Universidade de Aveiro Departamento de Comunicação e Arte
2018 Departamento e Engenharia Mecânica

Ana Salomé
Fernandes Caboz

Desenvolvimento de um Compactador Doméstico de Lixo
Development of a Domestic Waste Compactor

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Development of a Domestic Waste Compactor

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia e Design de Produto, realizada sob a orientação científica do Doutor António Gil Andrade Campos, Professor Auxiliar do Departamento de Engenharia Mecânica da Universidade de Aveiro, e do Doutor Maximiliano Ernesto Romero, Professor do Departamento das Culturas do Projeto da Universidade IUAV de Veneza.

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palavras-chave

Design de Produto, lixo doméstico, volume de lixo, compactador, compactação radial, eco-friendly.

resumo

O crescimento da população e da indústria levam ao aumento da produção de lixo. O volume e a má gestão destes resíduos são os principais fatores responsáveis por vários problemas ambientais e socioeconómicos. Tendo em consideração esta problemática que afeta a humanidade, o presente projeto pretende criar um produto que ajude a minimizar este flagelo.
O ciclo de vida do lixo inicia-se, maioritariamente, em ambiente doméstico. Assim, este trabalho tem como objetivo a criação de um produto que se enquadre neste ambiente e que contribua para a redução do volume de lixo. Adicionalmente, tenciona melhorar a qualidade do trabalho doméstico, o sistema de recolha de lixo e apoiar no processo educativo, enfatizando uma atitude de responsabilidade ambiental. Neste sentido, foi desenvolvido um compactador doméstico de lixo.

Encontram-se disponíveis no mercado alguns equipamentos desta categoria. No entanto, a grande maioria apresenta grandes dimensões, preço elevado e, os sistemas motorizados, consomem muita energia. Assim, este projeto tem como propósito, não só responder à problemática do lixo, mas ao mesmo tempo, criar um produto compacto, eco-friendly e adaptável a um contentor existente. Esta última característica, até à data, não está presente em nenhum compactador existente no mercado, tornando a solução inovadora.

A fim de realizar este projeto, vários esboços, testes e cálculos foram realizados, resultando na criação de três compactadores: convergente-radial, divergente-radial e por enrolamento. Cada um responde positivamente aos requisitos estabelecidos, compactando e reduzindo o volume do lixo. Tendo em conta estas três propostas, a compactação convergente-radial foi a escolhida para ser desenvolvida. Como resultado deste processo, obteve-se um equipamento pneumático que pode ser introduzido num contentor padrão, cilíndrico, de 15 litros.

Deste projeto resultou a criação de uma marca, *COBI*, que associa três produtos com diferentes funções. *COBI Bin* é o nome atribuído ao equipamento. Este, por sua vez, é introduzido dentro do *COBI Container*, que protege e suporta o sistema e todos os seus componentes. O terceiro elemento diz respeito a uma aplicação para smartphone, *COBI App*, criada para auxiliar o utilizador no uso do produto.

keywords

Product Design, household waste, waste volume, compactor, radial compaction, eco-friendly.

abstract

The population and industry growth have led to the increase in the amount of garbage on the planet. The volume and the poor management of the waste are the major factors responsible for several environmental and socioeconomic problems. Aware of this problematic that affects the Humankind, this project endeavors to develop a product that minimize this calamity.
Considering that the waste life cycle starts mainly in households, this final work is directed to a device that should be used at the domestic environment as the first step to contribute to the reduction of waste volume. Moreover, it improves the housework quality, the waste collection system and it is the basis of an educational process emphasizing an environmental responsibility attitude. In this way, a waste compactor was developed.

It is well known that products with the same aim have already been designed. However, most of them have large dimensions, are very expensive and the motorized ones consume a lot of energy. Thus, the present project has the purpose not only to respond to the waste problematic but at the same time attempt to achieve a low-cost, small and eco-friendly product adaptable to an existing container. This last feature, is not seen in conventional market waste compactors, makes this an innovative product.

To accomplish this goal, sketches, tests and calculations were done.
As result convergent-radial, divergent-radial and winding compactors were created. Each one of them responds positively to the product requirements, compacting and reducing the waste volume. From these three proposals, the Convergent-radial compaction was chosen to be fully developed, resulting in a pneumatic equipment which can be introduced in a 15 liters standard cylindrical container.

The development of this project also resulted in the creation of a brand, COBI, associated with three products with different functions. Thus, COBI Bin is related to the equipment, introduced inside the COBI Container, which protects and supports the system and its components. The COBI App is the third product created to support the customer in the product use.

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LIST OF SYMBOLS

R_c – Compaction ratio
v – Vertical
r – Radial
V – Volume
A – Area
h – height
u – Displacement
i – Initial
f – Final
r – Radius
π – Pi
P – Pressure
m – Mass
g – Acceleration of gravity
D_{ef} - Effective displacement
E – Young's Modulus
$\mathcal{E}$ – Strain
υ – Poisson's ratio
σ – Stress
F – Force
$N_{comp.}$ – Number of compartments
conv. – Convergent-radial system
div. – Divergent-radial system
τ – Torque

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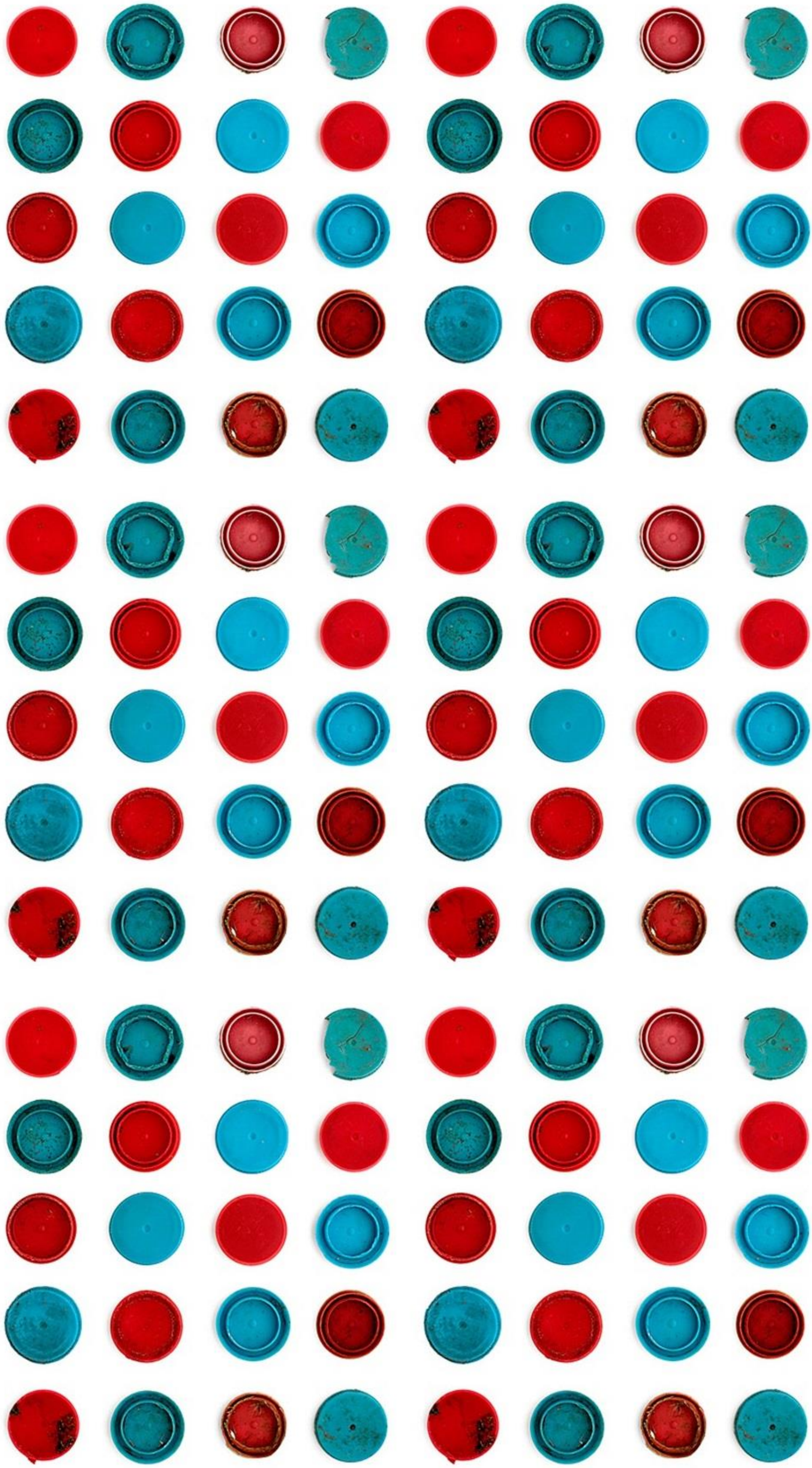

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1. INTRO-DUCTION

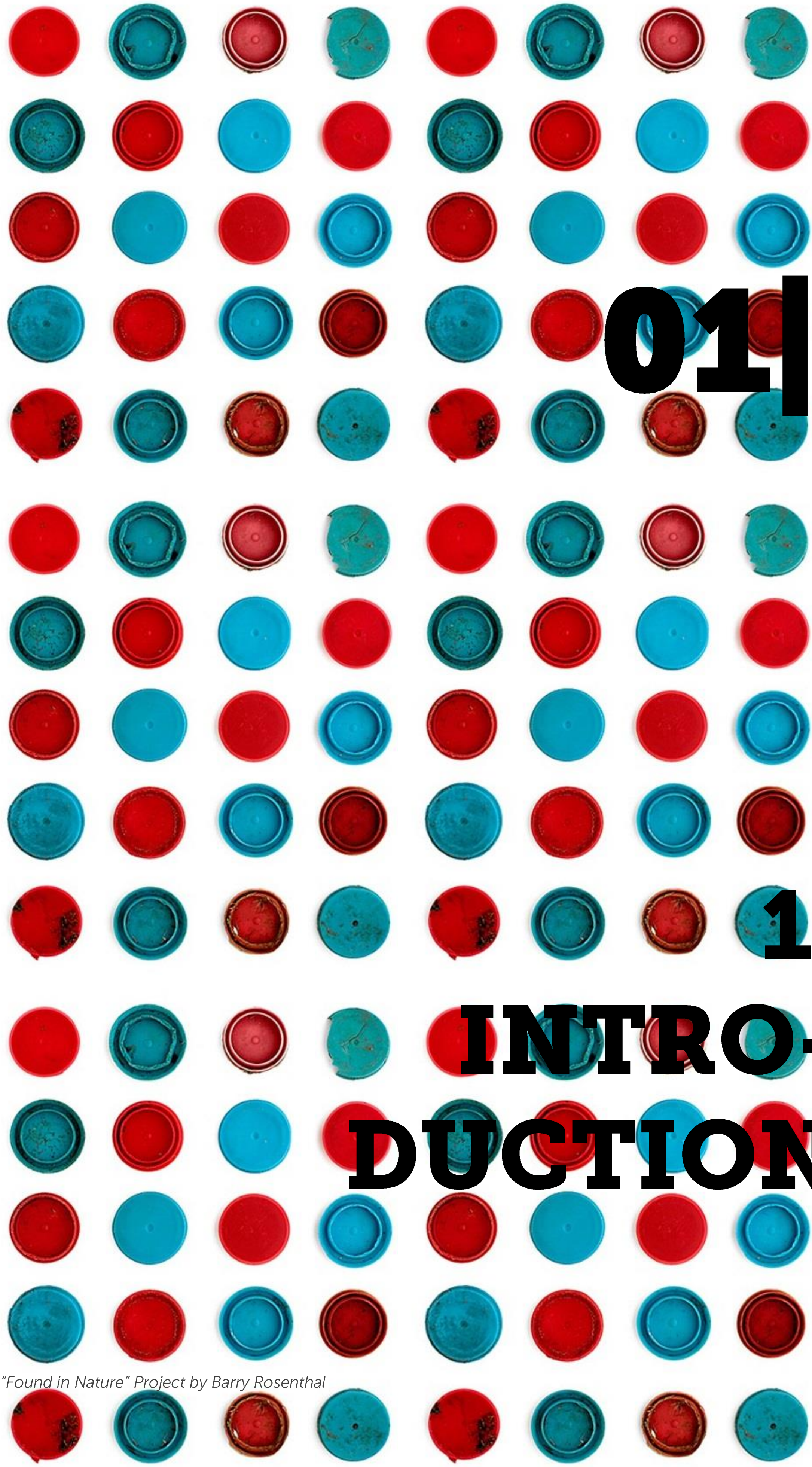


Figure 1: "Found in Nature" Project by Barry Rosenthal

1.1 Prob-lematic

“Waste includes all the items that people no longer have any use for, which they either intend to get rid of or they have already discarded.” (Eurostat Statistical Books, 2010, p. 97)

The excessive consumption of products, which is generated mainly due to the population growth, leads to the excessive use of natural resources and the increase in the amount of garbage generated.

Esben Larsen (Esben Larsen, 2018) says that the increase in the amount of garbage is due to consumerism. In fact, 99% of products bought by consumers turn into trash six months later.

Several environmental organizations argue that the current consumption of natural resources has already surpassed the planet's ability to regenerate, altering the balance of the ecosystem.

“Our use of natural resources has grown dramatically, particularly since the mid-20th century, so that we are endangering the key environmental systems that we rely upon.” (WWF International, 2016)

Figure 2: Scuba diver collecting trash from the Ocean, Photograph By David Jones, National Geographic Your Shot (National Geographic, 2015)

"Some 700 species of marine animals have been reported so far to have eaten or become entangled in plastic."

(National Geographic, 2015)

“Every year we dump a massive 2.12 billion tons of waste.”

(Esben Larsen, 2018)

[1] Lifecycle analysis goes through all the process since the extraction of the raw material until the disposal. This evaluation considers all products consumed as well as the elements that result from each activity.

To evaluate the ecosystem impact, product lifecycle analysis[1] must be done. Analyzing the waste life cycle, it starts mostly in the domestic environment. According to the Eurostat (Eurostat, 2010), in 2014, households and manufacturing activities produced the highest levels of waste generation.

As claimed by Daniel Hoornweg and Perinaz Bhada-Tata (Daniel Hoornweg, 2012), typically households waste are food, paper, plastic, glass, metal, textiles, special wastes (batteries, oil), hazardous wastes (paints, motor oil) and e-waste (computers, TVs).

“Household waste makes up the biggest portion of municipal waste.”

(Eurostat Statistical Books, 2010, p. 62)

In 2010, according to Eurostat Statistical Books (Eurostat Statistical Books, 2010, p. 38), the majority of European household and similar waste ends up in landfills. In addition to wasting resources that could be reused, the food waste that is deposited in the landfills releases polluting gases, such as methane.

According to Eurostat Statistic Books, in Europe, in 2006, almost 3 billion tons of garbage was generated, which 7% (205 million tonnes) refers to household waste. This study concluded that only Hungary, Turkey, Lithuania, Norway, Germany, Slovenia, and Bulgaria produced less municipal waste than in 1995 (Eurostat Statistical Books, 2010, p. 108).

"Specifically, many countries like the U.S. are creating far too much waste and filling up landfills at an alarming rate."

(Action Compaction Equipment, 2017)

In Portugal, provisional data indicates that, in 2017, approximately 4.75 million tons of urban waste was generated, which is equivalent to a daily production of 1.32 kg per inhabitant. This data shows that there has been an increase in waste production in Portugal since 2014, contrary to the data from 2010 to 2014, where there was a decrease in these values.

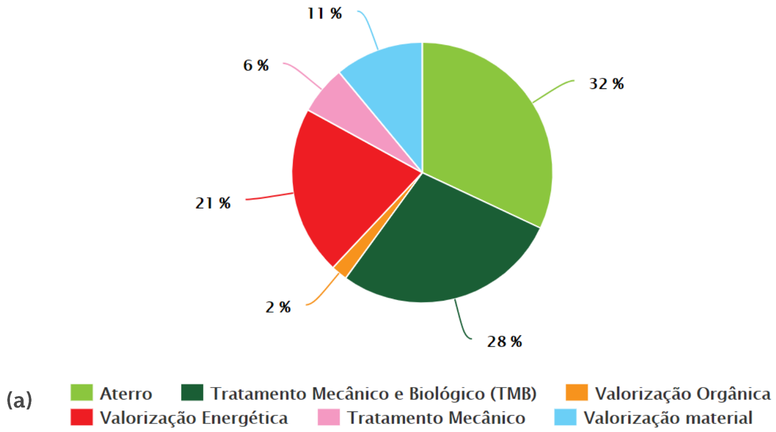
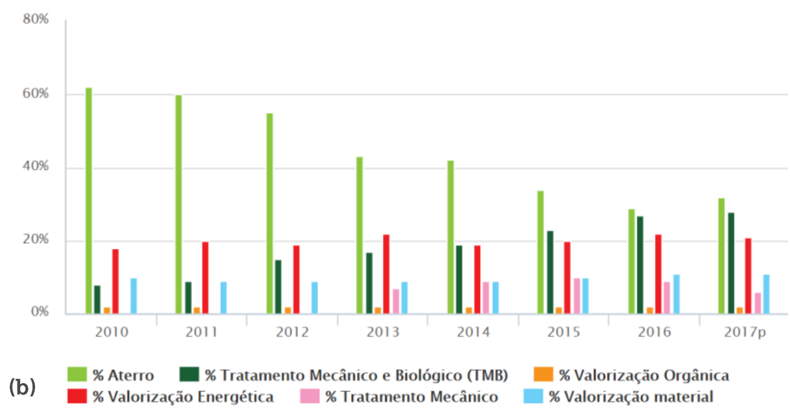


Figure 3:
(a) Urban waste management in Portugal, 2017 (REA , 2018);
(b) Urban waste evolution in Portugal, 2017 (REA , 2018).

According to the REA (Environment State Report), these values can be related to the increase of life quality in Portugal. However, the disposal of biodegradable municipal waste (RUB) in landfills increased by 2% from 2016 to 2017, although it has been decreasing since 2010.

Excessive waste production is alarming, nevertheless, the way it is treated is crucial to avoid further consequences.



“The World Bank estimates that about 4 billion people worldwide use these sites, and they are polluting rivers, groundwater, sewage systems, (...) also leading diseases (...) and causing many health concerns.”

(Action Compaction Equipment, 2017)

Figure 4: People in a dumpsite in eastern Jakarta

Excessive garbage production leads to: (i) fast depletion of landfills and (ii) lack of space to store and treat garbage. When garbage does not follow this path and it is exposed in cities, it also becomes a public health problem. Exposed trash contributes to disease transmission, respiratory diseases, diarrhea and dengue fever (Daniel Hoornweg, 2012).

According to the *United Nations Human Settlements Programme (UN-HABITAT)* (United Nations Human Settlements Programme (UN-HABITAT), 2010, p. 14), besides air, water is also affected. When the waste is not collected, can clog the drains causing water stagnation which attracts insects and contaminates the water that normally is used for consumption and cooking.

Figure 5: Marine turtle with a plastic bag

When garbage is not properly collected by the responsible authorities, is left on the streets and exposed to open air. Therefore, it is important to have a good waste collection system.

Usually, municipal councils or contracted companies are responsible for the gathering of the garbage from the production point (habitation, industrial areas) to the treatment point.

According to the "What a Waste" article (Daniel Hoornweg, 2012), the collection can be made in several ways like: house-to-house (trash is collected from each house); community bins (each citizen leaves the waste in bins placed in fixed points); curbside pick-up (citizens leave the waste outside their homes); and self-delivered (waste is delivered directly to disposal sites).

As claimed by United Nations Human Settlements Programme, most of the developed countries only in the 1970s implemented a solid waste management system when they were in the middle of a contamination crisis provoked by the exposed trash. Countries with a poor solid waste management have more health and environmental problems and less length of life.

"The disposal of biodegradable municipal waste (RUB) in landfill increased to 43% in 2017 (41% in 2016). This growth, in line with that of consumerism, was not accompanied by the addition of a differentiated collection."

(Ambiente, 2018, p. 54)

Figure 6: Garbage bags on the sidewalk

"Cañete, Peru, reports that most villages are without services; in Varna, Bulgaria, the 100 per cent coverage ends at the city borders and the city's five villages are each served with a single container that is collected once per month, if at all."

(United Nations Human Settlements Programme (UN-HABITAT), 2010, p. 96)

1.2 Solutions

San Francisco is one of the biggest example of waste management success. According to the article written by Anne Poirot (Poirot, 2017), this city was one of the first to achieve the target to divert 50% of waste from landfills. Moreover, San Francisco established a *zero waste* goal and also implemented recycling and composting rules.

According to Poirot, this success has five reasons: aggressive public policy, strong public-private sector partnership, efficient waste management system, economic incentive and education.

Figure 7: San Francisco bins

"The Fantastic Three" program of San Francisco, implemented in 1999, consisted of only three waste categories. In this system, the green bin is for compost waste, the blue for recycling and the black for trash that goes to landfills. This waste management system provides an easier and less confusing way to recycle. Unlike most of the European cities, paper, plastic, glass and metal goes to the same bin. Later, in recycling centers, the materials are separated and treated. To achieve the goals of the best city in waste management, some rules were implemented. One of them establishes a fine for those how left waste outside the bin.

“San Francisco was named the greenest city in North America and ranked No.1 in waste management.” (Poirot, 2017)

Figure 8: Waste-picker working at the dump

According to the article written by Paulo Cardoso (Cardoso, 2017), education is the "main tool for reaching the goal". Different educational programs were implemented to change the citizen's behavior. These campaigns served to draw attention to the waste production and how to do the recycling, reaching out to all communities. Farmers markets and urban gardens were also created, encouraging the population to have more eco-friendly habits.

"The industrialized countries must reduce their consumption of natural resources, limit the generation of natural resources, limit the generation of waste, increase recycling and avoid all exports of waste and technologies contributing to climate change."

(United Nations Human Settlements Programme (UN-HABITAT), 2010, p. 26)

Waste Management Hierarchy (Figure 9) shows how citizens should behave in relation to waste. In this hierarchy, prevention is on the top, which means the most desirable attitude to take. Then, comes the three layers that correspond to the 3Rs policy. First, reduce or minimization, when prevention it is not possible. Waste production must be minimized the most as possible. For that, users should buy only the essential, avoid plastic bags and opt for familiar, unpackaged, rechargeable and recyclable products.

The second is reuse, which gives the waste a new purpose without the need for modification by industrial processes (idhea, 2009).

The third is recycling, that is an industrial process where waste materials (glass, plastics, papers, metals) are transformed in new objects. This process replaces products in the same cycle. Therefore, recycling waste is part of a circular economy[2].

At the end of a product's life cycle, i.e. when a product can no longer be used, it can serve to produce energy, reducing the use of natural resources. This energy recovery corresponds to the process integrated into the recycling.

In the last position of hierarchy comes the disposal, which is the most unwanted process. As stated by the United States Environmental Protection Agency (EPA United States Environmental Protection Agency, 2017), landfills are the most common waste disposal places and also the most important to the waste management system. However, when biodegradable waste is in landfills, produces gases that contribute to air pollution if not captured.

[2] Circular economy, according to Eurostat (Eurostat, EUROPEAN COMMISSION, 2018), starts when the product is designed and accompanies it until it is recycled and re-marketed. This method aims to minimizing the waste generation by returning the products, in the end of their use, into the cycle again.

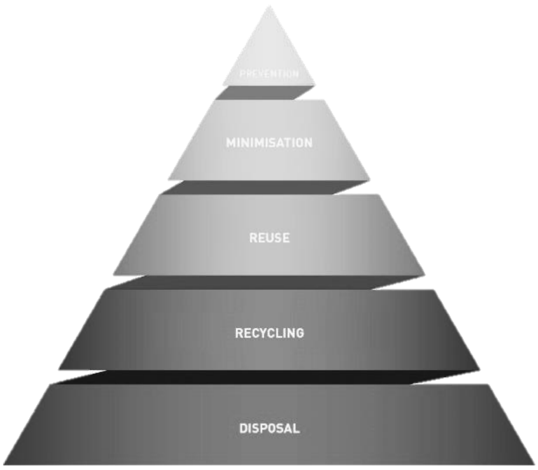


Figure 9: Waste Management Hierarchy

Figure 10: Different types of waste

Based on the article written by Paulo Cardoso (Cardoso, 2017), environmental education is fundamental for the sustainable and responsible mentality implementation. This, as the author affirms, must begin in childhood, encouraging the citizen from an early age to good practices of citizenship. The disclosure of these ideals is often done through the actions of non-governmental organizations and the government. These actions aim to encourage ecological practices in order to increase sustainability (Cardoso, 2017).

As claimed by the United Nations Organization (UN), sustainable development is the "one that allows making use of natural resources without depleting them, preserving them for future generations" (idhea, 2009).

To achieve this goal, it is necessary the users take conscient behaviors to preserve the environment. The first step is to prefer ecological products, which are the non-polluting, non-toxic and environmental and health beneficial products. This will also contribute to a sustainable economic and social development.

“In 2008, EU27 municipal waste recycling and composting rates increased to 40 % from 16 % in 1995 while waste landfilling rates decreased from 62 % to 40 %.”

(Eurostat Statistical Books, 2010, p. 63)

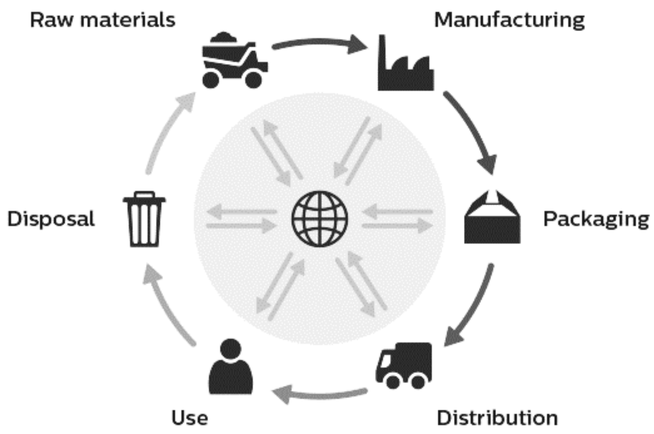


Figure 11: Product’s life cycle

In spite of the great improvements, there are still several examples of countries that have not been able to reach the objectives yet, most of them for lack of knowledge.

According to Quercus (Lusa, 2018), Portuguese people do not know how to reduce and separate waste and the difference between what is biodegradable and recyclable, and what happens after the waste goes to the container.

As already stated, recycling is one of the most desirable attitudes that citizens must take for waste reduction, in this way, this practice will be emphasized by the support of some important quotations.

"Belo Horizonte was among the first cities anywhere to recognize the informal recycling sector and build a policy of inclusion of informal recyclers in their recycling strategy."

(United Nations Human Settlements Programme (UN-HABITAT), 2010, p. 101)

According to the *idhea* (idhea, 2009), there are two types of recycling: post-consume and post-industrial/ pre-consumption. The first is the consumers' recycling. In the second, the material discarded by industrial processes is collected and recycled. It does not pass through the consumer.

Recycled materials are those which decomposition is slow or non-existent (glass, plastic - PET, PVC, PEBD, PS, ABS -, paper, metal). Therefore, these go through industrial processes to be replaced in the cycle with the same or other application.

According to Eurostat (Eurostat Statistical Books, 2010, p. 63), there are some aspects that users need to take in consideration when recycling. The materials need to be clean and uncontaminated. If one material is put into the wrong container it can prevent the whole batch from being recycled.

In Portugal, LIPOR - the entity responsible for the management, valorization and treatment of urban waste produced by eight Porto municipalities - published some suggestions for the recycling practice by consumers (Lipor, 2018). The first suggestion is to use two containers for household waste: one for organic waste (food) and the other for plastic and metal (yellow container). According to LIPOR, these two containers are sufficient. Due to the volume, glass can be stored separately, paper and card since they do not stink, can be introduced in a cardboard box, and put anywhere in the house. Besides that, when doing recycling, users must flatten the packages to reduce the volume. Thus, this strategy allows to increase the capacity of the container and the number of displacements to the bin. The packages must go to the container as clean as possible. So, they must be drained and, if necessary, washed to avoid smells.

Figure 12: Recycling packaging waste

In Portugal: “Got 7.5 million tons of packaging waste recycled in the last 20 years. There are 43 thousand recycle bins around the country. Seven out of ten Portuguese houses already recycle."

(Capucho, "Vinte anos de reciclagem, mas ainda se separa pouco lixo em casa", 2017)

“From the total waste collected in the incineration plant, the predominant ones are organic (38%), paper (16%) and plastic (10%)."

(Balasteiro, 2014)

After waste separation by the consumer and the delivery in the respective containers, the waste is collected by responsible entities. These can take different directions depending on what is intended. Recycle materials are sent to sorting centers, where they are separated according material types by manual and mechanical processes. As maintained by Balasteiro (Balasteiro, 2014), plastic materials are separated by optic machines, metals with magnets, and aluminum with Foucault current. After this process, products return to the market, ensuring the same recycling process.

According to the newspaper *Público* (PÚBLICO e LUSA, 2013), Portugal has 200 recycling yards, 29 sorting facilities, 35 landfills, 13 organic recovery units and two incineration plants.

As claimed by EPA (EPA United States Environmental Protection Agency, 2017), recycling has lots of benefits: helps to decrease gases and water pollutants emissions, saves and creates energy, provides raw materials, conserves natural resources, creates jobs, helps the community to be more ecologically responsible, and reduces the amount of trash routed to landfills.

Figure 13: Sorting facility

Figure 14: Organic waste (apple)

“A large part of household waste in European countries is related to the consumption of food and beverages.”

(Eurostat Statistical Books, 2010, p. 37)

In addition to what was previous referred, the recycling of organic waste should be mentioned because it can also be recycled.

Biodegradable or organic municipal waste is collected to obtain organic valorization by composting processes or anaerobic digestion. Municipal waste can be sent to Mechanical Treatment or Mechanical and Biological Treatment, which is subsequently sent for recycling or another recovery process. Also, can be used for energy recovery. As a last resort, if not possible to take advantage of the waste, this will be taken to landfills. (REA , 2018)

In Portugal, for example, the trash is taken to a deposit where is burned at 900 degrees Celsius, producing “(...) about 50MW, per hour (...)” (Balasteiro, 2014) of electrical energy.

In this process, gases are released. Although they are monitored and reduced, it is still harmful to the environment. Waste is reduced to 20% and takes approximately one and a half hour.

After burning, the slag is extracted. "slag can be applied to the paving of streets and roads, in addition to covering the waste deposited in the landfill" (Balasteiro, 2014).

In the landfill, the biogas is used to generate electricity. The rest of the waste is shredded and sent for composting.

It's also possible to shredder organic waste at home. This, besides reducing the waste volume, helps reduce the occupied space in landfills.

Shredders are mechanisms that turn waste into small particles. The majority consists of: a funnel, where garbage is introduced; grinding chamber, where there are blades or turntables, whose function is to grind the waste; and a container, where the particles are deposited.

Those mechanisms have lots of benefits: (i) do not cause any negative consequences for the environment; (ii) are practical and hygienic; (iii) reduce up to 60% of the waste volume; (iv) prevents the appearance of animals at home and on the streets; (v) reduces waste collection and treatment problems; (vi) are safe; and (vii) do not require maintenance for many years.

"(...) 100% of household waste, 30% to 50% is organic waste, concluding that the use of a shredder makes possible to directly discard 50% of the household waste."

(Ecologic Ibéria, 2018)

Figure 15: Several garbage bags on the sidewalk

The waste volume mainly affects the number of times that is necessary to remove and transport the waste to the bins and the number of bags used. The volume affects the domestic level, as well as the waste collection and processing. Most of the municipal services collectors have a specific time for pick up the waste, which often causes an overcrowding of bins and trash left on the streets.

"The accumulation of waste on the street increases contact possibilities and offers very good conditions for the propagation of germs, insects, rats and other disease vectors." (United Nations Human Settlements Programme (UN-HABITAT), 2010, p. 14)

The use of garbage collection vehicles results in gases emissions, contributing to environmental pollution. In addition, fuel consumption which is detrimental to the environment and an added cost for the municipalities and, consequently, for the citizens. Therefore, it is not only an environmental problem, but also a socioeconomic one.

"Collection and transport costs are much higher, as the longer distances imply increased time on the road and increased fuel consumption, and possibly the need for local transfer stations." (United Nations Human Settlements Programme (UN-HABITAT), 2010, p. 20)

Reducing household waste volume has several social and economic benefits. Organic waste, as said before, can be shredded to take up less space. Dry waste, on the other hand, can be compacted.

1.3 Waste Compaction

“Household trash compactors represent a crucial point in the history of Americans’ relationship with the things they throw away.” (Day, 2014)

A compactor is a device that allows to reduce the waste volume through its compression. It consists essentially of: (i) a container, where the packages are deposited, and (ii) a compression object, which has the function of compacting them. This compaction can be vertical, horizontal or radial. The associated technology can be mechanical, electrical, hydraulic, pneumatic or manual. There are several types of compactors containers: industrial, street and domestic. Industrial compactors are robust, safe and have great capacity. Normally, these are produced from stainless steel. This type of compactors is suitable for hotels, hospitals, restaurants and stores. (Saad, 2018)

Figure 16: Recyclables compressed into blocks at a Brooklyn facility

Street compactors are recent and still being implemented. According to *Bigbelly* (Bigbelly, 2018), the goal is to replace the normal container. Street compactors like *Bigbelly* reduce collections by 70-80%. This brings other advantages like the decreased of labor hours, vehicle wear, and fuel consumption, reducing carbon footprint and CO2 emissions.

Household compactors are smaller than the street ones, with less volume and compaction capacity. This type can be motorized or manual. Motorized compactors are very expensive, noisy, require maintenance and large energy consumption. Most of the popular trash compactors are very robust, taking up lots of space. However, they are more efficient than manual compactors.

These ones are more ecological because they do not need electricity to function, being also less noisy. They also need less maintenance, are less expensive and smaller than the motorized ones.

All compactors have advantages such as reducing the volume of waste, reducing the number of bags used, reducing the environmental impact and encouraging good practices of waste separation. The disadvantages include its inadvisability for glassware, chemicals and food waste; expensive; and maintenance requirement.

1.4 Function

Every trash compactors have the same base components: container, where waste is deposited; compaction body, which has the function of compressing the waste; compaction mechanism, which can be the manual, mechanical, hydraulic or pneumatic system.

Household motorized compactors are characterized by the operating principle described in Figure 17. First, (a) the user opens the drawer, (b) put the garbage bag into the container and (c) introduce the waste inside the container. To initiate the process, the door is closed (d) and then the compaction starts (e). The piston goes down, compressing the waste, and then comes up, returning to the initial position. After this, (f, g) the user can open the door and remove the trash or introduce more waste into the container and repeat the process until the container volume is reached.

Manual compactors consist of a container and a piston which, when pushed vertically, by the user, compacts the packages (Figure 17, e).

Figure 17: *Operating principle of a trash compactor* (KitchenAid, 2013)

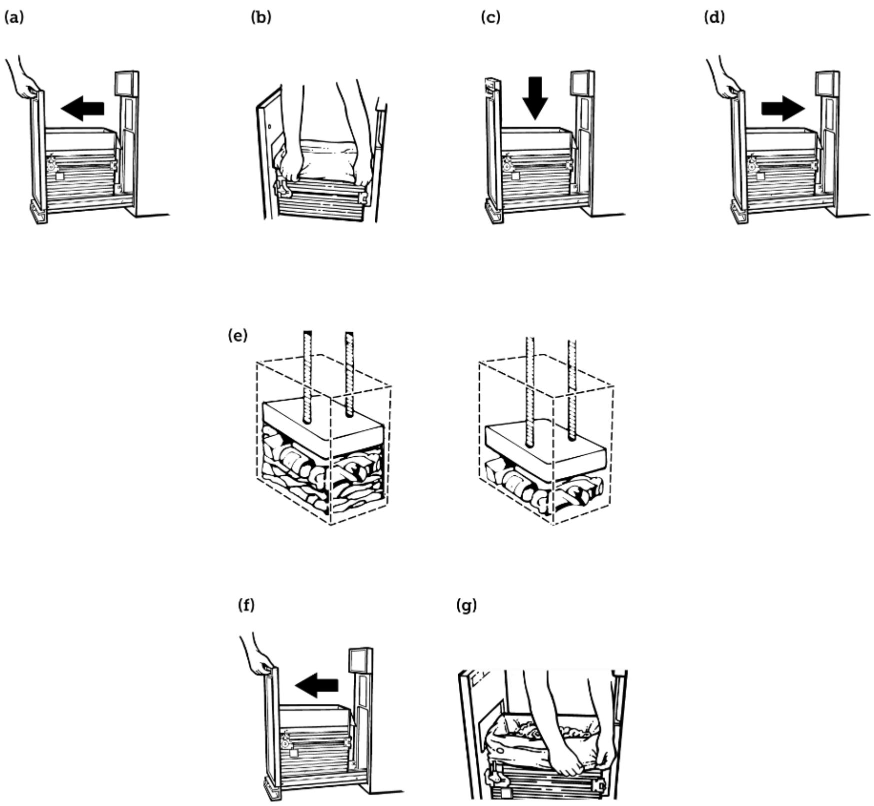


Figure 18: Jar of trash, Zero Waste campaign

2. STATE OF ART

2.1 Compactors

Figure 19: Crushed Soda Can

Figure 20: Street compactors:
(a) CleanCUBE Container;
(b) Solarbox Container;
(c) Bigbelly Container.

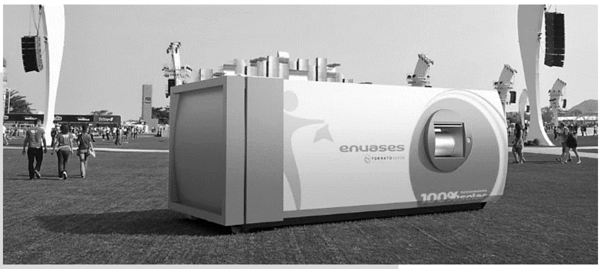
An example of **street compactors** is *CleanCUBE* (Figure 20, a), which compacts the packages through a motorized system (vertical compaction) powered by solar energy. Besides that, helps cities and waste collection organizations to reduce costs, eliminating unnecessary collection by using fill sensors (Ecube Labs, 2017). This company has offices in North America and Asia and has installed this product in over 40 countries.

(a)

Another example is the *Solarbox* represented in Figure 20 (b), developed by *Formato Verde*, a Portuguese company. It has large dimensions and can be compared to industrial compactors. It was developed to be introduced in the cities. Like *CleanCUBE*, it is also powered by solar energy (Formato Verde, 2017).

Bigbelly, which was founded in 2003, is another example of a system for smart cities with a street compactor container (Figure 20, c). This one is very similar to *CleanCUBE* and also has a garbage collection network which helps cities to be cleaner. The company office is in USA and the equipment is deployed in more than 50 countries (Bigbelly, 2018).

(b)



(c)

Manual compactors have some examples such as *Smush Can* made in Taiwan (Figure 21, d), *Compacting Garbage* from United Kingdom (Figure 21, e) and the *Trash Krusher* from USA (Figure 21, f). They have very similar characteristics. Both solutions have a handle which helps the user to push the trash down.

Figure 21: Manual compactors:
(d) "Smush Can" container handling;
(e) "Compacting Garbage" handling;
(f) "Trash Krusher" handling;
(g) "Stomp It" container;
(h) "Ecopod" container.

(d)

(e)

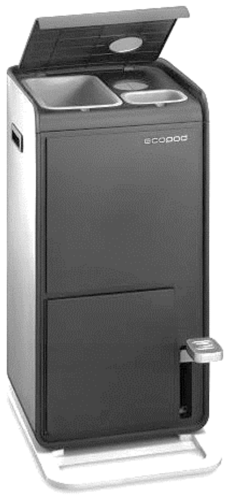
(f)

Another example is *Stomp It or Armstrong Bin* (Figure 21, g) (TUVIE, 2009), created by Sukwon Park and Sungwoo Park. Having a similar design to the accordion, it compacts the trash when stepped on by the user with the foot (vertical compression). In this category, prices are between € 100 and € 200.

Ecopod (Figure 21, h) is also a manual compactor but just for metallic and plastic waste. Packages are introduced in the appropriate slot, then the user steps on a foot pedal, which makes the equipment compact the waste (USA, 2017).

They have the advantages of not using electricity and the dimensions are similar to the existing containers. However, they have the disadvantage of being less efficient compared to motorized ones.

(h)



(g)

Figure 22: Motorized compactors:
(i) KitchenAid Compactor;
(j) Krushr Compactor;
(k) Maytag Compactor;
(l) Whirlpool Compactor;
(m) Broan Compactor;
(n) Gladiator Compactor.

(j)

(i)

In the category of **motorized compactors,** it was possible to collect several examples of brands with these types of equipment such as: *KitchenAid* (Figure 22, i), *Maytag* (Figure 22, k), *Whirlpool* (Figure 22, l), *Broan* from United States (Figure 22, m), *Krushr* from UK (Figure 22, j), *Gladiator* from Canada (Figure 22, n), and among others.

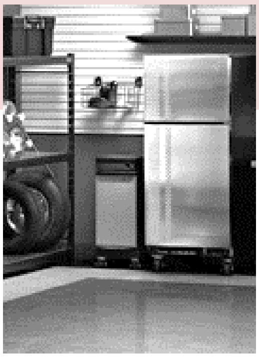
All of them are very similar (see Table 1). They vary in security, interface and exterior appearance. This kind of containers are made of stainless steel and have vertical compression. Motorized compactors are easy to use, have high capacity and provide an efficient compaction. However, they have a disadvantage such as high cost, maintenance requirement, large dimensions, high energy consumption and noise.

The latest motorized compactors have some improvements: a removable key to prevent accidental operation; built-in air purification compartments or charcoal filters for odor absorption; noise insulation; and reversible front panels, to enhance the appearance or integrate into the kitchen furniture.

(k)

(l)

(m)



(n)

	Capacity (ft³)	Compression power (hp)	Compression ratio	Price (€)
 ***Kitchen-Aid***	1.4	0.33	5	1115,33
 ***Krushr***	1.4	0.34	>4	977,95
 ***Maytag***	1.4	0.33	5	943,61
 ***Whirlpool***	1.4	0.33	4	728,96
 ***Broan***	1.55	0.75	6	1513,11
 ***Gladiator***	1.4	0.33	4	626,77

Table 1: Compactors comparison [Data source: Individual shop websites]

2.2 Patents

“It was much later in the 1970’s that the trash compactors that are used for residential purposes were used. John A. Boyd was among the first one to file a patent for compacting the household trash that was produced.” ("Who invented trash compactor?", 2011)

Figure 23 (a) is an example of Jonh A. Boyd patent. This one is a kitchen compactor which has a hydraulic system. The household water is used to supply the hydraulic cylinder. The water pressure pushes the piston which moves the lever arm. When the squeezer goes into the container, the waste is compressed.

(a)

(b)

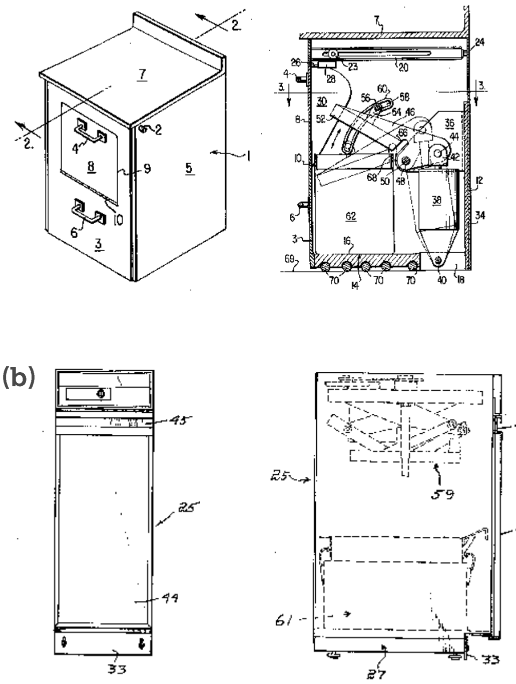
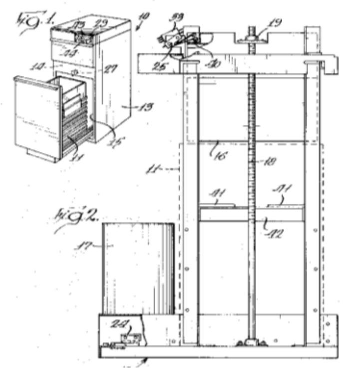


Figure 23:
(a) Kitchen compactor patent
(US Patente Nº US3691944A, 1971)*;*
(b) "Trash Compactor"
(US Patente Nº US4024806A, 1977)*;*
(c) "Refuse compactor"
(US Patente Nº US3613560A, 1969)*;*
(d) "Trash compactor"
(US Patente Nº US20150101499A1, 2011)*;*
(e) "Vacuum Compacting Trash Can"
(Corte Madera, CA (US) Patente Nº US20030136279A1, 2002)*;*
(f) "Trash compactor having a linear actuator"
(Depew, NY (US) Patente Nº US20140041535A1, 2012)*;*
(g) "Trash compactor"
(US Patente Nº US3899967A, 1973).

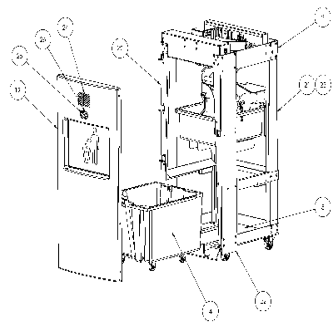
Companies mentioned above have the most of their products patented. *Norris Industries Inc.*, for example, has several registered patents. One of them is "Trash Compactor" (Figure 23, b) invented by Charles B. Weeks and Paul V. Choate. Registered on May 24, 1977, this invention is a compactor in which the system is supported by two sets of links interconnected by a common member. These links open and close and, when they do this movement, the head down compacts the waste and up returns to initial position, respectively.

Another example is the invention created by Michael J. Bottas, Thomas R. Macfarlane and Frank E. Miller, on November 5, 1969. Patented by *Whirlpool* company, "Refuse compactor" (Figure 23, c), is a system controlled by an electric motor which just initiates the process when the drawer is closed. Another patent is from *Compaction Technologies Inc.*, "Trash Compactor" (Figure 23, d) invented by Jim Hitchcock, Kenneth Judge and Luke Lundquist, and registered on April 4, 2011. This machine comprises a structure with a set of linkages and a drive mechanism to move the platen up and down.

(c)



(d)

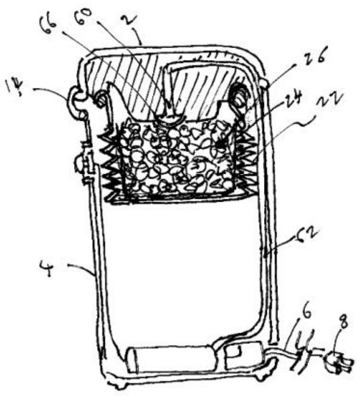


Vacuum compacting trash can" (Figure 23, e) was invented by Kenneth A. Tarlow on January 22, 2002. As the name implies the waste is compacted by a vacuum pump which removes the air inside the container.

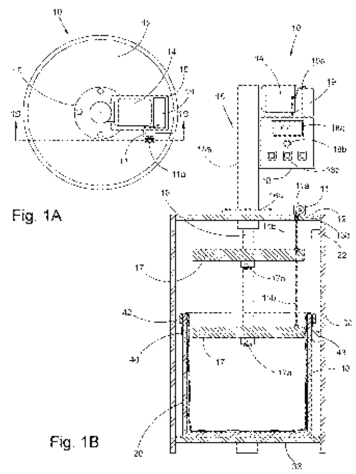
"Trash compactor having a linear actuator" (Figure 23, f) was invented by Nancy A. Shearer and Andrew J. Shearer. This one has a linear actuator with an electric motor, which can function with hydraulic or pneumatic devices.

Invented by Richard T. Powes, on August 20, 1973, the "Trash Compactor" (Figure 23, g) is a flexible container. When is closed, it compacts the waste. This product has a vacuum pump to reduce the pressure, which creates a differential pressure across the end container walls, forcing it toward one another. In this case, the inventor joined the vacuum system with the material technology.

(e)



(f)



(g)

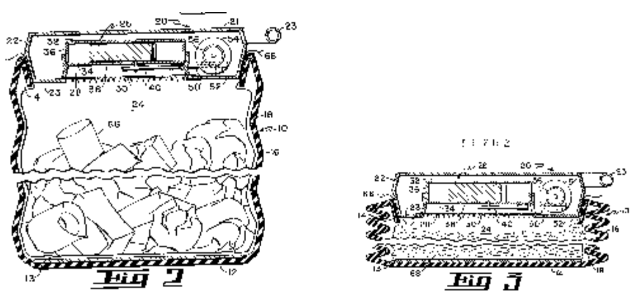


Figure 24: Street bin full of trash

3. PRO-POSAL

As previously noted, excessive production and poor management of waste can cause several environmental and socioeconomic problems. Attending to the waste life cycle, most of the waste starts in households. Therefore, several domestic products, like the examples in sub-chapter "2. STATE OF ART", have been developed. However, most of them are very expensive and have large dimensions. In addition, motorized compactors, besides having a remarkable compaction ratio, consume a lot of energy.

The present product aims to help to solve waste management problems as well. This one differs from the others because the main goal is not to achieve the maximum compaction ratio but have a unique and innovative compaction system, with a fair relationship between compaction ratio, price and size. Besides that, this product can be introduced in existing bins, which does not happen with the conventional waste compactors in the market.

The target of this product is the domestic kitchens, more focused on European ones. The aim is to give the users an autonomous and economic product that compact the domestic waste, improving the housework quality. As consequence, it will also improve the waste collection system and education, emphasizing an environmental responsibility attitude and promoting sustainability and circular economy.

The domestic waste compactor equipment has as main requirements: (i) use of recycled and eco-friendly materials and components, (ii) adaptable to an existing container, (iii) low manufacturing cost, (iv) minimum number of components, (v) cheap, (vi) low maintenance, (vii) compact design, (viii) intuitive and (ix) safe.

As result, this product is an equipment which can be introduced in a 15 liters standard cylindrical container. This product has two modules: (i) just the equipment and (ii) a container for one equipment. The container can be matched with other containers, side by side or back to back, thanks to the modular characteristic. Also provides the waste separation practice and gives to the consumer the possibility of make the pack according to their needs.

Besides the container, a mobile application model was developed. The aim of this APP is: (i) initiate the compaction remotely, (ii) receive information about the capacity left and error alerts, and (iii) clarify consumers doubts.


VERTICAL

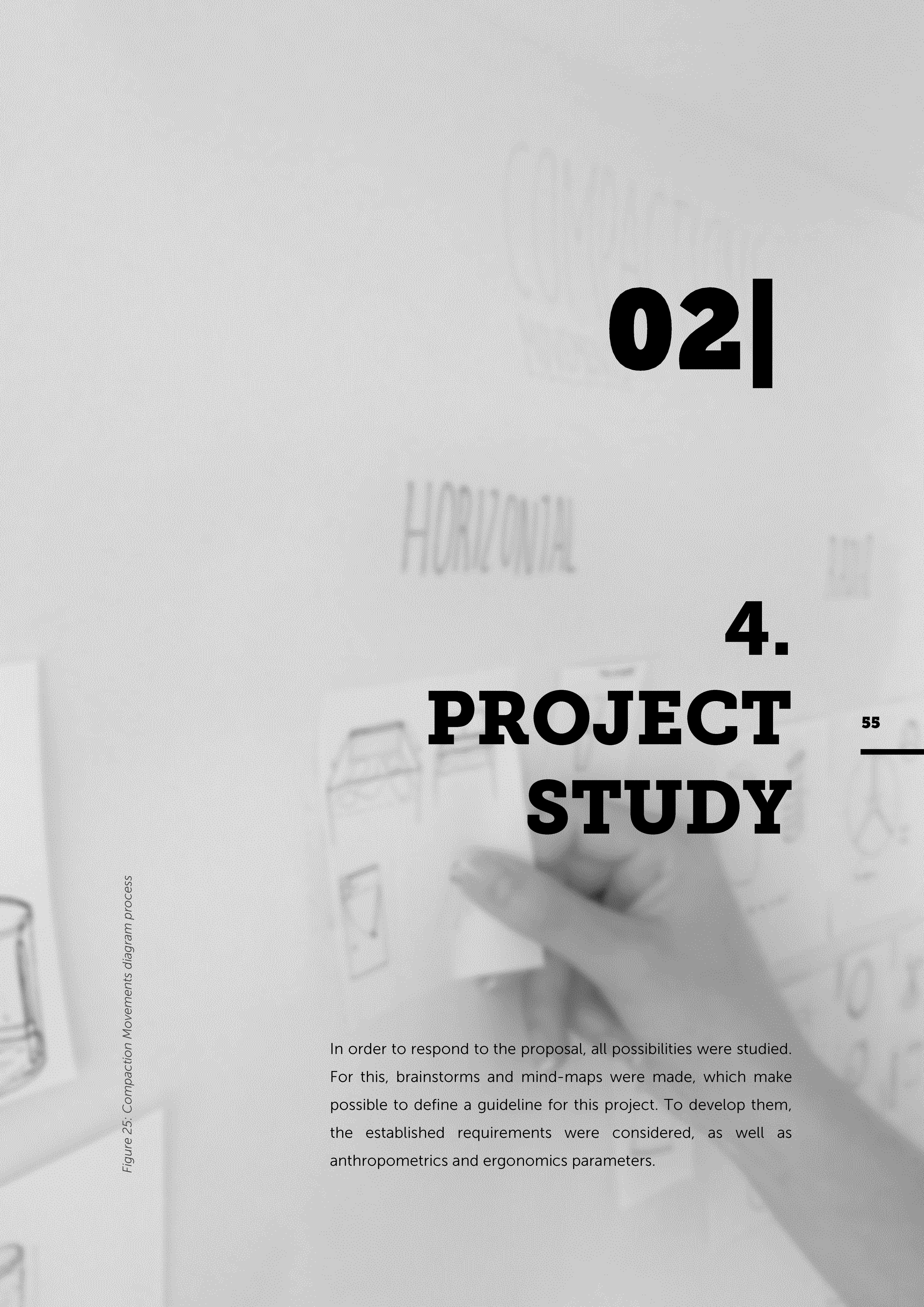


Figure 25: Compaction Movements diagram process

02|

4. PROJECT STUDY

In order to respond to the proposal, all possibilities were studied. For this, brainstorms and mind-maps were made, which make possible to define a guideline for this project. To develop them, the established requirements were considered, as well as anthropometrics and ergonomics parameters.

4.1 Context, User and Handling

Figure 26: Example of an European kitchen

Considering the information collected in sub-chapter "1.2. Solutions", most of the waste is produced in household kitchens. Therefore, domestic kitchens were settled as the target for this product. This room characteristics, such as waste production, can differ according to the people culture and lifestyle. According to the "Why Yanks Have Garbage Compactors and Brits Don't" article (Beautyon, 2014), the author affirms that the big consumer of trash compactors are US and countries which have to pay private contractors to collect the household trash and normally are charged depending on the volume of waste.

American kitchens are usually large and the compactors are consider as appliances and not just a container. However, this type of scenario corresponds to a lifestyle that is not common to all citizens in the world. Since the aim is to achieve the majority of the population, the target for this product is medium/small domestic kitchens. Attending to the NEDC (NEDC, 2012) article, European kitchens are smaller and have less counter space than the American ones. Therefore, and according to the requirements, European kitchens were established as the main targets.

According to John Aglionby article (Aglionby, 2018), more than half of the world's population are middle-class citizens. In addition to the previous information, this sector was considered the consumer target. Considering the AEG interview (AEG, 2017), consumers prefer:

Interactive, intuitive, innovative, attractive, low consumption and low-priced products.

In Portugal, such as in many European countries, consumers opt for cheaper products because the purchasing power is low. However, between a low-priced product and another with better energy efficiency, they prefer the second choice even if it is more expensive. Nowadays, men and women have an equal position in household care, meaning that the consumer can be both.

The day by day user, considering the type of product, can be adults or children (five years and older) with or without disabilities. However, the users who do the maintenance of the product are adults (twenty years and older).

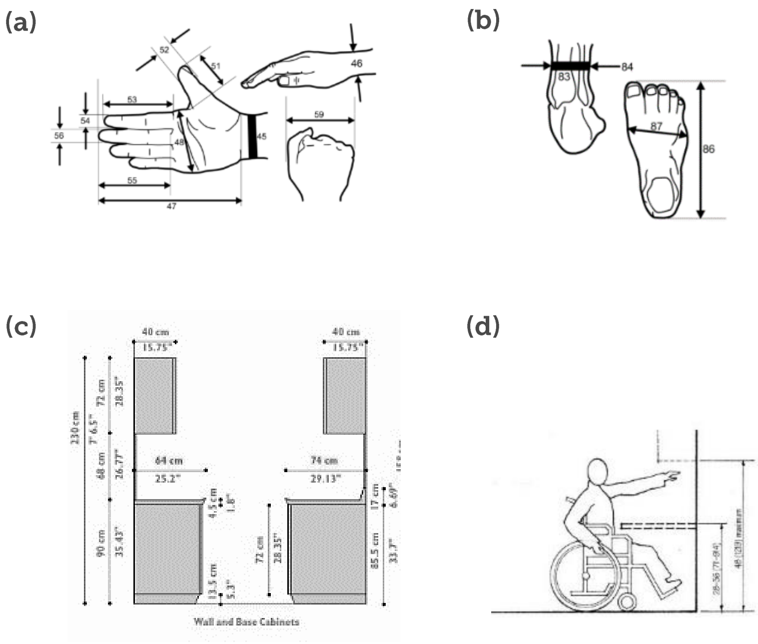


Figure 27: Anthropometrics:
(a) of the hand;
(b) of the foot;
(c) of an European Kitchen;
(d) of the space wheelchair.

To better respond to the user needs, with the support of anthropometrics and ergonomics databases, measures and accessibility requisites were established. Usually, domestic containers can be opened with the hands or the foot. Thereby, the correspondent measures were considered (Figure 27, a, b). Taking into account medium/small European kitchens space, the product respects also the respective dimensions (Figure 27, c, d). This helps to improve the handling of the container and the accessibility as well.

According to the previous information, the maximum of 71 cm for height and 64 cm for width was established and the hand and foot ergonomics will be also considered in the design.

4.2 Compaction Movements

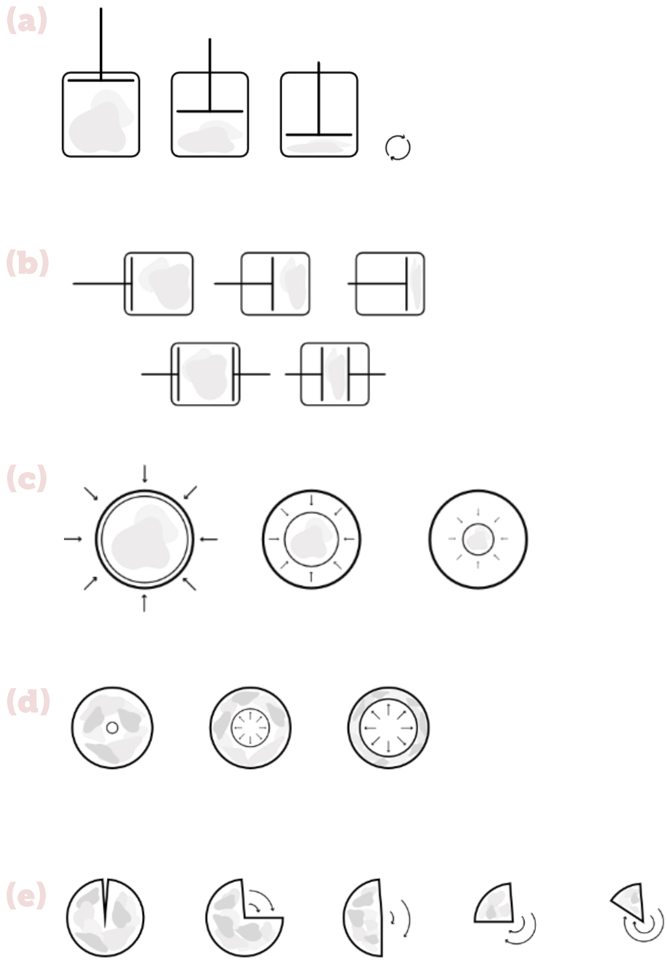
The existing domestic waste compactors are motorized or manual and have vertical or horizontal compaction movement (1.3. Waste compaction).

Vertical movement is related to top-down compression or vice versa (Figure 28, a). In the horizontal compression, the piston can move from left to right (or vice versa) or from both sides at the same time (Figure 28, b).

Besides these two movements, there is also a third called radial movement. As represented in Figure 28, c, the compacting part moves outside-in. Until the present document, there is no product with this movement.

Based on the existing information and after some brainstorms, several sketches were created, emerging the idea of two new movements, which gave the origin of two sub-typologies: radial inside-out (divergent) and gyroscopic. The first is similar to the existing radial one, however, act in the opposite direction (Figure 28, d). In the gyroscopic movement, the waste is compressed when the compacting part moves around an axis (Figure 28, e).

Figure 28: Compaction Movements:
(a) Vertical;
(b) Horizontal;
(c) Radial;
(d) Divergent-Radial;
(e) Gyroscopic.



4.3 Compaction Technologies

The compaction can have a mechanical, hydraulic, pneumatic or manual technology (1.3 Waste compaction).

As previously mentioned, manual technology does not need electricity to function. The user applies some force to make the system work. Therefore, to compress the waste, the user moves (pull, push or twist) one of the parts of the system.

Some of the existing products, with manual technology, are fully manual, like *Smush Can*, or can take advantage of the material characteristics to support the compaction, like *Stomp It*. Others have mechanisms which support the movement of the user, like *Ecopod* (see examples in chapter 2.).

Therefore, the manual system can be both – just manual or manual and mechanical. In this case, the mechanism is assisted by the applied force on the pedal by the user. However, the mechanism also could be electrically assisted if, instead of the pedal, a switch with a motor is applied.

The mechanical technology combines components such as belts, chains, gears, friction wheels, and others, creating a structure which, with an impulse (manual or electric), generate a movement with higher force or velocity than in a just manual act.

Hydraulic and pneumatic systems can also be integrated with mechanical technology. The hydraulic system consists of the transmission of an applied force, from one point to another, by a fluid (most often oil). This requires an appropriate container, where the fluid is disposed, and a pump to obtain the required force. Although it has a high maintenance cost, it can transport high levels of force and perform movements precisely.

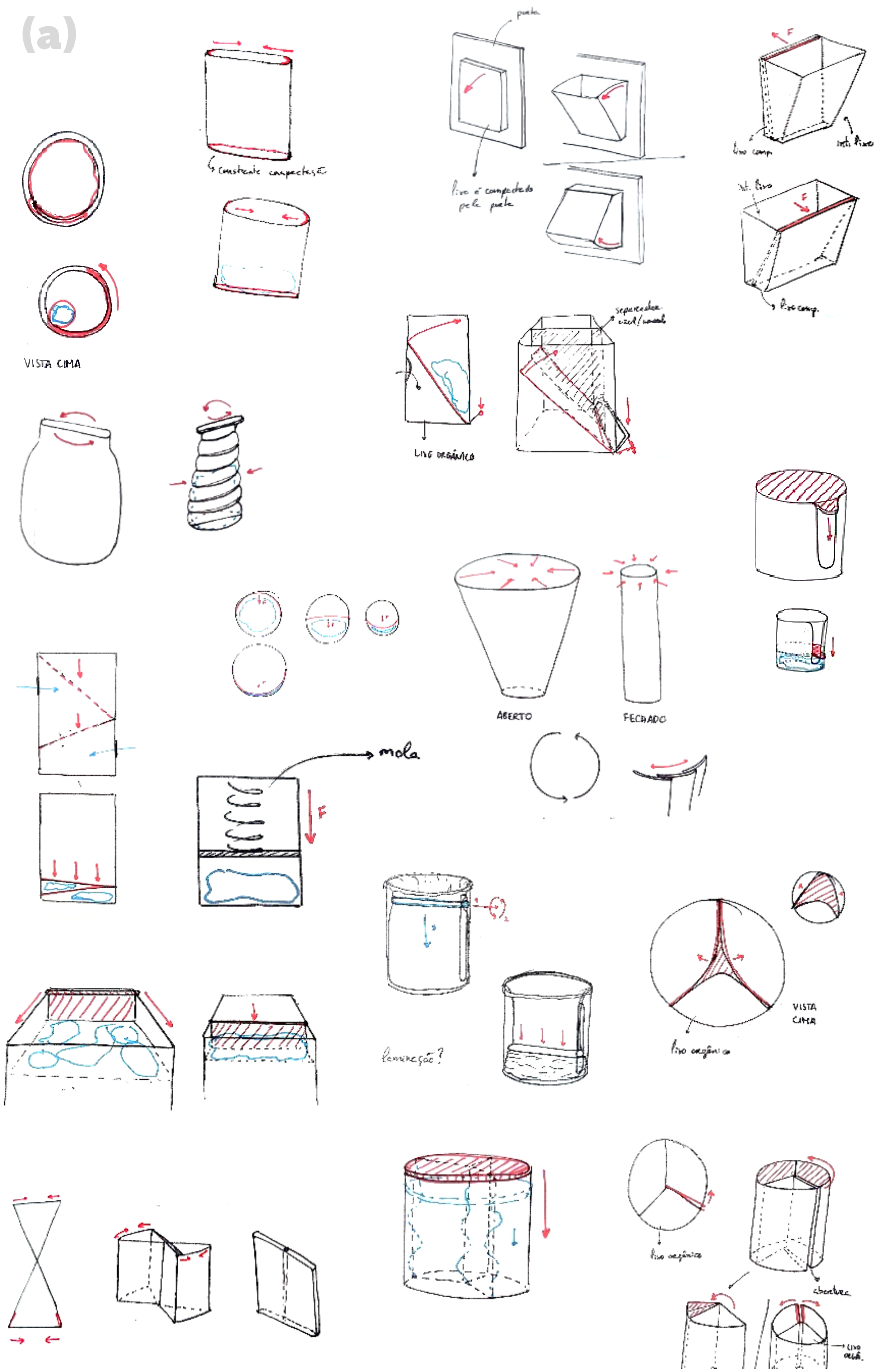
The pneumatic system is similar to hydraulic, but this one, instead of fluid, uses gases such as compressed air or nitrogen. This also requires a compressor and an air filter in scenarios where the presence of impurities affects its performance (Woodford, 2017). This system can generate less force than the hydraulic one, however, is not less effective, it depends where it is applied. According to Satyendra Sarna article (Sarna, 2015), pneumatic systems are better than the hydraulic because of their unlimited resource (air), durability and low maintenance, and consequently economical. Besides that, they are also environmentally friendly since they do not produce pollutants.

4.4 Oppor-tunities Analysis

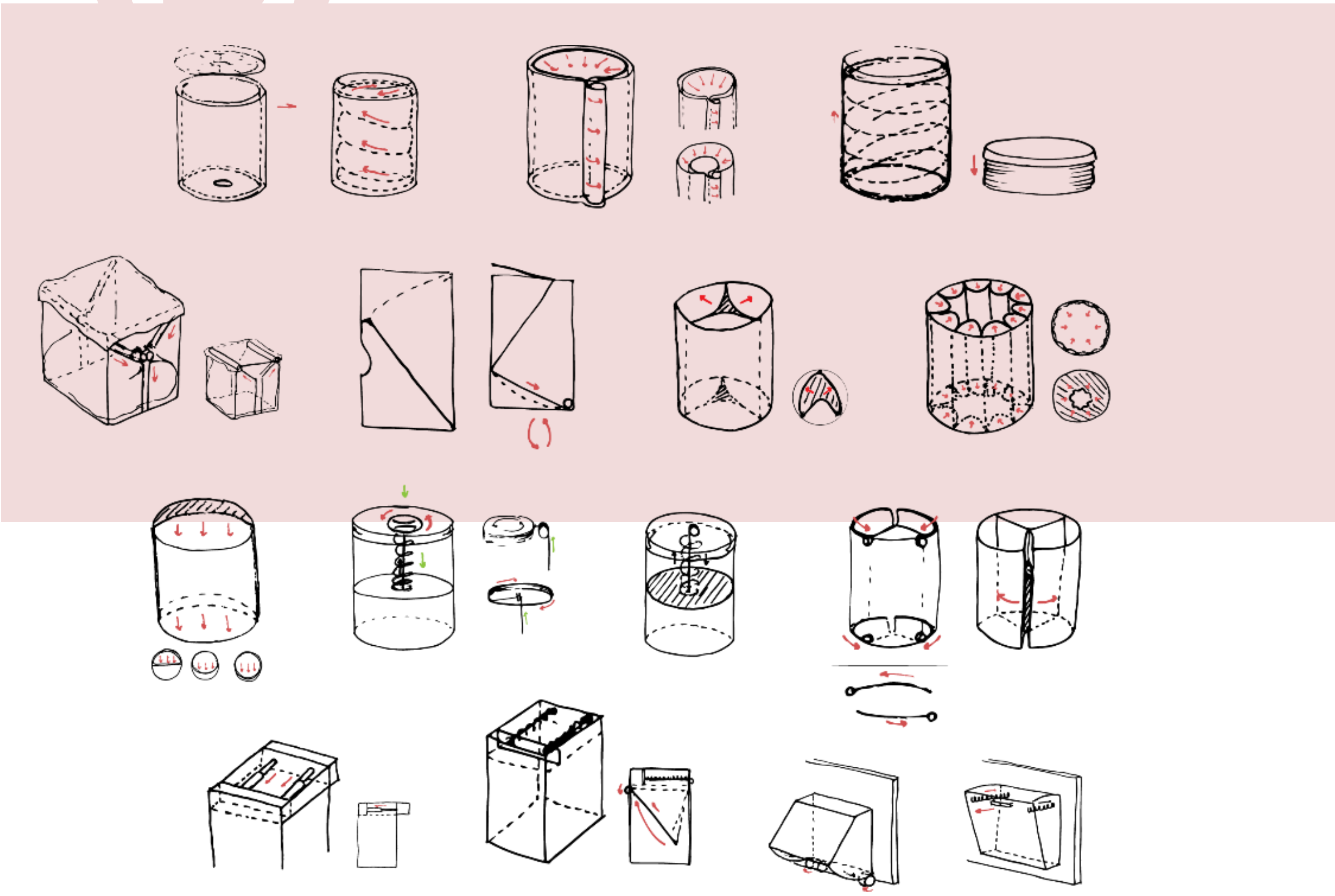
Figure 29: Quick sketches:
(a) Compaction movements;
(b) Compaction with technology.

With the previous research and the proposals made in chapter "4.2 Compaction Movements", the different categories of technologies were settled in one diagram (Figure 25) and, for each one of them, several systems were designed. From this operation one or two different technology systems resulted for each one of the previous proposals. Moreover, new designs of movement possibilities arose (Figure 29, a).

(a)

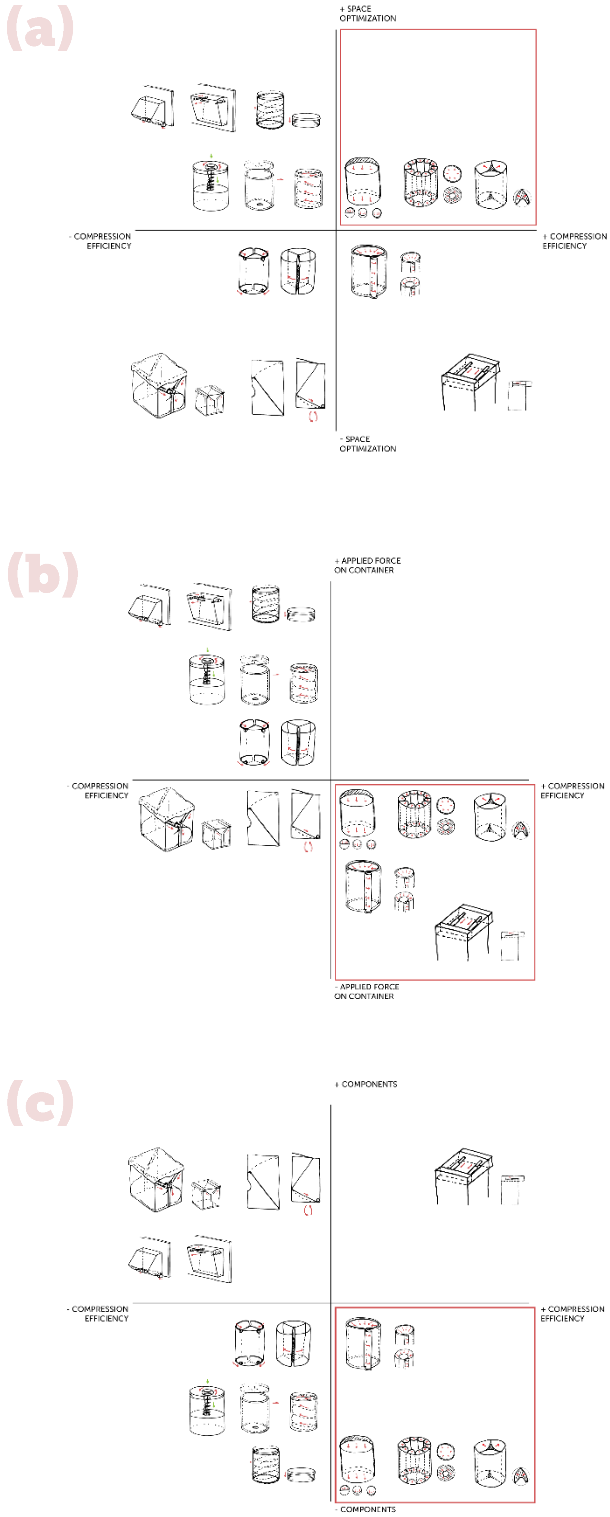


(b)



From these sketches new ones were made for each technology (Figure 29, b). With all these potentials products, there was the need to constrain the solutions. To support this process, Opportunity Maps were developed (Figure 30). Some restrictions were considered as main values to this instrument, such as (i) compression efficiency; (ii) space optimization; (iii) directly applied force on the container; (iv) number of components or equipment complexity (simultaneously the viability, the performance, the handling and the production). Furthermore, for each map was defined two opposite strategic dimensions. Then the sketches were divided and positioned in the map according to their characteristics.

Figure 30: Opportunity Maps:
(a) Space Optimization - Compression Efficiency;
(b) Applied force on Container - Compression Efficiency;
(c) Components Quantity - Compression Efficiency.



However, through this process, some of the sketches were not relevant or did not fit into the goals of the project. Thus, a first selection was made, attending to the established requirements, which result in twelve options.

Those twelve solutions were positioned in the charts and then the performance areas for each map were defined. The areas were selected according to the most desirable scenario for the project. After the distribution, the sketches outside of the areas were set aside, leftover only five proposals (Figure 31).

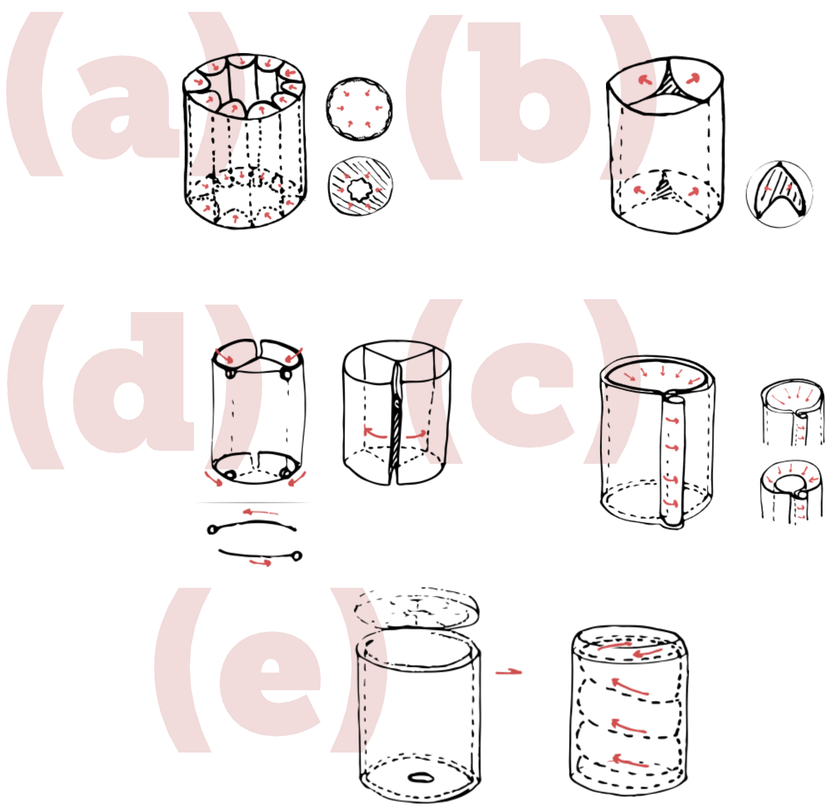


Figure 31: Top-five:
(a) Convergent-Radial Compactor;
(b) Divergent-Radial Compactor;
(c) Winding Compactor;
(d) Gyroscopic Compactor;
(e) Rotating Cover Compactor.

In this top five, the first one is the Convergent-Radial Compactor and corresponds to a radial compaction which can use a pneumatic or hydraulic system. However, the pneumatic technology was established, considering the purpose. In this product, a pneumatic bag expands - from outside in – compressing the waste in the middle (a).

The second, called Divergent-Radial Compactor, is similar to the first, however, the compression move is inside out (b). This one is divided into three parts, therefore, has the possibility of each part work separately.

The third suggestion, Winding Compactor (c), is also a radial compaction. Nevertheless, the compression is made by a mechanical technology which pulls the material that is surrounding the waste, rolling it up. This compaction can be manually or electrically assisted.

Figure 31 (d) corresponds to the Gyroscopic Compactor, the fourth selected option. The system has a gyroscopic movement and so the waste is compacted when one part of the container opens and moves around itself (the axis is the center of the bin). In this proposal, the system can be pneumatic or mechanic.

The last top-five solution is the Rotating Cover Compactor (e), which the main component is the cover. This part spins, twisting the bag fixed to it. When the bag twists, the waste is compressed. The system is radial and can be manual or motorized.

4.5 Vertical Compaction

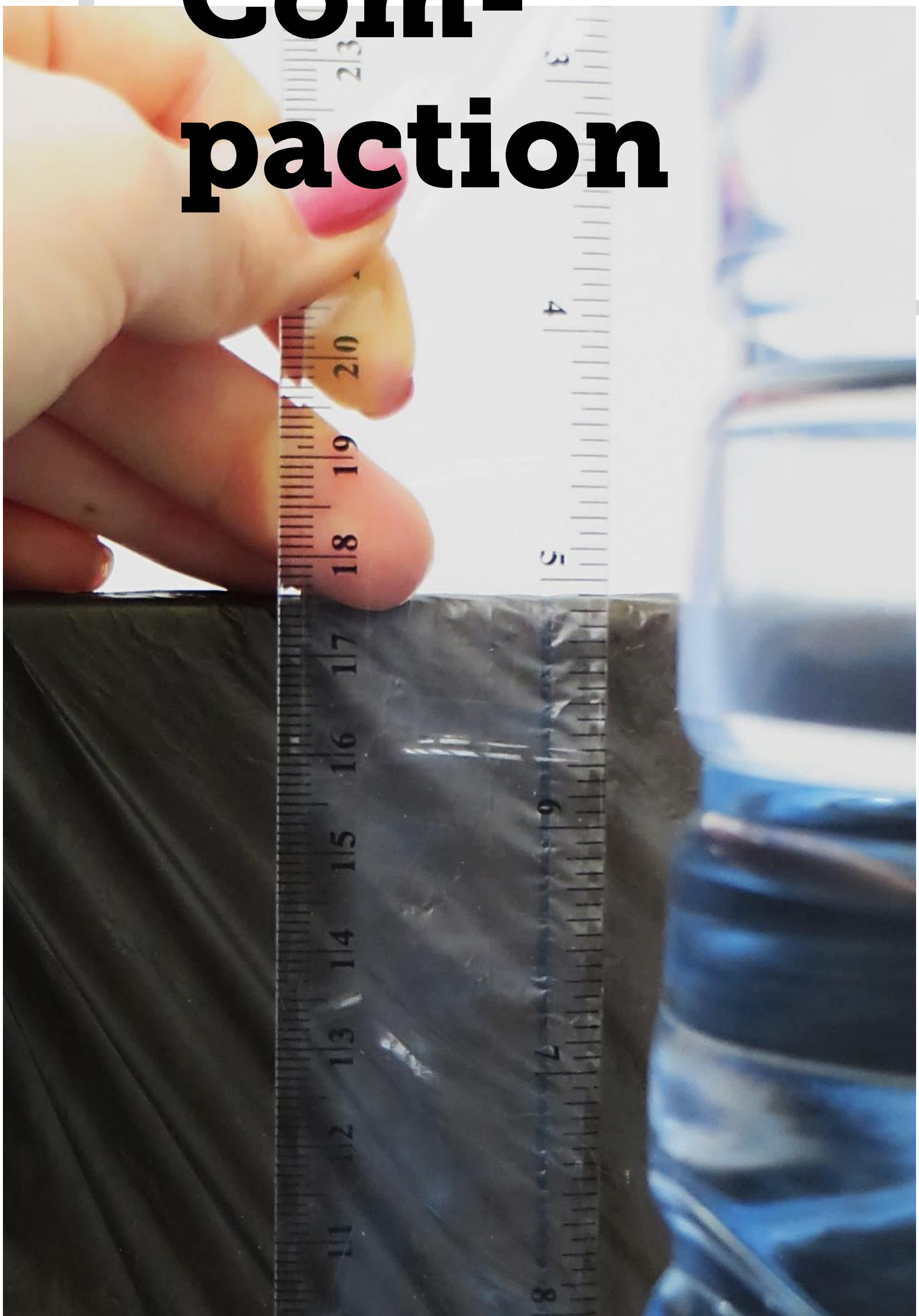


Figure 32: Compaction test, measuring trash displacement

Figure 33: Before and after compaction:
(a) Plastic trash;
(b) Paper trash.

To support the investigation and the consequent decisions, home compaction tests were made. The aim of these tests was analyze the required force to compact domestic waste. Some aspects were considered, such as measures (40 liters bin, since is the middle capacity on the market) and waste typology (plastic and paper). One of the requirements of the project is the recycling, therefore, two tests were made: one for plastic waste (Figure 33, a) and another for paper waste (Figure 33, b). The waste did not have a previous compression and there was not established any criterion for the disposal.

[3] Compaction ratio is the ratio between the initial and final volume. In the case of waste compactors, it corresponds to the times the waste volume decreases from the initial one.

For the experiment, I was used a 40 liters bin, domestic dry waste, a ruler, one cardboard and packages (1kg each). Into the bin, the plastic waste was introduced in the first test and the paper in the second. Then, the cardboard was placed on the waste. When the scenario was ready, the first package (1kg) was positioned on the board and the dislocation of the board was measured. Both values (mass and displacement) were registered (Figure 31). This process was successively repeated until the displacement reaches the maximum value possible, considering the conditions.

The displacement values were converted to compaction ratio[3] to facilitate the comparison between the information in chapter "2. STATE OF ART" and the new one. Then, the diagram on Figure 34 was made, considering these listed values.

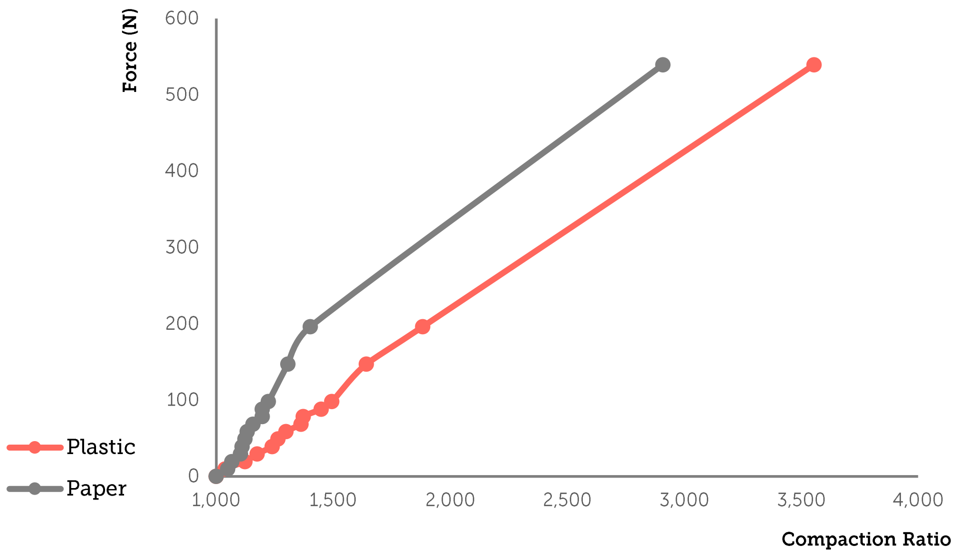


Figure 34: Test Load: Force - Compaction Ratio Diagram

Analyzing the diagram, it is possible to verify the difference between paper and plastic waste ratio, which is more substantial with the mass increase. According to this load test, the paper needs more force to compress than the plastic waste.

Besides this information, it is possible to observe a quick ratio increase in the firsts values. This happens because initially, the waste has high levels of porosity which means, as long the porosity decreases, more force is needed to compress the waste. Analyzing the load test values, with about 540 N, the ratio of the plastic waste was 3,56 and for paper waste was 2,91.

Considering Table 1, motorized compactors use a compression power between 0,33 hp (most common) and 0,75 hp which corresponds to a 4:1 to 6:1 ratio.

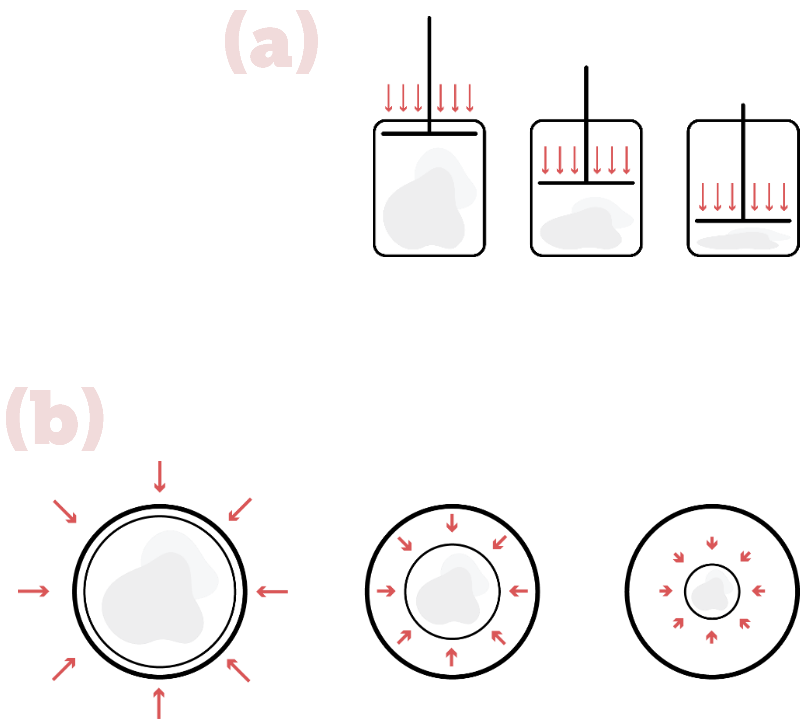
In manual compactors, the compression force is determined by the user strength. However, according to some manual compactors information (for example Joseph Joseph (Joseph Joseph, 2017)), most of these systems are expected to have at least a compression ratio of 3:1.

With this information, for this project, an efficient compaction ratio is settled in values between 3:1 and 5:1. Despite these values do not reach the minimum waste volume possible, they provide the user an expected result, responding to the aim of this project.

4.6 Radial Compaction

Considering the final top-five solutions (4.4 Opportunities Analysis), the majority are radial movements. Therefore, vertical and radial compactions were compared. In vertical compression, the force is exercised on the top of the waste. Thus, the compaction area is constant and the height varies (Figure 35, a). However, in radial systems, the force is applied around the waste. In this movement, the height is constant and the area is variable (Figure 35, b).

Figure 35:
(a) Vertical Compaction;
(b) Radial Compaction.



To verify the differences between the two compacting movements, the following process was made. First, a equation for each system was developed, emphasizing the compaction ratio (R_c). Considering,

$$R_{c_V} = \frac{V_i}{V_f} \qquad ; \qquad V = A \times h \ .$$

Figure 36:
(a) Compaction Ratio and Displacement Diagram for Vertical and Radial;

(b) Change in volume and Compaction Ratio for Vertical and Radial;

(c) Pressure and Compaction Ratio for Vertical and Radial.

In vertical compaction, the volume (V) depends on the height, therefore:

$$R_{c_v} = \frac{A \times h_i}{A \times h_f} = \frac{h_i}{h_f} = \frac{h_i}{h_i - u} \;,$$

where u is the displacement of the piston. In radial compaction, the volume (V) depends on the radius, therefore:

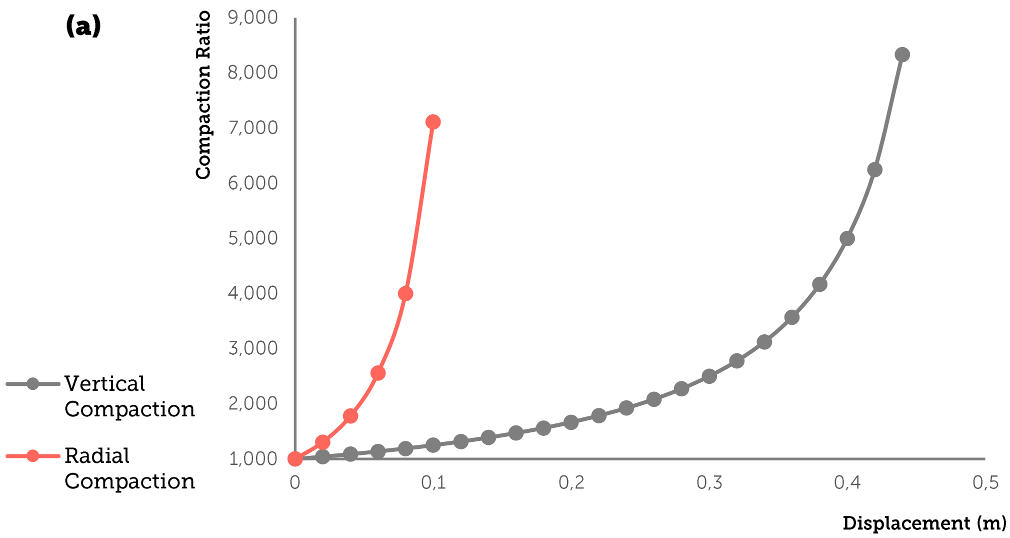
$$R_{c_r} = \frac{h \times \pi . r_i^2}{h \times \pi . r_f^2} = \left(\frac{r_i}{r_f}\right)^2 = \left(\frac{r_i}{r_i - u}\right)^2 ,$$

where u is again the displacement, however, in this case, it is the displacement of the radial movement. As a conclusion:

$$R_{c_v} = \frac{h_i}{h_i - u} \quad ; \quad R_{c_r} = \left(\frac{r_i}{r_i - u}\right)^2 .$$

To study the relation between the compaction ratio and the displacement, exemplary values were established for each variable and the diagram on Figure 36 (a) was created.

(a)



Considering the results, for the same ratio, the displacement in vertical compaction is higher than in radial. It means, with the radial compaction it is possible to achieve the same change in volume value with less displacement. Moreover, the volume changing was also analyzed.

Regarding the vertical compaction. Considering:

$u = \Delta h <=> u = h_i - h_f <=> h_f = h_i - u$;

$\Delta V = V_i - V_f$;

so, $\Delta V = A \times h_i - A \times (h_i - u) = A\big(h_i - (h_i - u)\big) = A.u$.

Then, the same analysis was made for radial compaction:

$$\Delta V = h \times \left(\pi.r_i^2 - \pi.r_f^2\right) = h \times \pi\left(r_i^2 - r_f^2\right) \ .$$

Considering:

$u = \Delta r <=> u = r_i - r_f <=> r_f = r_i - u$;

so, $\Delta V = h.\pi(r_i^2 - (r_i - u)^2) = h.\pi(2r_i.u - u^2) =$

$= h.\pi.u(2r_i - u)$.

The volume changing according to the compaction ratio:

$$\Delta V = V_i - V_f = R_c \times V_f - V_f = V_f(R_c - 1) = \frac{V_i}{R_c}(R_c - 1) \ .$$

$$\text{So, } \Delta V = \frac{V_i}{R_c}(R_c - 1) \ .$$

With these equations, the diagram of Figure 35 (b) was created. Through this, it is possible to observe the relationship between the variation of the waste volume and the compaction ratio for each movement, both have a similar behavior.

At last, the pressure and the compaction ratio were compared. Considering the values established in the previous step, the approximate pressure values for vertical and radial compaction were calculated. Considering,

$$P = E \times \varepsilon \ .$$

For vertical compaction,

$$R_{c_v} = \frac{h_i}{h_i - u} <=> h_i - u = \frac{h_i}{R_{c_v}} <=> u = h_i - \frac{h_i}{R_{c_v}} \ .$$

Therefore,

$$P = E \, x \, \varepsilon = E \times \frac{u}{h_i} = \frac{E}{h_i}\left(h_i - \frac{h_i}{R_{c_v}}\right) = E\left(1 - \frac{1}{R_{c_v}}\right) \ .$$

$$\text{So, } P_v = E\left(1 - \frac{1}{R_{c_v}}\right) \ .$$

For radial compaction,

$$R_{c_r} = \left(\frac{r_i}{r_i - u}\right)^2 <=> {R_{c_r}}^2 = \frac{r_i}{r_i - u} <=> r_i - u = \frac{r_i}{{R_{c_r}}^2}$$

$$<=> u = r_i - \frac{r_i}{{R_{c_r}}^2} \ .$$

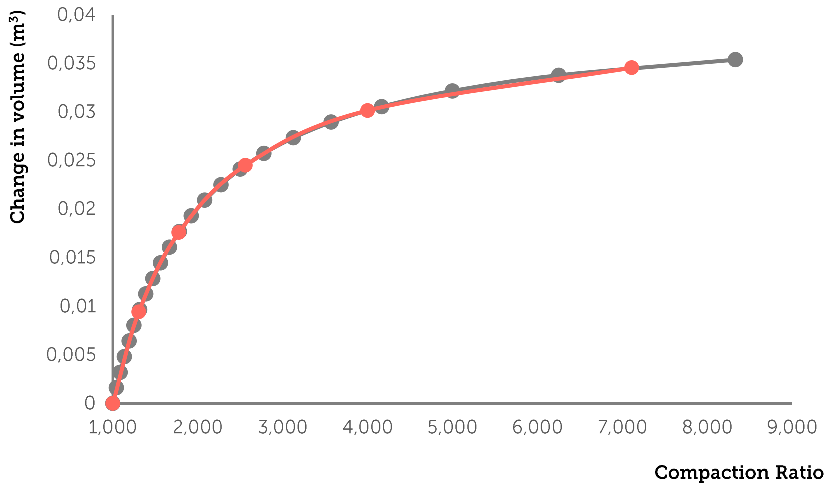
Therefore,

$$P = E \times \frac{u}{r_i} = \frac{E}{r_i}\left(r_i - \frac{r_i}{{R_{c_r}}^2}\right) = E\left(1 - \frac{1}{{R_{c_r}}^2}\right) .$$

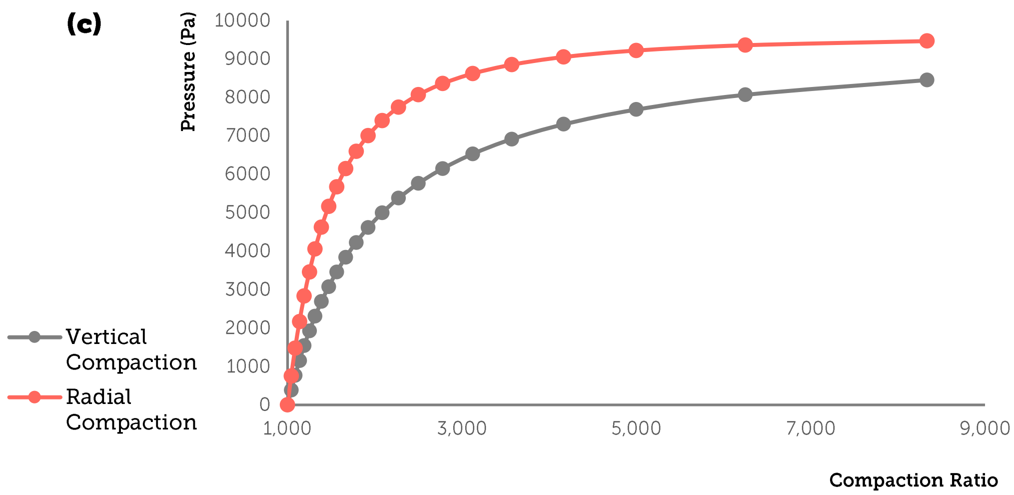
$$\text{So, } P_r = E\left(1 - \frac{1}{{R_{c_r}}^2}\right) .$$

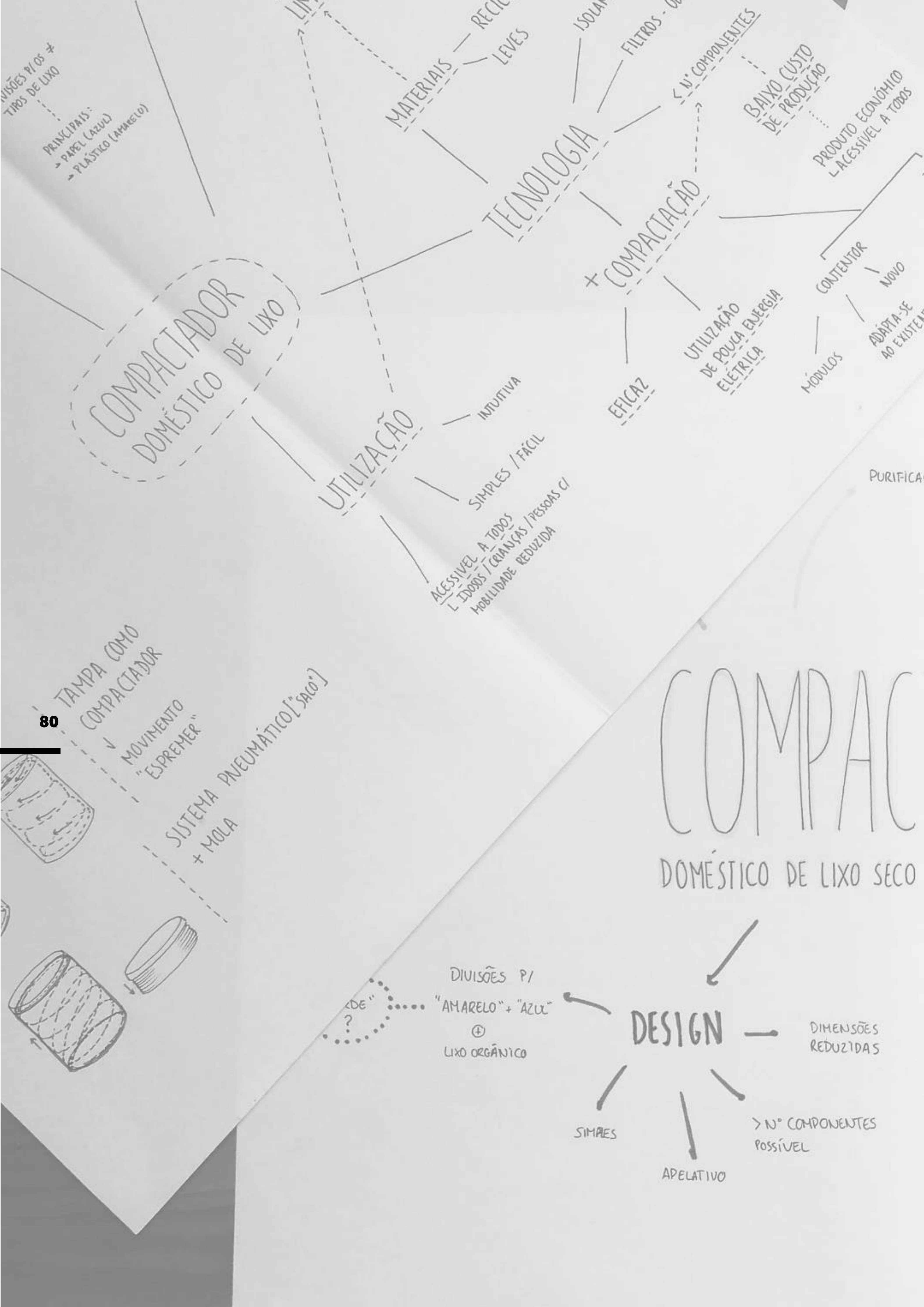
With these results the diagram on Figure 36 (c) was developed, where is possible to verify the relation between both compactions. According to this diagram, the vertical compression needs more pressure to achieve the same compaction than the radial. Despite these results being just exemplary, it is possible to conclude the, radial compaction is more efficient than the vertical.

(b)



(c)




COMPACTADOR
DOMÉSTICO DE LIXO
TECNOLOGIA
MATERIAIS
LEVES
FILTROS
< Nº COMPONENTES
BAIXO CUSTO DE PRODUÇÃO
PRODUTO ECONÓMICO
L ACESSÍVEL A TODOS
+ COMPACTAÇÃO
EFICAZ
UTILIZAÇÃO DE POUCA ENERGIA ELÉTRICA
CONTENTOR
NOVO
MÓDULOS
UTILIZAÇÃO
INTUITIVA
SIMPLES / FÁCIL
ACESSÍVEL A TODOS
L IDOSOS / CRIANÇAS / PESSOAS C/ MOBILIDADE REDUZIDA
TIPOS DE LIXO
PRINCIPAIS:
→ PAPEL (AZUL)
→ PLÁSTICO (AMARELO)
TAMPA COMO COMPACTADOR
MOVIMENTO "ESPREMER"
SISTEMA PNEUMÁTICO ["SACO"] + MOLA
PURIFICA
COMPAC
DOMÉSTICO DE LIXO SECO
DESIGN
DIVISÕES P/
"AMARELO" + "AZUL"
⊕
LIXO ORGÂNICO
DIMENSÕES REDUZIDAS
SIMPLES
APELATIVO
> Nº COMPONENTES POSSÍVEL

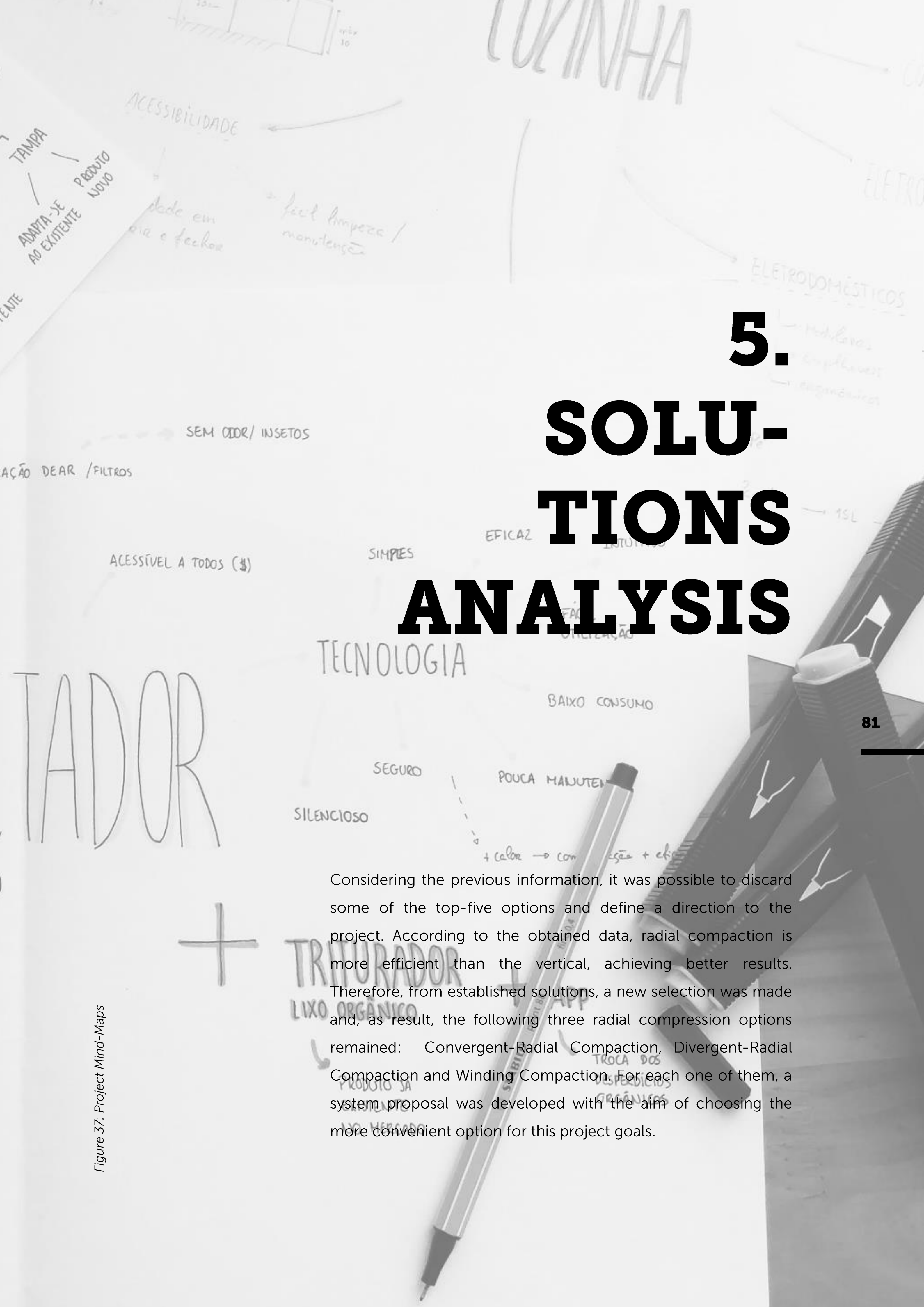


Figure 37: Project Mind-Maps

5. SOLUTIONS ANALYSIS

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Considering the previous information, it was possible to discard some of the top-five options and define a direction to the project. According to the obtained data, radial compaction is more efficient than the vertical, achieving better results. Therefore, from established solutions, a new selection was made and, as result, the following three radial compression options remained: Convergent-Radial Compaction, Divergent-Radial Compaction and Winding Compaction. For each one of them, a system proposal was developed with the aim of choosing the more convenient option for this project goals.

5.1 Convergent — radial Com- paction

(a)

(b)

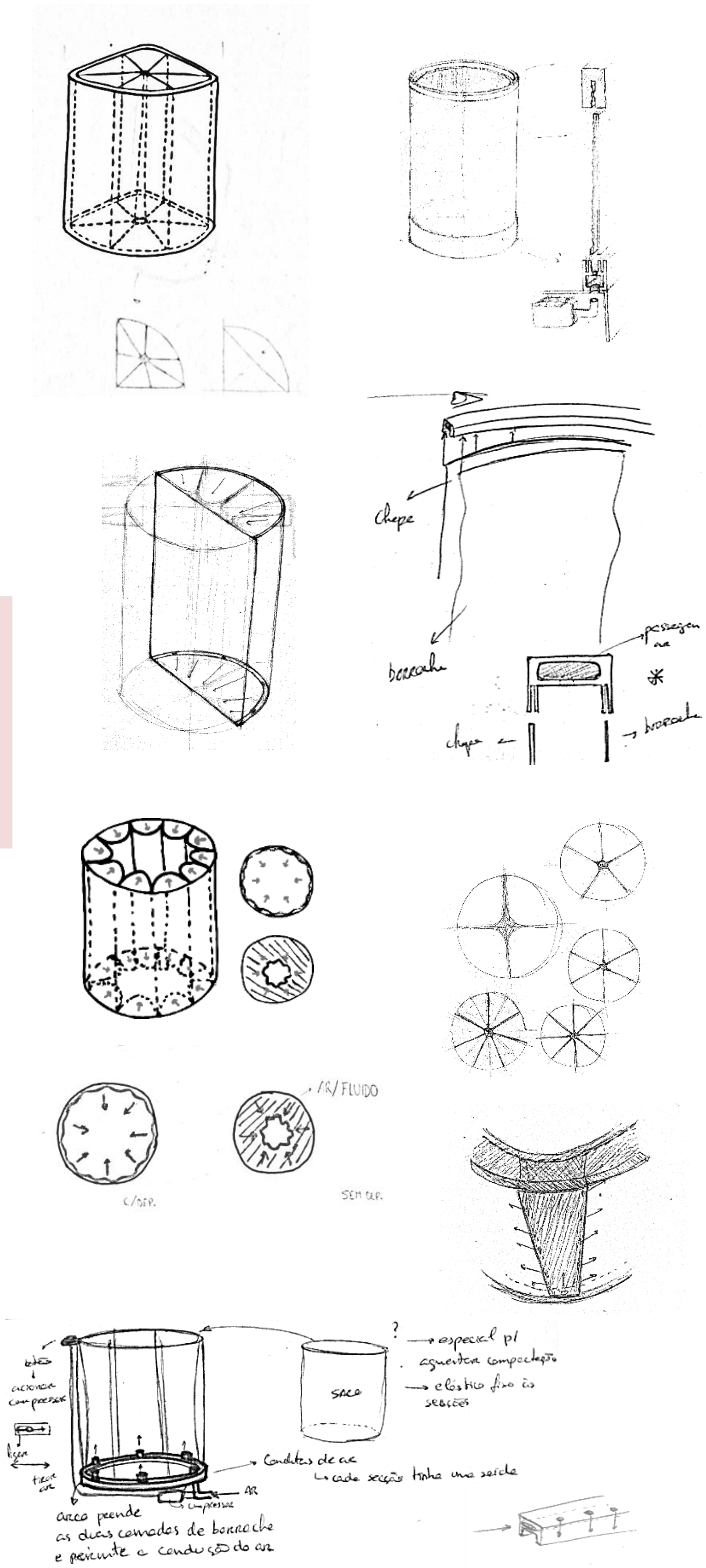


Figure 38:
(a) Convergent-radial compaction final proposal;
(b) Convergent-radial sketch process.

Convergent-radial compaction is a system where the waste is positioned in the middle of the bin and, with the support of pneumatic technology, is compressed reducing the volume.

The initial design of the equipment was enhanced, leading to the final proposal. In this process, parameters like manufacturing, assembling and maintenance were considered.

As result, this equipment is composed by the union of several compartments and each one has two parts: (a) a compacting barrier and (b) the support (Figure 39, a). These parts, together, form an "airbag". With an integrated compressor, each compartment is filled with air, compressing the waste in the middle. When the process is over, the compressor takes the air out and the compartment returns to the initial position (Figure 39, c).

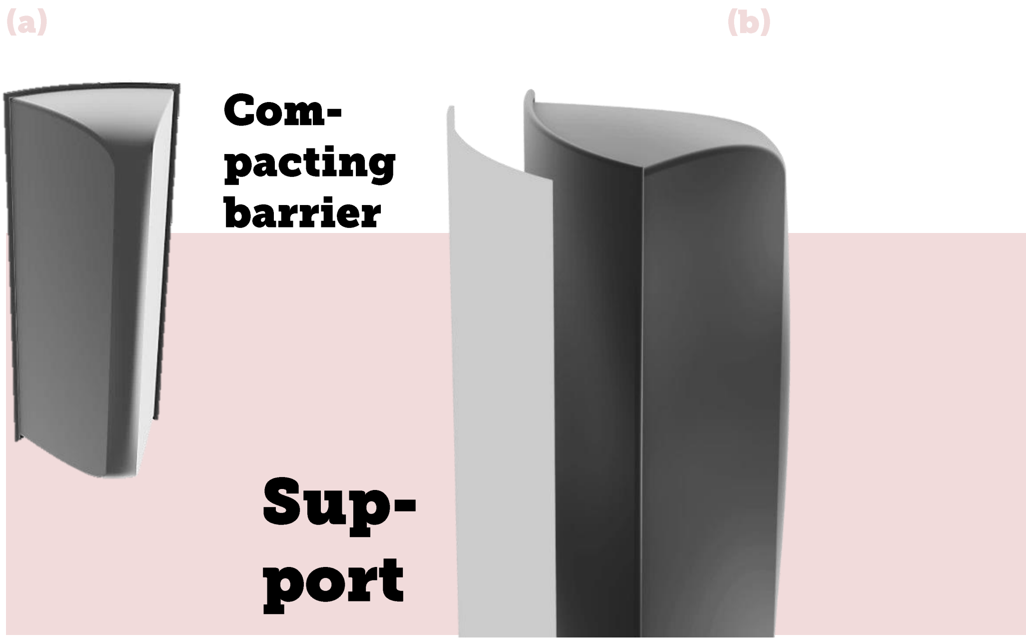
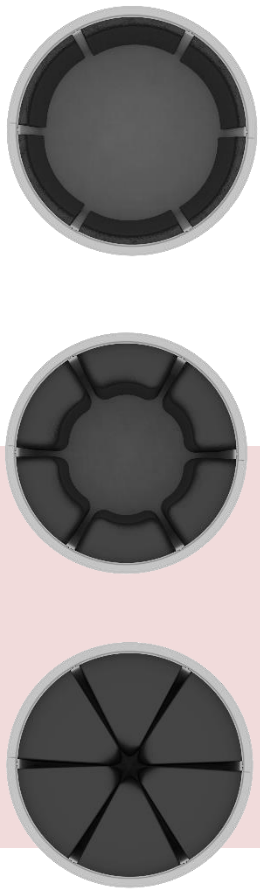


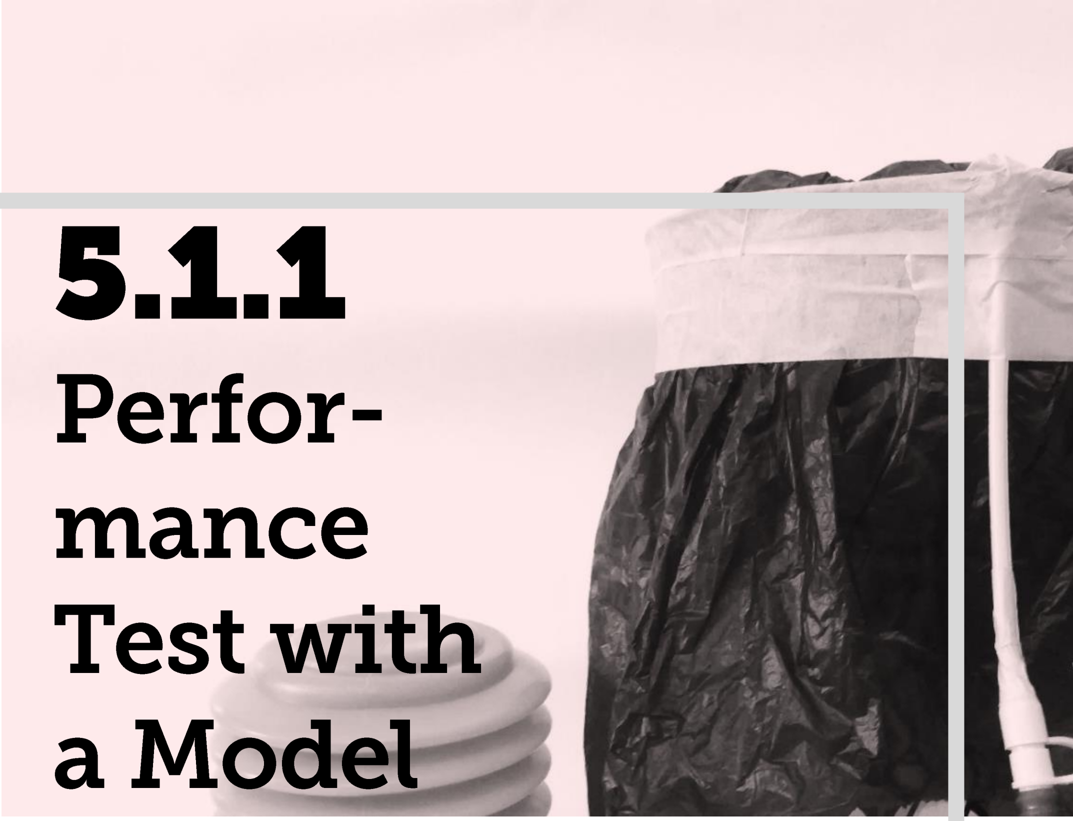
Figure 39:
(a) Compacting barrier;
(b) Compacting barrier and support;
(c) Operating sequence;
(d) Equipment components.

The compartments are introduced in a bin, which supports and joins them. Besides that, a pipe system is assembled. The pipe has one exit to each compartment and its function is to distribute the air from the compressor to the compartments. On the top and bottom of the bin there is a cover, to close it and fix these parts (Figure 39, d).

(d)

(c)





5.1.1 Perfor-mance Test with a Model

(c)

With the aim of testing the proposal design, models of the system were made.

In the first model, balloons, a pipe with holes to connect the balloons and a foot air pump were used to simulate the movement of the compartments. All those three components were connected (Figure 40, a). In the first experiment, only the closest balloon to the air pump connection was filling up. Keeping pumping the air, the first balloon burst, and the others remained empty (Figure 40, b). This experiment was repeated. This time, when the first balloon was filled out, the connection was interrupted, and the nearest balloon began to fill with air. The same process was repeated for all balloons. In the end, all were filled out and the appearance was similar to the intended.

Another experiment was made, in this one, instead of balloons, two plastic bags were used. To simulate the compartments, the bags were attached to each other on the top and bottom. Then, a hole was made to introduce the "pipe" and, connected to the this, was the foot pump (Figure 40, c). When the system was ready, the test was started pumping the air through the foot pump. Unlike the previous experimental this test did not need any intervention. As result, all the compartment was filled with air and the bin was totally occupied by the system (Figure 40, d). Besides this, the reverse process was also tested. Operating with the same model, the air was taken using a vacuum cleaner. As result, while the vacuum cleaner was working, the plastic stay attached around the container (Figure 40, e). With this model was possible to verify the system movement, obtaining the desired result.

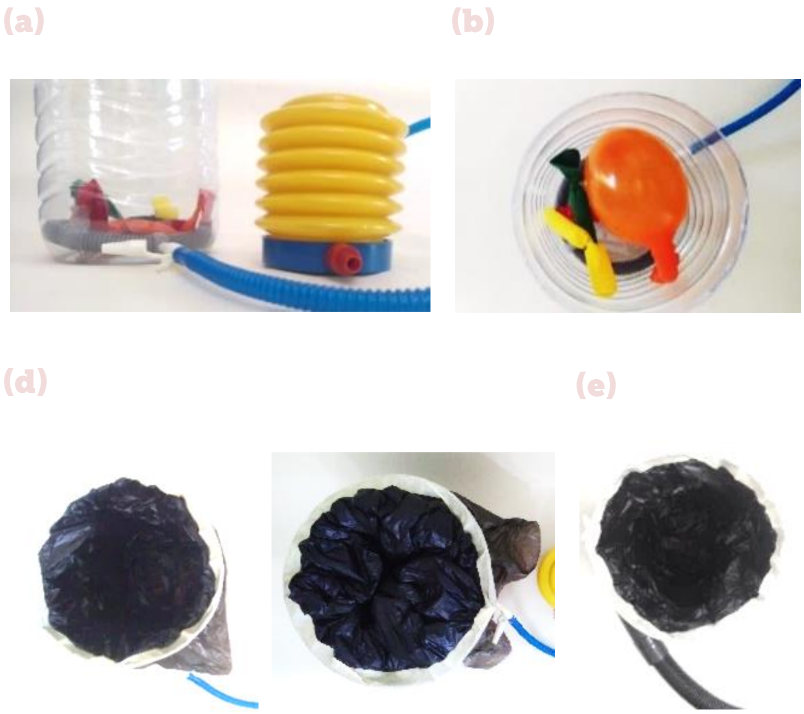


Figure 40:
(a) Convergent-Radial compaction model;
(b) First test with Convergent-radial model;
(c) Second test with Convergent-radial model;
(d) Before and after Convergent-radial test;
(e) Convergent-radial test: reverse process.

5.1.2 Numerical Analysis and Consider-ations

For all the numerical analysis the software *SolidWorks 2017*[4] was used. With these models, it was possible to simulate the system movement. However, it was not possible to calculate the pressure exerted on the components. Thereby, this study was made with analytical calculations and diagram analyses.

[4] This is a 3D mechanical CAD and simulation software, making possible to create 3D models of each part of the systems.

The calculation of the required pressure to reduce the waste volume was the first analysis made.

The values obtained in the vertical test (chapter 4.5 Vertical Compaction) were considered. Attending the container measures and the displacement values, pressure (P) and effective displacement (D_{ef}) were calculated.

$$P = \frac{m.g}{A} \qquad ; \qquad D_{\mathrm{ef}} = \frac{u}{h} \ .$$

With the last measured points, the Young's Modulus (E) of plastic and paper waste were calculated:

$$E = \frac{\Delta P}{\Delta D_{\mathrm{ef}}} \ .$$

Then,

$E_{\mathrm{plastic}} = 9604{,}196 \ \mathrm{Pa}$, and

$E_{\mathrm{paper}} = 6492{,}977 \ \mathrm{Pa}$.

Considering an average, the Young's Modulus is 4786,8 Pa for plastic and 5932,3 Pa for paper. However, the previous larger values were established because they can be seen as safety values. Besides, to study the forces relationship in radial compaction, displacement and radius values were established. These correspond to a standard cylindric 30 liters container.

With the new measures, waste strain (ε_r) was calculated for plastic and paper waste. For this, a radius variation was established and the displacement between these values was calculated:

$$u = r_i - r_f \qquad ; \qquad \varepsilon_r = \frac{u}{r} \ .$$

Then, the stress (σ_r) variation was studied also for both types of waste. For this, it was considered the following equation and a Poisson's ratio (υ) value of approximately 0,15.

$$\sigma_r = \frac{E}{(\upsilon+1)(2\upsilon-1)} \times (\upsilon - 1)\varepsilon_r \ .$$

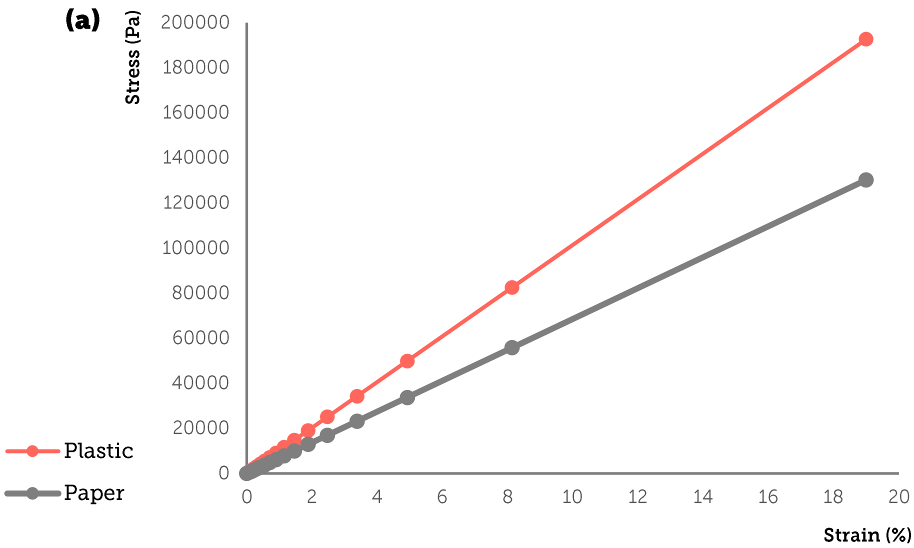
Although the compression of waste matches the plastic regime, the use of the previous elastic equation constitutes a safety factor because the elastic stresses are higher than the elastoplastic ones.

Figure 41:
(a) Stress and Strain Diagram for plastic and paper waste;
(b) Strain and Compaction Ratio Diagram for Radial compaction.

With the resultant values, stress and strain were compared with the support of the diagram below (Figure 41, a).

Both diagrams reveal proportional values of stress and strain, thus they still in the elastic deformation area. This means, when the force is removed, the material returns to the original position. Notice again that this an approximation. Generally, the waste behaves as an elastoplastic material. However, comparatively with the paper, the plastic waste needs more stress to achieve the same strain. This means the plastic is stiffer than the paper waste.

(a)



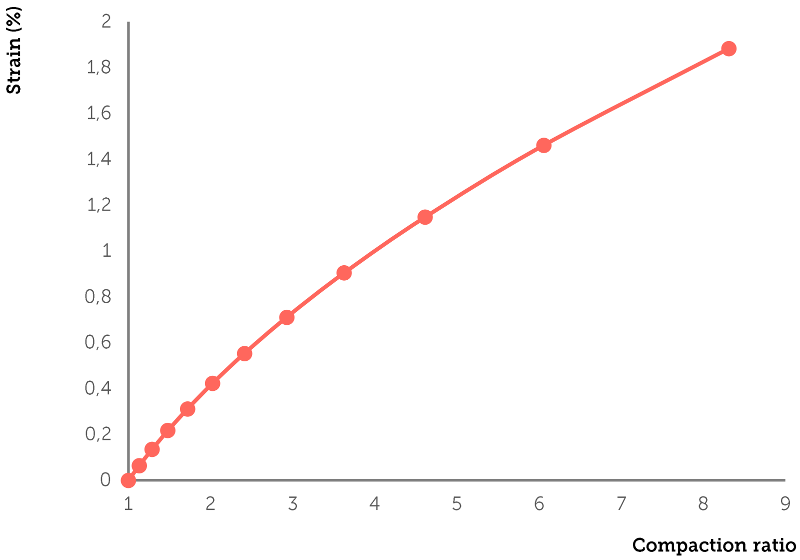
Furthermore, the relationship between strain and compaction ratio was also studied. For the compaction ratio calculus, the equation in chapter "4.6 Radial compaction" was used:

$$R_{c_r} = \left(\frac{r_i}{r_i - u}\right)^2 .$$

[5] Due to the high values obtained, the compaction ratio threshold value was established as 8, 31.

With the values obtained[5], the diagram of Figure 41 (b) was developed. This shows a curve as the result of compaction ratio and the strain increase. The percentage of distortion has a slight increase.

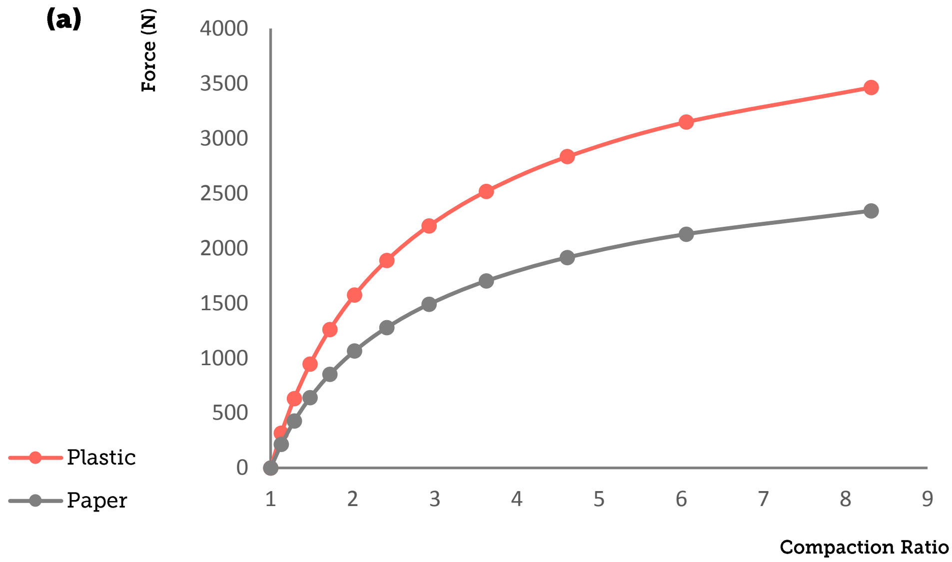
(b)



Lastly, with the gathering data, the force (F) was calculated for plastic and paper waste. These values were obtained using the following equation:

$$F = \sigma_r \times A .$$

With the results, the relation between force and compaction ratio was studied (Figure 42, a).



Analyzing the diagram, as long as the compaction ratio increases, the force to compact the waste rises asymmetrically. However, plastic needs more force than paper waste and this difference also increases as long as the ratio rises.

Figure 42:
(a) Force and Compaction Ratio Diagram for Paper and Plastic Waste;

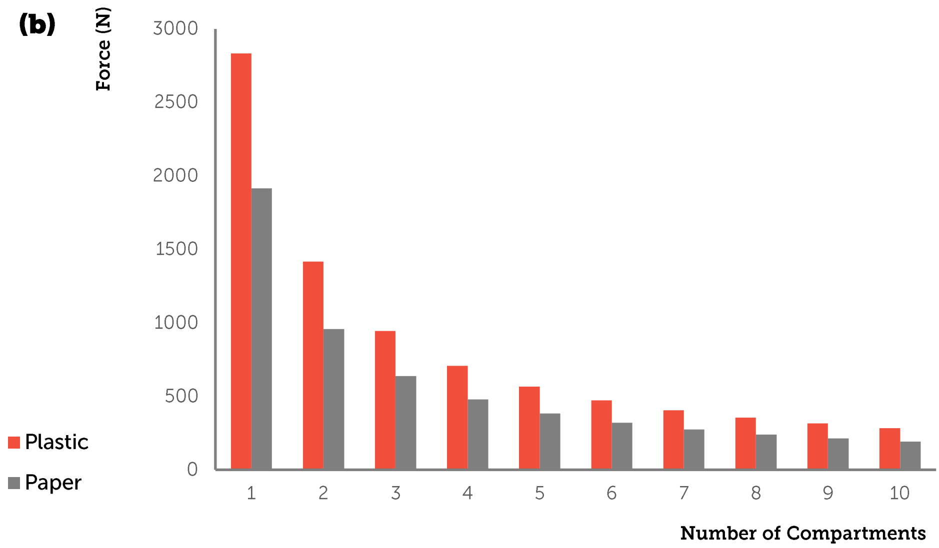
(b) Column graph of Force for each compartment and Number of Compartments relationship;

(c) Force and Compacting Ratio Diagram for one and each of six compartments, for plastic waste

Furthermore, the design proposed divides the system into several equal parts. To study this possibility, the force of one to ten compartments was calculated:

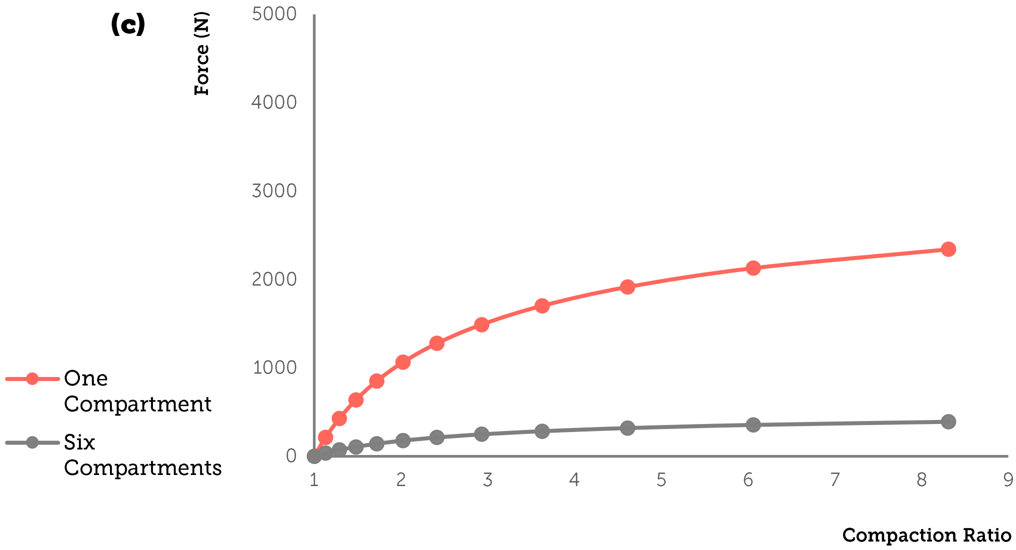
$$F_{N.comp.} = \frac{\sigma_r \times A}{N_{comp.}} \quad .$$

The results were compared with the aim of establishing the number of compartments suitable for the system (Figure 42, b).



As long as the number of compartments increases, the force required decreases. However, from the sixth compartments up, the force does not vary significantly.

Thereby, to study this option, the relation between those two parameters was studied specifically for one and six compartments (Figure 42, c).



Attending to the diagrams information, by using six compartments instead of one, the force applied from each compartment decreases. Besides, in the plastic waste, the difference between the two scenarios is substantial. Also, the force with six compartments remains almost constant after 4,61 of compaction ratio.

Attending to these facts and the requirement established in the chapter "4.5 Vertical Compaction" - compaction ratio between 3:1 and 5:1 – 4,61 was settled as the efficient compaction ratio for the developed product. This means, 2832,9 N is the recommended force to efficiently compact plastic waste and 1915,2 N to compact paper waste.

According to the Third Newton's Law, **"whenever one body exerts a force on another, the second exerts on the former a force with the same direction and intensity, but in the opposite direction."** (Albuquerque, 2012)

Therefore, the system must apply the same force (2832,9 N for plastic and 1915,2 N for paper) on the waste to achieve the compaction ratio established.

With this information and the compaction area values, the pressure to compact the waste was calculated:

$$P = \frac{\mathrm{m} \times g}{A} \ .$$

Thus, 1,14 bar of pressure for plastic waste and 0,77 bar for paper waste was the result. Thereby, the pressure established is 1,14 bar (2832,9 N) for the equipment.

Each compartment applies on the waste one-six of the total force, corresponding to 0,19 bar (472,15 N). With this value, is possible to compact both types of waste. However, this value corresponds to the minimum pressure. To prevent possible failures, a margin of error was established. The pressure applied by the existent domestic mechanical trash compactors on the market (chapter 2. State of Art) is between 3,5 bar and 7,5 bar (approximately), considering this, the maximum pressure for this project is 5 bar.

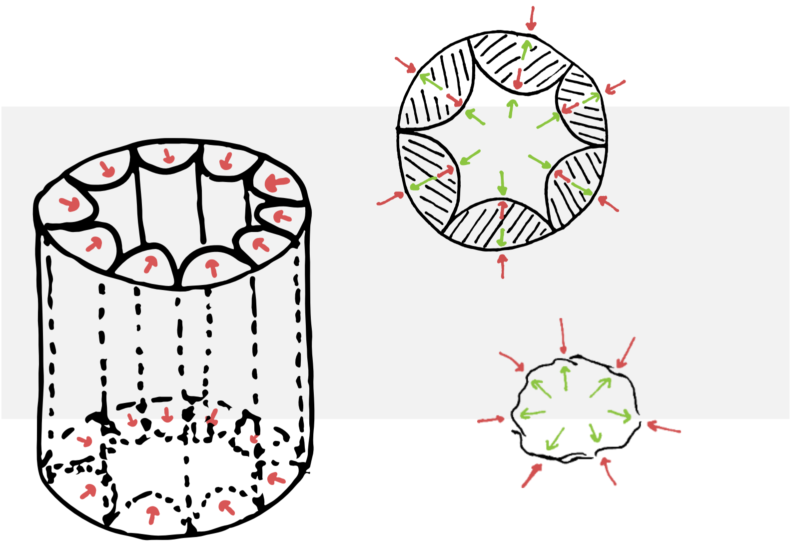


Figure 43: Free body diagram (equipment and waste)

Attending to the free body diagram, the surface which touches the waste is more vulnerable to tensions, friction and wear. Therefore, this part must be rigid to compress uniformly the waste and achieve better results. Each compartment applies on the waste one-six of the total force. Thus, must support 472,15 N.

During the compaction process, the air exerts force in the entire compartment – support and barrier. Therefore, the support receives those pressures as well.

5.2 Divergent — radial Com-paction

Divergent-Radial Compaction, like Convergent-Radial, has a radial movement and the packages are compacted through a pneumatic system. Both systems are similar. The difference between them is the compaction direction. While the movement in Convergent is outside in, in Divergent is inside out. However, the system composition and function are very similar too. In Figure 44, the evolution for this equipment is represented.

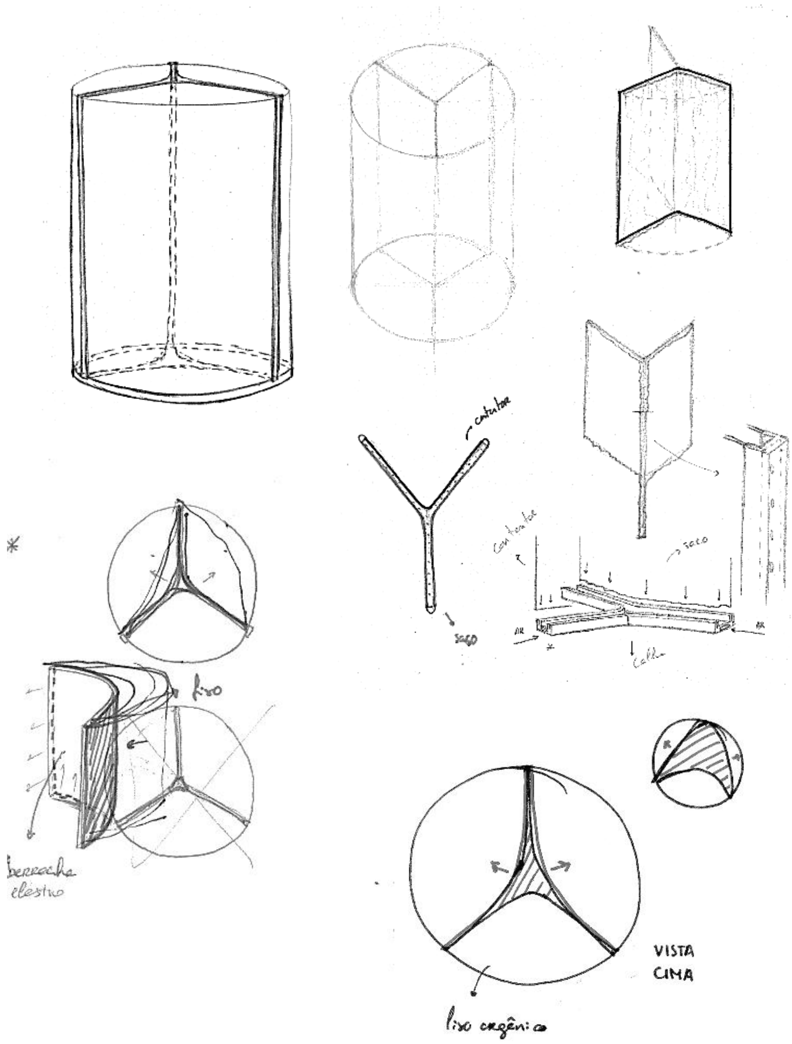
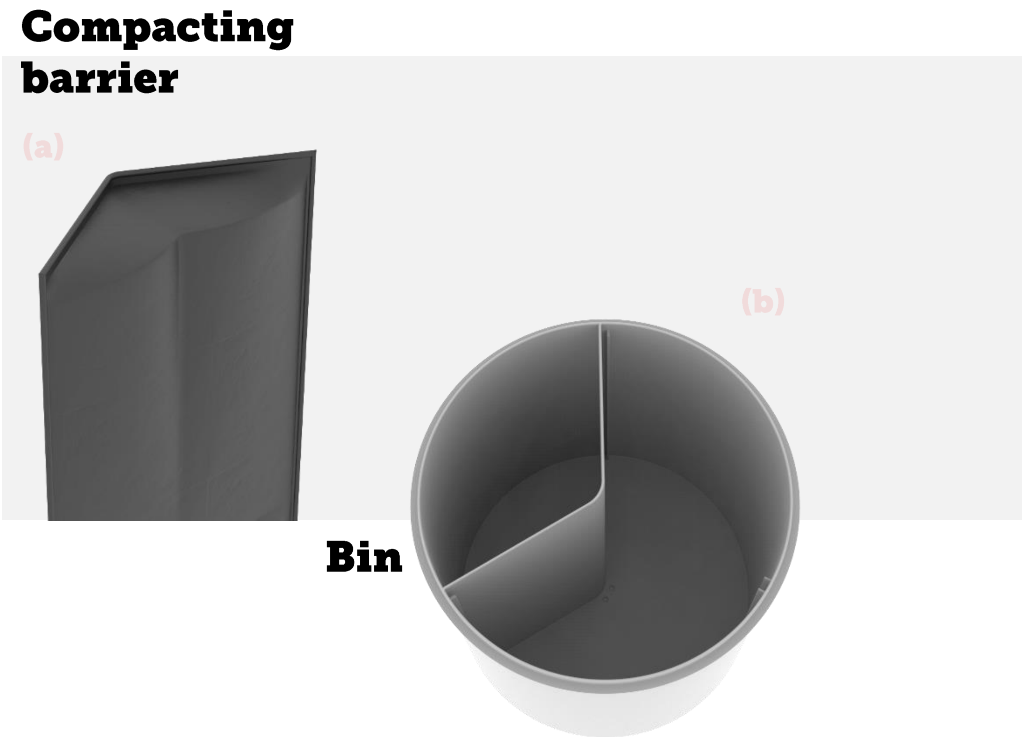


Figure 44: Divergent-radial sketch process and final proposal

Assembling, manufacturing and maintenance were also considered in this process. Similar to the Convergent, the final proposal is a system composed by: (i) a compressor, (ii) a bin and (iii) a cover and two compartments composed by (iv) a compacting barrier and (v) a support (Figure 45, d). The compressor also releases the air to each compartment and takes it out when the compaction is completed.

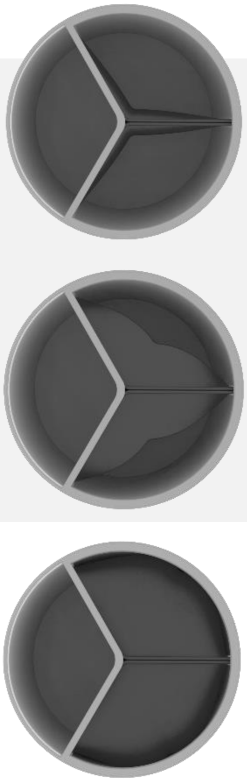
Figure 45:
(a) Compacting barrier;
(b) Divergent-radial compaction bin;
(c) Operating sequence;
(d) Equipment components



In this proposal, the system design is different from the Convergent. The compartments are positioned in the middle of the bin and each one fills one-third of it.

As in the Convergent-radial compaction, the bin surrounds the compartments. However, in the Divergent system, the bin has a structure inside which supports one side of each compartment (Figure 45, b). The bin fixes the compartments and supports the waste pressure. It also has two openings to attach the pipe connector, splitting the air from the compressor to each compartment, through a pipe. A cover, with the same design as the bin structure, fix the system.

(c)



(d)

In this proposal, the system was designed to have just two of the three sections with the compartments. Attending to the project proposal, besides optimizing the space, this characteristic facilitates the separation of the waste for recycling. In this way, two parts of the container have the function of compact the waste and the third is intended for non-compactable waste.

5.2.1 Performance Test with a Model

As in the previous proposal, a model of the Divergent-Radial Compaction was developed to study the system movement and viability. In this test, the three compartments had the system. The compartments were simulated using three cardboards pieces and a plastic bag attached in the borders (Figure 46, a). In each one of the cardboard, a hole was made to introduce a pipe. These were joined and fixed to a foot pump. When every part was positioned, the system model was introduced into a bin and the experiment started.

The foot pump was repeatedly compressed and each compartment starts to insufflate. As expected, the bags were moving inside out while filling with air. In the end, all space between the cardboard and the container were occupied (Figure 46, b). Like in the previous proposal, a vacuum cleaner was used to simulate the inverse process. Therefore, the bag returned to the initial position, remaining attached to the cardboard (Figure 46, c). With this experiment, the compaction system and movement were simulated and the viability of the system was verified.

Figure 46:
(a) Divergent-Radial compaction model;
(b) Before and after Divergent-radial test;
(c) Divergent-radial test: reverse process

5.2.2 Numerical Analysis and Consider-ations

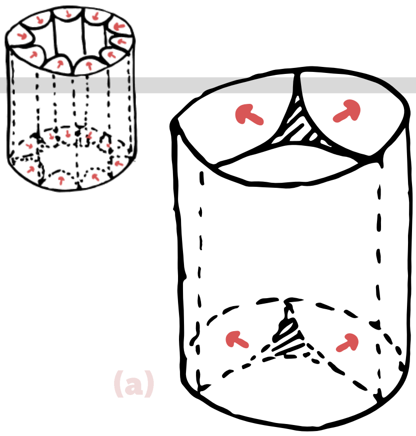

(a)

Figure 47: Free body diagram:
(a) Divergent-Radial and Convergent-Radial compaction;
(b) Forces applied on the equipment and waste

As in the Convergent-radial proposal, the system forces were analyzed. Considering this system with three compartments, Convergent-radial compaction forces are similar to Divergent-radial compaction forces. According to the free body diagram, demonstrated in Figure 47 (a), both have the same movement but opposite directions.

However, the forces applied on the system by the waste are different between the two solutions. In convergent-radial compaction the waste receives pressure from all directions, contrarily, divergent only receives from one side.

Considering the action-reaction force pairs, in Divergent compaction the waste will receive forces from all directions too. The system applies a force on the waste, the waste applies the same force on the bin and this return the same force to the waste. In the end, the waste receives the same force from all directions, such as in convergent compaction.

Besides, according to the free body diagram of both systems the applied forces are similar, therefore, was considered the same force values.

However, in Divergent-radial compaction just two-thirds of the container has the compartments. Therefore:

$$F_{\text{div.}} = \frac{F_{\text{conv.}}}{3} \times 2\ .$$

Considering the results of the chapter "5.1.2 Numerical Analysis", to achieve 4,61 of ratio, the compaction force must be 1888,61 N. Since:

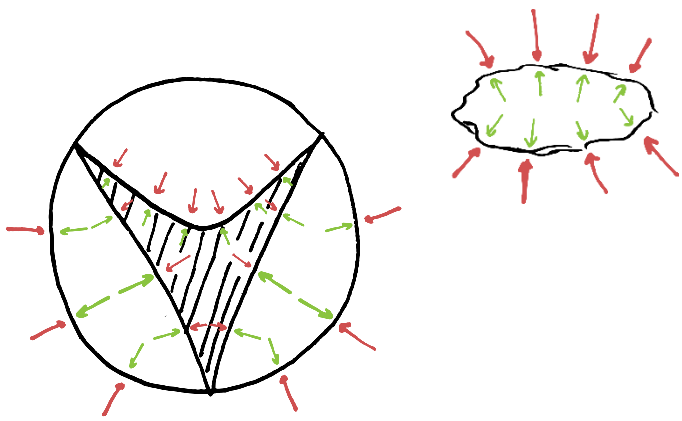
$$P = \frac{\mathrm{m} \times g}{A}\ .$$

Therefore, the system must have at least 0,76 bar to compact the waste. This pressure is applied to the waste, returning the same pressure to the system and, consequently, to inside the bin structure (Figure 47, b). In order to prevent breaks or deformations, the components must resist these pressure values.

Considering the information above, each compartment and the bin must resist to 944,3 N. However, the inside structure and half of each support part receive more pressure than the other half. As a result, the bin material must support forces of, at least, 944,3 N.

Each support, have the same function mentioned in Convergent compaction but, in this system, the pressure is not equally distributed in the support. The bin must resist all these forces and, mainly, support the third part of the container.

(b)

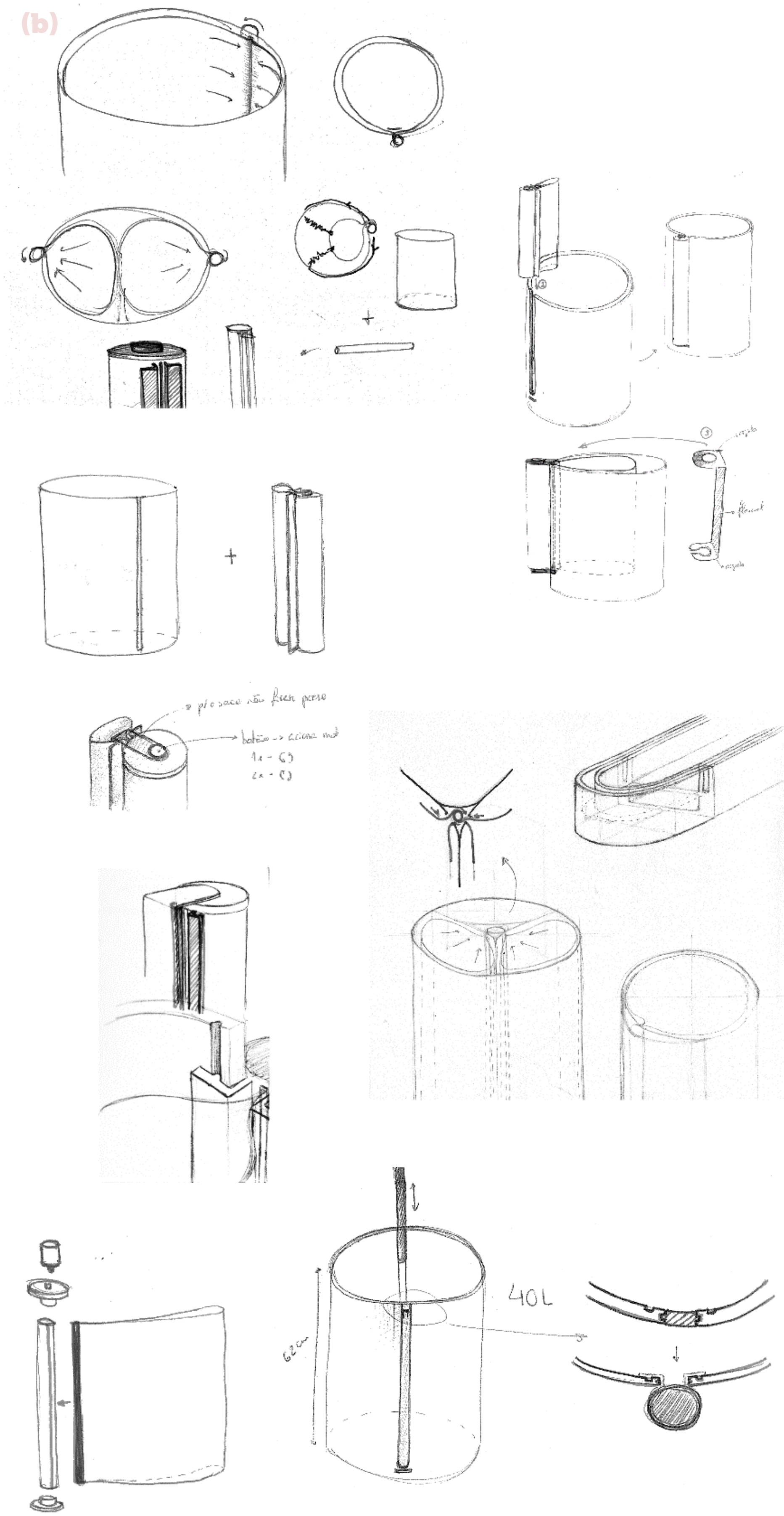


5.3 Winding Com-paction

(a)

Winding compaction, unlike the convergent and divergent compaction, use a motorized technology. In this system, the waste is compacted through a surrounding material (band) which is pulled and rolled up by a motorized system. When the compaction is over, the motor reverses the direction and the band returns to the initial position. To achieve the final design proposal, several sketches were made (Figure 48, b).

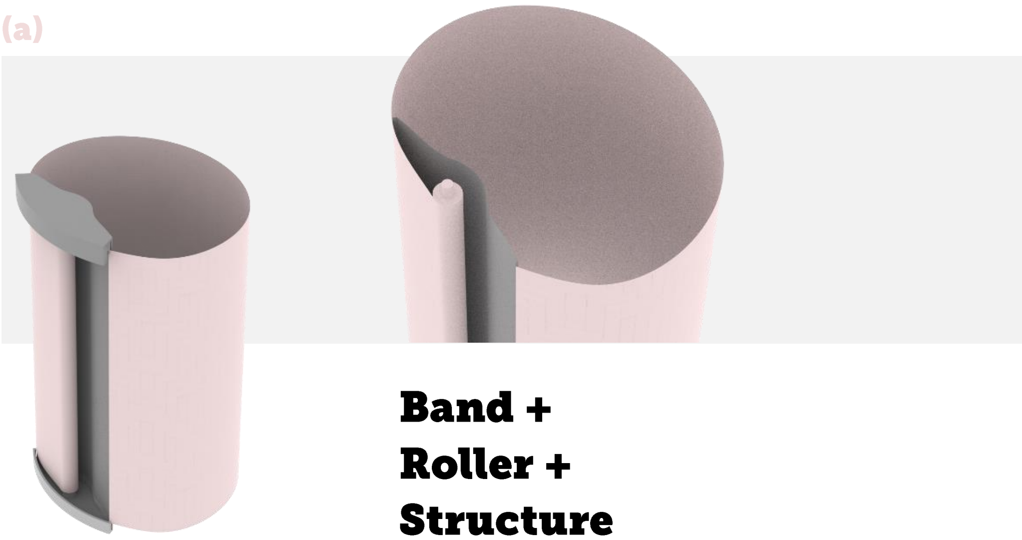
Figure 48: (a) Winding compaction final proposal; (b) Winding compaction sketch process



This shape analysis resulted in the proposal represented in Figure 48 (a). This choice was made considering the model tests and the free body diagram analysis (chapter 5.3.1 and 5.3.2). The system is composed by a roller and a motor which push and pull the band. The roller is inside the structure that supports and protects the equipment. One side of the band is fixed to the structure and the other to the roller (Figure 49, a). To support the movement, springs are fixed to the structure and surrounding the roller. When the system is working these components push the band, supporting the unroll movement (Figure 49, b).

The roller is fixed to the motor, which is assembled and covered under de bin. The bin shape was designed to integrate the equipment. This component has ledges which provide the attachment of the structure, the structure cover, the motor and motor cover (Figure 49, c). As in the other two proposals, this assembling originated a single piece.

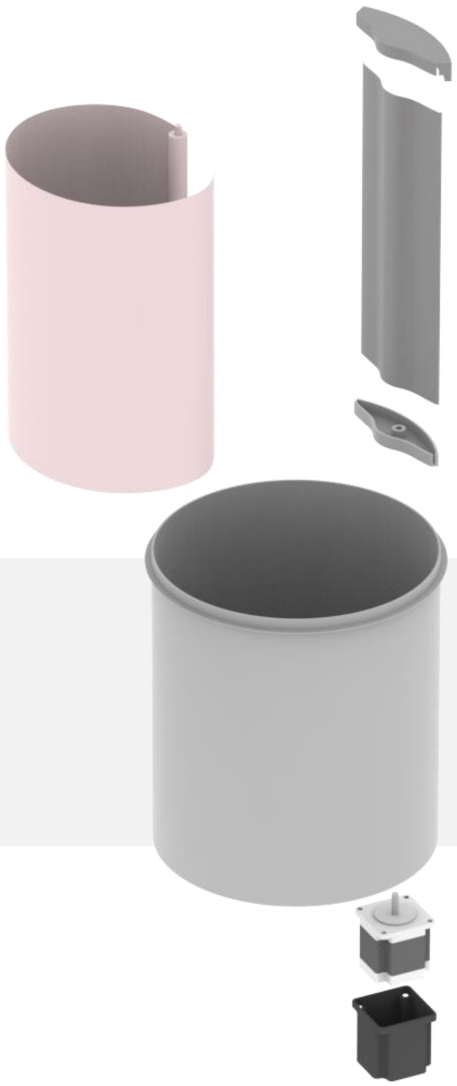
(a)



Band +
Roller +
Structure

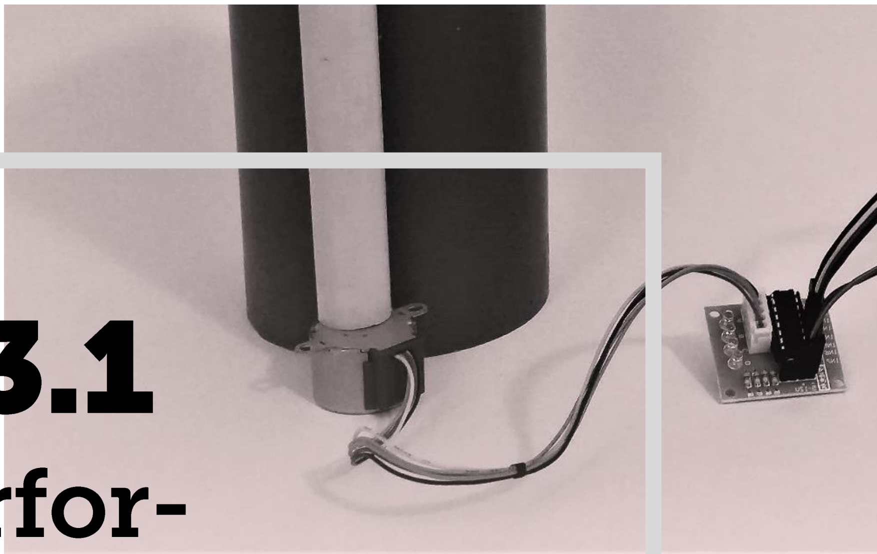
Figure 49: (a) Winding Compaction without bin; and band, roller and structure parts assembled;
(b) Operating sequence;
(c) Equipment components

(b)



(c)

(a)



5.3.1 Performance Test with a Model

With the aim to verify the performance of this proposal, a scale model was made. The materials for this experiment were a part of a large pipe and a thinner one, a stick, a plastic sheet, springs, and one Arduino with one Stepper Motor, one ULN2003 Stepper Motor Driver Board, two buttons and five jumper wires and six Female-to-male Dupont Wire. The code for the desired movements was introduced in Arduino, and the system was connected (Figure 50, a, b). For the model, the plastic sheet, folded in half, was attached to the stick and then this component was attached to the motor. A vertical cut was made in each pipe and a stick was placed inside the thinner one which was attached to the larger pipe afterwards. The plastic sheet was introduced inside the larger pipe. When all the components were connected, the Arduino was powered. In theory, to simulate the system, pressing the first switch, the motor turns, pulling the plastic sheet.

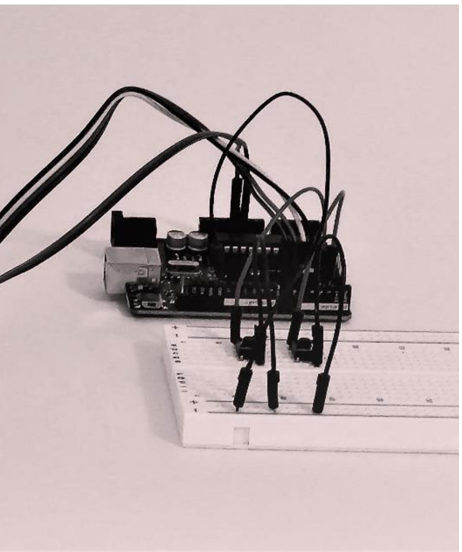
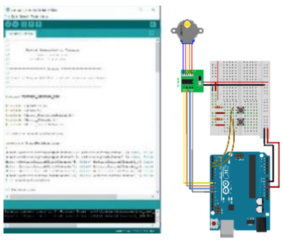


Figure 50:
(a) Winding Compaction model;
(b) Arduino platform and components diagram;
(c) System connection;
(d) Winding test: before and after;
(e) Model with elastics

Pressing the second switch, the motor turns in the opposite direction and the sheet returns to the initial position (Figure 50, c). In practice, when the first switch was pressed, the plastic sheet was pulled. However, when the second switch was pressed, the sheet wrapped inside the thinner pipe and did not return to the initial position. As a conclusion of this first experiment, the system works in one direction, but in the reverse direction, it needs a complementary element.

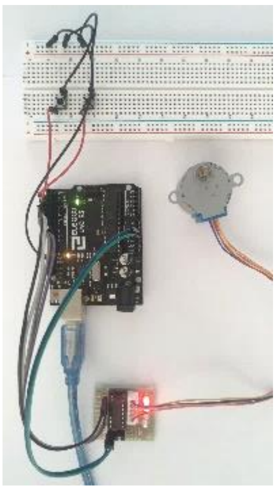
Considering this analysis, other experiments were made. After several attempts, springs were attached to the thinner pipe and a new test was made (Figure 50, d). With this assembly, the plastic starts to move. After several attempts were possible to reach an acceptable result. Nevertheless, the motor did not have enough strength to do a constant movement. Although it was possible to conclude the viability of the system movement, it is not hundred percent conclusive due to the components used.

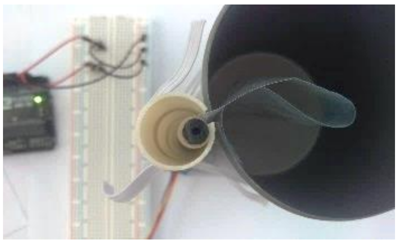
(b)



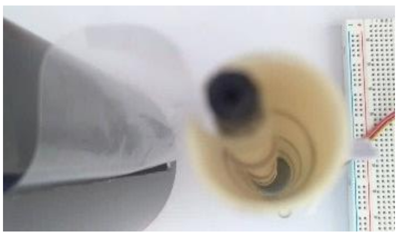
(d)

(c)





(e)

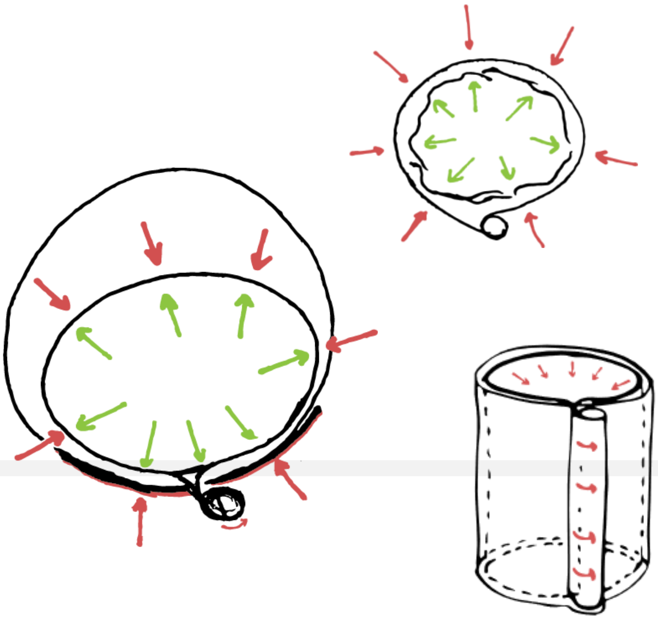


5.3.2 Numerical Analysis and Consider-ations

Considering the system movement and the free body diagram (Figure 51), the applied forces in the waste are the same as in Convergent-radial Compaction (see chapter 5.1.2 Numerical Analysis and Considerations). Thereby, the values collected in the correspondent chapter were used to develop this analysis.

The system applies a force on the waste, the waste applies the same force on the band and on the structure and, consequently, on the container. To obtain a 4,61 ratio, the waste will receive a force of 2832,91 N. To roll the strap, the mechanism has to do a correspondent force to pull it and compact the waste.

Figure 51: Winding compaction free body diagram



Considering this, it is necessary to calculate the motor force to achieve an efficient compaction.

According to the ratio established before, the correspondent force is 2832,91 N. Therefore, the force applied on the surrounding material is the same (Third Newton's Law) causing the same frictional force on the roller.

Torque calculation:

$$\tau = r \times F \, .$$

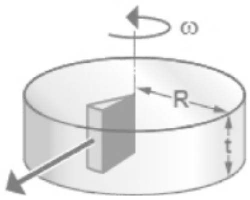


Figure 52: Momentum movement variables

Taking into account the equation, roller radius and torque are directly proportional. This means larger the roller radius higher the torque value. However, the roller cannot be too large because it would increase the system size and the consumption. Also it cannot be too small because may need more resistant material to support the force, increasing the costs. Therefore, 0,01 m was considered the proper radius. Attending to the established value, the motor must support 28,33 Nm of torque.

The motor power will be calculated with the rotation force value, considering:

$$\text{Power} = \frac{\tau \times \omega}{60},$$

$\omega = 2\pi \times n_{\text{rpm}}$.

Considering,

$n_{\text{rpm}} = 15$ rpm and $\tau = 28{,}33$ Nm ,

$$\text{Power} = 44{,}50 \text{ W} .$$

With these values, the torque value was established in 30 Nm and the minimum power required in 45 W. Thus, the chosen motor must meet these requirements. Besides that, it must be small to fit under the container and silent for not disturbing the user.

Attached to the motor is the roller which pushes the band, exercising a contrary force to it. This is the same as the waste compaction force (2832,91 N). The roller receives a torsion force, causing probably a fracture if the material does not resist elastically.

Fixed to the roller, the band is pulled and when the force of the waste is applied, the band must do a higher and opposite force to compress the waste. Since the waste needs 2832,91 N to achieve the desired compaction, to prevent cracks or plastic hinges, the band has to support more than this value. When the compaction is over, the material must return to the initial position and maintain a vertical position. The structure protects the equipment from the environment, receiving all the pressure from the waste. Considering the free body diagram (Figure 50), the waste will apply all the pressure received on the band and on the structure. In addition, one side of the band is attached to the structure and this is fixed to the container, i.e. when the waste applies 2832,91 N of force, the structure cover, the main part and the band fastening must support this force.

Inside the structure two springs are also assembled helping to return the band to the initial position. These components will also apply a force on the roller, however, this will be the minimum, considering the aim.

The structure is attached to the bin. When the structure is pushed by the waste pressure, the bin is also pushed with the same force. The equipment is assembled to the container. The motor is fixed under the container. Therefore, the motor also applies a force to the bin, which is proportional to their mass.

6. CONCLUSIONS AND PROPOSAL

The three proposals analyses led to the assurance of their viability. The three are possible to produce and comply the main function which is the reduction of the waste volume. Besides, considering the chapter "3. Challenge and Main Goal", each one meets the requirements of being unique and innovative, improving the housework quality and being adaptable to an existing container. Nevertheless, in each one of them, there are some requirements to consider before the production, such as materials properties and dimensions.

Between the three options, one was chosen for the final product. For this selection, pros and cons were established for each one. Convergent and Divergent-radial compaction, considering their similarity, were compared. Divergent compaction is more compact than Convergent, with this proposal, the user can recycle only with one bin, which will save space in the kitchen. However, this characteristic reduces the capacity for each compartment and restricts the use of the bin. With the Convergent equipment, the user can purchase just the needed amount of systems, and therefore, the product is more generic. Lastly, in the Divergent equipment, the bin receives higher pressure comparing with the other. This factor presumes a more resistant material to support that pressure, increasing its price.

Taking into account these features, the Convergent-radial compaction was elected between those two options.

Contrasting Convergent with Winding compaction, the Winding has the equipment inside the bin. However, this mechanism is concentrated on one side of the bin and, attending to its dimension, it reduces the effective space. The Convergent has the equipment equally distributed around the bin, differing in this way from the other system. At the operation level, the Winding equipment is more complex and have more components than the Convergent. Besides, according with the chapter 5.3.2, it is required 45 W, which may corresponds to a larger and more expensive equipment.

Considering this analysis, the Convergent-Radial Compaction was considered the most appropriated for the present project. In the next chapter it is described the development process of the final product with this equipment.

Figure 53: COBI Container

03|

7. PROPOSAL DEVELOP-MENT

Figure 54:
(a) COBI brand logotype;
(c) COBI shape sketches.

(a)

After choosing the equipment, the final product was designed. In this chapter the development of the product named COBI is reported. The name arises from the combination of "compactor" and "bin" (Figure 54, a). Besides, considering the established requirements, several diagrams and sketches were developed, and the product line was structured (Figure 54, b).

(b)

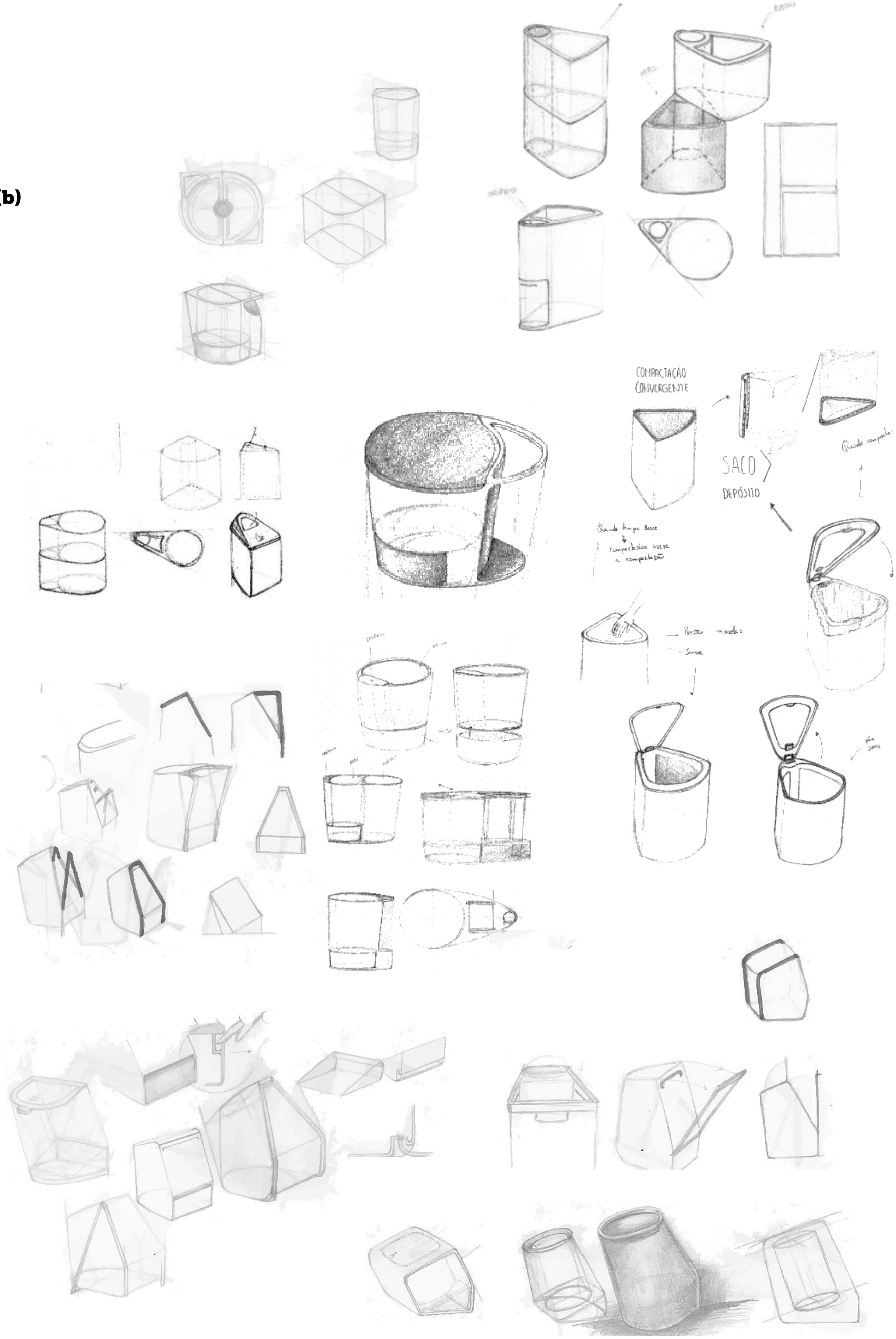


Figure 55:
(a) Examples of existing containers;
(b) Products design inspiration

While the development of this process, a research of existent designs was carried out (Figure 55, a). The knowledge acquired from these studies made possible the creation of new shapes and options. In this way, containers can be placed in four typologies, side by side, in a circle, vertically and a single container that can have several compartments. Most of the products are made of modular containers, which is also the desirable characteristic for COBI.

(a)

Besides the container samples, other products also served as an inspiration to draw new proposals (Figure 55, b). COBI can be related to domestic appliances because of their functionality. Therefore, considering some of these products, a minimal design with curves and straight lines that allows a better adjustment in kitchens was sketched. This kind of design also conveys a great sense of a clean and fresh environment, and it easily fits with other appliances.

(b)

The next step was the morphological analysis that is an important step in product design and development (Appendices: Table 2). This has resulted in several possible solutions for each product requirements. The morphological analysis allowed a systematic evaluation of the product structure by analyzing new solutions to each component.

(a)

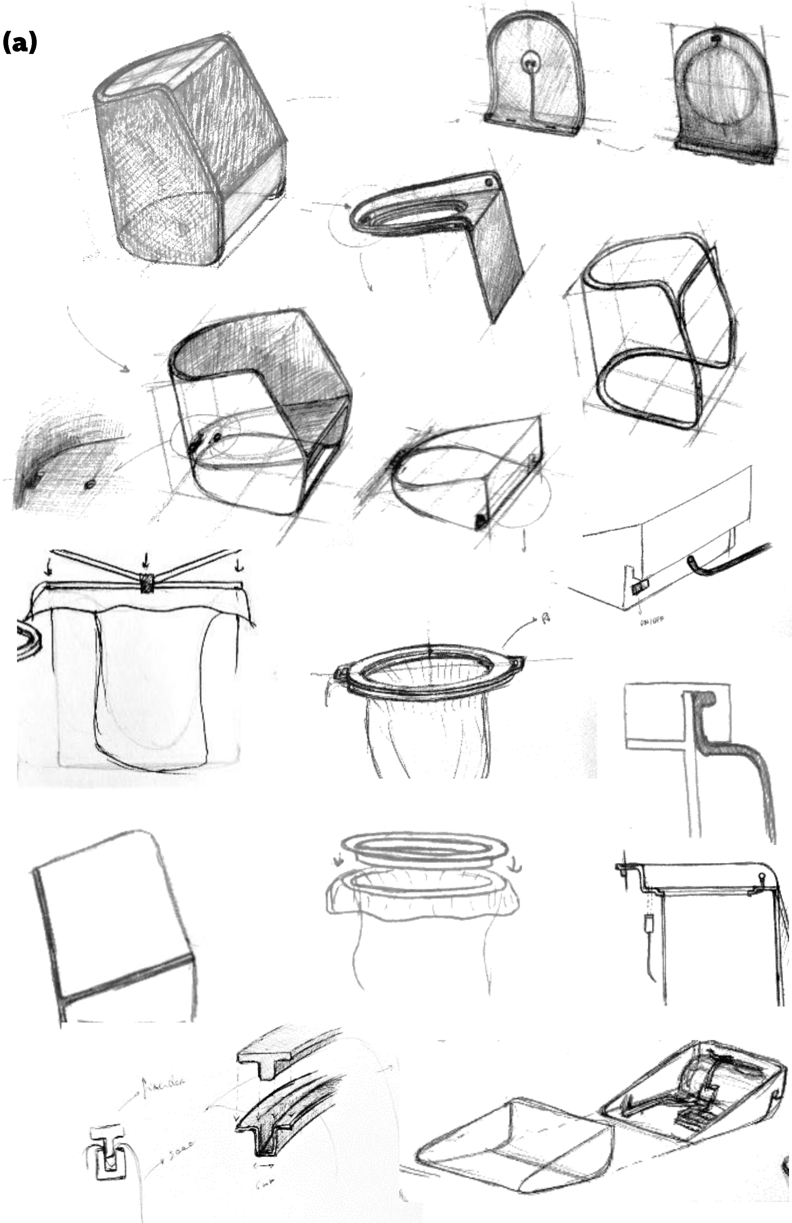


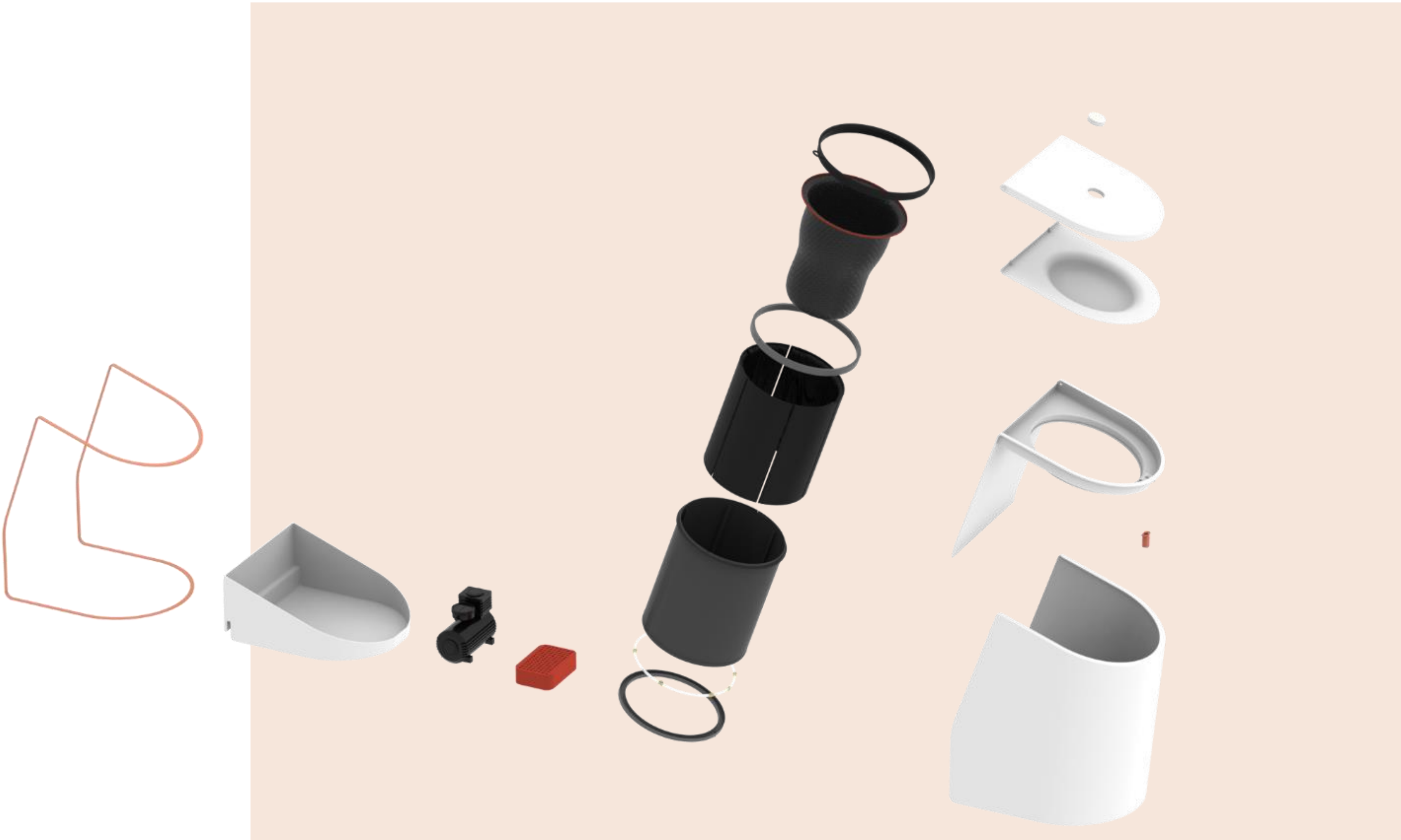
Figure 56:
(a) COBI components sketch;
(b) COBI Container;
(c) COBI exploded view;
(d) COBI Container positions;
(e) COBI Container colors;
(f) COBI open.

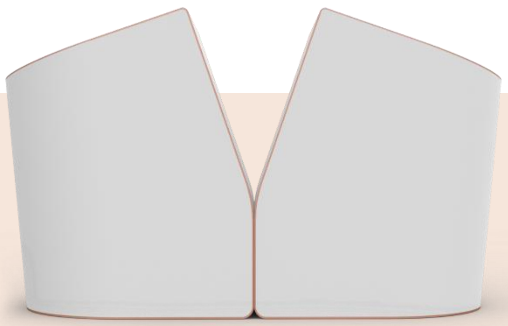
After the previous procedure and several sketches, the shape of the final product was achieved (Figure 56, b). COBI Container was designed attending to the project requirements and the equipment components. This is a 15 L container, where is introduced the COBI Bin. The inside shape respects the bin measures and incorporates the compressor and the electric circuit (Figure 56, c). The inclination provides a better accessibility and also allows to introduce the equipment components under the bin which can be easily accessible by the drawer behind the container. COBI Container is composed by six main parts easy to assemble, simplifying the maintenance and the manufacturing process.

(b)

Moreover, COBI Container can be matched with other containers, side by side or back to back and also be customized (Figure 56, d). The consumer is able to choose between the three colors available for the structure: (i) brown (material natural color), (ii) white and (iii) black, or select another color according with their taste (Figure 56, e). The surrounding locker color is RAL 8004 however, the consumer may also change to the metal original color.

(c)





(d)

(e)

(f)

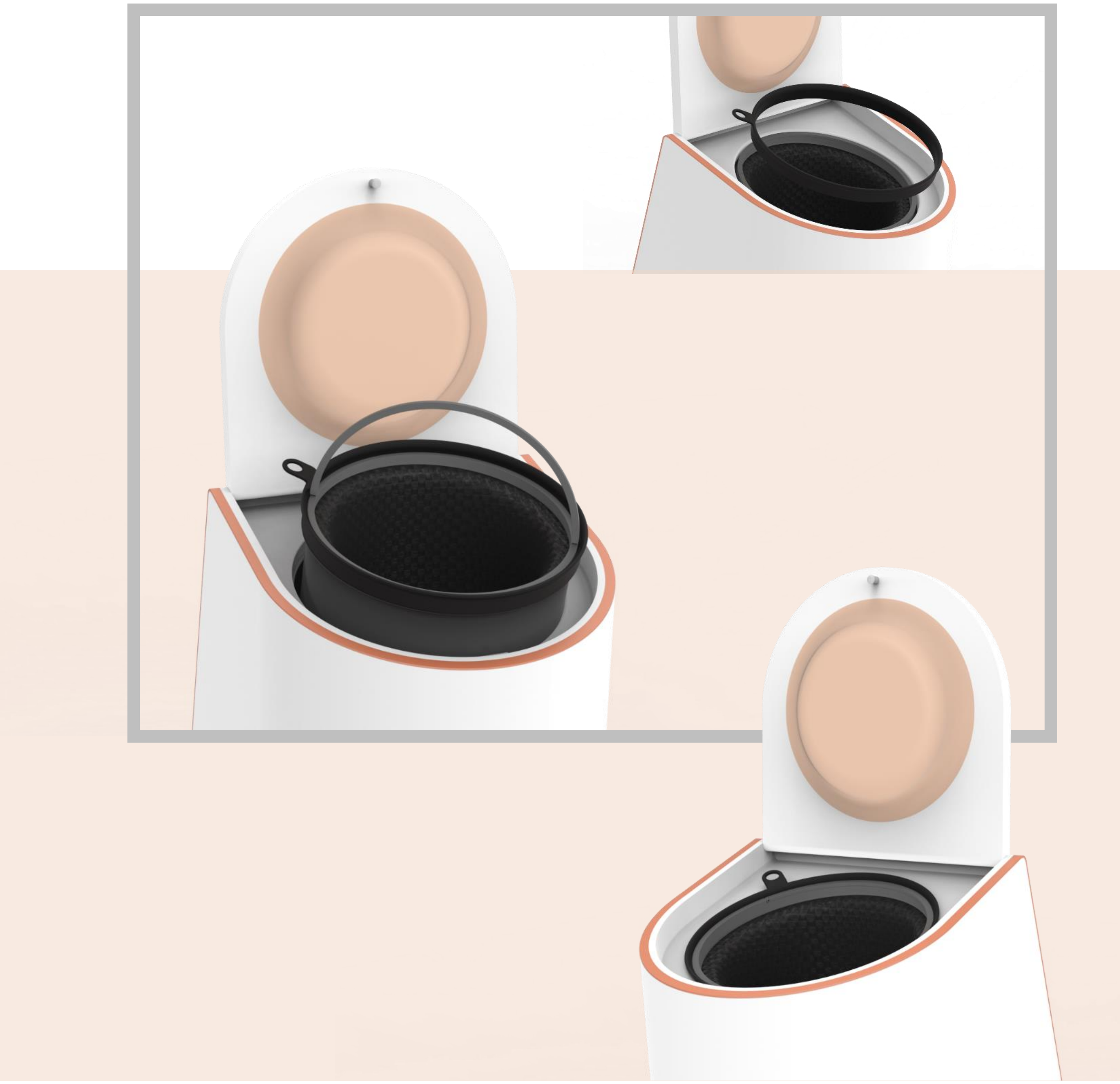
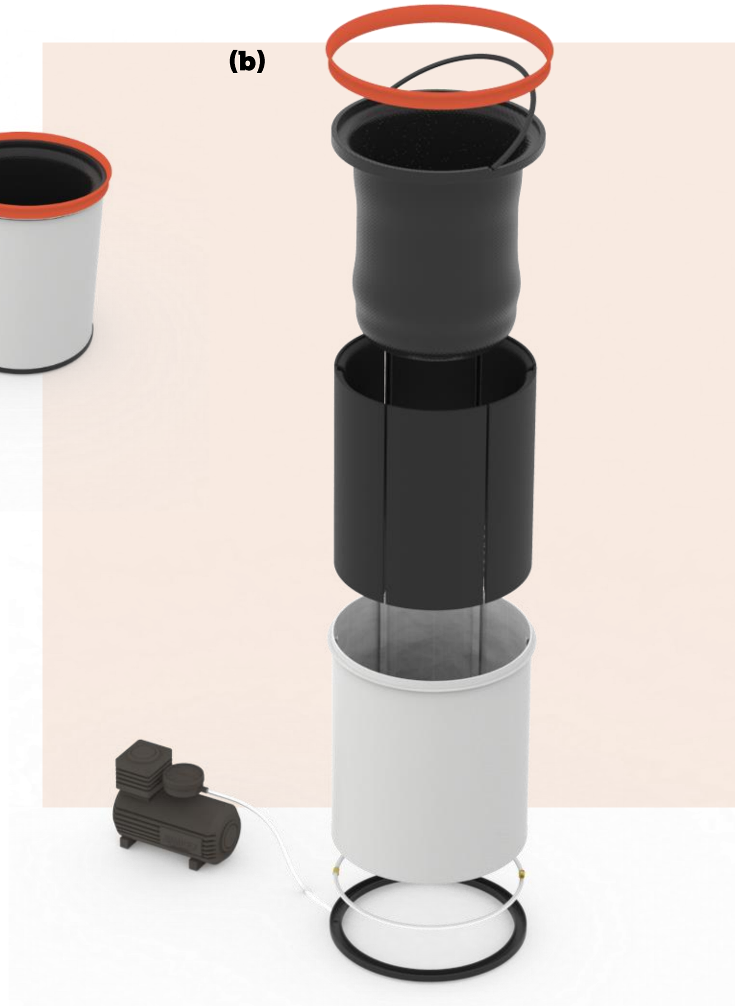


Figure 57:
(a) COBI Bin;
(b) COBI Bin exploded view.

At the same time, COBI Bin was improved. To the original constitution some components were added (Figure 57). First, a handler was designed to facilitate the management. This part is assembled to the bin cover. In addition, an integrated soft bag was joined. This part is important because protects the equipment from the waste pressure by covering it. Considering the compaction movement, the plastic bag goes along with the compartments during the process. Therefore, a bag locker was also incorporated. This is a flexible and light ring, easy to remove and assemble, which fixes the bag to the bin top.

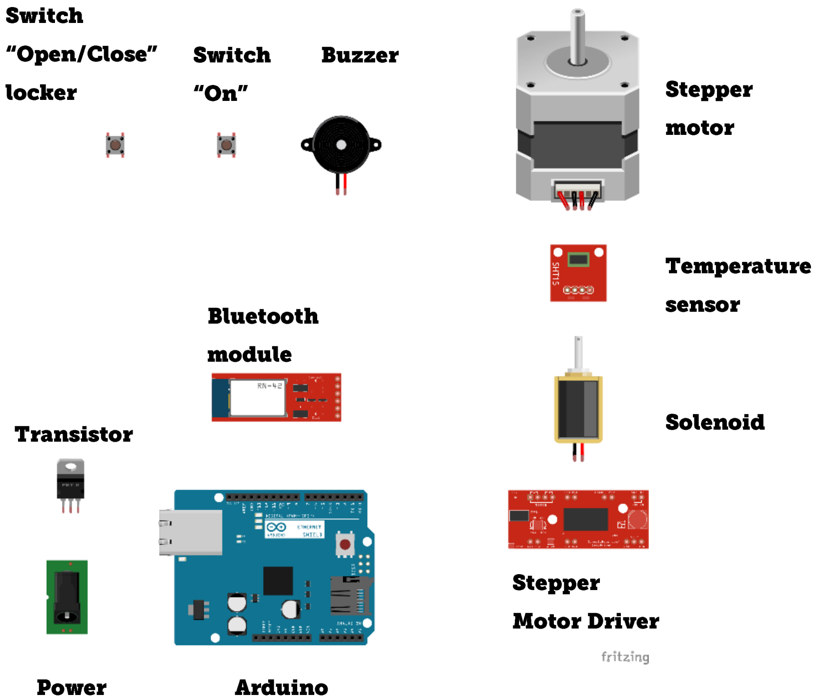
(a)

(b)



The equipment is also composed by an electric circuit. This is the combination of several parts connected to the circuit board, ensuring a safe operation. In the illustration bellow, the main components of the circuit prototype are represented (Figure 58).

Figure 58: Prototype electric circuit illustration (main components)



7.1 Mobile Application

(a)

COBI APP was developed associated with COBI Bin and COBI Container. This platform enables to start compaction remotely and inform in percentage about the capacity available of the bin. Besides, it gives information about the operation, sends alerts and answer user doubts about types of packages for recycling and maintenance.

Figure 59:
(a) COBI App Mockup;
(b) COBI app QR Code;
(c) COBI App screens.

The COBI packaging gives information about a QR Code to access App Store or Play Store that the user can download. COBI App first screens are related to the presentation of the product and also clarify the customer about the system operation.

(b)

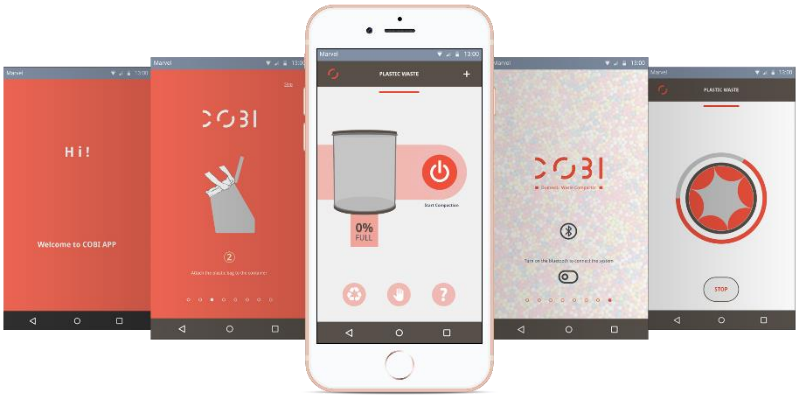
This information can be skipped appearing only in the first access, but it is possible to consult it in the main menu. After this step, the user must turn on the Bluetooth to connect COBI to the App. When Bluetooth is on, the App searches for near systems. The user can connect more than one COBI in the App and change their names.

The main page shows the percentage of the waste inside the bin, allows to initiate the compaction and enables the access to the information about the operation and the maintenance where the user can ask doubts, and also the menu to access the recycling process support.

When the compaction starts remotely, the user has the possibility to follow its evolution. If the lid is open, or the bin is full, or the system is too warm, an alert appears and the equipment stops.

After designing the App diagram, a model was developed. To develop this model, the Marvel website was used. This platform permits to simulate the application design and its steps and also creates a QR code for sharing this prototype (Figure 59, b). COBI App mockups are represented in Figure 59 (a and c).

(c)



7.2 Functions and Physical Components Analysis

Figure 60: COBI with a hand

In the development of COBI, tools such as Functional Diagram, Components Diagram and Product Architecture were used.

These tools (Appendices: Figure 66 and Figure 67) allowed to visualize and organize the product components and also to detect some gaps and missing parts. Functional Diagram provided a clear perception of the product, which also resulted in the development of Components Diagram and Product Architecture.

According to COBI functions diagram, "Connect the plug" followed by "Turn on the switch" are the first steps. "Maintenance" corresponds to components review or replacement. This function is related to the components under the bin and inside the equipment. “Open the lid” leads to several activities like “Introduce plastic bag”, “Introduce waste” and “Remove plastic bag”, followed by “Close the lid” and “Compact waste”, are the main functions. Each step is described in the functional diagram.

Through this analysis, the related components were highlighted, resulting the “Product Architecture” diagram (Appendices: Figure 66). This process allowed the verification and the settle of the required components leading to the development of the Components Diagram (Appendices: Figure 67). At the end of this process, COBI components were organized and defined.

COBI is mainly constituted by the equipment and the structure. The equipment as previously described is the assembling of several parts. The main component is the bin which integrates six compartments, and each compartment is composed by a support, a barrier and a pipe tap connector. Each tap connector is introduced into the pipe connector, fixed under the container. Six connectors are attached to pipes, and also a seventh connecting the circuit to the electric components.

On the top of the bin, a cover is assembled. This part closes the bin and fixes the integrated bag. The integrated bag hides the system and consequently protects it. The cover integrates a handle which provides the bin transport. A flexible ring is surrounding this cover and its function is to seize the plastic bag to the bin. This part is removable.

On the bin bottom, the integrated pipe and connectors are covered. This part hides the components and has a ledge to the seventh pipe connector.

The COBI structure is formed by a chassis divided in an inner and a surrounding part. The surrounding part supports the other and has openings to the electric wires and to introduce the bin seventh pipe connector.

The inner part assembles the lid to the rest of the structure and integrates the locker and electric wires as well. It also has a hole for the COBI Bin.

The lid also has two parts. The top part integrates the "Start" switch button and the respective wires. The bottom part has the locker pin and a ledge which supports the equipment in the compaction process. A lid-stay feature is assembled to the lid making it open automatically.

At the COBI bottom is a drawer. This part contains the electric equipment components, such as the compressor, the circuit board, the pressure controller, the solenoid and also a hole for the plug wire and the "On/off" switch button.

A surrounding part closes all the container structure, fixing the chassis and giving a pleasant detail to COBI Container. Considering the use of a different material between these components, the outer trace of COBI Container is highlighted adding value to the product.

The COBI Bin is associated to a mobile application, COBI App. The circuit board is also composed by a Bluetooth module providing this connection. This allows the communication between the COBI equipment and the user's Smartphone.

Considering the “Compact the waste” function, the compacting process can be initiated by pushing the “Start” button or through the COBI App. When this happens, the circuit board receives the signal and verifies the system temperature and if the locker is closed. When the lid is open, or the temperature sensor detects high levels of temperature, circuit board activates the buzzer and sends an alert to the COBI App. If the lid is closed and the temperature is normal, the circuit board turns on the compressor and the compaction process begins. With the pressure controller information is possible to calculate the waste volume on the bin and updates this information on the App. Therefore, when the bin is full, the user is informed.

7.3 Materials and Manufacturing Processes

After this analysis, some aspects such as materials and manufacturing process must be analyzed and established to achieve the intended result.

The components and material selection were made attending to (i) Components Diagram developed in the previous chapter, (ii) chapter "5.1.2 Numerical Analysis" information, (iii) materials properties information and charts, and (iv) company's catalogs. Also, the software CES EduPack 2016 was used in this analysis.

The components were divided into two groups: "New components" and "Standardized Components". The first group corresponds to the parts created specifically for this project.

Thereby, the materials and manufacturing processes were defined for each one. For this selection, aspects such as price and recycle fraction were considered. The second group is related to the components that can be acquired in the market.

To choose some of the COBI Bin components materials, the free body diagram was important to consider (chapter 5.1.2). As previous referred, over the compaction process, the system applies a force on the waste returning the same force to the system. Therefore, in order that the system could remain intact without scratches, the forces received and applied by each component must be the same to create a static system (First Newton's Law).

During the compaction process, the compartments apply forces on the waste and, vice versa. In addition, the bin and the lid also receive the force from the compartments and the waste. Considering this connection between forces, the materials were chosen.

Besides the relations among the compartments the bin and the waste, compartments also exert forces between each other. Therefore, the material of the barrier must be nonporous and resistant to fatigue (cyclic and repetitive tensions), abrasion, and resistant to friction and wear. At the end of the compaction, the barrier must return to the initial position and occupy the less space possible. Thus, this part must be very flexible and thin. The chosen material is the Recycled Rubber (Figure 61, a), which according to the data sheet provided by Rubber-Cal (Rubber-Cal, 2016) seams to meet the requirements. This is an eco-friendly material, made from recycled tire rubber. This material is resistant and durable. In the manufacturing process, using molds, it is cut and attached to obtain the desired shape. RF welded seams is the join process, that attaches the rubber without drilling the material.

The support, the bin and the lid must support the system forces, too. Therefore, these materials must be rigid, stiff, strong and have high toughness. The bin and the supports have the advantage of distributing the pressure between them. Attending to this analysis and the materials property information acquired through CES EduPack software (Appendices: Table 3), the Polyethylene (PE) was selected as the material of these components (Figure 61, b). However, their thickness varies. The bin and the lid are thicker than the support, leading to a different manufacturing process. The first two parts are produced by injection molding and the other is by extrusion. The support and the barrier are assembled to the flexible part also using the RF welded seams process.

To protect the system a bag was assembled. This material also must support the compaction pressure, reason why the Nylon was chosen (Figure 61, c). This material is stiff and resistant to fatigue. Besides, it is easily washable, recyclable and cheap (Appendices: Table 4). This part is sewed to the bin cover.

The bin cover and the pipe cover are also polymers. The bag cover must resist the bag tension during the compaction and support the bin weigh during the transportation. The pipe cover does not receive tension or pressure. Therefore, the material for these components is also Polyethylene (PE). The manufacturing process is thermoforming.

The bag locker must be flexible and support repetitive tension from the use. Therefore, the material is also the recycled rubber because it is resistant to physical abrasions and durable. The manufacturing process is injection molding.

The top lid, the inner and surrounding structure and the drawer do not receive specifically pressure. Therefore, to provide an ecological attitude, the chosen material for these components is the resulting product from the coffee grounds recycling. Kaffeeform is a company which already sells products with this material (Figure 61, d). According to Kaffeeform it is possible to achieve a dishwasher safe, light, durable, free of Bisphenol A (BPA), eco-friendly, carbon neutral disposal, biodegradable and a good isolator product (Kaffeeform , 2015). Therefore, the aim is produce these four components with the same raw material, using compression molding in the manufacturing process.

The surrounding locker must be resistant and support the container. Therefore, it is used Stainless Steel sheet (Figure 61, e) which is cut and then bent to obtain the final shape. In the end also acquire a TIG Welding finish (Appendices: Table 5).

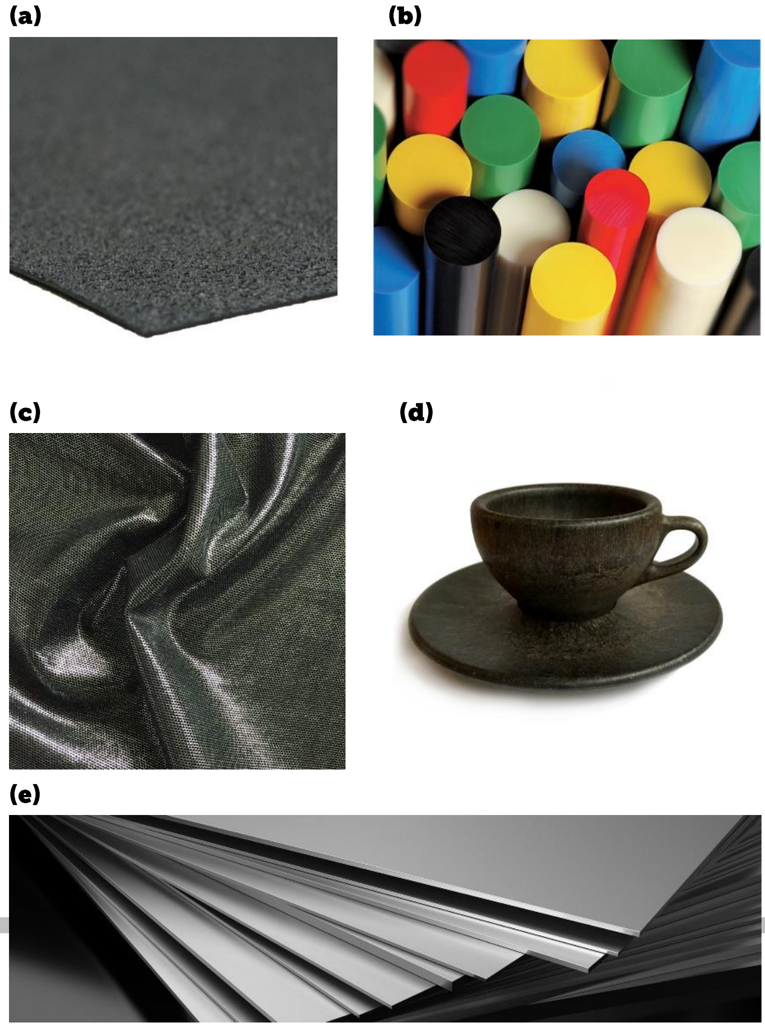


Figure 61:
(a) Recycled Rubber sheet;
(b) Polyethylene (PE) tubes;
(c) Nylon fabric;
(d) Kaffeeform coffee cup;
(e) Stainless Steel sheet

The standardized components were chosen attending suppliers' catalogs and online stores. As described in Components Diagram, the standardized components are: (i) Pipe, (ii) Pipe connectors, (iii) Pipe tap, (iv) Switch “Start” button with led, (v) Switch “On/off” button, (vi) Locker button, (vii) Locker, (viii) Lid-stay feature, (ix) Compressor, (x) Temperature sensor, (xi) Solenoid, (xii) Power supply plug, (xiii) Circuit board with (xiv) Transistor, (xv) Buzzer, (xvi) Bluetooth module, and (xvii) EasyDriver Stepper Motor Driver Board.

In this selection, some requirements were considered. Attending to the chapter 5.1.2, the compressor must respond in an efficient way to the pressure required (5 bar), it must also be small and silent. In addition, the components related to these components have to respond efficiently to the function and support this pressure. This is the case of the two ways electric solenoid air valve and the pressure controller. This component ensures the security of the system. When the established pressure is achieved, the equipment reverses or turn off the air flow. The other components do not have specific requirements, but they must be small and low-price.

Figure 62: Some standardized components examples

7.4 Design for Assembly and Design for Manufacturing (DFA and DFM)

Aiming to achieve a successful product, COBI Bin and COBI Container were developed considering always the assembling, manufacture and maintenance aspects. In COBI Container, the structure was divided attending to the best away to manufacture and produce the minimum number of parts. As result this part is composed by four components: inner structurer, surround structure, drawer and surrounding locker (Figure 63). Also, openings and fittings were designed to easily assemble the parts and, consequently facilitate the maintenance. The COBI Bin is also easy to assemble. The modular compartments and the fittings decrease the effort to remove and apply each part, in the manufacturing and during the maintenance.

All the parts have simple shapes with straight lines and without unnecessary ledges. These factors decrease the manufacturing costs and consequently provide a cheaper product for the consumer. Besides, the use of standardized components benefits this factor because choose standard products instead of production decrease the product final cost.

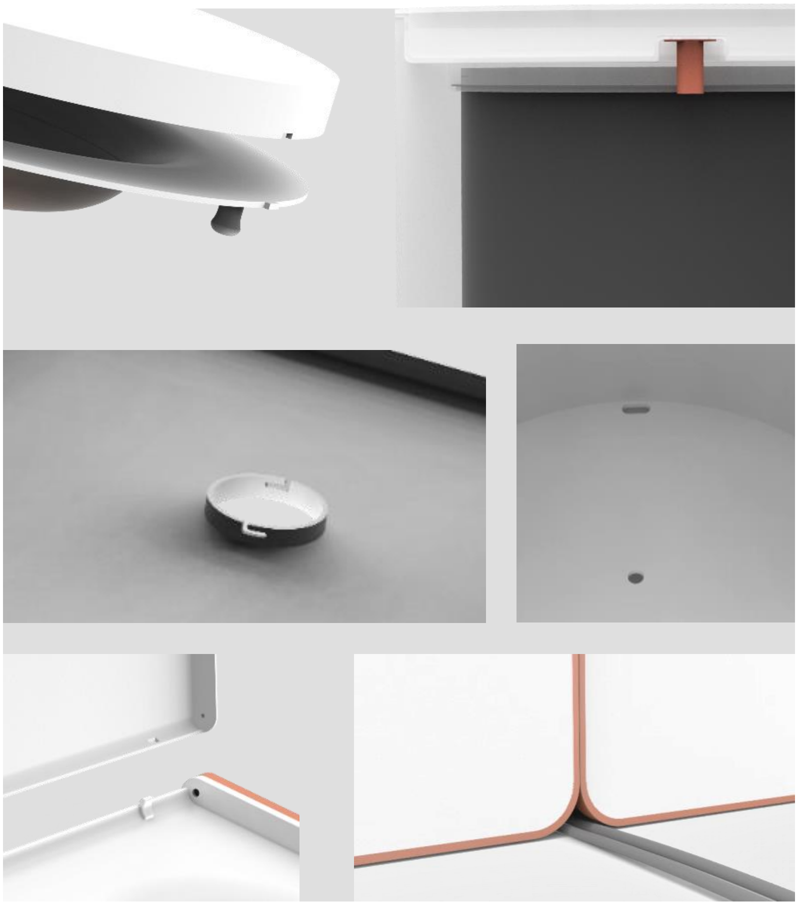


Figure 63: Manufacturing details

Figure 64: COBI mockup

8. CONCLU -SIONS

8.1 General Conclusions

Considering the results, this project answers the problematic of the waste volume as was exposed in the beginning and contributes to the improvement of the domestic waste management. Convergent-radial, Divergent-radial and Winding compaction are the results of the first part of this project. Each equipment responds efficiently to this problematic, reaching the intended aim. The radial movement is used in these systems and, as proved, it achieves better results than the vertical and horizontal compaction. All these three systems are adaptable to a standard 15L cylindrical container, with an intuitive usage and a compact design. In this way, the final products fit the project requirements.

The Convergent-radial compaction was the equipment used in the final project. This, as concluded in sub-chapter 6, was considered the most appropriate system, comparing with the other two, in order to respond to the project proposal. According to the analysis and calculations made, the equipment achieves an efficient compaction. Comparing this system with the existents, it is possible to assure the viability of the Convergent-radial compaction.

The development of this product matched positively with what was desirable. This is a modular and compact product and has standardized components which reduce the manufacturing costs, providing consequently a cheap product. The modular characteristic also facilitates the maintenance, offering, in this way, customer's satisfaction. The materials of the new components were chosen considering the recycling and eco-friendly requirements. So, due to these components, it can be stated that a compactor that follows the line of eco-friendly products have been reached. Moreover, this equipment obtains a fair relationship between compaction ratio, price and size.

Besides the equipment, a brand was created. COBI is an appliance brand whose main goal is helping the user to reduce the waste volume and improve the housework quality. COBI embodies the equipment (COBI Bin) and the container (COBI Container).

The COBI Container carries the equipment providing to the user a safer use. The product design intends to make the product more pleasant for the consumer. As in the COBI Bin, the materials were chosen considering the requirements for the project. The result is an eco-friendly and recyclable product. COBI Container resulted in a modular product that can be combined with other containers.

In addition, COBI App improves the user's experience. This mobile application was developed in line with the other two types of equipment and is a great help in the housework. With this it is possible to have quick interaction with the equipment, giving support to the user in any situation.

COBI also provides the waste separation practice and consequently improves the waste collection system and education, emphasizing an environmental responsibility attitude and promoting sustainability and circular economy.

Figure 65: COBI mockups

8.2 Future Works

In a near future, it is intended to build the prototype of these three products, the COBI Bin, COBI Container and COBI App, and proceeding with the product development, fixing eventual gaps and upgrading the system. The image design, including the brand and the mobile application can be possibly enhanced in order to accompany the development of the product and time evolution.

In a distant future, considering that organic waste treatment is an aspect that deserve to be explored, it is intended the creation of a mini shredder for this type of waste adjustable to the COBI Container.

Considering the possibility of creating fertilizers through organic waste, the shredder would facilitate this procedure and the COBI App would support the sharing of the resulting product. This way a service could be provided since the App would connect the COBI users with farmers or householders who need this type of fertilizer.

9. REFER-ENCES

"Who invented trash compactor?". (2011, March). Retrieved from Who Invented: http://www.whoinvented.org/who-invented-trash-compactor/

aalco. (n.d.). Stainless Steel - General Information - St St Introduction. Retrieved from aalco: http://www.aalco.co.uk/datasheets/Stainless-Steel_St-St-Introduction_61.ashx

Action Compaction Equipment. (2017, May 15). Waste Management. Retrieved from Action Compaction Equipment: https://www.actioncompaction.com/waste-management-problems-facing-world.html

AEG. (2017, Agosto 3). Entrevista AEG. (C. Trends, Interviewer) Retrieved from https://consumertrends.pt/entrevista-aeg/

Aglionby, J. (2018, September 30). More than half the world's population is now middle class. Retrieved from Financial Times: https://www.ft.com/content/e3fa475c-c2e9-11e8-95b1-d36dfef1b89a

Airtech Advanced Materials Group. (n.d.). Dahlar® RB 500. Retrieved from Airtech Advanced Materials Group: https://www.airtechonline.com/Dahlar-RB-500

Albuquerque, M. d. (2012). Leis de Newton: Lei de ação-reação. Retrieved from CFQ9:

http://www.cfq9.yolasite.com/resources/08_lei_acao_reacao_forcas_atrito.pdf

Ambiente, A. P. (2018). Relatório do Estado do Ambiente 2018. June : Agência Portuguesa do Ambiente.

Andrew Kasprowicz, F. S., Devin Keith Cochran, S. O., & Earl Warren Mann, G. A. (2004). US Patent No. US20040129810A1.

Ashby, M. (2010, Jan). Material and process charts . Retrieved from Granta Education Hub: http://www.grantadesign.com/download/pdf/teaching_resource_books/2-Materials-Charts-2010.pdf

Ashby, M. (2016, Jan). Useful Solutions for Standard Problems. Retrieved from Granta Education Hub: file:///C:/Users/Ana%20Caboz/Downloads/BOKUSEEN16+-+Useful+Approximate+Solutions+for+Standard+Problems.pdf

Balasteiro, S. (2014, Janeiro 14). Para onde vai o nosso lixo? Retrieved from Sol Sapo: https://sol.sapo.pt/artigo/96855/para-onde-vai-o-nosso-lixo-

Beautyon. (2014, Apr 25). Why Yanks Have Garbage Compactors and Brits Don’t. Retrieved from Hackernoon: https://hackernoon.com/why-yanks-have-garbage-compactors-and-brits-dont-d7abc7e59d7a

Beer, F. P., & Jr., E. R. (1998). Mecânica Vectorial para Engenheiros: Dinâmica (6 ed.). (A. P. Urgueira, Trans.) Portugal: McGraw-Hill. Retrieved 2018

Beijing Langwei momentos, tecnologia e ciência co., Ltd. (n.d.). Membrana Impermeável A Borracha EPDM. Retrieved from Beijing Langwei momentos, tecnologia e ciência co., Ltd: http://pt.lwgrout.com/waterproof-membrane/epdm-rubber-waterproof-membrane.html

Bigbelly. (2018). Solutions for Smart Cities. Retrieved from Bigbelly: Smart Solutions for Cities: http://bigbelly.com/solutions/city/

Bottas, M. J., Macfarlane, T. R., & Miller, F. E. (1969). US Patent No. US3613560A.

Boyd, J. A. (1971). US Patent No. US3691944A.

Burr, A. a. (1995). Mechanical Design and Analysis (2nd edition ed., Vols. section 5.2. Prentice-Hall).

Capucho, J. (2017). "Vinte anos de reciclagem, mas ainda se separa pouco lixo em casa". Diário de Notícias, 1. Retrieved from https://www.dn.pt/sociedade/interior/vinte-anos-de-reciclagem-mas-ainda-se-separa-pouco-lixo-em-casa-5703936.html

Cardoso, P. (2017, Jan 17). Educação Ambiental e Sustentabilidade. Portugal. Retrieved from https://jra.abae.pt/plataforma/artigo/educacao-ambiental-e-sustentabilidade/

CBS Interactive Inc. (2018). Broan 15XESS Programmable 15W in. Trash Compactor (Stainless Steel) Specs. Retrieved from CNET: https://www.cnet.com/products/broan-15xess-programmable-15w-in-trash-compactor-stainless-steel/specs/

Daniel Hoornweg, P. B.-T. (2012). What a Waste : A Global Review of Solid Waste Management. Washington, DC 20433 USA: Urban Development & Local Government Unit, The World Bank.

Day, A. (2014, May). UNPACKING TRASH COMPACTORS. Retrieved from DISPOSABLE AMERICA: EXPLORE THE

HISTORY OF DISPOSABILITY THROUGH OBJECT STORIES: https://disposableamerica.org/course-projects/anastasia-day/

Diário de Noticias. (2016, DEZEMBRO 21). Cada português produziu 464 quilos de lixo em 2015. Diário de Notícias. Retrieved from https://www.dn.pt/sociedade/interior/cada-portugues-produziu-464-quilos-de-lixo-em-2015-5564948.html

ECOBEMPOSTA. (2016, Jan 5). Como funciona o Sistema Ponto Verde. Retrieved from ECOS: https://ecobemposta.wordpress.com/2016/01/05/como-funciona-o-sistema-ponto-verde/)

Ecologic Ibéria. (2018). Para além de uma grande ajuda na cozinha, ainda é amigo do ambiente. Retrieved from Ecologic : http://www.ecologic-iberica.com/pag/Vantagens-2.html

Ecube Labs. (2017, November 11). CleanCUBE, the solar-powered trash compactor. Retrieved from Ecube Labs: https://www.ecubelabs.com/solar-powered-trash-compactor/

Eisberg, R. M., & Lerner, L. S. (1982). Física: Fundamentos e Aplicações (Vol. 1). (I. J. Albuquerque, Trans.) Brasil: McGraw-Hill . Retrieved 2018

EPA United States Environmental Protection Agency. (2017, January 19). Sustainable Materials Management: Non-Hazardous Materials and Waste Management Hierarchy. EPA. Retrieved from https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy#main-content

Esben Larsen, K. B. (2018, Janeiro 19). World waste facts. Retrieved from The World Counts:

http://www.theworldcounts.com/counters/shocking_environmental_facts_and_statistics/world_waste_facts

European Environment Agency. (2015, May 24). Retrieved from Growing pressures on ecosystems (GMT 8): https://www.eea.europa.eu/soer-2015/global/ecosystems

Eurostat. (2017, November). Household consumption by purpose. Retrieved from Eurostat Statistcs Explained: http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_consumption_by_purpose

Eurostat Statistical Books. (2010). Environmental statistics and accounts in Europe. Luxembourg: Publications Office of the European Union.

Eurostat Statistics Explained. (2017, May). Waste statistics. Retrieved from Eurostat Statistics Explained: http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics#Total_waste_generation

Eurostat, EUROPEAN COMMISSION. (2018, Janeiro). Circular economy – Overview. Retrieved from Eurostat: Your key to European statistics: http://ec.europa.eu/eurostat/web/circular-economy

Formato Verde. (2017, November 11). SOLARBOX: AUTOCOMPACTADOR SOLAR. Retrieved from Formato Verde: Waste Solutions: http://www.formatoverde.com/pt-PT/compactacion/solar-box.aspx

Frontgate. (2017). STAINLESS STEEL MANUAL TRASH COMPACTOR. Retrieved from Frontgate: https://www.frontgate.com/stainless-steel-manual-trash-compactor/kitchen-entertaining/kitchen-storagemaintenance/543613?SourceCode=ZZ50871&cm_mmc=Comparison+Shopping-_-Shopzilla-_-NA-_-NA&utm_source=connexity&utm_medium=cpc&utm_campaign=cse&CAWELAID=1202

Gladiator. (2017). Garage Compactor. Retrieved from Gladiator: https://www.gladiatorgarageworks.com/-[GACP15XXMG]-1700113/GACP15XXMG/

Go Green Together. (2016, September 28). Boosting Waste Management with Trash Compactors. Retrieved from Go Green Together: http://www.gogreentogether.ca/boosting-waste-management-with-trash-compactors/

Harrison, R. M. (n.d.). Pollution: Causes, Effects and Control.

Hitchcock, J., Judge, K., & Lundquist, L. (2011). US Patent No. US20150101499A1.

idhea. (2009). Materiais Ecológicos e Tecnologias Sustentáveis - Praticas e Aplicações. Retrieved from https://pt.scribd.com/doc/15920165/Materiais-Ecologicos-e-Tecnologias-Sustentaveis-Praticas-e-Aplicacoes

Joseph Joseph. (2017). Titan 30 - Trash Compactor. Retrieved from Joseph Joseph: https://www.josephjoseph.com/en-eu/titan-trash-compactor

Kaffeeform . (2015). Mission. Retrieved from Kaffeeform : https://www.kaffeeform.com/en/mission/

KitchenAid. (2013). INTEGRATED COMPACTOR: Use & Care Guide.

Krushr. (2017). 12 INCH RECYCLING TRASH COMPACTOR. Retrieved from Krushr North America:

http://www.krushr.com/12-inch-recycling-trash-compactor/

Lipor. (2018, Janeiro 10). Perguntas Frequentes - Reciclagem. Retrieved from Lipor: https://www.lipor.pt/pt/perguntas-frequentes/reciclagem/

Lusa, A. (2018). Cidadãos conscientes de problemas ambientais mas não sabem reciclar lixo, alerta Quercus. Observador. Retrieved from https://observador.pt/2018/06/05/cidadaos-conscientes-de-problemas-ambientais-mas-nao-sabem-reciclar-lixo-alerta-quercus/

M. Ashby, K. J. (2014). Materials and Design – the art and science of material selection in product design. USA: Butterworth-Heinemann.

Maytag. (2017). TRASH COMPACTOR - 1.4 CU. FT. Retrieved from Maytag: https://www.maytag.com/kitchen/dishwashers-and-compactors/compactors/p.trash-compactor-1.4-cu.-ft.mtuc7500afm.html

Minna Poikelispää, T. U. (2007). Virtual Education in Rubber Technology (VERT). Retrieved from https://www.tut.fi/ms/muo/vert/Executive_summaries.pdf

National Geographic. (2015). 10 SHOCKING FACTS ABOUT PLASTIC. Retrieved from National Geographic: https://www.nationalgeographic.com/environment/plastic-facts/

NEDC. (2012, August 28). DIFFERENCES BETWEEN EUROPEAN AND AMERICAN KITCHENS. Retrieved from NEDC: Design + Construction: https://www.nedesignbuild.com/differences-between-european-and-american-kitchens/

Nitto Kohki. (2018). AIR COMPRESSORS, VACUUM PUMPS & LIQUID PUMPS - GENERAL CATALOG. Retrieved from https://www.nitto-kohki.eu/en/products-en/pumps-a-compressors.html

Nitto Kohki. (n.d.). PUMPS & AIR COMPRESSORS. Retrieved from Nitto Kohki: https://www.nitto-kohki.eu/en/products-en/pumps-a-compressors.html

NOCTULA - Consultores em Ambiente. (2017). "Portugueses reciclaram cerca de 7,5 toneladas de resíduos em 20 anos". NOCTULA.

Pinto, M. S. (2013). Recolha de resíduos urbanos indiferenciados do município de Aveiro. Aveiro: Universidade de Aveiro.

(n.d.). Pneumatic Systems. Technological Studies. Retrieved from https://resources.hkedcity.net/res_files/201101/20110128101153_259037.pdf

Poirot, A. (2017, Mar 9). San Francisco's Race to Zero Waste Has One Last Major Hurdle. A Medium Corporation. Retrieved from https://medium.com/sustainable-food-systems/san-franciscos-race-to-zero-waste-has-one-last-major-hurdle-6c76ca8f2f86

Post, T. W. (2017, Nov 21). Drowning in garbage. Retrieved from The Washington Post: Democracy Dies in Darkness: https://www.washingtonpost.com/graphics/2017/world/global-waste/?utm_term=.a875151acda8

Powes, R. T. (1973). US Patent No. US3899967A.

PÚBLICO e LUSA. (2013). "Em Portugal há um contentor de lixo para cada 33 pessoas". Público.

REA . (2018, Maio 21). RESÍDUOS: PRODUÇÃO E GESTÃO DE RESÍDUOS URBANOS. Retrieved from Portal do Estado do Ambiente:

https://rea.apambiente.pt/content/produ%C3%A7%C3%A3o-e-gest%C3%A3o-de-res%C3%ADduos-urbanos?language=pt-pt

Rubber-Cal. (2016). Recycled Rubber. Retrieved from Rubber-Cal: http://www.rubbercal.com/sheet-rubber/recycled-rubber/

Saad, F. (2018, Maio 7). TIPOS DE COMPACTADORES DE LIXO. Retrieved from Manutenção e Suprimentos: http://www.manutencaoesuprimentos.com.br/conteudo/6463-tipos-de-compactadores-de-lixo/

Sarna, S. K. (2015, Nov 14). BASICS OF PNEUMATICS AND PNEUMATIC SYSTEMS. Retrieved from ISPAT Guru: http://ispatguru.com/basics-of-pneumatics-and-pneumatic-systems/

Shearer, N. A. (2012). Depew, NY (US) Patent No. US20140041535A1.

Tarlow, K. (2002). Corte Madera, CA (US) Patent No. US20030136279A1.

The Home Depot. (2017). KitchenAid: 15 in. Built-In Trash Compactor in Stainless Steel. Retrieved from The Home Depot: https://www.homedepot.com/p/KitchenAid-15-in-Built-In-Trash-Compactor-in-Stainless-Steel-KTTS505ESS/205999792

The Home Depot. (2017). Whirlpool: 15 in. Convertible Trash Compactor in Black. Retrieved from The Home Depot: https://www.homedepot.com/p/Whirlpool-15-in-Convertible-Trash-Compactor-in-Black-GC900QPPB/203571218?MERCH=REC-_-PIPHorizontal1_rr-_-205999792-_-203571218-_-N

The World Bank Group. (2018, March 27). The World Bank. Retrieved from Solid Waste Management:

http://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

Trinkel, B. (2006, Oct 15). CHAPTER 5: Pneumatic and hydraulic systems. Retrieved from Hydraulics&Pneumatics: https://www.hydraulicspneumatics.com/other-technologies/chapter-5-pneumatic-and-hydraulic-systems

Uncommongoods. (2017). Compacting Garbage with Odor Filter. Retrieved from Uncommongoods: https://www.uncommongoods.com/product/compacting-garbage-with-odor-filter

Uncommongoods. (2017). Smush Can. Retrieved from Uncommongoods: https://www.uncommongoods.com/product/smush-can

United Nations Human Settlements Programme (UN-HABITAT). (2010). Solid Waste Management in the World's Cities: Water and Sanitation in the World's Cities. London, UK; Washington, USA: Earthscan Ltd; Earthscan LLC.

Universidade Pública Portuguesa. (n.d.). Compactador de Lixo Doméstico. Retrieved from Bolsa de Tecnologia e Negócios: http://www.bolsatecnologia.pt/ProfileView.action?id=12072

University of Cambrige - Department of Engeneering. (2002, Jan 25). Material selection and processing. Retrieved from Materials eng: http://www-materials.eng.cam.ac.uk/mpsite/interactive_charts/default.html

USA, B. D. (2017). Ecopod: Residential Recycling Trash Masher. Retrieved from Treehugger:

https://www.treehugger.com/sustainable-product-design/ecopod-residential-recycling-trash-masher.html

Weeks, C. B., & Choate, P. V. (1977). US Patent No. US4024806A.

Whirlpool Corporation. (2018). Food scraps today, fertilizer tomorrow. Retrieved from Zera: https://wlabsinnovations.com/pages/zera

Woodford, C. (2017, Dec 16). Pneumatics. Retrieved from Explain that stuff: https://www.explainthatstuff.com/pneumatics.html

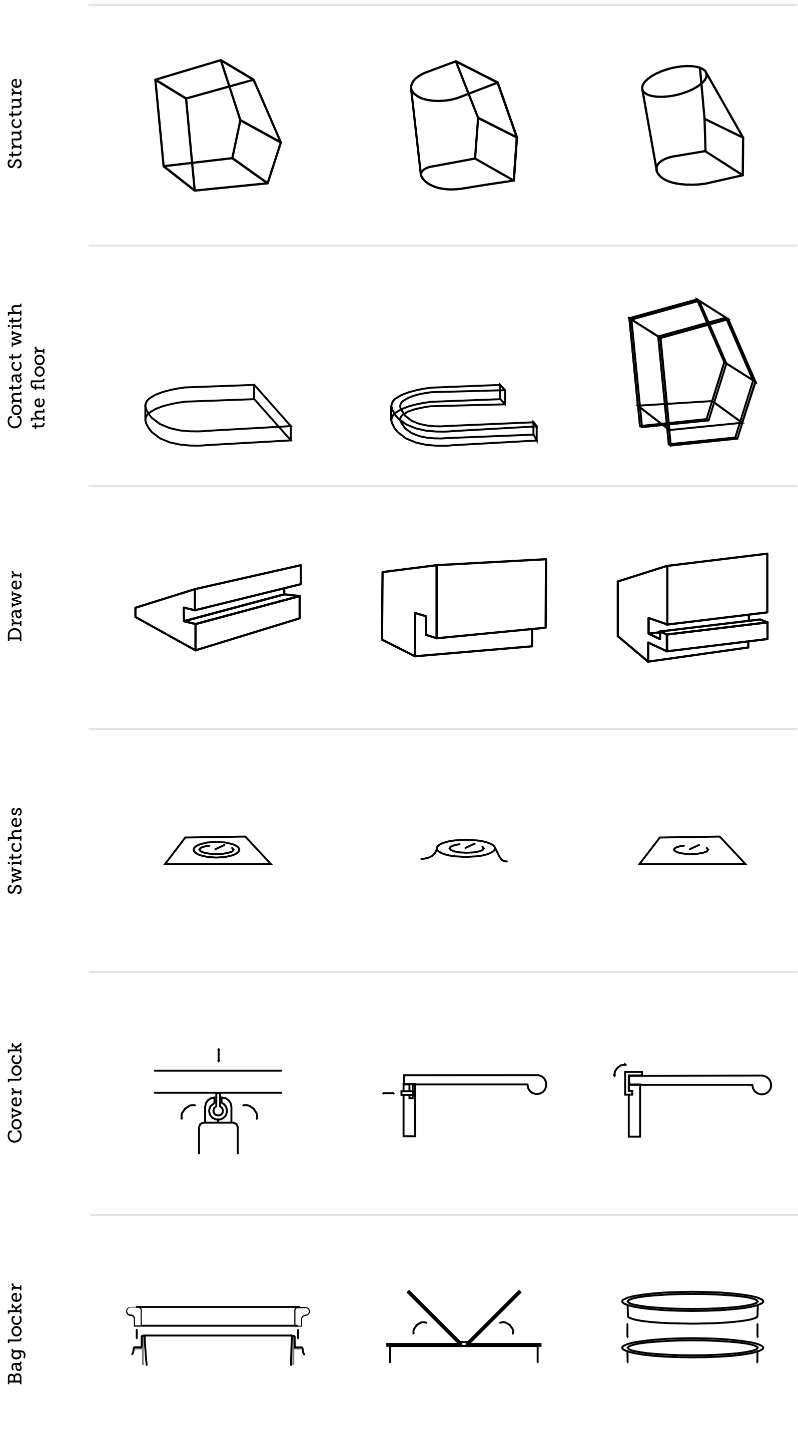
World Intelectual Property Organization. (2018). WIPO. Retrieved from Patents: http://www.wipo.int/patents/en/

WWF International. (2016). Living Planet Report 2016: Risk and resilience in a new era. Switzerland: FSC.

Yanko Design. (2017). DESIGN IS BEST WITH STOMPING. Retrieved from Yanko Design: http://www.yankodesign.com/2009/05/26/design-is-best-with-stomping/

10. APPEN-DICES

Table 2: *Morphological analysis*



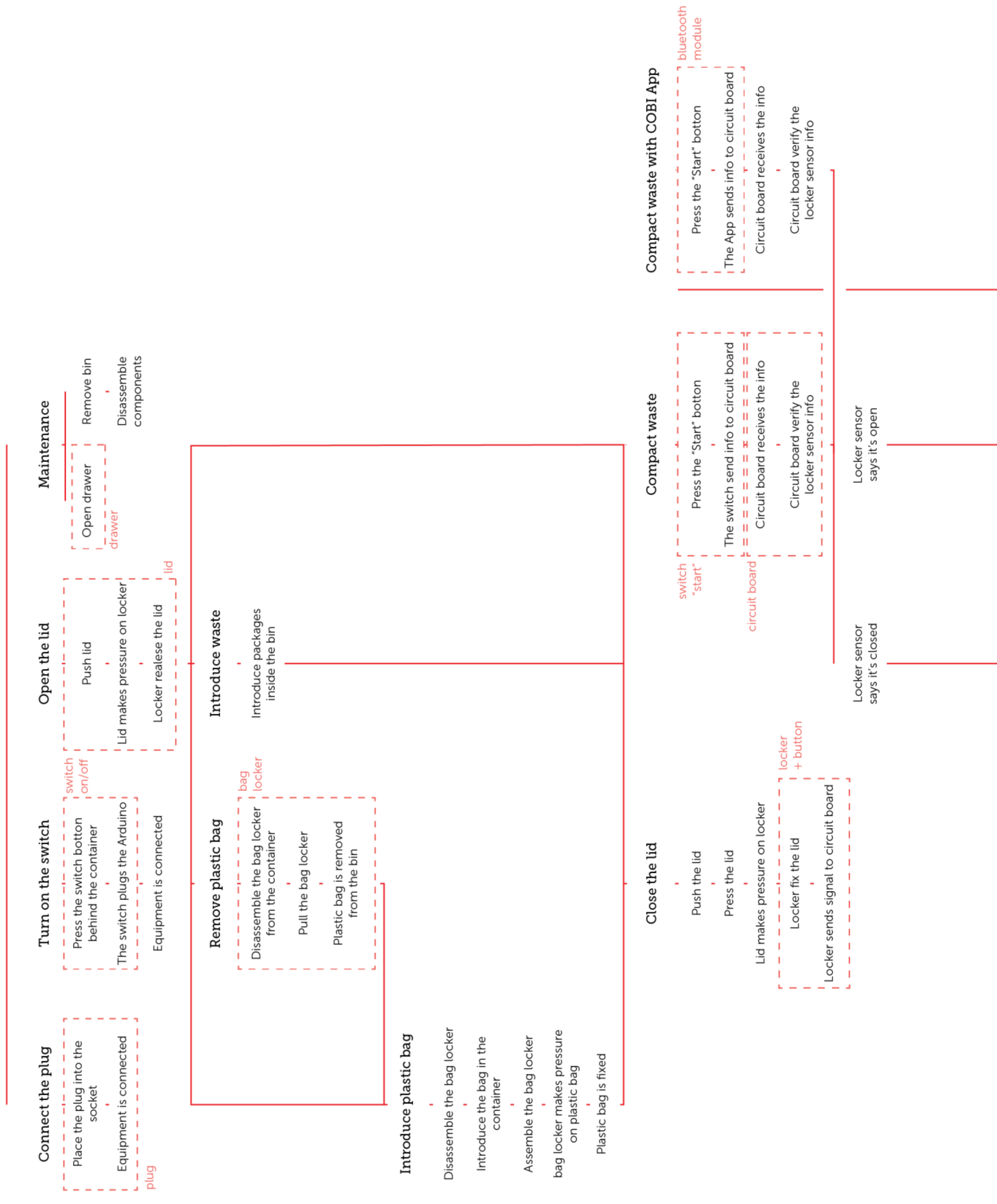
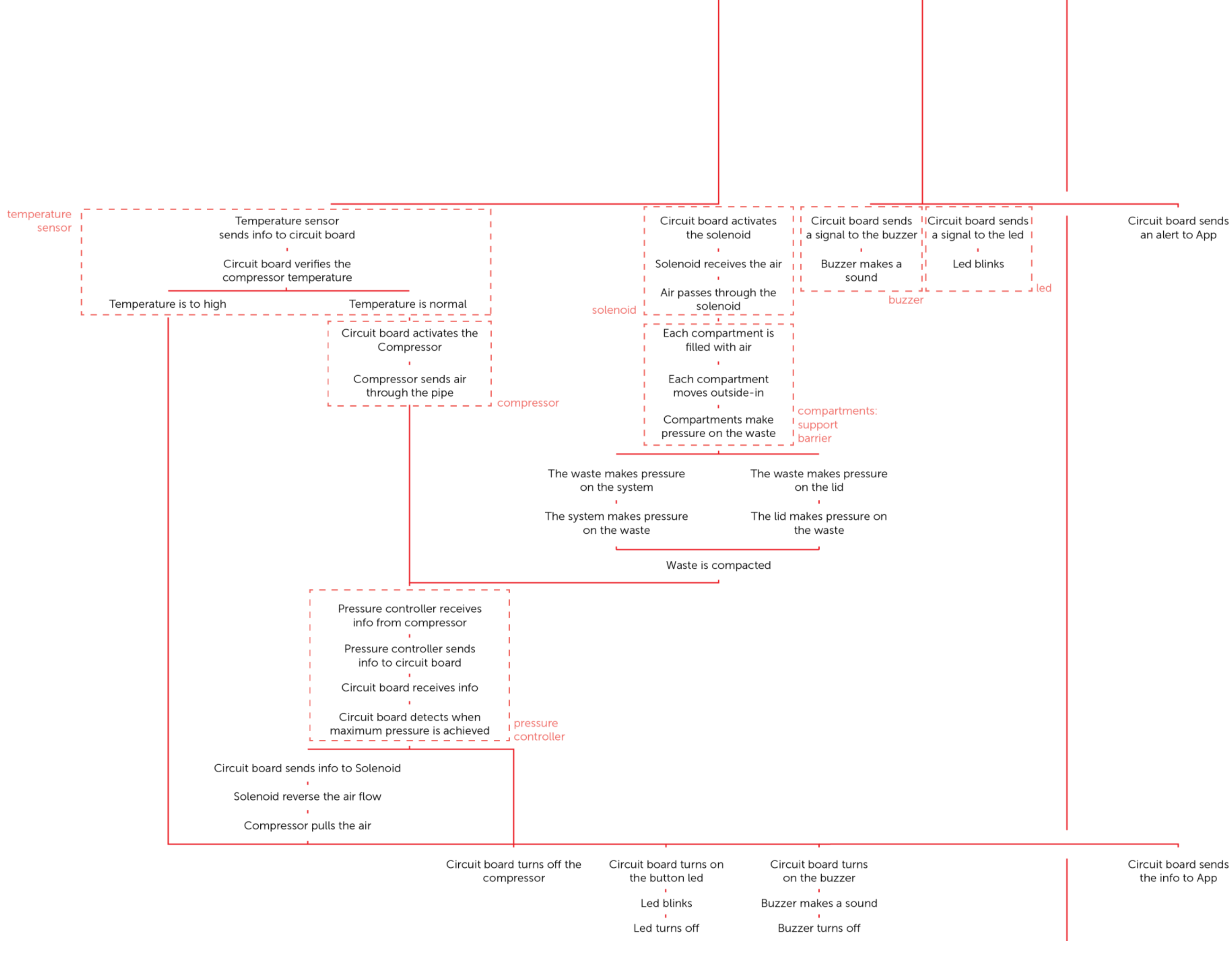


Figure 66: Functional Diagram with Product Architecture


temperature sensor
Temperature sensor sends info to circuit board
Circuit board verifies the compressor temperature
Temperature is to high
Temperature is normal
Circuit board activates the Compressor
Compressor sends air through the pipe
compressor
Circuit board activates the solenoid
Solenoid receives the air
Air passes through the solenoid
solenoid
Each compartment is filled with air
Each compartment moves outside-in
Compartments make pressure on the waste
compartments: support barrier
Circuit board sends a signal to the buzzer
Buzzer makes a sound
buzzer
Circuit board sends a signal to the led
Led blinks
led
Circuit board sends an alert to App
The waste makes pressure on the system
The system makes pressure on the waste
The waste makes pressure on the lid
The lid makes pressure on the waste
Waste is compacted
Pressure controller receives info from compressor
Pressure controller sends info to circuit board
Circuit board receives info
Circuit board detects when maximum pressure is achieved
pressure controller
Circuit board sends info to Solenoid
Solenoid reverse the air flow
Compressor pulls the air
Circuit board turns off the compressor
Circuit board turns on the button led
Led blinks
Led turns off
Circuit board turns on the buzzer
Buzzer makes a sound
Buzzer turns off
Circuit board sends the info to App

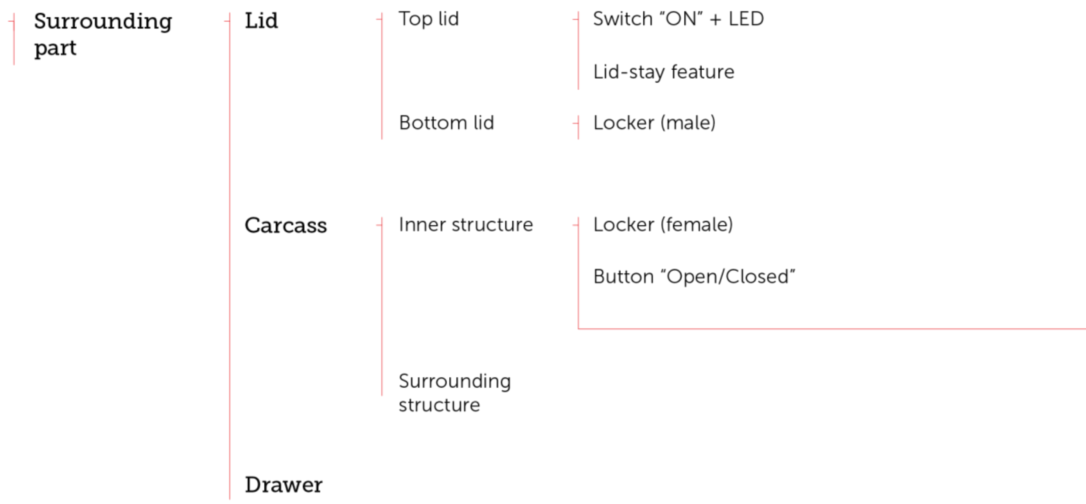


Figure 67: Components Diagram

COBI BIN

- Bin
  - Compartments
    - Support
    - Barrier
      - Pipe taps
- Bag locker
- Bin cover
  - Security bag
  - Handle
- Pipe cover
- Pipe
  - Pipe connecters
- Circuit board
  - Switch “On/Off”
  - Switch “Start” with led
  - Locker button
  - Buzzer
  - Transistor
  - Power supply female connector
    - Power supply plug
  - Temperature sensor
    - Compressor
  - Pressure Controller
  - Solenoid
  - Bluetooth module
    - COBI APP

Polyethylene (PE)

General properties

Density		939	-	960	kg/m^3
Price	*	1,82	-	2,23	EUR/kg

Mechanical properties

Young's modulus		0,621	-	0,896	GPa
Yield strength (elastic limit)		17,9	-	29	MPa
Tensile strength		20,7	-	44,8	MPa
Elongation		200	-	800	% strain
Hardness - Vickers		5,4	-	8,7	HV
Fatigue strength at 10^7 cycles		21	-	23	MPa
Fracture toughness	*	1,44	-	1,72	MPa.m^0.5

Thermal properties

Melting point		125	-	132	°C
Maximum service temperature	*	90	-	110	°C
Thermal conductor or insulator?		Good insulato			
Thermal conductivity		0,403	-	0,435	W/m.°C
Specific heat capacity	*	1,81e3	-	1,88e3	J/kg.°C
Thermal expansion coefficient		126	-	198	µstrain/°C

Electrical properties

Electrical conductor or insulator?		Good insulato			

Optical properties

Transparency		Translucent			

Eco properties

Embodied energy, primary production	*	77	-	85,1	MJ/kg
CO2 footprint, primary production	*	2,64	-	2,92	kg/kg
Recycle		✓			

Recycle mark

Values marked * are estimates.
No warranty is given for the accuracy of this data

Polyamides (Nylons, PA)

General properties				
Density	1,12e3	-	1,14e3	kg/m^3
Price	* 3,39	-	3,81	EUR/kg
Mechanical properties				
Young's modulus	2,62	-	3,2	GPa
Yield strength (elastic limit)	50	-	94,8	MPa
Tensile strength	90	-	165	MPa
Elongation	30	-	100	% strain
Hardness - Vickers	25,8	-	28,4	HV
Fatigue strength at 10^7 cycles	* 36	-	66	MPa
Fracture toughness	* 2,22	-	5,62	MPa.m^0.5
Thermal properties				
Melting point	210	-	220	°C
Maximum service temperature	110	-	140	°C
Thermal conductor or insulator?	Good insulato			
Thermal conductivity	0,233	-	0,253	W/m.°C
Specific heat capacity	* 1,6e3	-	1,66e3	J/kg.°C
Thermal expansion coefficient	144	-	149	µstrain/°C
Electrical properties				
Electrical conductor or insulator?	Good insulato			
Optical properties				
Transparency	Translucent			
Eco properties				
Embodied energy, primary production	* 115	-	127	MJ/kg
CO2 footprint, primary production	* 7,58	-	8,38	kg/kg
Recycle	✓			
Recycle mark				

Values marked * are estimates.
No warranty is given for the accuracy of this data

Table 5: *Stainless steel specifications*

CES 2016 EDUPACK

Stainless steel

General properties

Density	7,6e3	-	8,1e3	kg/m^3
Price	* 5,81	-	6,02	EUR/kg

Mechanical properties

Young's modulus	189	-	210	GPa
Yield strength (elastic limit)	170	-	1e3	MPa
Tensile strength	480	-	2,24e3	MPa
Elongation	5	-	70	% strain
Hardness - Vickers	130	-	570	HV
Fatigue strength at 10^7 cycles	* 175	-	753	MPa
Fracture toughness	62	-	150	MPa.m^0.5

Thermal properties

Melting point	1,37e3	-	1,45e3	°C
Maximum service temperature	750	-	820	°C
Thermal conductor or insulator?	Poor conductc			
Thermal conductivity	12	-	24	W/m.°C
Specific heat capacity	450	-	530	J/kg.°C
Thermal expansion coefficient	13	-	20	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductc

Optical properties

Transparency	Opaque

Eco properties

Embodied energy, primary production	* 80,3	-	88,8	MJ/kg
CO2 footprint, primary production	* 4,73	-	5,23	kg/kg
Recycle	✓			

Values marked * are estimates.
No warranty is given for the accuracy of this data