measure any big differences in the average recycle rate between income levels. If this factor has any influence, it is likely to be small.

### Education

Most if not all research demonstrates that on average, people with higher education have better recycling rates. (Sidique, 2010b; Callan & Thomas, 2006) This finding lends credibility to the statement that knowledge and personal attitudes have an important influence on a person's willingness to recycle.

## Environmental factors

### Population Density

Most researchers agree that population density has a negative effect on recycling rates, mostly because higher density means smaller living space and therefore less space to recycle. Even more important, higher density also makes kerbside collections, which are proven to be one of the most effective ways of collecting waste, less viable for municipalities.
(Callan & Thomas, 1997)

This correlation can also be seen in recycling data for Dutch municipalities. The lowest recycling rates are found in the largest and most densely populated cities.

Sidique (2010b) suggests that this effect is counteracted by the increased quality of infrastructure that can be present in dense areas, but this observation might only ring true for countries such as the US that have larger differences in wealth and development between urban and rural areas.

### Residence type

An analysis of different housing types by Timlett & Williams (2011) calculated the potential recycling rates (RR) for each of 7 different types. The researchers found that households in (semi) detached housing were the best potential recyclers, since they have a lot of internal and external space to store recyclables in. Terraced housing has less space inside and very limited space outside, and therefore a lesser potential RR. Mid/high rise buildings have the least inside space; however there are often communal collection spaces at some distance from the building. They are the types of housing with the lowest potential RR, because of the combination with another factor that is discussed next.



Earlier research by Timlett, Williams (2009) found that transience, the rate that people move house, has a big impact on people's willingness to recycle. People that move more often seem to be less inclined to organise their recycling habits. Because mid/high rise housing is often more transient, residents in these housing types were found to be less willing to recycle. Furthermore, this type of housing has a higher percentage of people renting. It has also been suggested that home ownership is also a factor that positively contributes to recycling habits.
(Oskamp et. al., 1991)

This phenomenon can be explained by the fact that it takes time and effort to start recycling. A person needs to find out how the recycling is done in their living area and where the bins are located, as well as how to organise the recycling in their own home by finding space and the means to store different kinds of waste. People that don't live in one place for long may not find it worth it to go through this effort every time.
(Tonglet, Philips, Read, 2004)

### Bin size and collection frequency

A study done in the UK by Abbot, Nandeibam & Oshea (2011) found that there is a negative relationship between the RR and the collection frequency of residual waste. It was explained by the assumption that people will have to keep the recyclables from their residual waste to keep the bin from filling up too soon. This leads into the assumption that having smaller containers in your home will make you separate your waste better. This was also researched in the study, they found that the smallest bin they tested (a 120L wheelie bin) produced the best results for improving the RR.

## Social factors

### Social pressure

An external driver for recycling behaviour is social pressure. People seem to be more inclined to recycle when their friends, family or direct environment do it as well. (Sidique, 2010a)

### Knowledge and abilities

As mentioned before, education and knowledge have a positive effect on recycling behaviour. It is important that people know what recycling is, how it works and what the advantages are. Also, they need to know how the collection of separated waste is organised in their neighbourhood to be able to participate. This knowledge can serve as an intrinsic driver for recycling behaviour.

### Habits

Another factor that cannot be overlooked is that people are creatures of habit. It can be very difficult to change someones behaviour when they are used to their personal way of collecting waste. The research by Timlett & Williams (2011) showed that situational factors can influence people by 'locking in' certain bad habits. This happens when they can justify their bad behaviour with the factors that make it hard for them to participate, such as having 'no room'to collect waste separately, or having no disposal facilities nearby.

Habits can be changed however. Such a change is usually very hard, but can be easier during a big change in a person's life, such as a move or having a child.
(Witt, Wood & Tam, 2005)

## Convenience

The biggest factor in recycling behaviour is convenience, as has been found by multiple studies.
(Bernstad, 2014; Domina & Koch, 2002).

Convenience has multiple facets that are important: time and effort, money, and space. 'Time and effort' is mostly measured in the distance that people have to travel to dispose of their waste, but is also about the time and effort that is needed to organise people's waste collection setup. 'Money' is about the monetary costs of setting up and participating in recycling, such as buying a recycling bin or paying for fuel to drive to a recycling centre. 'Space' is mainly about the space in a person's residence that is occupied by the collection equipment, but the relative space for different waste fractions inside the bins can also be a factor. Together, these factors have a limiting effect on a person's willingness to recycle. The most important part about a new waste collection system is to make these barriers as small as possible, so that people will be more willing to participate in the recycling efforts.

These factors are largely influenced by the environment, and this is a factor where design can come into play.

## Conclusions

The biggest takeaway that arises from this wide scope of research is that people's recycling habits cannot be determined by one single factor. There is a plethora of different things that influence whether or not someone separates their waste, and how well they do it. The research done by Timlett & Williams (2011) suggests that high recycling rates cannot be achieved through thoroughly tackling only one part of the problem. Instead, all the different factors have to be addressed in a balanced way.

They proposed that you can see the problem as a see-saw that needs all the factors on the same side to tip it the right way (towards a high RR). The following figure is an adapted version of it that makes a distinction between drivers and barriers of recycling habits.

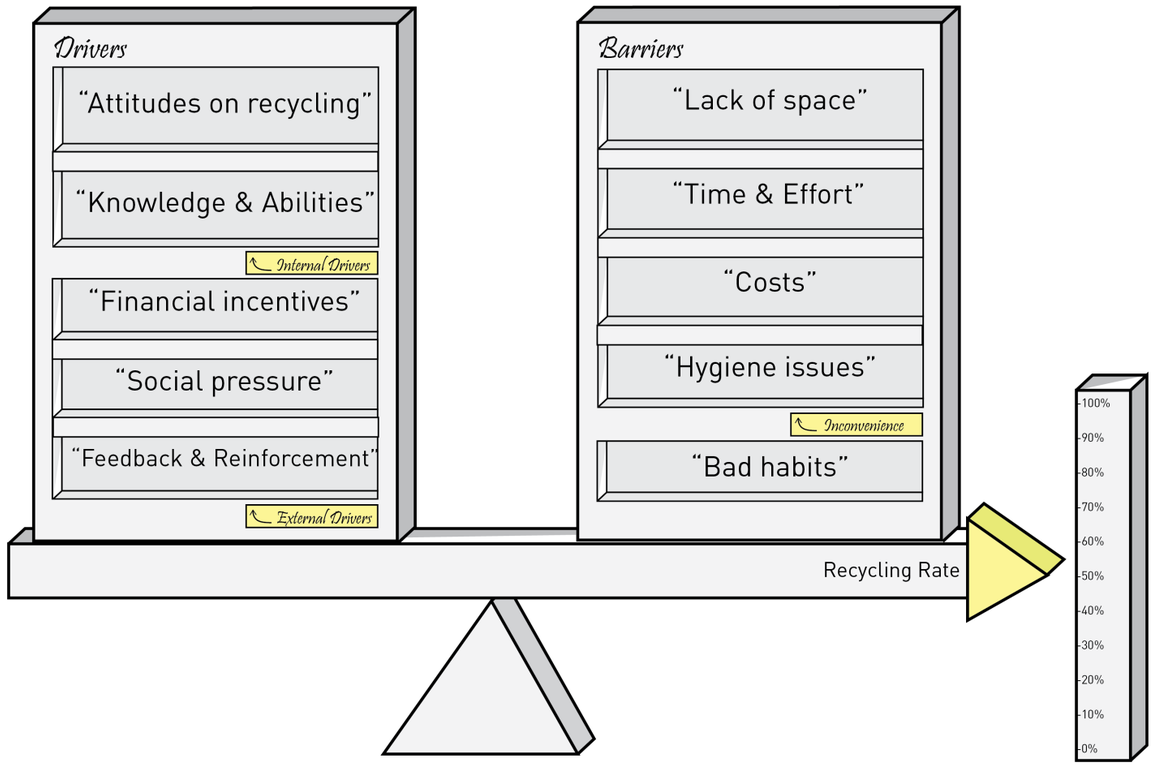



*Figure 5 - Drivers and Barriers for Recycling Behaviour*

Most of the effect that the aforementioned socio-demographic factors have can be attributed to the attitudes and knowledge of the residents. The environmental factors mostly have an effect on the barriers like 'lack of space'and 'time and effort'.  Some factors, such as income, have an influence on both sides: having more income will lower the monetary component of inconvenience, but it will also diminish the effect that financial incentives to recycle have.

Research by Barr (2007) supports this model, also noting variables such as knowledge, social pressure and convenience. Barr's model delves even deeper into the psychological part of recycling attitudes, discussing traits such as environmental values, altruism, and intrinsic motivation, and their respective effects on behavioural intention (which is similar to what is called attitudes on recycling in this report). The model also notes that intent does not always mean that the actual behaviour is displayed, as other barriers may still stop people from acting.

## Situation in Rotterdam

As mentioned before, the separation rate in Rotterdam is only 21%, making Rotterdam the 3rd worst-performing municipality in the Netherlands. This statistic can be explained using the drivers and barriers discussed earlier in this chapter.

First of all, the high population density of the city is an indicator. The two worst performing municipalities, The Hague and Amsterdam, are the 1st and 4th densest cities in the country respectively. High density usually means a high number of high-rise buildings. As mentioned on page 11, high rise apartments have less-than-average space to store garbage, even when leaving the absence of a garden out of consideration. Kerbside recycling does not happen around these buildings, and a longer walk to the collection bins means a larger investment of time and effort is required. Additionally, high-rise districts have higher percentages of people renting, and by extension more transience.

A second factor is that living in urban areas will decrease people's willingness to interact with strangers, and gives people a high rate of anonymity. (Zito, 1974) Because of this, there is little social pressure to drive recycling behaviour.

Finally, as the city does not employ any kind of DIFTAR, there is no real financial incentive for people in Rotterdam to improve their behaviour.

# Part II
# Research on the 'Ideal Future World'

"Finding the methods of how the waste cycle could be organised in an ideal yet realistic way."



## 5. Defining the Ideal World

In order to be able to imagine an ideal world, we first have to define the qualities that make the situation ideal. Since the ambition is about becoming a circular city this seems clear:

**In the ideal situation the amount of material from the waste stream that is being reused in the production of new consumer goods is as high as possible.**

This statement comes down to two main criteria. The first of these criteria is the quality of the (separate) collected materials. The quality and purity of the output of the waste processing decides the usability of the processed materials for production. The other criterion is the amount of materials that are collected separately, which is directly linked to the rate of participation by the citizens. If more people separate their waste, the amount of reintroduced material increases.

This is where a contradiction occurs: The best method for the municipality to increase the quality of the collected material streams is to have a more complex system, by having as many separate waste streams as needed. This way the streams are very pure and lead to high grade recycled material.

However, making the collection system more complex will increase barriers to recycle, making the participation rate lower. Having more separate waste streams will mean that the system is harder to understand, which also negatively impacts this participation rate.

Therefore, a balance needs to be found in the complexity of the base system of waste management in Rotterdam.

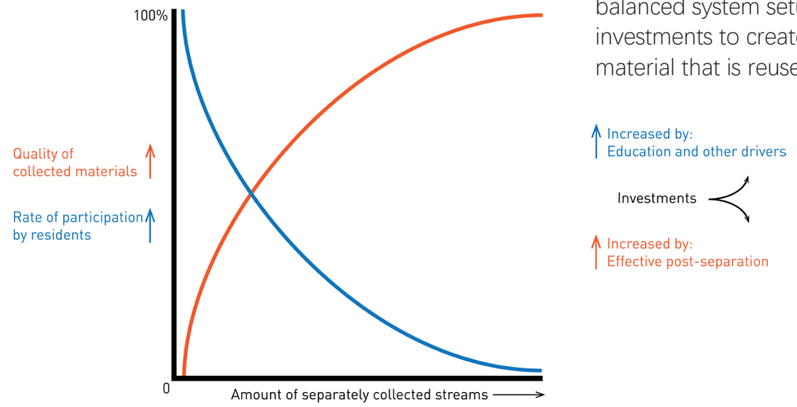



*Figure 6 - Assumed functions of quality and quantity of collected materials over the amount of collected streams*

Figure 6 shows the assumed functions of the two criteria (quality of material and participation rate) given by the amount of waste streams that are collected. The balance can be shifted around by changing this amount, depending on which part is more important at the moment.

Luckily, there are also methods to increase the two factors. The rate of participation is influenced by the drivers and barriers found in chapter 4, meaning it can be increased by fostering the drivers by providing education and providing monetary or social incentives, and by reducing the barriers of inconvenience and breaking bad habits.

The quality of collected materials can be increased by good post-separation and better cooperation between the different waste processors and recycled material producers.

These investments can be made to offset the balance in the right direction. For example, when the municipality decides to increase the amount of collected streams, more education and incentive will be needed to keep the participation rate up, This change would be needed because people need to be informed about the increasingly complex specifics of the recycling system. By contrast, the amount of waste streams might be lowered, but then there need to be better post-separation methods to keep the quality high enough by separating the combined waste fractions. A strategy for the municipality to collect more recyclables flowing from these arguments can be found in appendix E

In conclusion: the ideal world has to have a well-balanced system setup, together with the right investments to create a situation where the amount of material that is reused is as high as possible.

# 6. Context: the New Pompenburg Project

The city of Rotterdam has promised to provide more housing for its residents, and an opportunity was found to expand within its city limits. In the heart of Rotterdam near its central station, a small area by the name of Pompenburg is one of the last places in the city that has been left undeveloped after its destruction in the bombing of 1940. This is mainly due to the presence of a railway through the heart of the area. In the past it used to be the location of the 'Hofplein' rail station, which was the final stop of a railway to Den Haag and Scheveningen. Even though this line no longer exist, the railway between Rotterdam central station and Dordrecht is still present. Since this railway is an important and busy connection, it has been difficult for any developer to plan and build in Pompenburg whilste still adhering to the strict regulations that the railway company Prorail pose.

A consortium consisting of J.P. van Eesteren, Dura Vermeer and Synchroon has accepted the challenge of transforming the area into a pleasant and valuable part of the city, and they have published their vision for this new neighbourhood. The following is an overview of these plans.

## The development vision

The Pompenburg area is situated on the crossroads of three separate neighbourhoods in Rotterdam, these being the Rotterdam Central District (RCD), the "Zomerhofkwartier" (ZOHO) and 'het Oude Noorden. The plans by the consortium of developers aim to connect these neighbourhoods together, overcoming the barriers posed by the railway. They plan to achieve this goal by establishing physical connections such as roads and bridges, but also through using the identity of the area itself by extending the character of the adjacent neighbourhoods into the three parts of the Pompenburg area. In its centre will be the repurposed building of the old Hofplein station, and the high-rise buildings along the edge of the area will create the effect of a valley within the city.

The Pompenburg area will have a layered composition, with the different layers fulfilling different functions. The ground layer will be a neighbourhood level, with facilities for the residents of the area, like parks, shops and bike lanes. It will be a series of connected public spaces. (Also see the green area in figure 8)

*Figure 7 - The development vision of the new Pompenburg area that was made by Synchroon*



Another level will be a city park that will be built partly over the existing railways, and partly on top of the old railway station building, including the area where the old railway connection used to be. It will act as a public space on a city-wide level, inviting the people from all over Rotterdam to visit.

These layers will be connected with bridges that are a re-adaptation of the current 'Sky Boulevard', which is an elevated walkway that connects the different parts of the area across the rails.

The living space is envisioned as a mix between high and mid-rise buildings along the edges of the Pompenburg area. It will include some 400 to 600 residences in different price ranges, together with commercial space. In this way it is hoped to create an area that houses a broad mix of different kinds of people with different backgrounds and income levels.

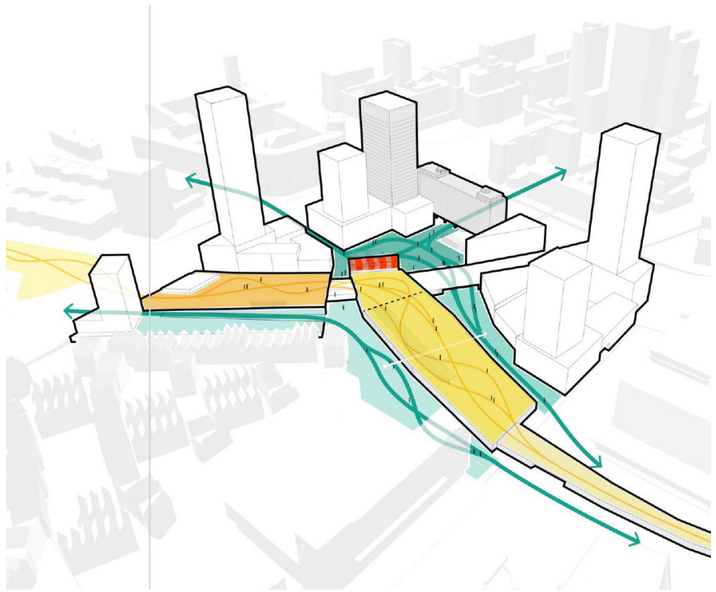


*Figure 8 - Layers and connections within the development vision*

## Opportunities for waste system design

The development of a new city area such as Pompenburg involves planning for all the different streams that move through it: think of streams like traffic, water, energy, and of course material. Since the aim of this project is to optimise a part of the material stream, the waste stream, the New Pompenburg project provides a perfect opportunity for rethinking the way the waste moves through the city.

In chapter 4 it was found that bad recycling habits are a barrier to recycling behaviour, but that a large change in a person's life will make it easier to break certain habits. Therefore a new neighbourhood with new residents might be a blank slate for the recycling behaviour. If the system is designed well enough, people will be more likely to start recycling since they are forming new habits to fit in their new context.

A driver for recycling behaviour found in the same chapter is the social pressures that neighbours and friends exert on a person. Because the New Pompenburg area will be a healthy mix of people from different backgrounds, it will hopefully help the more environmentally conscious residents provide an example for the recycling behaviour that the city hopes to instill. It will therefore be important that the recycling in the area is a visible process.

A challenge for the waste collection in the Pompenburg area is that the developers are aiming to make the neighbourhood a car-free zone. Cars are guided into underground parking areas while the centre of the neighbourhood stays free of them, excepting one road through the area that allows cars to enter as 'guests'. This ambition poses a problem for the waste collection services, as they still need their vehicles to empty the containers in the area. How this problem is tackled needs to be considered in the final design.

Lastly, the New Pompenburg project provides an opportunity for the city to test a new system of waste collection on a smaller scale, or perhaps act as a stepping stone towards a better system. The effect of this new system can be monitored to be able to predict the implications of a wider implementation.

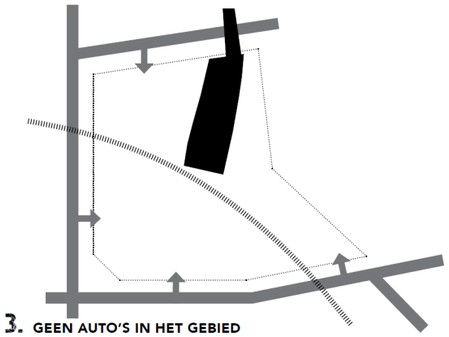



*Figure 9 - "Free Pompenburg" - No cars in the area*

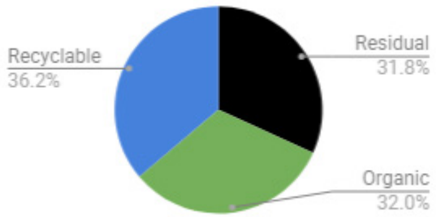
# 7. Other Systems Around the World

| Country | Recycling and composting | Incineration with energy recovery | Incineration without energy recovery | Landfill |
|---|---|---|---|---|
| Germany | 65 | 22 | 13 | 0 |
| South Korea | 59 | 24 | 1 | 16 |
| Austria | 58 | 35 | 0 | 4 |
| Slovenia | 58 | 1 | 0 | 36 |
| Belgium | 55 | 43 | 1 | 1 |
| Taiwan | 55 | no data | no data | no data |
| Switzerland | 51 | 49 | 0 | 0 |
| Netherlands | 50 | 48 | 1 | 1 |
| Sweden | 50 | 50 | 0 | 1 |
| Luxembourg | 48 | 35 | no data | 17 |

*Figure 10 - A list of the best recycling countries in the world*

In the search for the ideal situation of waste collection for Rotterdam it is also interesting to see what other cities around the world are doing about the same problem. The countries with the highest recycling rates are found in Figure 10, and the cities in these countries would be a good place to look.

**Legend:**




The graphs show the collection rates for the country and the city respectively. note that in some cases the exact data was unavailable and is therefore missing from the infographic

**Sources for the data found in this chapter**


Germany
-(VierusTom, 2019)
-("Aufkommen an Haushaltabfällen", n.d.)
-(Connective Cities, SUBV Bremen, 2016)

USA
-(Meaghan, 2018)
-(EPA United States, 2018)
-(Calcycle, 2017)

Korea
-(Vinceau, 2019)
-(Seoul Metropolitan Government, n.d.)

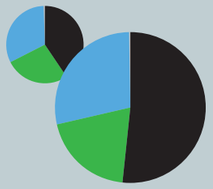
Taiwan
-("How Taiwan Has Achieved One of the Highest Recycling Rates in the World", 2019)
-(Municipality of Taipei, 2018)

Slovenia
-(SNAGA, n.d.)
-(Copenhagen Resource Institute, 2014)
- ("Cena, obračun in plačevanje za storitve ravnanja s komunalnimi odpadki", 2019)

Netherlands
-(Gemeente Horst aan de Maas, n.d.)
-(Rijkswaterstaat, n.d.)


## Bremen - Germany

Germany is currently the best recycling country in the world. The city of Bremen has a similar population to Rotterdam (around half a million) and is also a harbour city. However, it collects almost twice as much organic and recyclable material.



Collection rates

**Specialty:**
Although the infrastructure for collection is similar to that of the Netherlands, Germany's recycling is done mainly with the green dot system (grüner punkt). German law states that the manufacturer of packaging waste is responsible for its processing, so therefore they have to pay to receive the green dot on their packaging which allows it to be collected in special recycling bags. This system also makes it clear for consumers when something can be recycled. Other European countries, including the Netherlands, have adopted aspects of this methodology.

**Way of paying**

Flat Fee

**Landfill rate (Germany)**


## San Francisco - USA

While the USA isn't known for its effective waste management, the city of San Francisco is known as one of the best recycling cities in the world, with a recycling rate of around 80%.
This high rate is mainly because the city succeeded in fostering an environmentally conscious attitude in its citizens and has a very user-centred approach to waste collection.

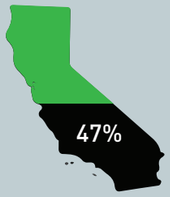
Collection rates

**Speciality:**
In California, most cities make use of single-stream recycling, a system where there is just one bin for all recyclables such as paper, glass and other packaging materials. This system has been very effective in increasing the participation of California's residents. San Fransisco has been investing heavily into facilities where this single stream can be separated again into its sub fractions.

**Way of paying**

Size of Residual Containers

**Landfill rate (California)**




## Seoul - South-Korea

In the past, the South Korean capital was having a lot of trouble with their increasing amounts of waste, and was therefore one of the first to implement a DIFTAR system, back in 1995. It was found that the Koreans are a big producer of food waste, and as a result, the collection of this fraction has received extra attention in the infrastructure and promotion of recycling in the city.

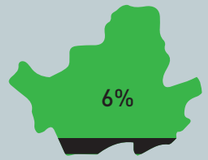
Collection rates

**Speciality**
Seoul mostly uses strict regulations to enforce recycling behaviour. Monetary incentive is used by making people pay for the volume of their waste, and also with heavy fines for incorrect separation behaviour. This behaviour is tracked by having the residents use an electronic ID to access the collection stations.

**Way of paying**

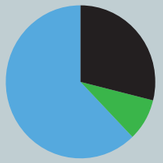
Taxed residual bin liners

**Landfill rate (Seoul)**



## Taipei - Taiwan

Taiwan has in the past been known as 'Garbage Island'. Since then, the government has put a lot of effort in changing its waste management systems. They have for example reduced the amount of waste that is being landfilled to less than 1%, which is not so common in east-Asian countries.



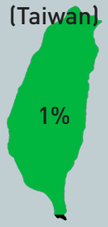
Collection rates

**Speciality**
In Taipei, instead of personal or public containers, the citizens have to hand their garbage directly to the people on the garbage truck. The trucks have a fixed schedule, and announce their presence with classical music so that the people can come outside to deliver their trash. The workers make sure the waste ends up in the right truck, since there are usually multiple trucks for different waste-fractions.

**Way of paying**

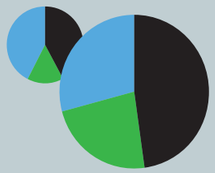
Taxed residual bin liners

**Landfill rate (Taiwan)**




## Ljubljana - Slovenia

Perhaps a surprising entry on the third place in the world's best recycling countries is Slovenia. The capital Ljubljana was one of the first cities in Europe to set zero-waste goals, and won the EU's European Green Capital award in 2016.



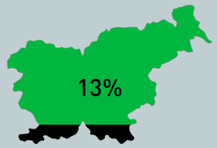
Collection rates

**Speciality**
The city has relied on promotion campaigns to foster a positive recycling attitude in the city. They have for example used a song by a beloved Slovenian folk singer to be associated with the 'reduce, reuse, recycle' mantra. They used different ways of communicating, such as posters, TV spots and social media incentives.

**Way of paying**

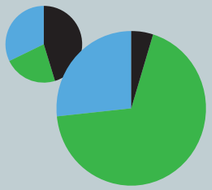
Size of residual + organic containers

**Landfill rate (Slovenia)**




## Horst aan de Maas - the Netherlands

Within the Netherlands, the municipality with the best recycling rate is a collection of towns in the province of Limburg with a combined amount of about 40.000 residents. High recycling rates are possible because people generally have the space to place multiple containers for the different fractions. Moreover, the municipality has put extra effort in optimising their system.



Collection rates

**Speciality**
The recycling system consists of kerbside pickups for all of the large fractions, as well as charging extra costs for residual waste. The municipality did this by repurposing all the bins for residual waste into those used for PMD waste, while residual waste has to be offered in special taxed bags. Alongside these measures, they had a successful information campaign to teach the residents about the recycling system.

**Way of paying**

Taxed residual bin liners

**Landfill rate (Netherlands)**




## Conclusions

Although there are many small differences in the way the different waste collection systems in the world are set up, they follow the same main concept. Kerbside pickup of waste combined with the use of public containers has been proven to have effective results, and all cities in this analysis have some form of this way of collection. The main difference lies in which kinds of fractions are collected, and in what way. Usually these are similar to Rotterdam's, with streams like residual, organic, paper, glass and packaging. Sometimes, distinctions are made within these streams, like dividing garden and food waste, different colours of glass or plastic and metal packaging. The specific kinds of streams will likely have mostly to do with the arrangements with the processing companies that the cities work with.

An important similarity between these cities that is not shared by Rotterdam is that most of them do use some form of DIFTAR, making their residents pay more for unsorted residual waste. The ways of paying tax differ between weight, volume or frequency methods but they all follow the same principle.

Out of the special methods of increasing collection rates, those in San Francisco and Germany seem the most applicable to the situation in the Netherlands. While the German system is a good way of reducing the amount of packaging material that is being used and increasing the clarity of home recycling, the system used in California is a source of inspiration for how things could be done differently. It proves that single stream recycling can improve the collection rates in a city in a big way, if it is done in concert with fostering the right attitudes and knowledge as well as giving other kinds of incentives.

### Problem with collection rates

However, we should not forget that these are cities that are known for their collection rates. Even though collection rates are often confused with recycling rates, they are not the same thing. The collection rate is the rate at which a city diverts its waste from landfill and incineration, into separated fractions of usable material. The recycling rate is, or should be used for the percentage of waste that is actually being reused as a material or other kind of resource such as compost or biogas.

While it seems these numbers should be similar, this is regrettably not always the case. For example, a large part of the California recyclables are shipped overseas to Asia, only to be found of unsuitable quality and landfilled anyway. The largest importer of Californian waste, China, recently adopted a new policy that rejects any recycling waste with purity levels less than 99.5%. However, this led to the waste finding its way to other countries such as Malaysia, which has an even lower capacity to deal with it.
(Hook, Faunce, Blood & Reed, 2018)

In the manner described above, a city such as San Francisco can boast an 80% collection rate while still having a recycling rate of less than half of that. The exact numbers are hard to find because only the collection is measured and published.

We need to remember that half of the path to becoming a circular city is providing materials from the waste stream to the production processes that keep the city running. This goal can only be achieved if those materials have the right quality.

That said, collection is still an integral part as well, and the lessons that can be learned here shouldn't be overlooked.

What Rotterdam and the rest of the Netherlands are doing well is that almost none of the municipal solid waste (MSW) gets landfilled. Even the residual waste is being put to a good use by the waste-to-power plants. This already provides us with a healthy baseline to start improving from.

# 8. Sorting Technology Analysis

## Current waste sorting technologies

Gundupalli et al. (2017) have provided an extensive overview of MSW processing technologies. They make the distinction between direct and indirect sorting. Direct sorting uses the characteristics of the waste materials to do the sorting, such as their size and density or their magnetic properties. Indirect sorting is when the materials are recognised and separated by a computer system with certain actuators such as compressed air nozzles or deflectors that can move in and out of the way.

This chapter lists the sorting methods that are currently in use in sorting facilities, and some technologies that have been proposed for sorting but haven't seen widespread use in waste processing.

## Direct Sorting Processes

### Rotating drum screen

Often used as a first step in the sorting process. It consists of a large drum that is lined with holes increasing in size that rotates to move the waste downwards. This method divides the waste by size, the smallest items falling through the holes at the start of the drums, and the largest falling out the open end of the drum.

*Figure 11 - Rotating Drum Screen*

*Figure 12 - Ballistic Separator*

### Ballistic separator

Shaking platforms that are placed at an angle separate items with different density and geometry. The heavier and more 3d shapes roll down the slope, while light and flat waste is slowly thrown upwards by the particular shaking motion. Oftentimes, the platform itself works as a sieve, separating a third fraction of fine material.

This technique is used in paper sorting to separate the paper from cardboard, and in packaging waste sorting to separate foils and other thin plastics from the hard plastic containers.

This type of sorting has some similar methods such as disk separators, which work on the same principle but use different configurations.

### Air classifier

A sorting process where the waste passes over a column of rising air. This process will also divide the waste by density and geometry. The lighter wastes such as films, plastic bags or paper are blown upwards, while the heavier items fall down. It is used in separating waste fractions, but also for example in removing the paper labels in the processing of glass or PET bottles.

### Magnetic and eddy current sorting

These are used to separate metals from other kinds of waste. Magnets, usually on a moving belt, attract the ferrous metals to remove them from the waste stream. Non-ferrous metals are not attracted by the magnet and are therefore sorted using the following method. An eddy-current separator uses a certain quality of spinning magnets to repel non-ferrous metals such as aluminium to also separate them from the rest of the waste.

### Electrostatic sorting

This is a separation process that uses electric fields to charge particles. Different kinds of material receive a different charge, and this can be used to separate them. This method is mainly used in mining operations, but can also be used to retrieve certain minerals from E-waste and for sorting plastic particles.

## Indirect Sorting Processes

A newer but increasingly common sorting method that employs cameras to sort by optical qualities. Usually infrared or near-infrared light is reflected from the waste on the belt and detected by a camera. A spectrograph analyses the reflected light to determine the material of the scanned object. The sorter uses precisely timed blasts of air to 'shoot' selected items into a different receptacle to create two lines.

This technique is currently mainly used in sorting the different kinds of plastic into separate lines, but different kinds of sensory methods can be used for other types of waste as well.

For example: lasers can in combination with a camera map the 3d shape of items. Combined with scales this can also give an indication of density. A materials colour can also be detected using cameras. This is used in sorting glass and paper/cardboard fractions.



*Figure 13 - Optical sorter*

Other kinds of detection include laser spectrographs or X-ray for identifying metals.

## Manual sorting

None of the processes above has a constant 100% efficiency rate: oftentimes, foreign materials remain in a sorted waste fraction. Most recycling centres therefore employ people to take out any material that the sorter might have missed, or materials that cannot be processed by the sorting line. In some cases, manual sorting only happens at the end of the line, but other places have manual sorting after every major sorting step. In spite of the fact that increased efficiency has already decreased the need for manual labour, it seems that it will take some time before this sorting method can be phased out completely.

## Upcoming sorting technology

### Hydrocyclone sorting

A direct sorting technology that has seen much use in mining operations. It uses centrifugal forces in a funnel-like machine to separate materials in the carrier liquid (usually water) by density. Research proves that this method can be used in MSW sorting to separate different kinds of plastics into very (more than 99%) pure streams. (Richard et al., 2011). However, before the plastic can be fed into this sorter, it needs to be ground down into pieces with a size between 0,5 and 120mm. The heavier particles move outwards and downwards, while the lighter ones will stay in the centre and are moved upwards.

### Jigging and Froth flotation

These are two direct sorting methods that use the characteristics of particles in a fluid to separate them. Jigging is done by bringing the fluid with waste particles on a shaking bed. The differences in buoyancy and density cause the heavier particles to separate from lighter ones. This can be used for separating metals and plastics.

Froth flotation is a method that uses the hydrophobic quality of plastics to separate them from the rest of the waste fractions. The plastic particles attach to air bubbles that have been created in a tank and form froth on the surface of the water, while the other particles sink to the bottom.

### Optical sorting development

Since optical sorting processes are computer driven, the recognising of waste types might be improved by machine learning and neural network developments.

Koyanaka & Kobayashi (2011) describe their success in using neural networks to improve the sorting accuracy of vehicle shredding, to sort different metals with optical sorting processes. Because the programme receives feedback from its failures, it is able to learn from them and improve. Machine learning is a big technology trend, pioneered by companies such as Google. It can be expected that this technology will improve in the coming years, making separation processes more accurate and precise. These improvements will lead to an increase in the amount of material that can be post-separated and the purity of the separated streams.

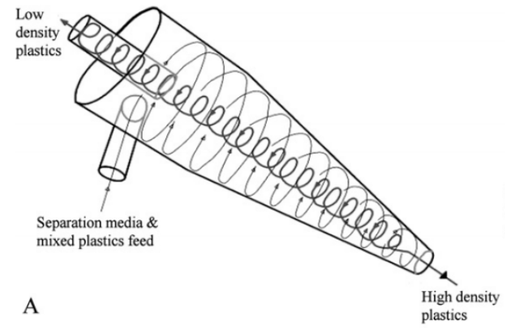



*Figure 14 - Principle of the Hydrocyclone*

## Transition into post-separation

As mentioned before, the recycling rates for plastic and other packaging waste in Rotterdam are very low (about 7%). The sorting techniques mentioned in this chapter make it possible to separate this fraction from the residual waste instead. This has prompted Rotterdam's waste processor AVR to build a new sorting facility to process the waste before it moves to incineration. (AVR, n.d.)

Feil et al. (2016) made an analysis of a post-separation sorter in which they attempted to sort plastic waste from samples of both German and Dutch MSW. Using a similar setup to the new facility in AVR (drum sorters, air classifiers, film grabbers and NIR optical sorting) they found that they were able to take about 40% of the plastic from the residual waste. It was then separated into rigid plastics, films and a fraction for refuse derived fuel. These fractions were also cross-contaminated, and thus required further sorting.

The researchers found that the quality of the rigid plastics (if they were sorted correctly) was comparable with those that were collected separately, but the film fraction's quality was severely hampered by being in contact with organic material. This will pose a big problem for the reusability of the films.

The researchers predicted that the efficiency of the sorting can be improved to about 50-60%. Assuming that the results of this study are an indicator for the new post-separation line, this prediction would mean that AVR can help the municipality increase the collection rate of plastics by more than 50%. However, the quality of the materials that are collected, especially when the mixed plastics are not sorted further, will decrease if this method is employed. Since the purity of the collected materials must be near 100% to keep reusing them in a circular system (where for example bottles can be remade into bottles), post-separation of plastics might not be conducive in the ambition to become a circular city. This  is especially the case if it stops people from source separating their plastics, like AVR is suggesting they do in their promotional material.

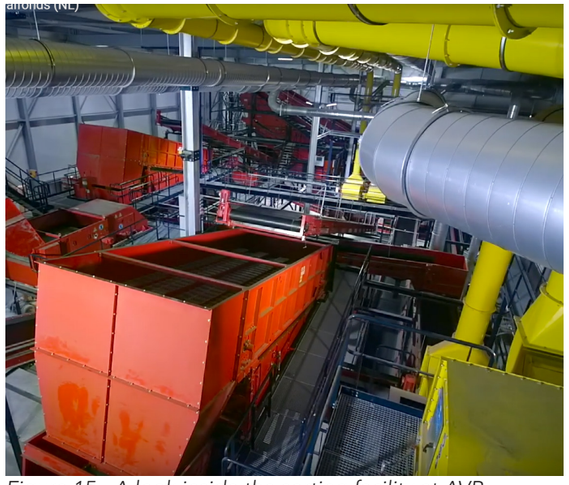


*Figure 15 - A look inside the sorting facility at AVR*

## Conclusion

Knowledge about how waste is sorted and how it could be sorted has the potential to be very helpful when setting up a collection system for MSW. Because collection and post-sorting processes influence each other greatly, they need to be considered together to maximise the efficiency of the waste processing system. The matter of which items can or cannot be separated from each other needs to be considered when deciding what waste is collected together, so that the municipality ends up with the highest possible quality of materials to hand over to the processing companies.

In the future it might be possible to post-separate all waste with a (near) perfect efficiency. This would be ideal, since it would make source separation obsolete. This would mean that waste collections become very simple and efficient, and it would deal with the challenges presented in densely populated urban areas. However, there are many aspects that still need to be solved before we can even think about this scenario. For instance: how can you make sure that materials such as paper do not degrade in contact with the other waste?

It seems that for now, a combination of source- and post separation methods will remain necessary.



# 9. The Ideal Future Scenario

The analysis of the context of waste collection in Rotterdam is concluded with the 'Ideal' future scenario for the city. The scenario consists of a set of considerations for the municipality on how to approach the road to becoming a circular city. This approach will also be the basis for the product design phase of the project, which will include requirements and opportunities that follow from the different parts of the analysis.

## The importance of material quality and source separation

Part of being a true circular economy is the ability to reuse the materials from the waste in a similar manner to their original purpose. Instead remaking bottles into cheap furniture or artwork, it should be possible to remake bottles into new bottles. Otherwise, virgin materials will always be needed and the city cannot be called truly circular.

The main challenge in achieving this ideal is maintaining the material quality through the consumer and collection steps. Because many kinds of similar but different materials are collected from households together, materials end up being contaminated with other kinds. This problem needs to be solved before these materials can be reused properly, either by making sure this contamination does not happen, or by sorting the materials after the fact. The balance between these two methods needs to be maintained carefully to achieve a successful and cost-effective waste treatment system in the city.

Discussed on the previous page, AVR made the decision together with the municipality to build a post separation line for residual waste to increase the capture rate of collected plastics, metals and drink cartons by more than 50%. This effort is an applaudable one in itself;

**however, the municipality has in addition decided to gradually stop separately collecting the PMD fraction from the city, removing existing PMD containers.**

This might be a problematic decision for two reasons: first of all, it was found that post separation will provide material of a reduced quality to that of source-separation, since the amount and nature of contaminants in residual waste is higher and less foreseeable than those in recyclable fractions. (Jansen, Feil, Pretz, 2017) This problem is irrelevant if the waste otherwise ends up in an incinerator, but by replacing source separation completely the highest grade material is lost.

Secondly, this decision damages the image that the municipality has been trying to build in the city for years: that recycling is important and that people should think about what they throw away. There is a risk that telling people not to bother collecting packaging waste also has a negative impact on the collection of other materials. Besides, it completely negates the impact that the trend of increasing environmental consciousness might have on recycling rates.

Overall, the municipality should keep in mind that recycling is not just about the diversion rate (as discussed on page 22). They should keep themselves informed of the result of the processing of their city's waste to make sure it is being used in an optimal way. Further decisions about policy can be made with that information in mind. This is because the quality of post separation is fully dependant on technology, while source separation quality can be increased by the many different factors that are discussed throughout this report. The following is a quote from the paper by Jansen, Feil & Pretz, (2017), who analysed the viability of post-separation of PMD waste in the Netherlands:

> Further research is needed to clarify if – and if yes, to what extent –MSRW as a source of plastics has an impact on the actual recycling stage. These plastics are typically much dirtier than those from a source separation system. The DSD specifications which are commonly used to describe the quality of the sorting products leave no room for this peculiarity. (...) This may lead to significantly lower recoveries during the recycling stage. (p. 175)

If it turns out that post-separated PMD waste is of equal value to source separated material, the municipality can make the well-informed decision to stop the collection of the latter. However, this report will offer an alternative solution that will make it easier for both the citizens of Rotterdam and the municipal collection personnel to collect the PMD waste, which will complement the post-separation that is already being done.

## Ideal world considerations

### Strive for a balanced approach

The research discussed earlier in this report demonstrated that increasing recycling rates is best done by a balanced approach to the different problems associated with recycling. Different people have different reasons for (not) recycling, and Rotterdam especially is a collection of many different people from different backgrounds. It is therefore important to have a broad solution area that includes providing information, convenience, and incentives, instead of fully focusing on one problem.

Design Consideration:

**The design of a waste collections system in a building should encompass the multiple facets that affect recycling behaviour, instead of focusing on a single factor.**

### Important waste fractions

There are lots of considerations that need to be taken into account when deciding which types of waste are collected where. The municipality is collecting 6 different streams within the city. To recap chapter 4: these are residual, organic (GFT), paper, glass, Packaging (PMD) and textiles.

Between them, they also vary in importance. Figure 16 shows the relative amounts of these fractions that are collected both separately and within the residual waste. The left graph shows the weights of the fractions, while the right shows the volumes. (The conversion table that was used is found in appendix B)

Looking at the left graph, you can see that organic material is by weight the biggest fraction that could be collected separately. While this material is being used in (and even important to) waste-to-energy processes, separating it from the rest of the waste would increase the quality of materials that are post-separated from residual waste as well as increasing recycling rates.

A life cycle analysis by Gao et al. (2017) indicated that processing food waste by anaerobic digestion or composting is much preferable to incineration, partly since the latter will cause acidification and eutrophication in the surrounding environment because of the release of nitrogen dioxide.

In the right graph in figure 16 you can see that the PMD waste encompasses as much as half the total volume of all the waste that is collected locally by the municipality. Separating this fraction will decrease the volume of the residual waste by a large amount, and the PMD waste lends itself to shredding or compressing to reduce the volume locally, which will decrease the frequency of collections that are needed.

Out of all the fractions, textile is a somewhat different waste type from the rest. The residual, organic, PMD, paper and glass fractions all have in common that they are produced constantly, since they are the result of daily consumption of items such as supermarket products. Think of matters such as food leftovers and the packaging materials that were used to hold the food. Textiles are more of an incidental kind of waste, similar to chemical waste or discarded electronic devices. Therefore, these are not as important for the waste collection system as the others.

Design consideration:

**The new system should focus on the collection of these five main waste types: Residual, organic, PMD, paper and glass. If there has to be a priority, the residual, organic and PMD wastes are most important in a waste collection system. since they consist of the largest relative amounts. However, all other fractions can be included in another way, for example in the information that the residents are provided with in the building.**

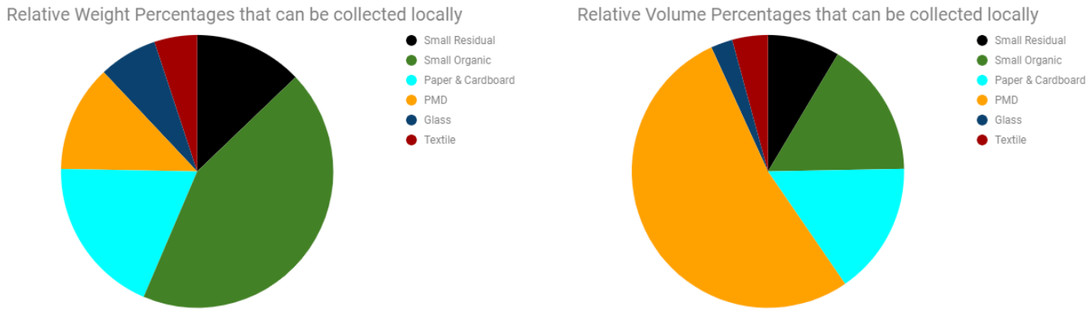



*Figure 16 - Relative amounts of Rotterdam's locally collected MSW in weight and volume percentages*



### Considering what materials to accept

In the recyclable waste fractions, the result of processing is very important. To be able to keep reusing a material over and over, its quality should be maintained during the waste processing steps. It is therefore important for the municipality to be aware of the result of the processing of these recyclables, to see whether they are actually being reused in a similar way to their original purpose. It would be good to discuss with the processing companies if there is any accepted waste that lowers the quality of the result material significantly. These might (for now) be better suited for energy production alongside the other residual waste.

An example of this change would be any paper material that has been in contact with food being thrown in with the organic waste. Contaminated paper lowers the quality of the paper recycling process, but paper is also an organic material which can be composted or digested. Another example might be plastic foils: these are hard to sort and mostly result in low quality material since they are contaminated easily. These might for now be better suited for the residual waste.

Design Consideration:

**The new system should make it clear what waste is being accepted as recyclable and what should go in the residual waste instead. An opportunity for the design would be to consider how the design could allow for changes in what is being accepted.**

### Residual waste as the largest distance

One of the reasons for people not to recycle is that it always takes more effort than just dumping everything in the residual waste. This is due to the separation that needs to take place at home, and because finding and going to the appropriate containers that are usually farther away than the residual bins. This added distance is a big issue for high-rise residents, since they never qualify for kerbside pickup schemes and have to instead bring their waste to a collection point. One way to make it easier for the residents is to have the recyclable fractions collected closer—or at an even distance—to the residence as the residual waste. In this scenario, recycling can be seen as an equal option instead of as an extra effort when bringing waste to the containers.

Design Consideration:

**The design should make bringing away recyclable waste easier to do than, or equally easy to do as bringing away residual waste.**

### Using Differentiated Tariffs... or not?

As mentioned in chapter 3, the municipality of Rotterdam has decided not to implement any kind of DIFTAR waste tax in the city. Even though most of the cities with high recycling rates do practice DIFTAR, there are viable arguments to be made against implementing it.

While it does increase the amount of waste that is collected in the organic and recyclable waste streams, this waste will likely include more items that do not belong in the waste fraction. Since keeping the quality of the material high is important, it is better for the city to try and incentivise its residents in another way. If the city does change its mind and starts using DIFTAR, it should implement some kind of way to check what is being thrown away to be able to give warnings or fines to those that abuse the system.

Design Consideration:

**The new system should incentivise residents to recycle their waste, preferably in a non-monetary way.**

## The next step: Design Phase

The design considerations found in this chapter were combined with the findings from the rest of the research part into a programme of requirements. This programme can be found in Appendix C.

The goal for the design will be to increase the collection of organic waste and useful recyclables, while keeping the capture rate of waste at 100%. The design will be a way for residents to collect and hand in their MSW that will increase the amount of waste collected separately.

The context of the design will be new high rise neighbourhoods in Rotterdam, particularly the New Pompenburg area. Since the municipality is interested in solutions for waste collection that they can offer the developers, this is an interesting context to design for.

The design will take place in the space in and around the new high-rise buildings.

# Part III
# Design of the Re-Posit system





The start of the design phase consisted of mapping out the context for the design, particularly the journey of waste from high-rise buildings to waste processing.

The stakeholders were identified, and mapped depending on their interest and influence on the project. In figure 18 can be seen who the most important stakeholders are.

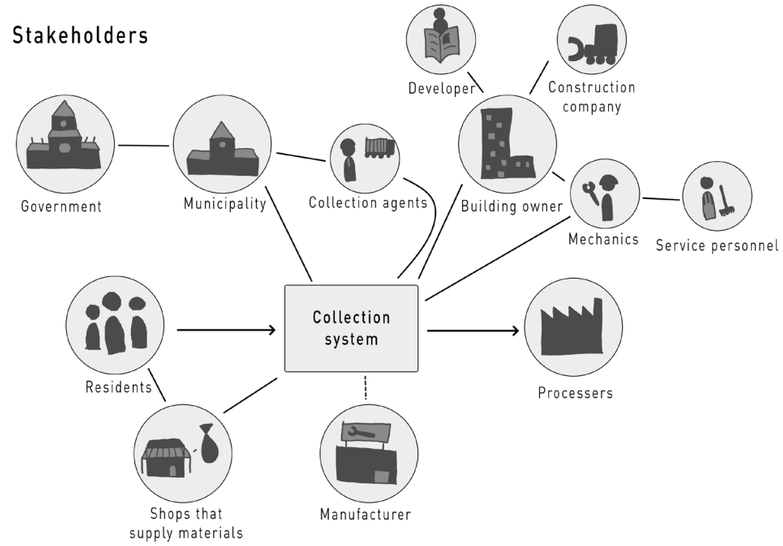



*Figure 17 - Stakeholder identification*

**Important stakeholder concerns:**

Municipality
- Increasing recycling rates
- Decrease costs of collection
- Providing a good service to residents

Building owner
- Low maintenance costs
- Low use of floor space
- Good service to residents
- Fire safety
- Building cleanliness

Developer
- Providing an attractive living space
- Lowering costs
- Keep out cars from the neighbourhood

Residents
- Easy access to waste facilities
- Having an attractive living environment
- Having low time, effort and costs for recycling

Collection agents
- Easy collections
- Safe and clean handling of waste

Government
- Adherence to regulations
- Increasing recycling rates

Processors
- Receiving high grade materials to work with

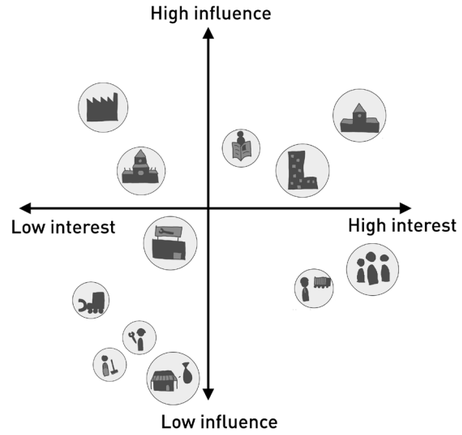



*Figure 18 - Stakeholder mapping*

Next, a function diagram was made to help think about the possible functions that the new design should/could fulfil.

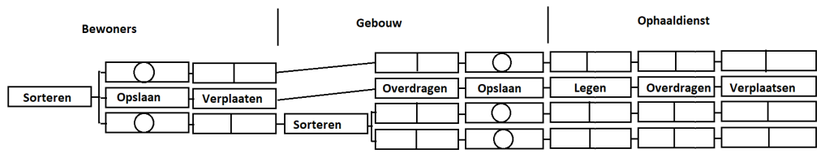



*Figure 19 - Function Diagram*

# 11. Ideation

Finally the waste-journey was mapped in the following way: the different stages of the waste journey (found from the function diagram) are connected with the findings from the research and the stakeholder concerns to see which issues should be addressed where. Improving the resident side of collecting waste is done by applying the drivers and barriers for recycling found in chapter 4, while the concerns for the collections and processing part are derived from the 'ideal future scenario' in chapter 9, and the concerns found during the stakeholder mapping.

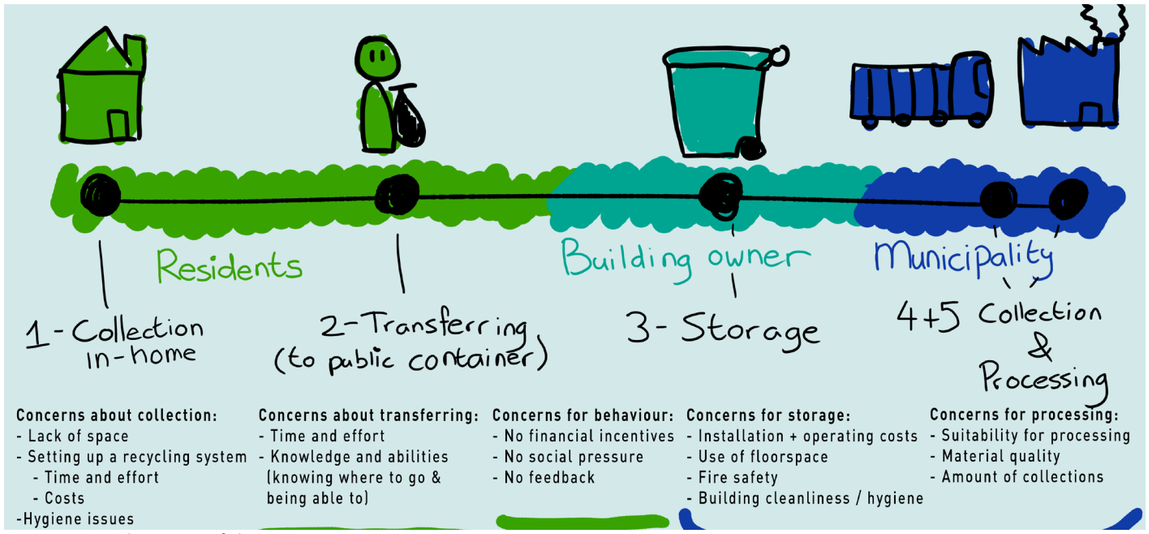



*Figure 20 - The map of the Waste Journey*

Next, ideation was done on the different concerns that were collected in the waste journey map.

Ideas were generated on topics such as how to store waste in a home, how to transfer waste to containers and where to store the waste in the building; but also to expand upon certain ideas.

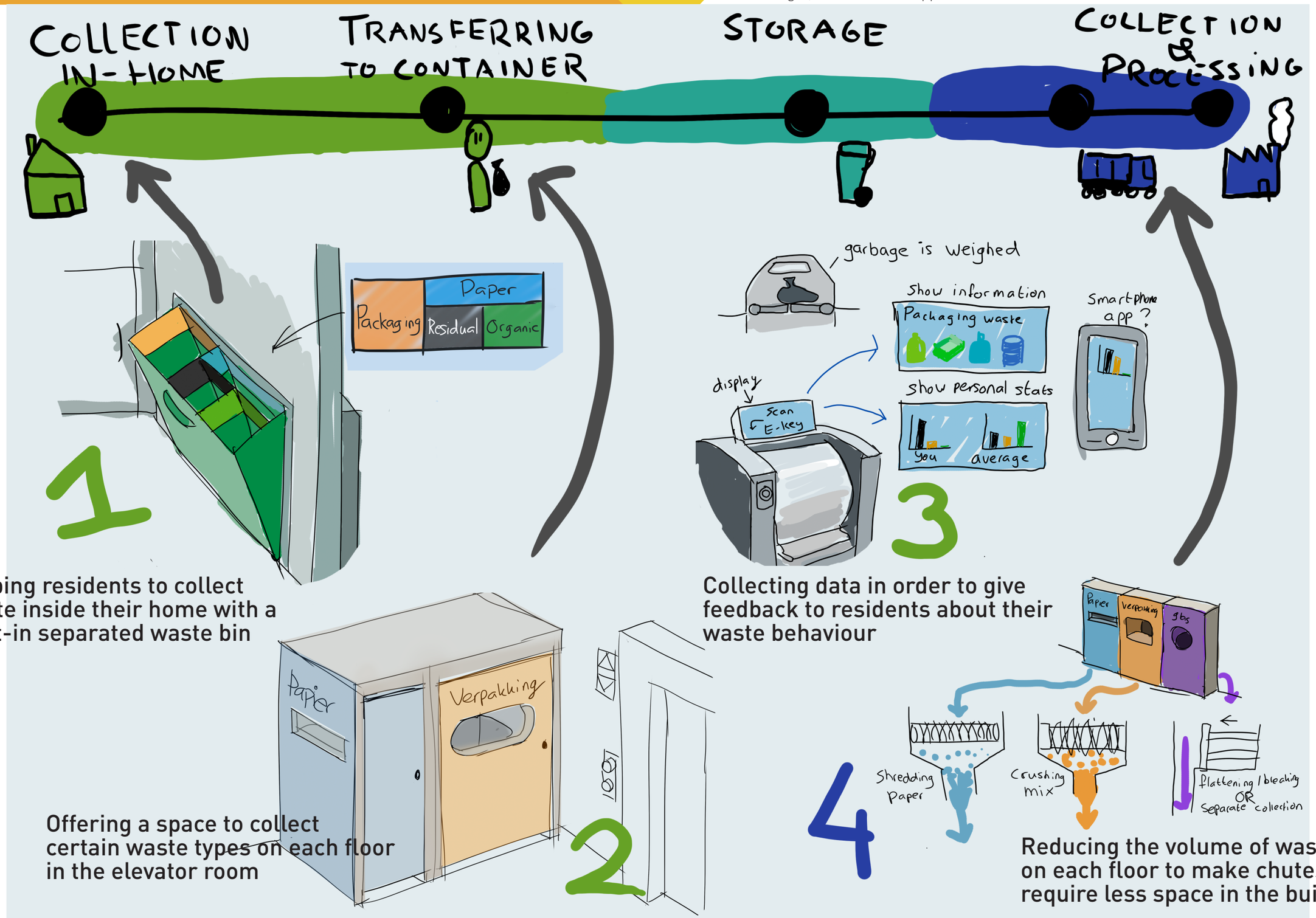
For example: How could a trash container be combined with a vending machine, and what should it dispense? Or how can you give certain privileges to people that recycle well, and what should those privileges be? A building might have an extra elevator that only the recyclers are able to use, or perhaps people should receive stickers for their mailbox to show their neighbours that they recycle.

The ideas were afterwards grouped according to their topic and on which part of the waste journey they provided a solution. These groups of ideas were eventually further developed into the different concept directions that are shown in the next chapter.


*Figure 21 - Photographs from the ideation done in a sketchbook*

# 12. Concept Directions

From the ideation, the ideas and findings were bundled in concept directions for each of the steps found in the waste journey map. This is a logical proceeding, since the ideation took place along the stretch of the waste journey, and the different problems for each step each require a specific solution. A more detailled explaination of the different concept directions, along with their advantages and disadvantages, can be found in appendix F.




Helping residents to collect waste inside their home with a built-in separated waste bin

Collecting data in order to give feedback to residents about their waste behaviour

Offering a space to collect certain waste types on each floor in the elevator room

Reducing the volume of waste on each floor to make chutes require less space in the building

# 13. The Re-Posit System: Overview

As discussed in the design considerations, for a solution for waste collection to have a significant impact, there needs to be a good balance in addressing the different issues instead of focusing on just one particular problem. Just like a clockwork, it will only run when all the parts are in place. Therefore the final concept is a combination of the different concept directions. This way, the new system for waste collection in high-rise buildings will possess the different qualities that are needed to improve recycling behaviour. In this chapter the conceptual design of this system is elaborated upon.

This is the Re-Posit system. It is a system that allows easy collection of the five most important waste fractions within a high-rise neighbourhood or other densely populated urban setting. It aims to make it more attractive for people in the neighbourhood to recycle their waste and to optimise the material flow out of the buildings. Besides this it will provide information about how recycling can be done, as well as collect data about the collected waste to provide insights to the municipality and the residents themselves.

## 1 - The in-home waste buffer

Inside every residence will be a designated area for the residents to collect their recycling waste. It deals with the difficulty that people have in setting up a way of collecting the different waste types, by offering the space and means of doing so from the moment they move into the house. It consists of a set of drawers in different shapes and sizes that can be built into a wall in the kitchen, and it allows some room for people to come up with their own preferred recycling setup. This part follows concept direction 1.

## 2 - The waste receptacle

The receptacle is where the residents will be able to deposit any of the five main waste types. By allowing this, it lessens the effort that is needed for recycling, since the user does not have to go looking for the correct container, or walk further than he does for disposing of their residual waste. They will only have to tell the system what kind of waste they are throwing in. The receptacle is placed in a location that is convenient for the residents, and from this place the waste is moved towards the pick-up point. This part follows concept direction 2

## 4 - The waste pickup-point

The waste is transported to this location and sorted automatically into the right container, going by the information provided by the residents. The pickup-point is placed in a location that is convenient for the collections personnel, who will empty the containers and take the waste from this point to its destination. This is especially advantageous for an area such as New-Pompenburg, since it will make it possible to keep the area free of cars and garbage trucks alike.

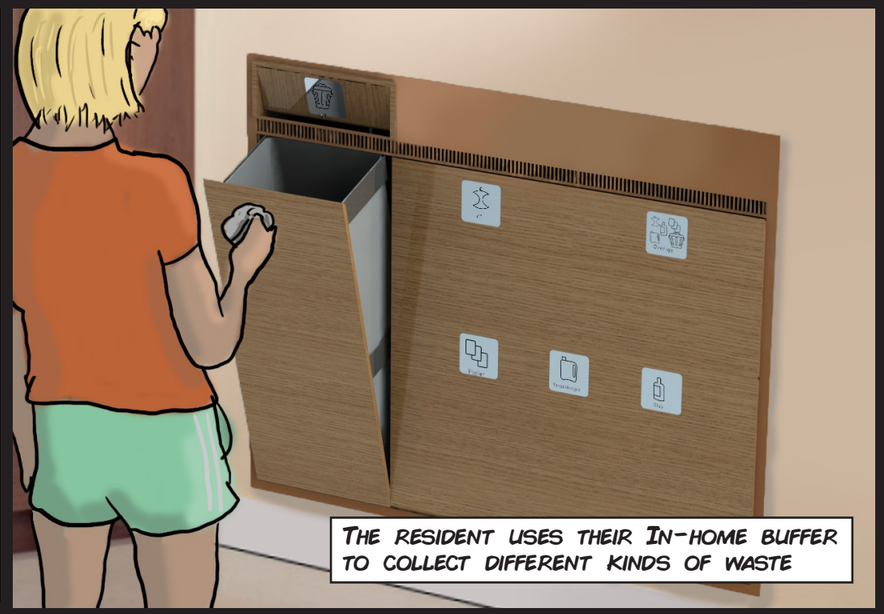
## 3 - The waste transport network

This part consists of a series of chutes and/or conveyors to move the waste from its collection point to the pickup point. In buildings of today, one location is chosen for collecting and storing the waste, which is a compromise for accessibility between residents and collections personnel. By splitting it up into two separate points and moving the waste between these points automatically, the locations for these points can be selected to be optimally accessible for both these groups.

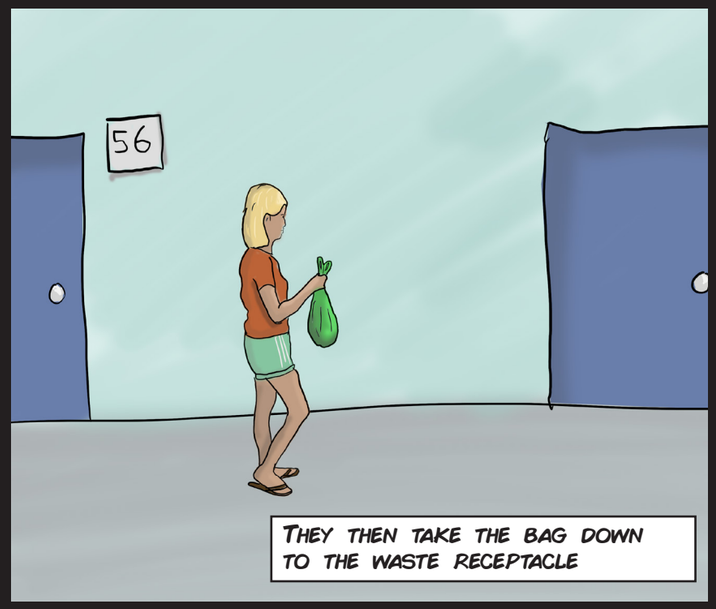
Together with these is a design of the way that information is provided to the residents about the requested recycling behaviour, as well as the considerations for the digital platform that is used to provide feedback to the residents of the building. This part follows concept direction 3.

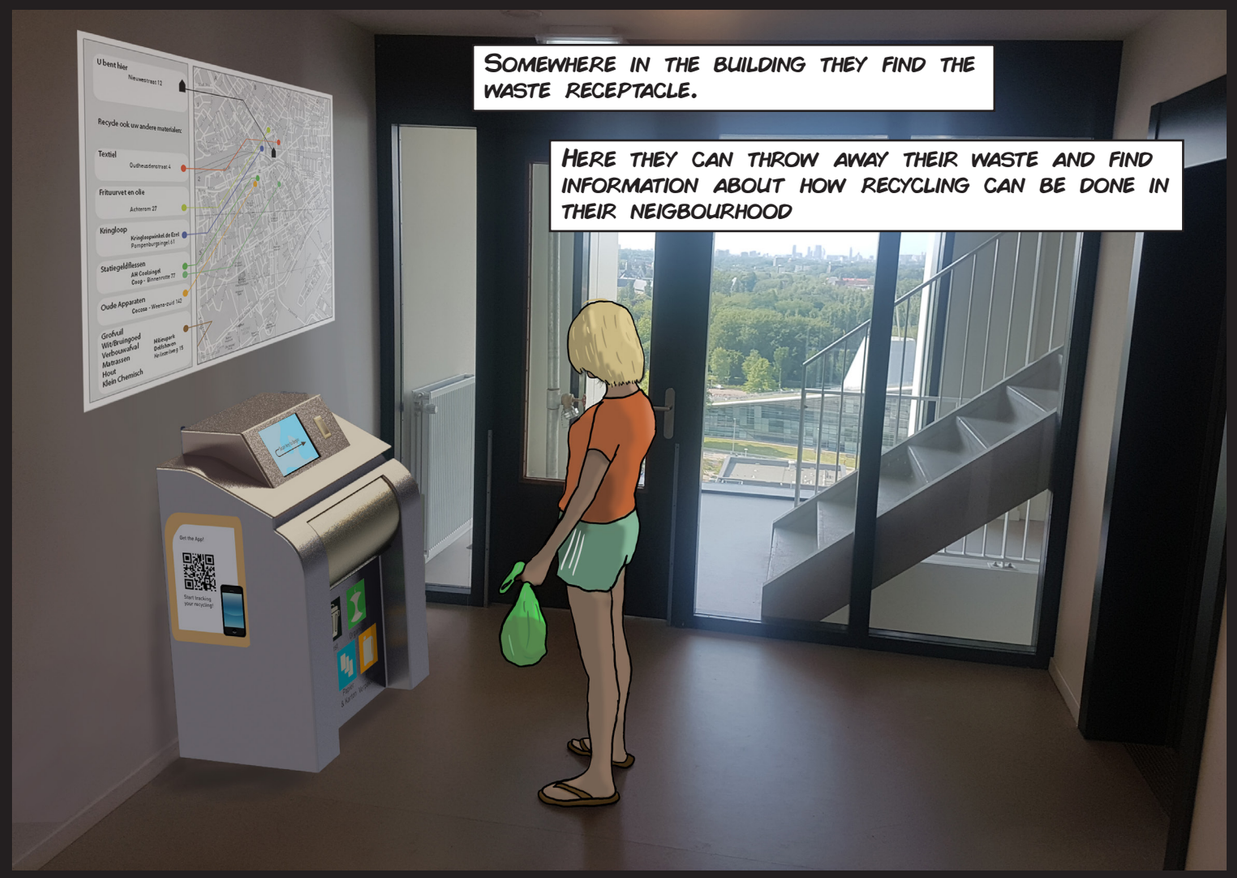
## Daily use of the Re-posit system

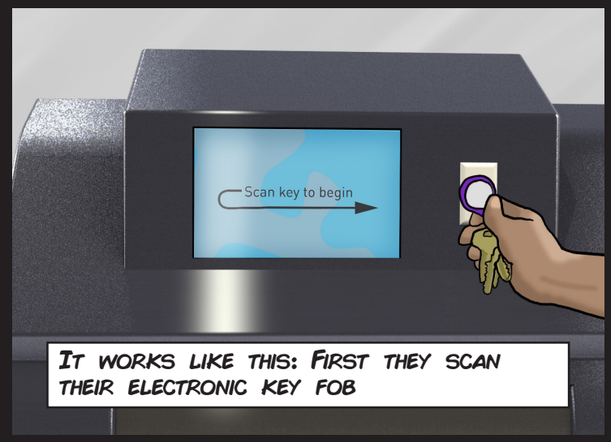
Here is an overview of what the routine of a person using the system would look like.



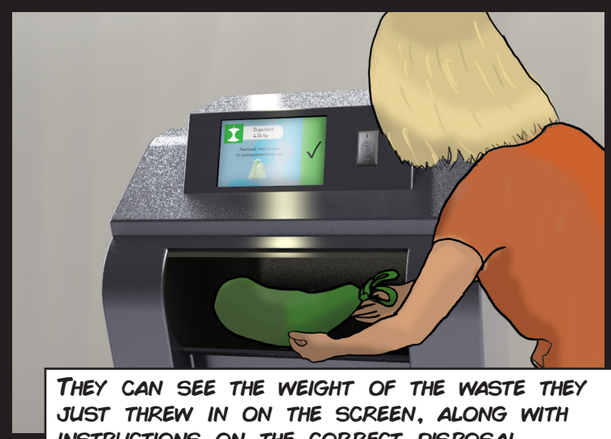









## Selecting the locations

The Re-Posit system will transport the waste between a location that is convenient for the residents, to one that is convenient for municipal collections. Described here are the considerations that should be taken when selecting these locations.

### The Waste Receptacle

The waste receptacle is the location that the residents will go to dispose of their waste. To make it convenient for them, this receptacle should be somewhere close to their apartment, most preferably along the route they take when leaving the building.

In table 1, a few locations were highlighted: One receptacle in the lift room on each floor, One in the entrance hall of the building, and one outside in front of the building.

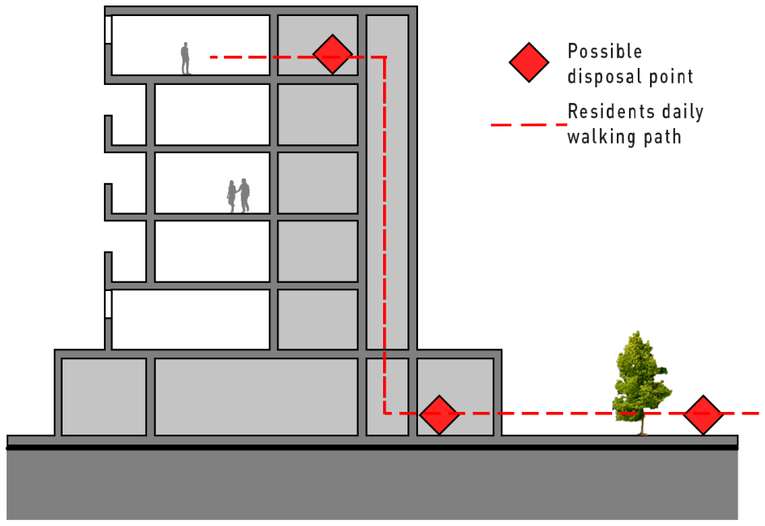



*Figure 22 - Possible locations for the waste receptacle*

| Location | Main Advantages |
|---|---|
| In the lift room on each floor | This would be the most convenient location for the residents, since recycling would take them only a few steps outside the door. Because the convenience is so high, the need for a large buffer at home would also go down, since making trips with small amounts of waste would become more viable for them to do. This will in turn make it so that the waste inside their home won't start smelling, since it does not need to be kept for several days. |
| In the entrance hall | This location is less convenient for the users, but it would make the investment needed to install the system a lot smaller. Only one receptacle will be needed for each building, and there will be no need for a garbage chute to take the waste down. This will save space on the inside of the service core, which will increase the usable floor space on each floor. Additionally, the other issues with garbage chutes are circumvented, such as the noise, fire hazard, smells and the possibility of bags breaking open on impact after falling down the chute.<br><br>By keeping the receptacle inside the building, it is less accessible to unauthorised persons, and therefore less prone to vandalism. |
| Outside | Keeping the receptacles outside of the building will save valuable space inside. In addition, like other garbage containers the Re-Posit receptacle is at risk of smelling badly. Having the receptacle outside will keep the smell outside of the living space of the residents. |

*Table 1 - Main advantages per location*

Out of these options, placing the receptacle in the entrance area of the building seems like the most sensible choice. Even though the convenience of having it in the lift room will be much higher, any improvement in the actual collection rates for recyclables likely won't outweigh the increased costs of implementing all the needed parts for per-floor collections. Having the receptacle inside will likely also be a better choice. Here, the system does not need to be weather-proof, it will only be used by the residents of the building, and there is more space around the receptacle for the needed information about recycling. The value of ground-floor space is less than that on higher floors, and the smell will be less of a concern than usual because the waste is not stored inside the receptacles themselves.

### The Pickup-Point

The pickup-point should be in a location that is convenient for the municipal collections personnel. This means that the location is accessible from the road, so that a garbage truck can park near to it. In Pompenburg this means that the pickup points should be along the outside of the neighbourhood, since the plan is to stop cars from entering the inner part.

The image shows that there should be at least one pickup-point for each group of buildings, and in this point all the waste that is discarded in these buildings will end up. It might even be possible to connect certain groups of buildings via transport lines in between, in order to have one single pickup point for all these locations. This won't be possible for the locations that are divided by the railway however.

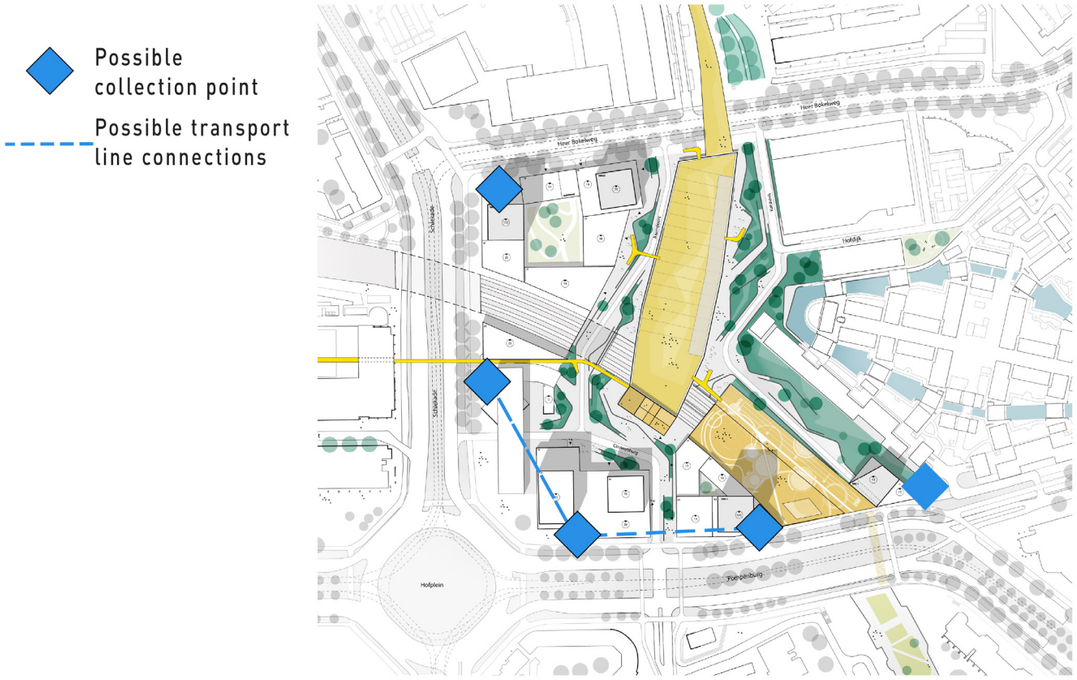



*Figure 23 - Possible locations for the pickup-points*

# 14. Re-Posit in Detail: In-Home Buffer

Good recycling starts at home. This part of the system will help people that move into their new apartment to start recycling easily and immediately. It consists of a set of drawers that are built into a wall in the kitchen area, with space to collect each of the five main waste fractions with room to spare for some additional types of waste such as batteries or frying oil.

In this design, it is suggested which drawer can be used for which waste fraction, however the exact organisation is left up to the resident. The leftmost container is designed to hold 35 litre waste bags for pedal bins, the upper drawers are 20 litres and can be lined with bags as well, for example for collecting organic waste. The lower drawer is 56 litres in size and is designed to fit a standard grocery bag, which can be used to collect and transport the waste collected in it, but it can also be used for loose plastic or glass bottles. The lower drawer also has a compartment for collecting paper, but the compartment divider can be moved or removed as desired.

The design will give the residents a space for collection without taking this space from their living environment. The drawers are equipped with a push mechanism that opens the drawer fully after pressing it inwards. When pressed again, they are locked in their closed position. The leftmost bin is opened by pressing the panel above it, making the bin tilt forwards. Because this bin is likely to be used the most, it is convenient for it to close automatically similar to a pedal-bin.

Different people will have different requirements for their recycling system. Therefore, the In-home buffer was designed to allow the user some amount of control over how the subdivision of what to collect where is made. To help the user make this subdivision and understand how the product is meant to be used, the drawers include a set of tiles that depict the different types of waste. These tiles are inserted into indents in the drawers, and will serve both as a reminder of the waste that is collected in this drawer, as well as a use cue for the opening mechanism.

The scenario on the next page depicts the first use of the product, and it shows how making the subdivision is done.

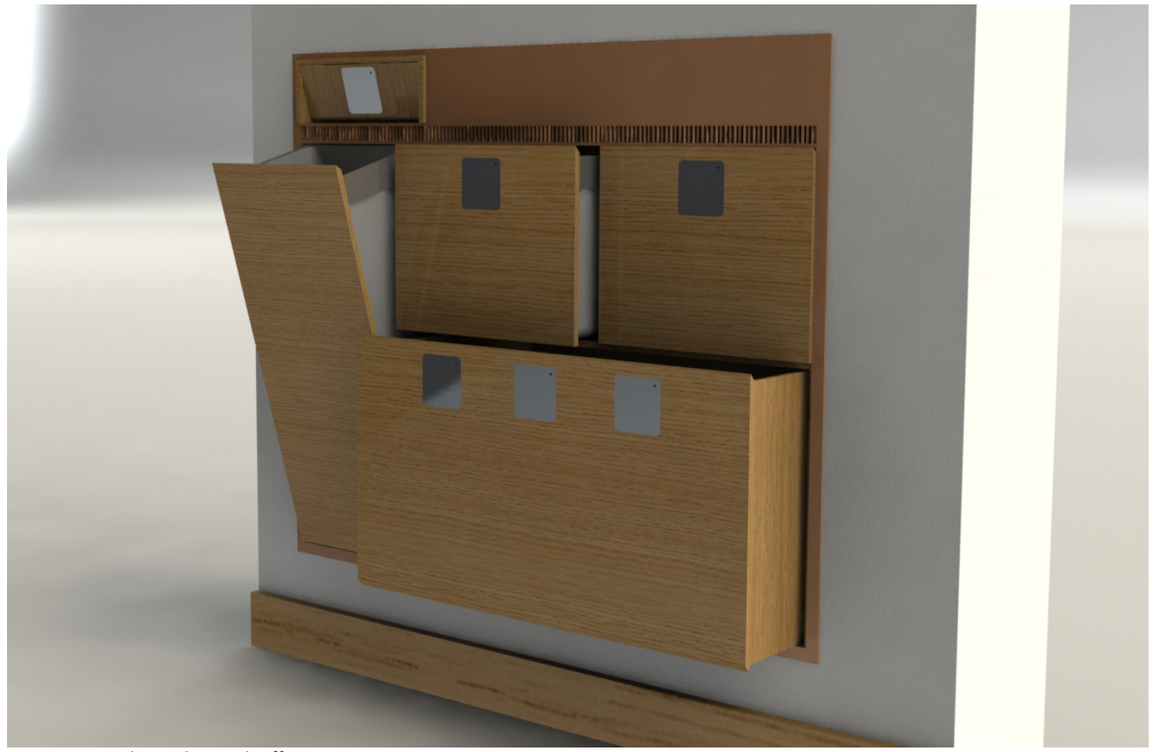
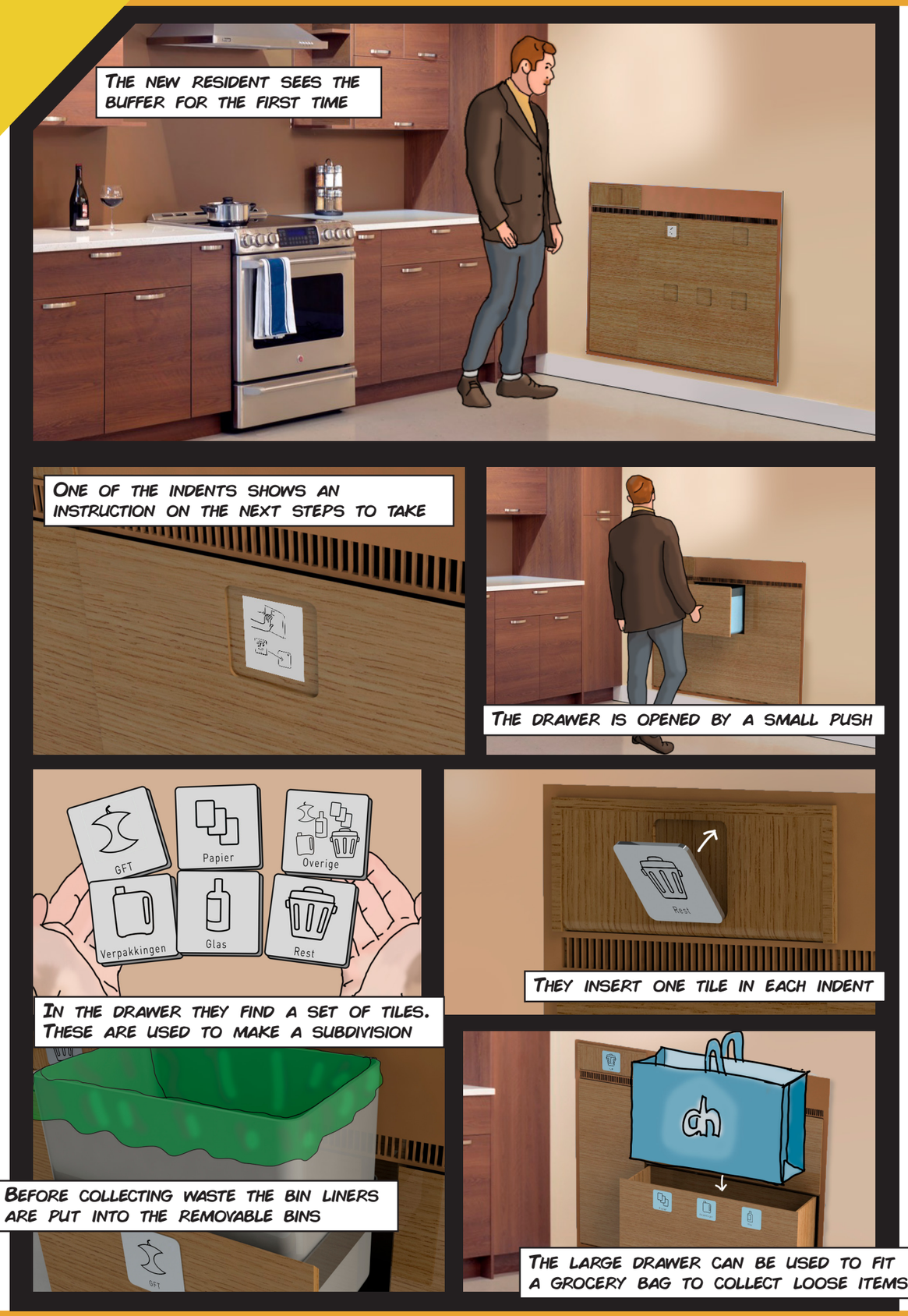


*Figure 24 - The in-home buffer*





## Details

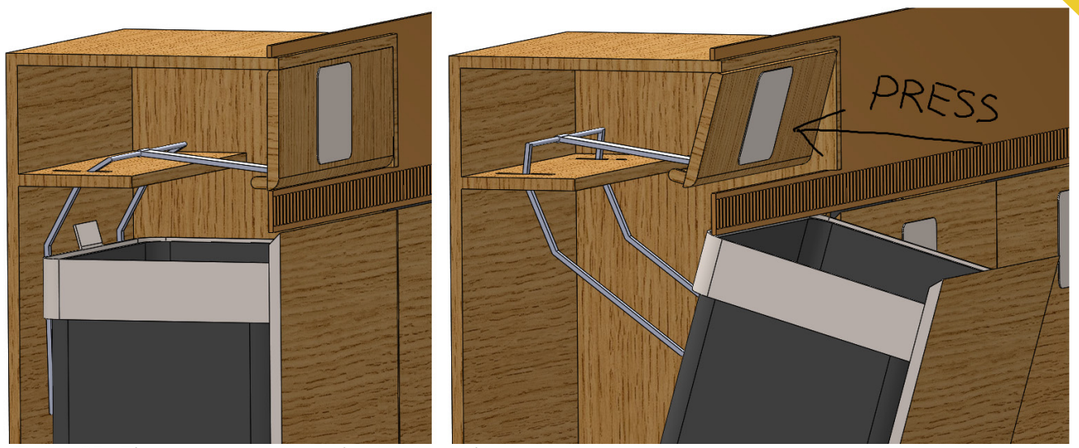



*Figure 25 - The press to open mechanism in working*

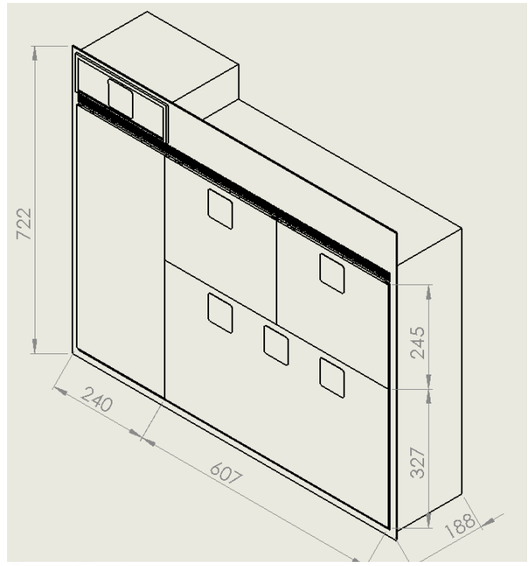



*Figure 26 - Approximate measurements in mm*

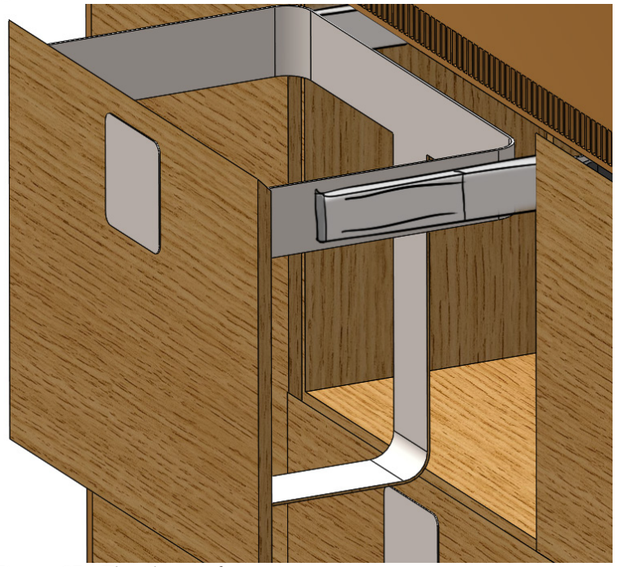


*Figure 27 - The drawer frame*

*Figure 28 - Examples of how different layouts for the different wastes can be made*



## Design considerations

The following is a summary of the considerations that were made in the design of the in-home buffer.

### Design

The buffer is designed to be unobtrusive, since waste is something that most people don't want to be prominent in their house. This is done by having the bulk of the product inside the wall, and having the front side be flat and continuous, hiding the lines between the drawers. The tiles will still give an indication of how the drawers are opened. The drawers use a press-to-unlock mechanism, which will make them easy to open, and it will remove the need for a space in between the drawer fronts where the user can get a grip.

### Sizes of bins

The sizes are based on the relative volumes of the average waste disposal in Rotterdam, as well as the dimensions of the typical waste products for those fractions and the sizes of the liners that are typically available. The depth of the drawers is designed to be the smallest dimension (25cm), so that it can be built into the wall more easily, limiting the space needed in this direction. The volumes of the bins are more than sufficient to hold the waste that an average household produces in two weeks. Only, the largest volume drawer is not large enough to hold the average volume of residual waste that a current household in Rotterdam produces in this time. In this way the design also encourages the residents to recycle, because doing so reduces the volume of the residual waste enough to fit it inside the buffer.

### Material

The material for the outside panels of the buffer should correspond with the material used in the kitchen. This design uses wood, but it is possible to change it according to the design of the kitchen space. The tiles are made from a different material to highlight their placement, in this case aluminium or steel.

### Drawers

The drawers are designed to contain a certain kind of waste without specifically saying what kind. The user should be able to take the waste directly from the drawer to the disposal point, this is facilitated by having the bins be removable. This makes it possible to easily insert liners in them, or even take the entire bin to the disposal point. One exception is the lower drawer. This drawer is designed to hold other kinds of bags, such as tote or grocery bags. This allows the users to collect waste that should not be bagged when disposing, and take them straight to the disposal point.

The structure that holds the bags is designed to be lightweight. Other than this, removing the waste bin will make the drawer unusable for other purposes besides waste collection, which should encourage the user to really use it in the intended manner.

### Tiles

The tiles are designed to be easy to place into the indents in the drawers. Removing them doesn't have to be easy per se, since a new subdivision is not likely to be made often. Therefore they should be put in place by pressing them into the indent. A small hole is present in the back of the indent to make it possible to remove the tile by pressing it from the backside with some kind of rod. The front sides of the tiles have decals to show one of the five main waste fractions, also including one for 'other waste' that can be used to show where for example batteries or oil are collected.

The tiles are meant to make the user think about how they want to set up their recycling system. However, it shouldn't feel like they are forced to use it in a specific way. Therefore it should be possible to insert the tiles backwards, showing a blank surface. This is for those people that specifically don't want to recycle a certain kind of waste shown on the tiles, or for those that dislike the appearance of the decals.

### Air vent

On the upper side of the panel surrounding the drawers is a line of small holes. This is meant to let air circulate inside the drawers somewhat more. From personal experience with recycling, closing off a waste bin from the air will accumulate the bad smells coming of the waste inside. When the bin is then opened, the smell is extra apparent. Open bins will let the smells out gradually, which makes it almost unnoticeable.

# 15. Re-Posit in Detail: Receptacle

The receptacle will be the location to bring your most common waste types. It is located in a space that is convenient for the residents of the new building, and it will make sure that there is no more difference in the efforts of bringing away your recycling- and your residual wastes.

The body of the receptacle contains a rotating waste chamber that is powered by an electric motor, and controlled by a processing unit. The system communicates with the user via a touchscreen. Next to the touchscreen is a NFC tag reader, that is used to identify the user by scanning their key fob. Data is collected on the amounts of waste that are thrown away for each household, and this is done by weighing the waste that is inserted before sending it down into the transport line.

As shown in the user journey on page 37, the receptacle is used by first scanning the key fob and telling the system what waste is going to be entered by pressing the screen. The waste chamber will then rotate into its open position. After the user confirms they have finished entering waste, the chamber rotates further to close the receptacle. In its closed position, also visible in figure 30, the weight of the chamber and its contents are recorded. The chamber will stay in this position until the start of the transport line is clear, after which it will rotate further to allow the waste to exit downwards.

*Figure 29 - The waste receptacle in its environment*

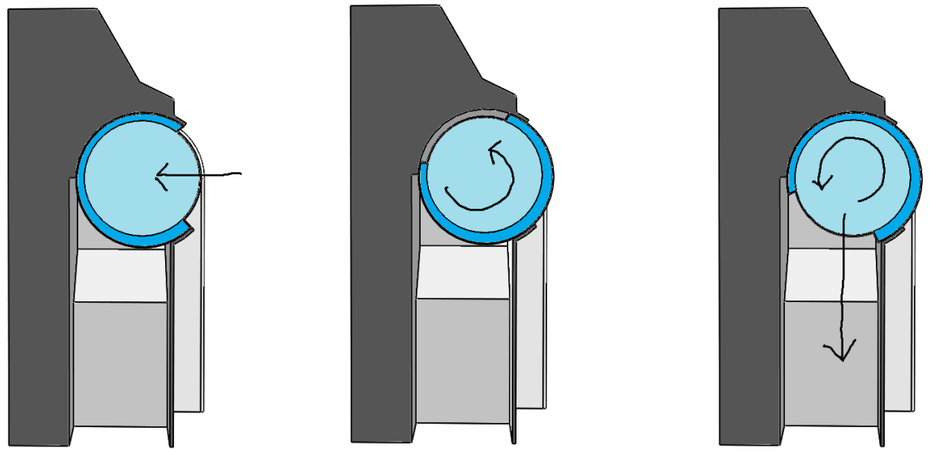



*Figure 30 - The mechanism of the waste chamber inside the receptacle*

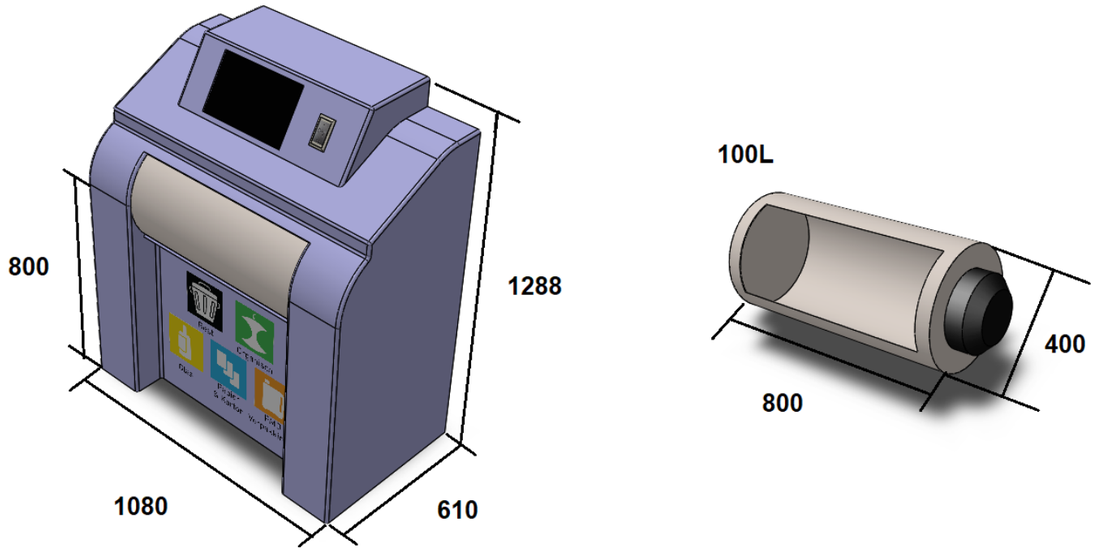



*Figure 31 - Approximate measurements of the receptacle and the waste chamber in mm*

## Design considerations

Design

The receptacle was designed to resemble an underground container, to make the purpose more apparent to the users. This includes the choice of material, which is steel. The front of the receptacle shows icons and the names of the waste types that are accepted to make it clear to the users that they can enter more than just the residual waste.

### Dimensions

The size of the waste chamber is dependent on the size of the transport line that will take the waste to the pickup point. The receptacle should keep out the waste that might get stuck in this line. The transport line should be able to transport bags with a size up to 40cm in width, so the waste chamber of the receptacle has a diameter of 40cm as well. The length of the chamber is also chosen to be able to accommodate a large trash bag, 80cm will be sufficient for most of the waste.

### Screen

The touchscreen has a size of 15 inch, which means it is about 32x21cm. This is roughly the size of a tablet device, which will make the screen easy to read. This is necessary because it has to display multiple kinds of information. For instance, it needs to show the weight of the entered material, and some instructions on how to provide the waste. More about the information provided to the users is found on page 52.

### Key fob technology

The receptacle is only able to be used when the user identifies themselves. This has multiple reasons. First of all, it is used to connect the collected data about the amounts of waste to a specific household, in order to give them feedback about their recycling behaviour. This is one of the drivers for recycling behaviour found in chapter 4. Secondly, identification is also needed to prevent abuse of the system. If items are found inside the system that do not belong there, of if the system is frequently used in the wrong way, the person responsible can be found by checking the data collected by the receptacle. Thirdly, by connecting the data to a household, it enables the municipality to offer additional incentives for recycling behaviour in the future. It would for example be possible to reward households that recycle well with discounts for certain shops.

The choice for a key fob system as opposed to any other kind of identification is because it is a technology that is already used in new apartment buildings to provide easy access to several common areas in the building without the need for multiple keys. The buildings in Pompenburg will likely also make use of a similar technology. Its use in the Re-Posit system will speed up the identification process from using a password system, and it is preferable to a ‘waste pass’ because the key fob is something that people already carry with them at all times. This means that won’t form a barrier to the waste collection behaviour.



# 16. Re-Posit in Detail: Waste Transport Line

The waste needs to be transported from the locations of the waste receptacles to that of the pickup point. Depending on the chosen location for these points, the waste needs to be moved vertically or horizontally, or both. Vertical transport of the waste can be done with garbage chutes, while horizontal transportation can be done using belt conveyors. Further elaboration on the design of these transport methods needs to be done before it can be implemented, but this report shows the possible implementation based on existing logistics systems.

## Vertical transport

The waste can be transported downwards from higher floors using a garbage chute system. These systems have been used in high-rise buildings for a long time to increase the ease of waste disposal for the residents. The popularity of these systems has declined due to concerns over hygiene and safety, but modern systems have alleviated some of these concerns by including modules like automatic cleaning systems and computer controlled input hatches.

The location of the chute will usually be inside the service core of the building. This is a shaft that houses multiple pipes and utilities, and it is usually coupled with that of the elevators. Most regular waste chutes are cylindrical, with a diameter of around 30 to 60 cm. This includes sound-dampening and fireproof layers of material. In case of the Re-Posit, this diameter should be at least 40cm to prevent medium-sized bags from getting stuck inside. Bags that are too large and might get stuck won’t be able to enter the receptacle, and will therefore pose no danger to the system.

As mentioned, modern garbage chutes usually have some kind of automatic cleaning system. These are usually housed on top of the chute, on the same level that houses the elevator machine room. They typically use sprinklers to spread cleaning detergent around the insides of the chute and the chute intakes. This mostly alleviates the concerns over the hygiene in the spaces around the waste intake.
(Central Chutes, nd)

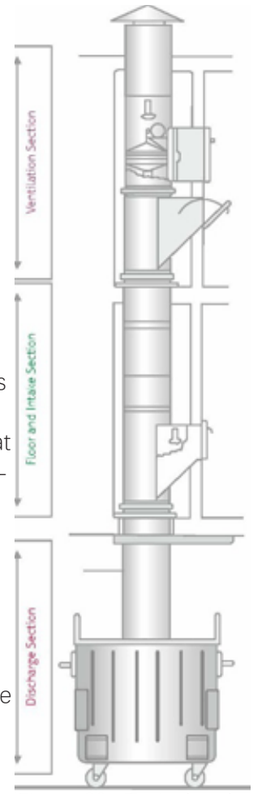



*Figure 32 - Typical garbage chute*

## Horizontal transport

The waste from the receptacle will fall down on a conveyor that takes it to the pickup point. The best type of conveyor for this purpose is a cleated belt conveyor. This type works using a rubber belt that is wound around two or more pulleys that rotate the belt around them. The belt has several vertical flaps, the so called cleats, which divide the belt into compartments. This will allow the system to keep track of the items on the belt, by allocating them to a specific compartment. The cleats also have the function of pushing the waste upwards on inclined surfaces. This is to get the waste back up above the ground level.
(MK North America, n.d., “Cleated Belt Conveyors”, n.d.)

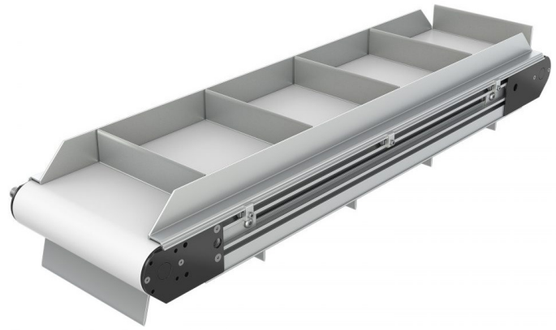


*Figure 33 - Cleated belt conveyor*

Another option would be to use so a called ‘tilt tray’ conveyor system, that makes use of loose trays that are pulled along by a chain, instead of sectioned parts of a belt. The trays can have flared edges to the same effect as the cleats on the rubber belt. When it comes to the sorting step, these trays can be tilted up or downwards to move the material on the tray into the right container. This method will likely make the sorting step easier, although the downside is that material might fall in between the trays, after which it can become very difficult to clean up.
(Bastian Solutions, n.d.)

# 17. Re-Posit in Detail: Pickup-Point

In the case that the conveyor spans over a larger distance, its location should be just under the ground level in order to keep it out of the public space, while still being accessible for maintenance and cleaning. For this purpose there should be a trench in the floor of the building that is around 50cm wide and 80cm deep. On the bottom of the trench will be the conveyor, and the top will be covered with panels that people can stand on but which can be removed to access the conveyor.

The conveyors are computer controlled. The computer program will keep track of the type of waste in each compartment, and it will regulate any junctions that connect multiple receptacles to one pickup-point by stopping the belt when the next step in the line is not cleared.

## Comparison to the AVAC

There is a proven method for waste collections that also transports waste underground, similar to the Re-Posit system. It is called Automated Vacuum Collection, or AVAC, and it is being used in over 30 countries to make collecting waste easier in dense urban areas. In the Netherlands, the cites of Almere and Arnhem also use AVAC systems, which are called 'Ondergronds Afval Transport' or 'OAT' there.
(BBC News, 2008)

AVAC works by having a network of pipes in the underground space, coupling the collection points to the disposal points. The disposal points in this case are underground containers, they collect waste in an underground buffer. When the buffer is full, it opens up into the network of pipes below, where it will get sucked to the collection point using a vacuum that is generated by powerful pumps. It is used to transport waste over up to 2km.
(Kaliampakos & Benardos, 2013)

The main difference between this method and the method used in the Re-Posit system is that an AVAC system still needs a separate receptacle for each waste stream, because the buffers can only contain one kind of waste. The Re-Posit system collects the materials together at the end of the line instead of at the beginning, and therefore needs just one receptacle per location.

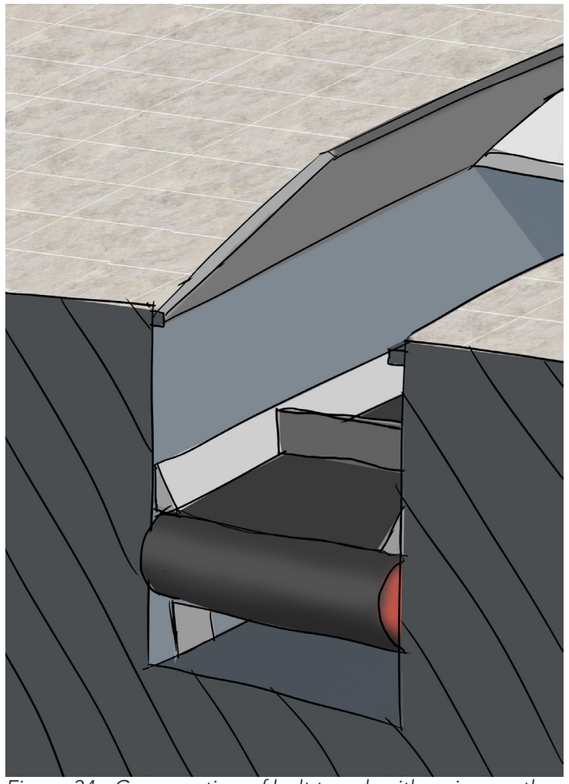


*Figure 34 - Cross section of belt trench with a view on the openable floor panel*

The pickup-point is the location that the waste is collected and stored before being picked up by the municipal collections. It arrives in this location through the conveyor belt system.

In this room, the conveyor system ends is a sorting system that makes sure the waste ends up in the right container. This can be done using computer controlled deflectors that push the waste off the conveyor at the right time. Because the system knows how many rotations of the conveyor it takes to bring the waste from the start to the end of the belt, it can determine the exact timing that is needed for this push.

The waste can be stored in standard waste containers, which can be emptied using the current equipment that is used by the municipal collection service. This means that the Re-Posit system will not require any alterations to the current methods of collecting waste. However, one of the main advantages of this setup is that it is a lot more flexible: the amount and types of waste that are collected can be changed more easily because the changes do not have any impact in the public domain, whereas adding or removing containers on the street would.

Because the pickup-point is only accessed by trained workers, concerns about safety and aesthetics are less crucial, making changes to this room more viable.

One other factor that is more feasible in the pickup-point in comparison to current collection methods is volume reduction. Some waste fractions can be reduced in volume by a large percentage through compressing or shredding. It was calculated that shredding PMD waste would lead to a 90% reduction in the volume of this material, which can save a lot of space or amount of collections that are needed. This means that it would be advantageous to install a compactor or shredder inside the pickup-point, if it is possible to do with the space that can be allocated there. There are other benefits to shredding PMD waste, which were explored during a previous iteration of the concept. More about the topic of shredders can be found in appendices F and H.

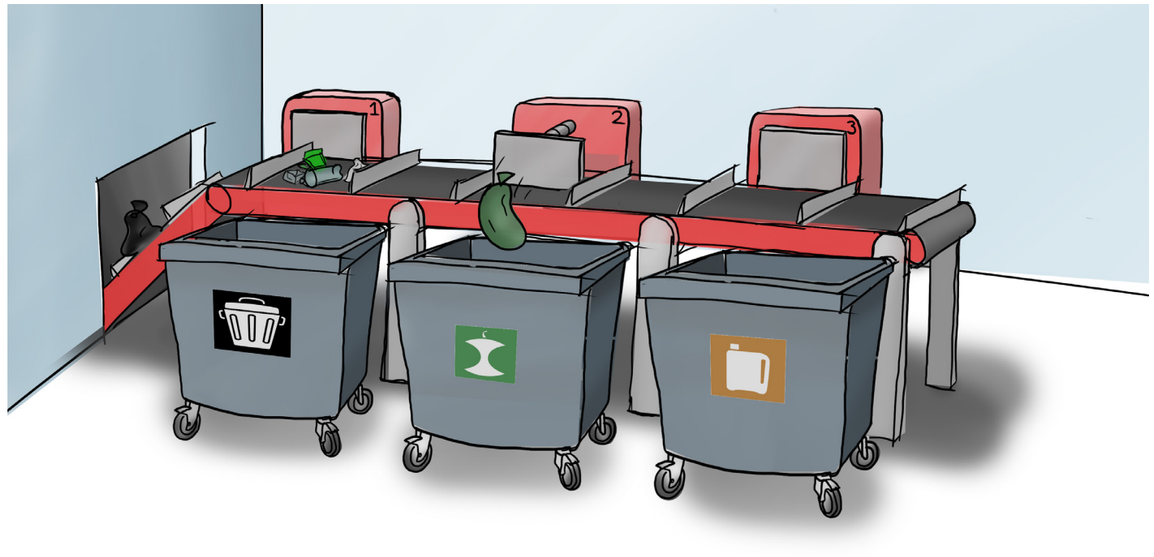



*Figure 35 - Example of how the pickup-point might look*

# 18. Re-Posit in Detail: Recycling Information Provison

In the research part it was discussed that knowledge about the recycling process is an important factor in increasing the recycling rates. It is therefore also an important part of the system to show the residents how the recycling is done, not only the five main waste fractions that are collected by the Re-Posit system, but also the other types of recycling and their locations. The location of the receptacle should become a kind of recycling hub that helps the residents to find the necessary information.

This consists of 2 parts: The first is to inform the residents on the items that are collected in each waste fraction, and also show them the items that shouldn't be in the waste fraction but that are commonly included anyway. Together with this, there should be some information about how to hand in the specific fractions. For instance, organic waste should only be offered in biodegradable bags, and glass can only be offered in closed cardboard boxes. This last factor is necessary to stop broken glass from being spread around the transport line, and the removal of paper/ cardboard is already a step in glass recycling.

The information is provided in a leaflet that can be taken from the receptacle area. (Figures 37 to 39) This way, the residents can take home the information to study it. This is because sorting the waste correctly happens at home, and not when the user is throwing away the collected waste.

The back side of the leaflet shows additional instructions on how to use the receptacle, as well as what happens to the waste after it is deposited by the resident. This helps them understand what influence their efforts have on the system, which will contribute to their motivation to recycle.

The second part of the information provision would be to have an overview of where the other recycling fractions should be taken to. This can be in the form of a map of the neighbourhood that shows the different locations of containers for the types of waste that are not collected in the building. The map should not only include the municipal collections, but also for example supermarkets or stores that take certain items such as returnable bottles (statiegeldfles) or E-waste, and the location of the nearest 'millieustraat' and the items that can be delivered there. It can also show the location of second-hand stores (kringloopwinkels) in the neighbourhood where people can bring items that others might be able to still use.

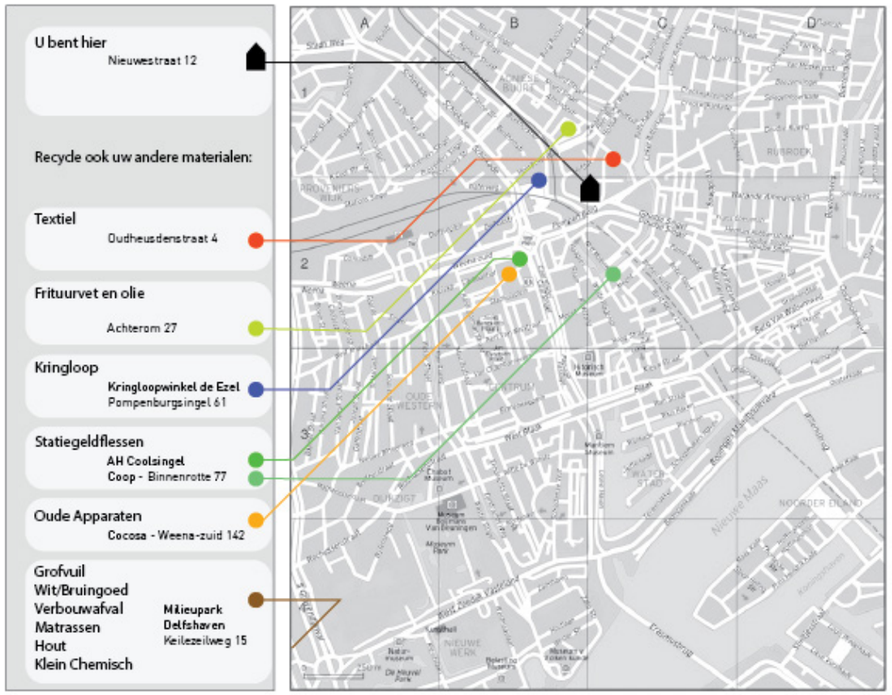



*Figure 36 - Map of where to bring other kinds of recyclable items*

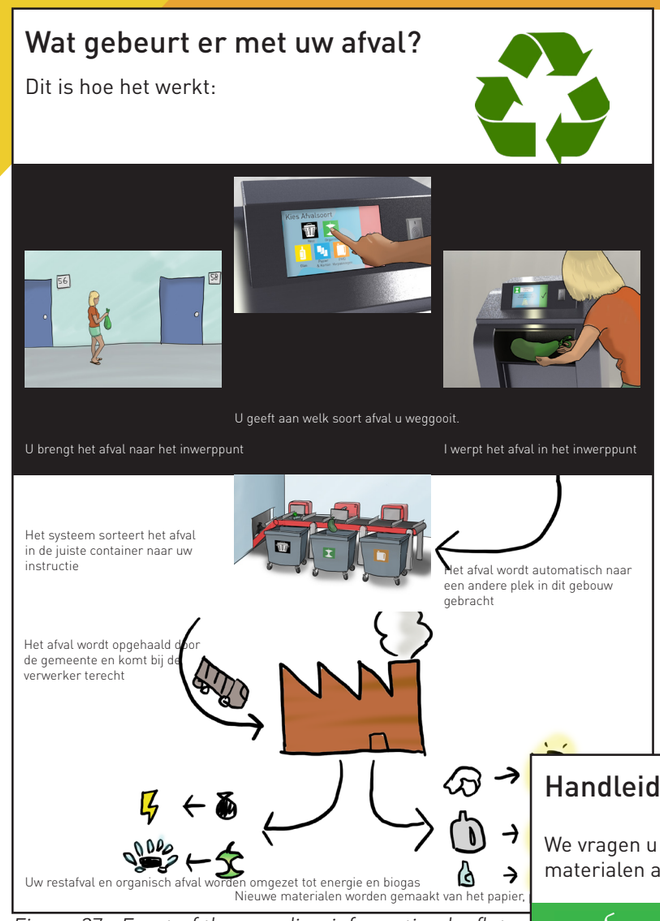



*Figure 37 - Front of the recycling information leaflet that shows the use of the recycling system together with what happens to the waste*


*Figure 39 - The leaflets can be distributed in this way, by hanging a box for them near the receptacle*


*Figure 38 - Back of the recycling leaflet that shows the waste types, their accepted items and the disposal instructions*

# 19. Re-Posit in Detail: Feedback Provision

To provide feedback to the residents about their recycling behaviour, the data that is collected with the Re-Posit should be made available to them in the form of a mobile application and/or a website.

Residents would be able to find out how much material they have recycled over a certain timespan, and compare this with an average for the whole building or the whole neighbourhood. This will also provide some of the 'social pressures' that were discussed in chapter 4, since people will get a sense of their neighbour's behaviour as well. This needs to be done in a way that doesn't raise data privacy concerns however, To this end, the system needs to be very clear about what is done with the data that is collected.

The application can express this data not only in the form of dry statistics, but also by connecting the amounts of waste collected with the result of the processing. The residents might be shown their contribution to paper recycling in the amount of paper that has been (re)made in amounts of a4 sheets, or perhaps in the amounts of energy, water or trees that have been saved in the papermaking process because of their recycling. The energy saved might be expressed into cups of tea that can be heated with it, or into how many times your phone could be charged.

The residents can be made aware of this application with the use of a poster on the side of the receptacle or on the wall near it. This poster has a QR-Code that brings them straight to the download page of the app.

Coincidentally, one of the stakeholders of the Pompenburg project, Dura Vermeer, has already seen this opportunity for user feedback and have developed their prototype app.
(SAP Nederland BV, n.d.)

Their application, named Fleur, would track the amount of waste that is thrown away by working together with modified versions of underground containers that track the amount of waste that is thrown in. They had the exact same idea about using this data to give feedback and show comparisons to the general level of waste behaviour in the neighbourhood. This application would be perfect to use together with the Re-Posit.

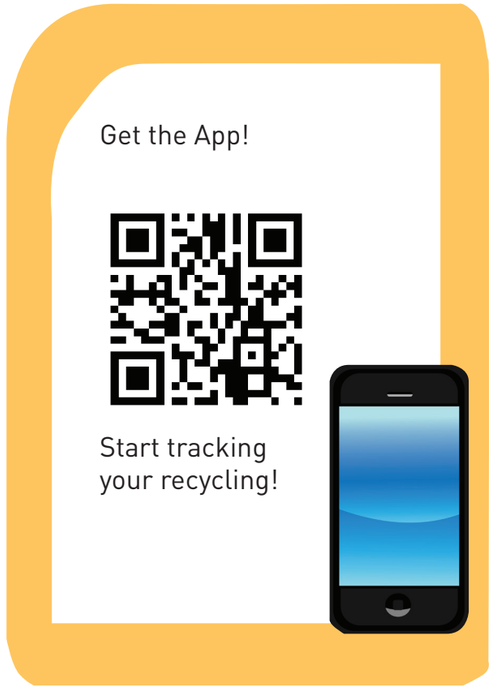



*Figure 40 - Example of a poster that lets people know about the app*

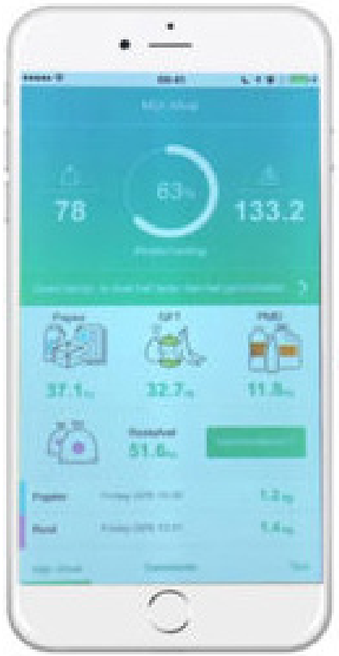



*Figure 41 - The 'FLEUR" app, made by SAP Nederland in partnership with Dura Vermeer*



# 20. Relation to the Current/Future system

Because a new high rise area in the city is likely to exist for decades to come, the Re-Posit system needs to both fit into the current context and be adaptable for future changes in the realm of waste collections. This chapter will show how this can be done.

## Opportunity for collecting commercial waste

The new Pompenburg project will offer both residential space and commercial space in the new buildings in the neighbourhood. The Re-Posit system will take care of the waste from the residential use, but should this mean that the commercial waste is collected by other means? Much of the waste from commercial use such as retail shops and offices are very similar to residential waste, so it would be fully possible to connect these businesses with the Re-Posit system as well.

This can be done by installing a modified receptacle inside each separate commercial space, which no longer requires any personal identification but is instead associated with the specific business. The data collected from this receptacle can be used to determine the fees that the business has to pay for the processing of their waste, since they don't normally make use of municipal collections. The waste would be transported to the same pickup-point as the municipal waste, and be similarly collected.

Although the inclusion of commercial waste would be more taxing on the system, the efficiency of waste collection in the neighbourhood would increase significantly. There would be no need for multiple different companies to drive into the neighbourhood to collect the different commercial wastes, which would save on collection costs as well as on traffic.

## Using the collected data

The data about the weight of waste that is collected by the Re-Posit system can be very valuable for the municipality. As mentioned, they will be able to precisely see how well recycling is being done by the residents, and this can be used to measure the impact of any change that is made on the recycling efforts.

Another use of the data would be to actively motivate people to recycle better. This can be done by offering extra incentives to recycle, but the method of doing so must be considered carefully.

This system will allow the municipality to easily start implementing DIFTAR, to make residents pay more for residual waste. However this system was designed with the current waste tax in mind, being a flat fee for all the different kinds of waste. Because it is very convenient for people to offer recyclable waste, it would also be easy to cheat on the system by telling it that the residual waste they are offering is something else, thereby dodging the extra tax. Because the different kinds of waste are fed into the same receptacle, the barrier for this behaviour would be lower since it would be harder to get caught doing it. Although it would be possible to retrieve the perpetrator using the collected data, this might not always be easy to do.

## The Re-Posit system in the future

From the research about the current system of recycling it became clear that the choice of waste fractions that are collected is dependent on many different factors. To name a few, it depends on the materials that are commonly used in production processes for products and packaging, the value of these materials, and the technologies that can sort and process these materials into new ones.

It might not be too far-fetched to assume that what and how waste is collected might change in the coming years. Sorting technologies might become more advanced, allowing for combined-stream collections of the current recycling fractions. (Some more about this is said in appendix E) Or it might happen that new materials become recyclable, creating a need for additional collection streams.

The Re-Posit system is designed to make it easy to make changes in the types of waste that it collects. The following steps are needed when a change is made:

- Make the changes in the pickup-points:

This would entail changing the amount of deflectors and containers in the room, and possibly a short extension of the conveyor to be able to place them.

- Reprogram the receptacle:

New options need to be selectable in the menu, and the system must know the location of the related container in the pickup-point

- Update the information:

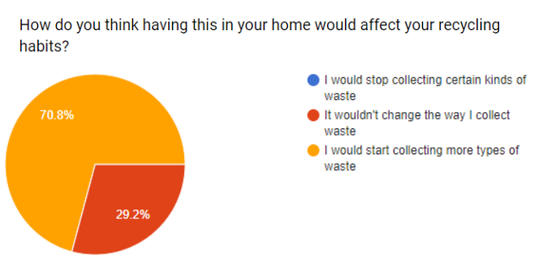
This involves printing new information leaflets and changing the decal on the receptacles accordingly.

# 21. Evaluation

In order to get a sense of the attitude of people towards the Re-Posit system, and to get a first insight into whether it would actually make people start to recycle more, a study was conducted in the form of an online questionnaire. The participants were found in the residents' Facebook group of a high-rise building in Delft. The full questionnaire and the responses can be found in appendix I, but a summary is given in this chapter.

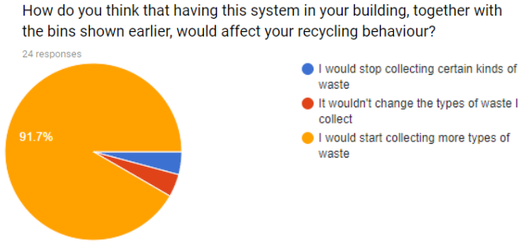
To begin with, the participant was asked some questions about their recycling habits, in order to gain insight into the baseline that can be improved with the design.

Next, the participant was shown the In-home buffer. They were asked to make their own division of waste types over the different waste bins, to start them thinking about the collection of these materials. Following this, they were asked whether having this in their home would change the amount of different waste types they would collect.




70% of participants responded that they would collect more kinds of waste separately. Those that responded they wouldn't usually commented that they still would not know where to bring the waste, and that they would therefore not change their habits. Another reason simply was that they already collected all of the waste types mentioned.

Next, the receptacle was introduced. The participant was shown how disposing of waste would work, in the scenario that they would have to go down with the elevator to throw away the waste. Next, the same question was asked: Would it change the amount of waste types you collect?




This time, around 90% of the participants responded that they would. Of the persons that didn't, one mentioned that they thought using the receptacle would take too long, which is a valid concern.

Next, they were asked about whether their answers on the previous question would change if they just had the receptacle without the in-home buffer, and whether their answer would change if the receptacle was located on the same floor as their home. The answers on these questions were interesting, since 80% responded that they would still collect the same amount of waste types regardless of them not having the in-home buffer in their house. This contrasted with the answer that they gave earlier. The question about having the receptacle on the same floor was responded with more of a split, with about half the participants saying they wouldn't change the amount of waste types collected depending on the floor they have to bring them to.


Finally, they were asked the question whether they would be interested to see the data that is collected by the receptacle. This provided some mixed answers, ranging from enthousiasm to concerns about privacy.

## Conclusions

There was an overall positive response towards the Re-Posit system, with the participants mostly responding that they would increase the amount of waste types they collect and commenting that they would want to make use of this system. The contradicting answers on the in-home buffer seem to mean that having either the buffer or the receptacle would help recycling efforts, but in a system that combines them the receptacle is a lot more important in defining the habits of residents, since after seeing this the participants seemed to care less about the buffer. It also validates the assumption that it would most likely not be worth it to have a receptacle on every floor: People are already used to bringing the waste downstairs, and are already motivated enough by the convenience of being able to bring everything to the same location.

An interesting note is that people are somewhat concerned about what is done with the data. A few participants voiced that they were afraid it would be used to tax them, and were therefore against the idea.

## Discussion

This way of validating the concept was done as a quick and easy method of gaining some insights, later validation on this topic could better take place in the form of 1-on-1 interviews with residents from high-rise buildings. Besides this, the way of questioning turned out to be somewhat confusing for the participants, and led to some unexpected answers. Instead of asking participants if they would increase or decrease the amount of waste types they collect, it would have been better to have them make a selection of the specific kinds of waste they would collect using the scenario presented in each question. This would also make the results more insightful.

To add to this, this method of evaluation is unsuitable for gaining insights into whether decreasing the efforts of setting up a recycling system actually helps, as well as insights on the longterm effects of the system on recycling behaviour. This can be investigated using a test with a prototype system that takes place over a longer amount of time.

# 22. Viability of the Re-Posit System

## Unique Selling Points

The Re-Posit system will take care of most of the issues that stop people from recycling their waste, and hopefully increase the collection rates of recycling waste significantly. Looking back at the drivers and barriers for recycling behaviour in chapter 4, most of these factors are covered by the system. It offers knowledge by presenting all the information that residents need, it enables financial or other incentives, and it gives feedback and social incentive by showing the data about the collected waste to the residents themselves, comparing them with their neighbours.

Also, the lack of space that people might have is solved with the in-home buffer, as well as the time, effort and costs needed for setting up a recycling system. The effort for disposing of the waste is lowered by the system, and habits are broken by forcing the residents to think about recycling right at the moment they move in to their new home.

Besides this, the Re-Posit system will increase the efficiency of waste collection, since the waste is all gathered in a few locations where it can be collected together. For the building owner, it lowers the amount of public space that is needed for containers, and it removes the need for waste storage from the public areas as well.

## Costs

These advantages come at a cost however. The expenses needed for installing this system in the new buildings of New-Pompenburg will, by very rough estimate, fall into the hundred-thousands of euros. Most of these expenses will have to be made for creating the network of automated transport of waste through the buildings and/or the neighbourhood. Yet, this means that the larger amount of the costs can be mitigated by the careful selection of the collection and pick-up points. Vertical transport is less costly than horizontal transport, and selecting locations that are closer together will decrease the total costs of the system. The developers of the new buildings are therefore able to weigh the convenience of the system against the costs of implementation, and come to an optimal design.

Next to the costs of implementation, there are also running costs that have to be made to keep the system going. A small part of these are the costs for electricity to power the receptacles, the conveyor lines and the sorting installation. The largest part will consist of maintenance and cleaning of the various parts, which again can be decreased by shortening the transport lines. Other running costs are incurred by the software side, namely by maintaining the feedback platform, performing software updates and data storage.

## Management and Value

The Re-Posit system is a premium solution for managing the waste collection in high-rise buildings. But who owns it? And how do they pay for it? In the context of Pompenburg, the buildings will be owned by housing associations Vestia and Havensteder. They might become the owners of the Re-posit system. Alternatively, it would be possible to have an external company own the system, and have them provide any cleaning or maintenance that is needed. This company might be a specialised company that just manages the Re-Posit system, but it can also be one of the companies that manage (commercial) waste collection in the city, such as Renewi. This last category is worth considering, since these companies also have a lot of expertise on waste, and the existing equipment to also collect the waste from the buildings. This will make collection more efficient, also because they can combine the municipal- with the commercial waste collections. The data collected by the Re-Posit system can be used to determine a fee that the municipality can pay to the collection company for the service that they would otherwise have to offer themselves.

As to the costs, the Re-Posit system will create value that can help to pay for them.

- Recyclable waste is worth more to processors than residual waste, either through subsidies or the intrinsic value of the materials. By collecting more of these materials, they produce more value in this way than conventional waste collection.
- The system will help make municipal collections more efficient, by amassing the waste of multiple residences or even multiple buildings together, and by enabling the integration of commercial wastes. This will save on the expenses that are made for collections.
- The system provides increased convenience in recycling for residents as a service to them. This can warrant an increase of the monthly service costs that tenants pay as part of their rent.
- The system helps the city of Rotterdam to achieve their ambitions of becoming a more circular city. It is therefore in their interest to provide subsidies or other kinds of funding to help this system come into being.

## What next?

The next step would be to work out the system from a concept to a detailed design, specifying the exact dimensions, materials and parts. Especially more attention is needed towards the system of transporting and storing the waste. An example would be to reconsider the exact methods of transportation, since conveying the waste would be an expensive solution. However, these factors are also heavily dependent on the design of the buildings the system would be implemented in, and would therefore require close cooperation with the developers.

Furthermore, the design of the information that is provided is also meant as an illustration of the kind of information that is needed, the exact data also depends on more specific concerns. One example is the way that glass is supposed to be deposited into the system: It will require some further testing to find out if loose glass is safe to enter the system, or that it indeed needs to be put in some kind of other container such as a cardboard box.

Finally, the design needs to be evaluated in a more extensive way. The impact on recycling rates would have to be assessed in a long-term pilot study where the system is simulated in some way to provide the same ease of recycling for the test participants. By elaborating on the design, a more specific cost assessment can be made, and this can be used together with the evaluation to get a better idea of whether the system is worth its cost.

# 23. References


These references include those in the appendices

Abbott, A., Nandeibam, S., & Oshea, L. (2011). Explaining the variation in household recycling rates across the UK. Ecological Economics,70(11), 2214-2223. doi:10.1016/j.ecolecon.2011.06.028

Abbott, A., Nandeibam, S., & Oshea, L. (2013). Recycling: Social norms and warm-glow revisited. Ecological Economics,90, 10-18. doi:10.1016/j.ecolecon.2013.02.015

Attero. (n.d.). Onze verwerkingstechnieken. Retrieved July 4, 2019, from https://www.attero.nl/nl/onze-verwerking/uw-organisch-afval-wordt-compost-en-energie/onze-verwerkingstechnieken/

Aufkommen an Haushaltsabfällen. (n.d.). Retrieved July 5, 2019, from https://www.statistikportal.de/de/aufkommen-haushaltsabfaellen

AVR. (n.d.). Verandering geeft energie. Retrieved March 29, 2019, from https://www.avr.nl/nl/plastic-scheiden-uit-de-grijze-vuilniszak

Barr, S. (2007). Factors Influencing Environmental Attitudes and Behaviors. Environment and Behavior,39(4), 435-473. doi:10.1177/0013916505283421

Bastian Solutions. (n.d.). Tilt Tray Sorter. Retrieved from https://www.bastiansolutions.com/solutions/technology/conveyor-systems/sortation/conveyor/tilt-tray-sorter/

BBC NEWS. (2008, December 09). Chutes to suck waste from estate. Retrieved July 6, 2019, from http://news.bbc.co.uk/2/hi/uk_news/england/london/7772752.stm

Bernstad, A. (2014). Household food waste separation behavior and the importance of convenience. Waste Management,34(7), 1317-1323. doi:10.1016/j.wasman.2014.03.013

Callan, S. J., & Thomas, J. M. (1997). The Impact of State and Local Policies on the Recycling Effort. The Economics of Residential Solid Waste Management,301-313. doi:10.4324/9781315240091-20

Callan, S.J., Thomas, J.M. (2006). Analyzing Demand for Disposal and Recycling Services: A Systems Approach. Eastern Economic Journal Vol. 32, No. 2 (Spring, 2006), pp. 221-240

CalRecycle. (2017, August). State of Disposal and Recycling in California 2017 Update[Pdf].

Cena, obračun in plačevanje za storitve ravnanja s komunalnimi odpadki. (2019, April 24). Retrieved from https://www.vokasnaga.si/jp-voka-snaga/odpadki/pogosta-vprasanja/cena-obracun-placevanje-za-storitve-ravnanja-s-komunalnimi

Central Chutes. (n.d.). Central chutes brochure[Pdf].

Cleated Belt Conveyors. (n.d.). Retrieved July 6, 2019, from https://www.solidswiki.com/index.php?title=Cleated_Belt_Conveyors

Connective Cities, SUBV Bremen. (2016, July 6). Waste-Management in Bremen and the legal Base[Press release]. Retrieved July 5, 2019, from https://www.connective-cities.net/fileStorage/Veranstaltungen/Dialogveranstaltung_Tuerkei_2017/Waste_Management_in_Bremen_and_the_legal_Base_en.pdf

Copenhagen Resource Institute. (2014). Capital factsheet on separate collection[Pdf]. Retrieved from https://www.municipalwasteeurope.eu/sites/default/files/Organising integrated waste management - Slovenia.pdf

Domina, T., & Koch, K. (2002). Convenience and Frequency of Recycling. Environment and Behavior,34(2), 216-238. doi:10.1177/0013916502342004

EPA United States. (2018, July). Advancing Sustainable Materials Management: 2015 Fact Sheet[Pdf].

Feil, A., Pretz, T., Jansen, M., & Velzen, E. U. (2016). Separate collection of plastic waste, better than technical sorting from municipal solid waste? Waste Management & Research,35(2), 172-180. doi:10.1177/0734242x16654978

Gao, A., Tian, Z., Wang, Z., Wennersten, R., & Sun, Q. (2017). Comparison between the Technologies for Food Waste Treatment. Energy Procedia,105, 3915-3921. doi:10.1016/j.egypro.2017.03.811

Gemeente Horst aan de Maas. (n.d.). Afval inleveren of laten ophalen. Retrieved from https://www.horstaandemaas.nl/afval-inleveren-laten-ophalen

Glass Recycling: How Do They Do It? (n.d.). Retrieved July 7, 2019, from https://www.secondhand4business.com/glass-recycling/

Guerrero-Witt, M., Wood, W., & Tam, L. (2005). Changing circumstances, disrupting habits. PsycEXTRA Dataset. doi:10.1037/e529412014-144

Gundupalli, S. P., Hait, S., & Thakur, A. (2017). A review on automated sorting of source-separated municipal solid waste for recycling. Waste Management,60, 56-74. doi:10.1016/j.wasman.2016.09.015

Hook, L., Faunce, L., Blood, D., & Reed, J. (2018, October 25). Why the world's recycling system stopped working. Retrieved from https://www.ft.com/content/360e2524-d71a-11e8-a854-33d6f82e62f8

How It's Made (2015, April 12). Retrieved March 07, 2019, from https://www.youtube.com/watch?v=2c8YxMb0tlk

How Taiwan Has Achieved One of the Highest Recycling Rates in the World. (2019, January 03). Retrieved from https://www.smithsonianmag.com/innovation/how-taiwan-has-achieved-one-highest-recycling-rates-world-180971150/

Jansen, M., Feil, A., & Pretz, T. (2016). Recovery of Plastics from Household Waste by Mechanical Separation. Retrieved June 2, 2019, from http://www.vivis.de/phocadownload/Download/2012_wm/2012_WM_169_176_Jansen.pdf

Kaliampakos, D., & Benardos, A. (2013). Underground Solutions for Urban Waste Management: Status and Perspectives[Pdf]. ISWA.

Kinsella, S., & Gertman, R. (2007). Single Stream Recycling Best Practices Implementation Guide(Publication No. DRRR-2011-028). California: Conservatree.

Koyanaka, S., & Kobayashi, K. (2011). Incorporation of neural network analysis into a technique for automatically sorting lightweight metal scrap generated by ELV shredder facilities. Resources, Conservation and Recycling,55(5), 515-523. doi:10.1016/j.resconrec.2011.01.001

Meaghan. (2018, March 16). An Overview of Single Stream Recycling. Retrieved July 5, 2019, from https://www.lrsrecycles.com/an-overview-of-single-stream-recycling/

MK North America. (n.d.). Cleated Belt Conveyors. Retrieved July 6, 2019, from https://www.mknorthamerica.com/Products/cleated-belt-conveyors/

Muncipality of Taipei. (2018). 環境保護統計年報 107年[Pdf]. Retrieved July 5 from https://www.epa.gov.tw/Page/B84B65A4FDDF5864

Northern California Compactors Inc. (2019, January 11). Plastic Recycling - Processes, Stages, and Benefits. Retrieved June 2, 2019, from https://www.norcalcompactors.net/processes-stages-benefits-plastic-recycling/

Oskamp, S., Harrington, M. J., Edwards, T. C., Sherwood, D. L., Okuda, S. M., & Swanson, D. C. (1991). Factors Influencing Household Recycling Behavior. Environment and Behavior,23(4), 494-519. doi:10.1177/0013916591234005

Over Rotterdam circulair. (n.d.). Retrieved July 4, 2019, from https://rotterdamcirculair.nl/over-ons/

Primary double shaft shredder TB. (n.d.). Retrieved from https://www.forrec.eu/products/primary-double-shaft-shredder/tb.html

ReShare. (n.d.). Bestemming van de kleding. Retrieved March 7, 2019, from https://www.reshare.nl/bestemming-van-de-kleding

Richard, G. M., Mario, M., Javier, T., & Susana, T. (2011). Optimization of the recovery of plastics for recycling by density media separation cyclones. Resources, Conservation and Recycling,55(4), 472-482. doi:10.1016/j.resconrec.2010.12.010

Rijkswaterstaat. (n.d.). Afvalmonitor. Retrieved February 2019, from https://afvalmonitor.databank.nl/

Rotterdamse woningmarkt naar een nieuw evenwicht. (n.d.). Retrieved July 4, 2019, from https://evr010.nl/evr-2019/wonen-en-ondernemen-schuren/rotterdamse-woningmarkt-naar-nieuw-evenwicht/

SAP Nederland B.V. (n.d.). Beter afval scheiden dankzij technologie Dura Vermeer. Retrieved from https://mobileinnovationlab.sap.nl/beter-afval-scheiden-dankzij-technologie-dura-vermeer

Seoul Metropolitan Government. (n.d.). 서울시 생활폐기물 발생량 및 처리현황 통계. Retrieved July 5, 2019, from https://data.seoul.go.kr/dataList/datasetView.do?infId=370&srvType=S&serviceKind=2

Sidique, S. F., Joshi, S. V., & Lupi, F. (2010a). Factors influencing the rate of recycling: An analysis of Minnesota counties. Resources, Conservation and Recycling,54(4), 242-249. doi:10.1016/j.resconrec.2009.08.006

Sidique, S. F., Lupi, F., & Joshi, S. V. (2010b). The effects of behavior and attitudes on drop-off recycling activities. Resources, Conservation and Recycling,54(3), 163-170. doi:10.1016/j.resconrec.2009.07.012

SNAGA. (n.d.). ON OUR WAY TO ZERO WASTE SOCIETY[Pdf]. Retrieved from https://www.municipalwasteeurope.eu/sites/default/files/SI Ljubljana Capital factsheet.pdf

Timlett, R., & Williams, I. (2009). The impact of transient populations on recycling behaviour in a densely populated urban environment. Resources, Conservation and Recycling, 53(9), 498-506. doi:10.1016/j.resconrec.2009.03.010

Timlett, R., & Williams, I. (2011). The ISB model (infrastructure, service, behaviour): A tool for waste practitioners. Waste Management, 31(6), 1381-1392. doi:10.1016/j.wasman.2010.12.010

Tonglet, M., Phillips, P. S., & Read, A. D. (2004). Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: A case study from Brixworth, UK. Resources, Conservation and Recycling,41(3), 191-214. doi:10.1016/j.resconrec.2003.11.001

VierusTom, T. (2019, February 04). How to recycle trash in Germany: It's easier than you think! Retrieved July 5, 2019, from https://www.livingdreams.tv/environment/how-to-recycle-trash-in-germany-easier-think

Vinceau. (2019, June 07). Don't Trash Talk South Korea's Waste Management System. Retrieved July 5, 2019, from https://medium.com/@vinceau/dont-talk-trash-about-south-korea-s-waste-management-system-7a11e15ff0e1

WastedLab. (n.d.). Turn your waste into discounts. Retrieved June 2, 2019, from https://wastedlab.nl/en/

Wrap. (2010). Case Study: Good practice of Near Infrared sorting of plastic packaging(pp. 1-11, Rep.). Banbury.

Yau, Y. (2010). Stakeholder engagement in waste recycling in a high-rise setting. Sustainable Development,20(2), 115-127. doi:10.1002/sd.468

Zito, J. M. (1974). Anonymity and Neighboring in an Urban, High-Rise Complex. Urban Life and Culture,3(3), 243-263. doi:10.1177/089124167400300301

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Learning Center Kunststof Verpakkinsafval, Eureco & Wur. (n.d.). Samenstelling ingezameld kunststof/PMD verpakkingen – het effect van inzamelsystemen[Press release]. Retrieved July 4, 2019, from https://www.nedvang.nl/wp-content/uploads/2019/02/LCKVA-Rapportage_Samenstelling_kunststof_PMD_verpakkingen.pdf

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Sutco. (n.d.). Ballistic Separator. Retrieved July 7, 2019, from https://www.sutco.de/en-de/components/ballistic-separator

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Waste management - Waste Management Wholesaler from Hyderabad. (n.d.). Retrieved July 7, 2019, from https://www.indiamart.com/wastewing-technologies/waste-management.html

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Reusch, W. (n.d.). Polymers. Retrieved July 7, 2019, from http://organicavirtuale.altervista.org/www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/polymers.htm

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Circulair met Fleur. (n.d.). Retrieved July 6, 2019, from https://www.cirkelstad.nl/circulair-met-fleur/



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