# 3rd Symposium on

# International Innovation, Engineering & Entrepreneurship

# 2022 Strasbourg

**ECAM Strasbourg-Europe**
**January 13th, 2022**

I2E2 is presented by

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**Strasbourg, France, January 2022**

# Content

# Foreword

**"There is a way to do it better – find it"**
(Thomas Alva Edison)

The third edition of the $I^2E^2$ Symposium has been affected by the ongoing pandemic again. Students and tutors had to switch back to the now well-known virtual format. Despite such difficulties, the results proposed were more tangible than ever.

After more than four months of intensive work, the teams were able to deliver their projects in innovation, finding better ways to solve everyday challenges. We could see a great investment in environmental issues at this edition. More than half of the projects were focusing on recycling, waste management, end of life products and sustainable harvesting.

In the above-mentioned areas, innovation plays a major role in the process not only by proposing new products but also by instigating new ways of consumption. The breakdown of these practices leads to changes, for both consumption and use. Yet, the biggest challenge is to incite a breakthrough in the students' mindset, from an individual to a collective perspective, and from national to international spheres.

Building an international team requires efforts from all stakeholders, at all levels. I congratulate the international teams of tutors from Fontys University of Applied Sciences, ECAM Strasbourg-Europe, Hochschule Ulm, University of Applied Sciences Technikum Wien and EUSS Barcelona who supported the students and projects. Without them, this symposium would not come to light.

Innovation is made of success and failure, of finding new ways or, as Thomas Edison has stated, finding a way to do it better. One thing is certain, the $I^2E^2$ Symposium is preparing the student-engineers for the times coming ahead.

Strasbourg, January 13th, 2021

Leandro Di Domenico

ECAM Strasbourg-Europe

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ECAM Strasbourg-Europe - January 13th, 2022

# Developing concept for lowering plastic packaging for supermarket.

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***Abstract*— It is the most discussed topic in recent years: Sustainability, our large-scale plastic consumption and with that, also large-scale plastic pollution, global warming and the damage it does to the health of people and animals. One of the sectors that has a very large share in this is supermarkets sector. Because of this, there was a demand for an innovative solution to drastically reduce this single-use plastic consumption. This paper will therefore address the question: "How can plastic packaging in supermarkets in The Netherlands be reduced with an innovative technical solution as part of the I2E2 project?" The solution to this problem that we discuss in this paper looks at the single-use plastic packaging around ready-to-eat meals and pre-cut fruits and vegetables. The first part of the solution looks at the transportation of these products. This is solved through a reusable box that can only be opened when it is put in the machine. The second part of this solution is the machine where the consumer can have their own chosen meal put together through a U.I. that is dropped into a reusable microwavable tray that can be taken home. This eliminates all plastic packaging of these products. In this paper you can read about how this design came about. Furthermore, through a market research, we identified who the customers would be and what the potential growth of this concept would be.***

***Keywords*—Sustainability, global-warming, single-use-plastic, supermarket.**

## I. INTRODUCTION

It will not have escaped anyone's attention that there is a major problem with the current use of plastic in the Netherlands, both by consumers and by companies. On average, 26,000,000,000 pieces of plastic packaging are used and therefore thrown away in the Netherlands alone. A very large part of this is caused by supermarkets and the way they package their products. The problem with plastic is that it's not re-used most of the time and that it is a material that can't be recycled properly and therefore a lot of plastic ends up in nature. In addition, the production process of plastic releases many harmful chemicals, including CO2, into the air. Burning plastic also releases a lot of harmful substances. The reason we want to reduce plastic pollution with this project is because it causes climate change and is therefore not sustainable at all. In addition, a lot of plastic ends up in the ocean which causes life in the ocean to be endangered by swallowing or becoming entangled in the plastic waste. Micro-plastics can also get into people's food through these sea creatures or in other ways. This, along with the fact that some plastic can be harmful if it comes in contact with our food, ensures that this plastic problem is also a danger to human health. This problem must be remedied by drastically reducing the use of plastic. Considering a very large portion of plastic consumption is through supermarkets, this project will focus on this sector. For this project, an innovative concept was devised to provide a solution in contributing to the reduction of plastic pollution on a relatively large scale. Therefore, the purpose of this research is to describe an innovative technical solution for reducing plastic packaging in supermarkets

This paper will approach the question answer: "How can plastic packaging in supermarkets in The Netherlands be reduced with an innovative technical solution as part of the I2E2 project?"

First, the background section looks at the current solutions for, and the competitors that currently exist in the area of, packaging products in supermarkets. Then further explanation is given of the design of the concept, both mechanical and electrical. In chapter business potential, there is further explanation about the market research about the size and growth of this market, about the business and marketing analysis done, about the target market and about the financial picture of this concept.

## II. Background

Countless consumer goods can be found all in one place in the supermarket. Unfortunately, this also is the hub of plastic packaging waste coming from these goods. Most of the single use non-biodegradable plastic comes from supermarket. This plastic is not recyclable and enters the waste stream heading to landfills and oceans and pollute our planet.

With the emerging ideas of circularity in business and design, single use packaging, especially one with a footprint as large as polymers, does not fit in this concept. The usage of plastic in covering products is about to face challenges due to global and local agreements on achieving global neutrality before the end of the century. However, with the industry generating one-time-use plastic being so advanced, it is a challenge for the people to come up with solutions that can offer an alternative capable of competing with the positive attributes (such as: cheap, lightweight, sterile, etc.) of plastic.

### A. *Our solution*

Normally, the food produced in the factory are packed in a single use plastic packaging which are thrown away after its used. But with the solution shown in figure 1, the food produced in the factory is packed in the sealable box. The box cannot be open during the transportation and during the storage in the supermarket, in order to avoid human contact with food and decrease the chance of food being contaminated. This box is temperature controlled and holds 1 type of cooked ingredient. This box is transported to supermarket and the only way to open the box is when it goes inside the machine which unlocks the seal. From the machine, the consumer can order the meal through easy-to-use user interface. The food is dropped in the reusable microwable tray which consumer can take home. After the consumer can bring the tray back to supermarket and they get a deposit like plastic bottles. Likewise, the boxes when empty from the machine they are also transported back to food factory for refill. The idea is to be a part of circular economy and with this solution no plastic package goes to waste.

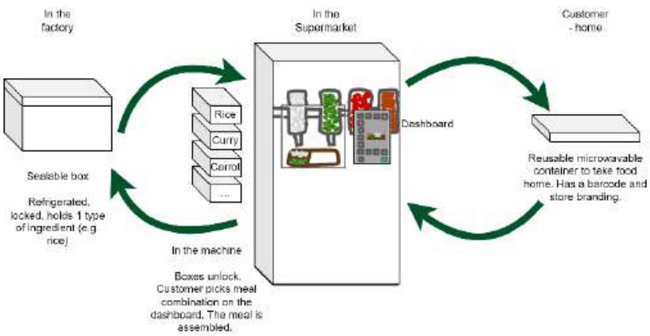



*Figure 1: System overview*

With this solution not only plastic packaging is eliminated but also there is an opportunity for consumer to customize their meal. They can customize either with the ingredients they like or how much amount they want. Furthermore, it is relatively convenient since the machine is placed in the supermarkets and comparatively more affordable than the competitors. Additionally, it is a lot healthier than a traditional microwable meal which are packed and stored for a few weeks in the supermarket and has a lot of preservatives in them to increase the food's shelf life.

The process of the supply will be as followed. The boxes with ingredients will be filled machinal in the food factory. The boxes will then be transported to the supermarket which they will be stored and eventually placed in the dispenser. This process is not fully lean since there could be a case to have the dispenser units filled and transported, resulting in not using the box at all. However not only will this mean a drop in efficiency in transport due to the dispenser units being unable to transport as much food as the boxes will. It will also bring another risk to the process, the risk of the dispenser units being damaged during the transport. Which could result in object breaking and ending up in the food. Since the product is heavily in contact with working with food, food safety is much more important than efficiency. Therefor the use of boxes for the transportation is chosen.

### B. *Existing solution*

Currently a lot of single use plastic packaging is used to keep the pre-cut vegetables and ready-to-eat meals fresh and save. Also, a lot of conservatives are required to increase the shelf life of a product. Supermakets are full of packaging and plastic is the most common material used. Despite this supermarkets have started to find ways to decrease the amount of plastic used. Some packages have been replaced with paper packaging or other materials which are bio degradable. There are also more and more stores having a plastic free section where most food is stored in bins and the customer can take out what is needed. The problem with this solution is that not all foods can be sold like this without compromising health and food safety, and that often single use plastic is still introduced at some stage in the products lifespan.

Secondly, with the existing solution the consumer is unable to personalize their meal. For example, if a consumer would like a meal for 2 or more people, then he needs to buy multiple meal in different packaging, which is again produce more waste. Furthermore, the combination of personalized ingredients is also not possible which is a big factor people don't buy this kind of food often because it gets boring after few times. Lastly, in the packaged meal the food is cooked long time ago and is filled with preservatives to increase the shelf life which is not healthy for daily consumption.


*Figure 2: Existing solution for ready-to-eat meal*

*C. Competitors*

An increasing awareness on plastic pollution and an increase in the demand of convenience products allows for a lot of competition. But the market that our system is planned to be a part of is so large that there is still plenty of room for new ideas and innovations. The competitors can be divided into two sections the competition on the convenience side and the competition on the sustainability side.

On the convenience side there are a few very obvious competitors; the manufactures of ready-to-eat meals, companies like Thuisbezorgd, hello fresh, take away restaurants and the conventional pre-packaged meals. These companies all offer ways to make eating dinner easier. They have quite low prices to give them a competitive position in the market, but none of them really strives for a sustainable solution. There are also less obvious convenience competitors such as sally the salad robot, a robot to which a user can order a somewhat customisable salad.

On the sustainability side the competition is more diverse. Plastic enters the environment in many different ways and in many different steps in the product lifespan. For our competition we want to focus on food packaging as that is also the area the system will be operating in. Supermarkets are nowadays looking for alternatives for plastic packaging and slowly this is being applied on places where plastic is not needed. This will not be possible for all products as food safety is very important. There are currently many initiatives for producing biodegradable materials that can be used as packaging. These materials are currently not yet cost effective, especially when compared to their very cheap counterpart, plastic. KFC, the fast-food chain, has been experimenting with eatable packaging. They designed a coffee cup that can be eaten after the coffee is consumed. Ideas like this only solve a small fraction of the problems as eatable packaging would not work for any product.

There is not one solution that covers everything with one system. This very complex problem requires multiple innovative and different solutions. It requires multiple companies to work together and not against each other.

## III. DESIGN PHASE

*1) Mechanical*

The total machine is being divided into different subsystems to create a better overview for milestones and concepts. The subsystems consist of:

- Ingredient Storage Unit. This carries the different ingredients in large portions from the supplier to the local store in a food-friendly manner. These are continuously cooled.
- Dispensing Unit. When the ingredients are being transported using gravity, the Dispenser regulates the portions with a volumetric portioning wheel. Fig, 3.

*Figure 3, Dispensing Unit, the subsystem that divides the ingredients into portions.*

- Tray Conveyor. The food is being dropped onto a tray which is being positioned by a conveyor belt. The conveyor moves an empty space on the tray underneath the Dispensing Unit for it to be filled with the according portion of ingredients. Fig, 4.

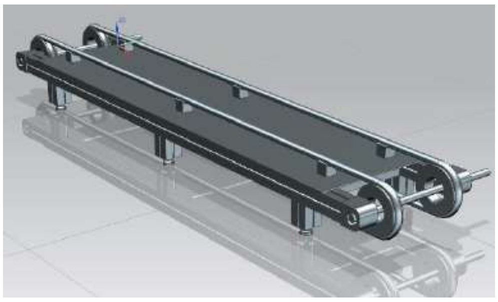


*Figure 4, Tray Conveyor, the subsystem that transports the tray underneath the according Dispenser.*

- Tray Presenting Unit. For a customer to receive the appropriate ingredients, a tray is being used to transport the food from the machine into their home. The tray is awarded onto the Tray Conveyor for it to be filled. The Tray Presenting Unit is the entry and the exit of the final product. Fig, 5.

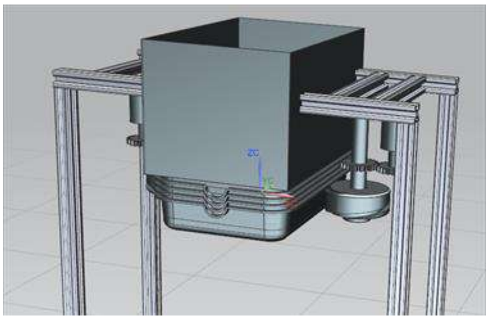
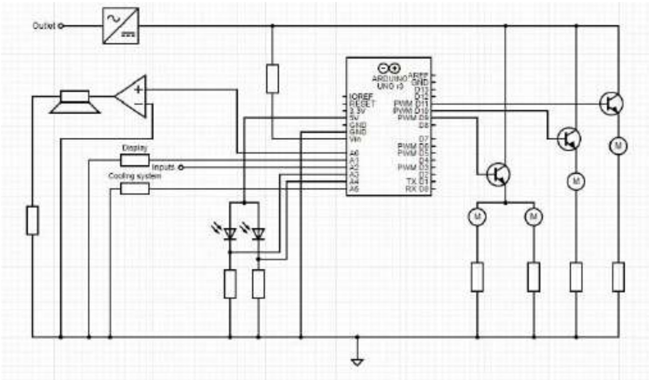


*Figure 5, Tray Presenting Unit, the subsystem that drops the customer's plate onto the Conveyor belt to be filled.*

For each developed subsystem, separate concept choices have been made to assign the most efficient tool for the job. Each system and every component are vital for the total ability to work properly. The main modules have been chosen using the Kesselring, and the Morphological Chart Method.

The mechanism of the tray presenting unit is made using a denester roll with an indent that ejects 1 tray per one rotation due to the slit in the roll (Figure 5). A rotating motor is used to facilitate movement. The intermediate components are a shaft, two rotating gears and a ball bearing that allows rotation for the second gear. 30 trays are expected to be put in the machine which results in a load of 4.8 kg.

*2) Electrical*




The system is powered by a regular outlet. The AC voltage of the outlet is converted by an AC/DC converter to a DC voltage of around 24V. This voltage is used to power the entire system. The brain of the system is an Arduino, or an ESP32 which is a slightly more advanced version of the Arduino. This microcontroller is used to manage and control the entire system. It can control the different motors using a PWM signal. These motors control three different blocks of the system namely, the plate dispenser, the conveyer belt and the food dispensers. For the plate dispenser two motors are needed for a consistent and reliable outcome.

The microcontroller is also connected to the user interface, this U.I. is the place where the user can interact with the system. It consists of a touch screen display, which can send the input data to the microcontroller, and a speaker. These are used in combination to convey different information to the user such as the different available meals, the processing time and some audio feedback from the speaker.

The sensors which are monitoring the machine are updated after every interaction with the machine to ensure up to date information on the state of the machine. This is used to tell users whether things are available or whether maintenance by the supermarket is needed. It is also used to troubleshoot issues that might evolve after longer periods of use.

*3) Materials*

For the machine to operate in a hygienic manner, all surfaces must be at a food grade standard. materials for boxes, trays, dispensing systems, and conveyors must be easily cleanable and/or replaced to ensure a healthy environment. The area of maintenance is accessible from the back of the machine with ample room to clean each component. The number of exposed components to the customer is limited to the bare minimum for safety, and health issues, but can be maintained when necessary.

Everything the food touches needs to be safe for human health, this consists of: The trays, Dispensing System, Tray Dropping System, and Conveyor Belt. The material appointed is PP, Polypropylene. This is not only safe when scratched, or heated until a certain temperature, it is also relatively cheap and has a smooth surface. This causes food not to stick and makes it easy to clean.

4) The trays and boxes

The boxes and tray are designed in a way which fits the dispenser unit. In order to prevent human contact with the food, a special concept of opening the boxes in the dispenser unit is made. The material of the boxes and trays needs to be able to be reused. Therefor the material (PEI) of the boxes and trays need to withstand cleaning. Research has been done into the pollution of cleaning the boxes and trays, the research shows that the cleaning the trays and boxes also causes a lot of pollution therefor in the future another way of cleaning the trays and boxes needs to be investigated.

## IV. BUSINESS POTENTIAL

### *A. Market research*

Market research was carried out to identify the opportunities of the potential product and tailor it to the market, to understand the target group and observe the competition. Both primary and secondary data were investigated to assess the business potential.

*1) Market size and Growth*

Research shows that the current global market size of ready to eat meals in 2019 was almost 160 billion US dollars and 183 billion in 2020. In The Netherlands, from 2015 to 2019 revenue of this market increased from 475 to 700 million euros, and by 2030 the industry is expected to grow over 100 billion euros [1]. Out of the multi-billion-dollar sector, supermarkets and hypermarkets hold almost 60% of the market, while convenience, speciality and online stores among others create the other 40%, which shows that innovation in the supermarket field would gross the largest impact.

It is important to mention that the market has been growing steadily since the year 2013 and is projected to grow by 5.5% by 2027 [2]. The drivers of this market are evolving convenience food tendencies and the increasing disposable income of consumers as well as urbanization and the factors that come with it [3] This proves that this market will exist for a long time and keep growing due to more and more people moving to cities and having less time to prepare food.

*2) Business and marketing analysis models*

The use of the SWOT analysis technique has provided an overview for the business. Some of the biggest strengths is being a solution to the pollution problem and fulfilling customers' needs. The opportunities are a growing market as the environmental problems demand sustainable and circular solutions as well as a possibility to expand into wide-ranging choices and customizations of the product the company produces. The weaknesses are uncertain customer acclimatization to the product and a large required initial investment compared to the current market solutions. The threats are the current speed and convenience of ready meals, an increase of online ordering and competition.

Porter's Five Forces method was used to identify the impact of the operating environment of the business. Presently, there is little competitive rivalry as this is an innovative business. The closest competitor is considered to be Sally the Salad robot. More competition in this area will drive the advancement of the technology. The threat of substitution is the current ready to eat meal market as it is. Their familiarity overpowers customers' choices, however in the future this will change due to the amount of pollution the current system causes and their influence will decrease significantly. New entrants could be even more innovative solutions however, they are not a threat at the moment but new developments have to be monitored regularly. The force from suppliers pushes many machines to be produced due to bulk materials being cheaper. The buyers are crucial and will have to be informed about the importance of circularity so they can see the value in the product.

| Production operation | Price an hour [€] | Price [€] |
|---|---|---|
| Sawing | 65 | 850 |
| Drilling | 65 | 1250 |
| Lasering | 120 | 850 |
| Welding | 70 | 1000 |
| Bending | 70 | 900 |
| Milling | 90 | 3200 |
| Assembling | 160 | 6500 |
| Electrical assembling | 200 | 4500 |
| Programming | 200 | 3000 |
| Material | - | 7500 |
| Testing | 150 | 4500 |
| Cleaning | 120 | 1500 |
| Logistic | 60 | 600 |
| Total | - | 36150 |

*3) Customer*

Consumers of ready to eat meals and pre-cut vegetables and fruits in the Netherlands were surveyed by the project group. From a range of people from under 18 to 80+ it was found that on average, one person buys 8,5 pre-packaged meals or greens a month; the most popular places to buy them are Albert Heijn, Jumbo and Lidl, and the biggest annoyances with the current system are packaging waste and uncustomizability of the meals [4]. It can be estimated that a meal costs roughly 4 euros [5].

From market research the customer segment is defined as supermarkets & their customers who need quick, convenient and healthy meals and/or sustainably packaged food. Knowing that the environmental issue surrounding the current ready to eat meal use is relatively new, it is expected that large supermarket chains might not be the very first pioneers towards sustainability in this field. Which is why the environmentally conscious "green" supermarkets, and their customers are anticipated to be the early adopters of this product.

*B. Pricing strategy*

*1) Production costs*

In order to estimate the production cost, the total production needs to be separated in different actions. The prices an hour is based on experiences from internships. Most operations are logic therefor further explanation is not necessary. After components went through some operations these components needs to be cleaned before they can be assembled together. The cleaning of the components is quite expensive since the workspace needs to be clean and the cleaning equipment is quite expensive. When the components are cleaned they are ready for assembling. The price an hour for the assembling and electrical assembling is slightly higher than average since this has to be done in an clean environment. When the assembly is fully assembled, the machine will get tested in order to guarantee it's quality. Once it's tested, logistics will make the machine ready for transport. This means that the machine gets packed in a way that no dirt can come in the machine, logistics will also take care of the transport of components inside the factory. The estimated cost of production is 36150 euro. With an approximate 10% risk insurance the end production cost will be 40000 euro.
The selling price of the machine will be 80.000 euro. This number is based on the loans which need to be paid back but also the production cost of the machines that are not sellable since they didn't go through the test. In the future we expect the selling price to drop. Not only because higher volumes will make the costs go down but also the improvement in the production process which will decrease the number of failed machines.
The cost per meal for the costumer depends on certain things we have no say about. The cost of buying the food and the prices for every square meter in a supermarket times the square meters necessary for the machine.

*2) Investment goals*

In order to be able to produce the machines there need to be done some investments. Starting with a building where production is done, we estimate 500.000 euro in order to buy this building. The reason for buying the building instead of renting it is that in the building certain workspaces need to be very clean and construction needs to be done in order to keep it that clean. We estimate this to be 100.000 euro, another 10.000 for storing racks and 25.000 euro for a truck. For the machines used in production we estimated another 250.000 euro. This is excluding a laser since a laser machine will cost too much for the beginning. But eventually a laser machine will be bought. For the boxes and tray, molds needs to be created. We estimate these costs to be around 100.000 euro.

## Conclusion

The research question was: "How can plastic packaging in supermarkets in The Netherlands be reduced with an innovative technical solution as part of the I2E2 project?". In this paper it was shown that by means of a ready-to-eat meal dispenser machine the amount of plastic packaging can be reduced. This machine consists of a storage unit for the different ingredients, the dispensing unit for the dispensing of the food, the tray where the food is placed on, the conveyor belt that moves the tray and the transport box for moving the food towards the supermarket in the first instance. By combining these elements into one large design, an opportunity has been made to reduce or even eliminate the plastic packaging of ready-to-eat meals and pre-cut fruits and vegetables in a supermarket. This research also revealed that the market for ready-to-eat meals is huge, has been increasing, and is expected to increase even more. It also showed that this innovation would have the greatest impact in the supermarket sector. The weakness of this concept appeared to be the customer acclimatization to the product, however, the demand for sustainable solutions is increasing and the convenience of this product will quickly incline the customer to use it, as our survey showed. The selling price of 80.000 euro could be seen as expensive however this machine could benefit the supermarkets in many ways. When a supermarket buys a lot of machines at the same time the selling price will be able to be reduced. Making it even more interesting for the supermarkets to purchase one. All in all, we can conclude that by applying this technical innovative idea, a solid effect on the plastic pollution problem can be given which is needed in this current time.

## Acknowledgment

We would like to thank Maarten Haasnoot for guidance during this project. Maarten Haasnoot has been the tutor for this project group and has provided the project group with insights, guidance and knowledge regarding the project structure, the idea and the business side of the project. Chris.. has been helpful for this project for her input on the business side of the project. Also the team from the university of Barcelona has been a great asset in this project. Their input has been mainly related to the design of the boxes and trays.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Solutions for lowering the environmental impact in food packaging.

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***Abstract: One of the main environmental concerning about food packaging is the plastic consumption and its associated environmental impact in numerous forms: ranging from health effects on animal and human health to the obvious effects on the global warming. This problem is associated to the high levels of plastic packaging used in the food industry and retailing. In this study, we will investigate if there are some solutions to reduce this environmental impact by replacing the single-use plastics. The solution should be polyvalent for any kind of packaging and it should satisfy the needs in relation to keeping all the products safe. Our proposal is to study packaging solutions that allow multiple uses without wasting it. For doing this, we need an option that can be cleaned and returned to the supermarket like a reusable Food container or tray. It also should be transportable and taken to a home by the people. With this innovative solution, we will reduce the plastic consumption and its environmental impact.***

***Keywords: Market, environmental impact, greenhouse effect, single-use plastic, packaging, reusable.***

## I. Introduction

Plastic packaging has been used worldwide to protect food from the contamination and damage caused by humidity, moisture, microorganisms, light, gases and animals or insects. It is very useful and helps us to preserve the food for a longer period bringing us the possibility to transport it from one place to another. However, it has become one of the most polluting items nowadays.

This is the starting point of our project: it consists of the design and conception of food containers that could replace the packaging in the markets, reducing the material used in this area and by that reducing also the waste generated.

In this report we will analyse the life cycle of our food container design and the way we recommend using it, comparing it to the life cycle of the plastic used in the conventional packaging and the impacts of both. These impacts will contemplate the carbon footprint, the global environmental and human health impact.

## II. GOAL AND SCOPE

### A. Definition

Our target is to reduce the packaging used in foods, which it is difficulty comes when considering the job well done that the actual package does by fulfilling its function perfectly. Packaging in foods weigh very little, that means that they can be carried from one place to another without increasing the weight we are carrying and still be very resistant, letting us carry relatively heavy weights in most cases.

Another positive aspect of the actual packaging solution is that they are very cheap to produce, so you can use lots of them without paying much money. That is also a negative point, because it is so affordable that people tend to not reuse it as much as they could and to throw them away without hesitation. This is the main reason why packaging is one of the most polluting products and it is the first thing that comes to mind when somebody thinks about pollution on our planet.

Our idea was to design food containers to be used in the Barcelona municipal food markets that mainly offer bulk food (fresh meat and fish, vegetables and fruits and ready-to-eat food). The main idea is to design a packaging that customers could reuse several times for free and only leaving a deposit. Our work will also include the developing of a tray that could be used in an innovative food dispenser that is being developed by students from Fontys University in the Netherlands.

The idea of working with markets came because they tend to work with bulk food more than supermarkets do, so our product would make more sense in a place where already packaged food is practically non existing. In fact, having a real impact in supermarkets is highly challenging if they do not are the direct responsibilities of the packaging of their suppliers. Our audience would be people who buy in a municipal market and more specifically people who tend to go to these kinds of markets more often. This is because of the idea surrounding our product, which involves a food container borrowing system, meaning that the food container must be given back to the market in a preestablished frame of time.

The option for supermarkets is to design a tray in which the bulk food will be dispensed and then the customer takes it home, then the system is the same as the market, the tray is returned to the supermarket and the cycle starts again. The food would be dispensed in a machine which has been designed by Fontys University.

Talking about the alternatives of using packaging in foods, there are lots of other options that are better than the original product and have lower impacts on the environment. If these alternatives are used lots of times and have a larger life than the classic plastic bag, we could say that other good options could be the cloth bag, the traditional shopping cart, raffia bags or compostable bags, all of them being far better alternatives. In the case of municipal markets, we don't find much of those, and if we consider the plastic used in the food industry, we could say that supermarkets waste even much more plastic.

The system we came up with starts when the personnel that work in the market use a food container to put the food inside. By choosing between all the food containers available with different sizes that are in the store and picking the most appropriate size for the product being bought. The customers could take all the food containers to their house and place the food where they want. The design of this product gives us the possibility to put this food container directly inside the fridge or microwave, as it can hold the temperature, so it is easy to store the food containers inside the fridge or heat the food in a microwave.

Then, when the user has finished all the food inside the food containers, they should bring them back to the market in a specific point or in any shop, where specific personnel hired by the market would clean them so the cycle would start again.

### B. Functional Unit

a) In order to be able to compare both packaging solutions a unit of measure is needed, this has to be equally representative for the two packages. Kilograms could not be used because the food density can vary hugely, so the measure that fit the most was volume. So the study has been done with litters of packaged food as a unit.

### C. System Limits

1) Geographic system limits: The life cycle analysis is applied to Spain because data has been more accessible to find, for example, the per capita consumption and the market materials. But the application of the food containers can also be done in The Netherlands.

2) Temporary system limits: The packaging should last at least two years so the comparison between the two packages is studied with a two-year time frame, nevertheless if the package would manage to endure more than two years then the LCA result would be even better.

3) Natural system limits: In this study we have used the package used in the markets in Spain, not only the material of the package itself but the procedure to manufacture the package too. The markets from Spain have granted us this information, so this will be used in the project.
   The only problem comes when the study is tried to be carried in the supermarket, because no data has been found about the material nor the procedure of its package.

## III. INVENTORY

We have carried out a search of the annual consumption per capita in Spain [2]. With this data, the next step is to carry out the necessary calculation to determine the number of necessary calculations to determine the number of necessary units of packaging to cover the determined consumption [3]. (Figure 6)

The calculation has been carried out in such a way that the number of packaging units necessary for each type of food is determined, also with the aim of comparing the traditional packaging required with the new packaging designs.

We needed to know the packaging that was being used with each product to calculate how much plastic was being used, there is a flow chart showing which packaging corresponds to each food [1].

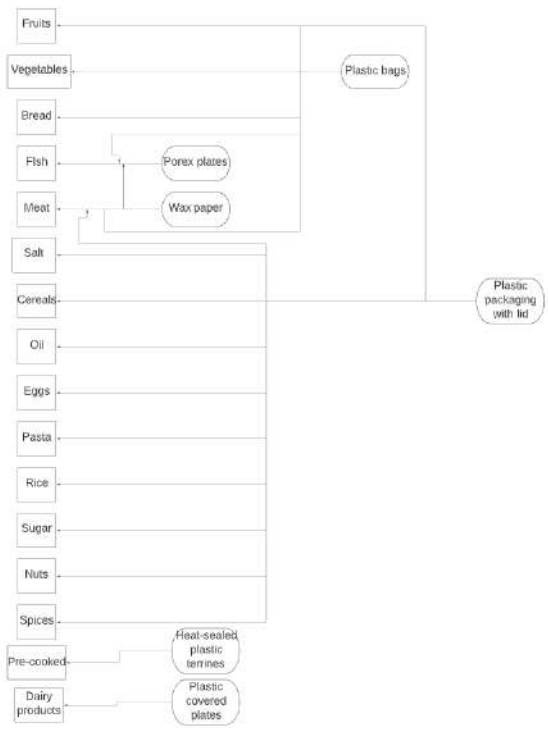


*Figure 1: Conventional market inventory scheme*

Now we will show a list for each of the two options (one showing the current package used for one person per year and the other showing the food containers that the same person would use instead), there is a calculation of the necessary units of each type of packaging to cover the whole food an adult would consume in a year time in Spain. Also, we have the mass per unit corresponding to each of the different types of packaging.

In the case of the new method (using food containers), the number of units indicated in each of the types of packaging is calculated using only one type of food container for the whole food consumed in a year by one adult in Spain.

On the other hand, in the case of the traditional method, the units of each packaging are determined considering that all those types of packaging are being used at the same time to cover the consumption determined by the previous consumption calculation.

### *A. Conventional markets inventory for one person: [4]*

-Plastic bags: 57u; Weight/u = 2.56g
-Plastic bottles with lid: 56u; Weight/u = 19g
-Wax paper: 57u; Weight/u = 17.10g
-Plastic covered plates; 80u; Weight/u = 14.3g
-Polystyrene plates: 34u; Weight/u = 5.2g
-Heat-sealed plastic terrines: 6u; Weight/u = 28.6g

### *B. New method markets inventory for one person:*

-EUSS food container: 1000ml: 423u; Weight/u = 128.18g
-EUSS food container 750ml: 558u; Weight/u = 107.12g
- EUSS food container 500ml: 839u; Weight/u = 83.22g
- EUSS food container 250ml: 1675u; Weight/u = 54.97g

In the case of the new method using food containers, the number of units indicated in each of the types of packaging is calculated using only one type of food container for the whole food consumed in a year by one adult in Spain.

On the other side, in the case of the traditional method, the units of each packaging are determined considering that all those types of packaging are being used at the same time to cover the consumption.

## IV. MATERIAL AND DESIGN

When the goal and scope has been determined, a design and material choice for the new package must be done. Keeping in mind that the target is to have a better replacement (not only when it comes to pollution) the software CES has been used, this allows us to put various filters regarding material properties. To do the choice a previous benchmarking has been done to eliminate possible materials like wood or metal. So then only plastics that were highly recyclable suited the application.

The intention of the material proprieties filters is to have a plastic which is suitable for; microwave and frost use, can be manufactured using the moulding procedure, can endure water and organic solvents, can endure the sun and not being flammable.

Once the filters had been applied only 4 materials were suitable. So, some comparisons were made between the 4. The first comparison was the price and the Young modulus divided by the density, so we could know which material had the best strength/weight ratio and the cheapest material. Allowing us to have a light, strong and cheap container. (Figure 7)

The second and last graph was done looking for the less polluting material when this is recycled, this was the PP copolymer, but since the PP has a higher percentage of material recycled, is lighter, stronger, and cheaper. (Figure 8)

Finally, the material chosen was the polypropylene (PP) homopolymer, which comes from thermoplastics, but it has a flame retardant additive. Once the material is chosen, the next step is designing the food containers and trays.

### *A. Tray*

When it comes to the tray this has a simple form with three divisions, that allow the user to put three different types of food in the machine developed by the Fontys university.

This tray has a 1.33 litre capacity, a size of 160x45x260mm, a weight of 280gr and it has the possibility to put one above the other because the lid fits with the bottom of the tray.

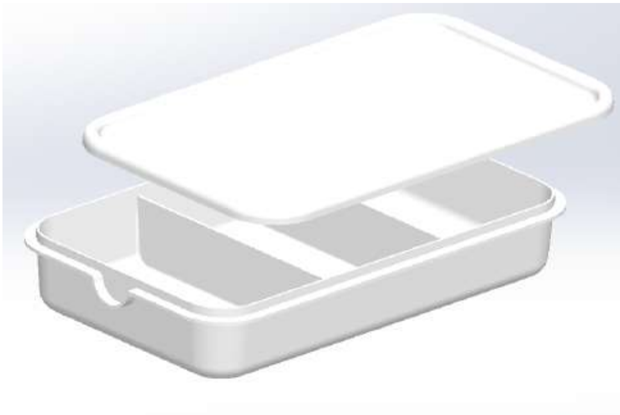

Figure 2: Design of the tray used in the dispensing machine of Fontys

### *B. Food container*

The design of the food container is very simple, and all the 4 variants have the same proportions. The 4 variants have different capacities: 250 ml, 500 ml, 750 ml, and 1000 ml. The food containers have been designed to fit one inside the other, so they occupy less space in the market.

Figure 3: Food container designed to be used in market

The weights and dimensions are the following:

250ml food container
Weight: 42,2 gr
Size: 85x50x107

500ml food container:
Weight: 64 gr
Size: 103x61x131 gr

750ml food container:
Weight: 82,1 gr
Size: 116x68x148 mm

1000ml food container:
Weight: 98.07 gr
Size: 126,5x74x161 mm

## V. IMPACT

ReCiPe has been used as the impact method in our LCA study. This allows us to present results in terms of impact categories and, consequently, much easier to understand. The objective of this method is to transform the results from the inventory, into indicator scores, a much shorter list. These scores express the relative severity of an environmental impact category.

### *A. Conventional markets packaging*

As it can be seen in the next flowchart the PET sealed tray is the one with the highest impact when it comes to the package of the markets.

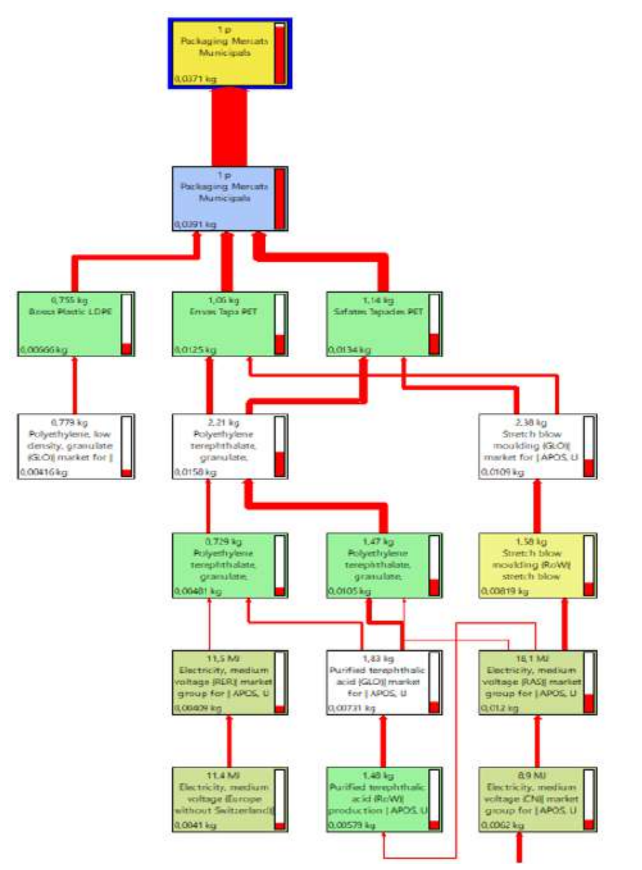


Figure 4: Life cycle assessment for actual municipal markets packaging

The category in which conventional supermarket's packaging have the higher impact is water consumption and terrestrial ecotoxicity, followed by fossil resource scarcity, ionizing radiation and human non-carcinogen.

### *B. New method market packaging*

In this case we have more than one option, as we have four types of packages. So, this is going to be an analysis of all the types choosing the best option in any kind of evaluation.

First, we have the characterisation, where the food container of 250ml has the highest punctuation in all the categories except terrestrial ecotoxicity, and water consumption. Exactly where the conventional packaging has the highest level of impact. On the other side, we have that the best option in the case of characterization is the food container of 1000ml, because it has the best punctuation in general on the categories, except some of the categories where the best option is the traditional packaging. But in any case, the food container of 1000ml does not reach by far the levels at which the traditional one maintains the highest levels of impact. (Figure 10)

The level of damage in this case is like the level of impact in the case of the characterisation, the food container of 250 ml has the highest level of impact in all three categories. In this case, we have that the best option of the food containers is the food container of 1000ml. As we can see, it has the best punctuation in all three categories (human health, ecosystems, and resources). (Figure 11 & 12)

The first bar (green) is the impact which comes from the municipal market's packaging, the second one is the 1000 ml food container. The orange one is the 750 ml food container. The fourth bar (yellow) is the 500 ml food container and the last one is the 250 ml food container. (Figure 11 & 12)

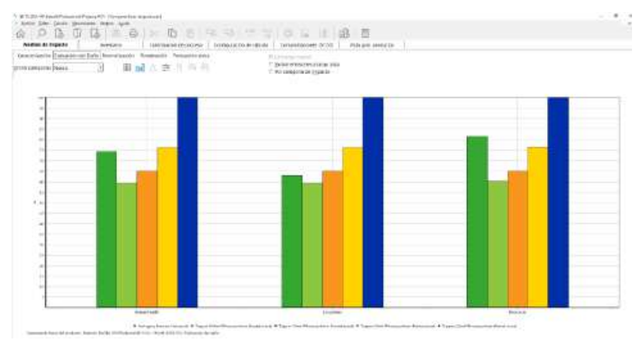

Figure 5: Impact analysis damage evaluation in percentage for two years of the 1 litre food container, 750 ml food container, 500 ml food container, 250 ml food container and the market packaging

To finish, we have the results of the ponderation. As we can see, the punctuations decrease so much in the categories of ecosystems and resources but maintain the same levels in the category of human health. At the same time, we have the same results in the damage evaluation. The best option remains the food container of 1000ml and the worst option is the food container of 250ml even a step behind the traditional packaging.

## VI. Analysis of Results

Once the LCA has been carried out, as explained above, we have realized that replacing the current packaging for the proposed food container is beneficial. This statement can be seen in figure 31 which gradually shows the impacts on human health, ecosystems, and resources. In figure 31 it can also be noticed that first, we have the 1 litre food container, then the 750 and 500 ml food container, but the 250ml one is above the current packaging. This could be due this study is calculated for the biannual cost of just one type of taper, not a combination.

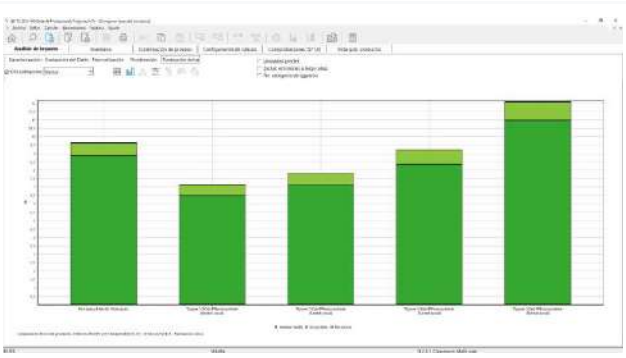

Figure 6: Impact analysis unique punctuation for two years of the 1 litre food container, 750 ml food container, 500 ml food container, 250 ml food container and the market packaging

## VII. Conclusion

Given the results it can be concluded that the new package design is more eco-friendly (even with a very pollutive washing procedure) than the market package used nowadays if this endures at least two years. Then if this could endure more then the difference between them would be bigger.
The results if the food container lasts two years have as the less pollutive option the 1 litre and being followed by the 750 and 500 ml, the only one that pollutes more than the market packaging is the 250 ml food container. This could be due to different factors. The first possible factor could be that the washing procedure used in the software is the one used in a washing machine instead of a dishwasher machine. The other possibility could be that the study is only considering two years and does not take full profit of the food container.
Or simply that the 250 ml food container is simply not as eco-friendly as the other options and there is no way it could be less pollutive than the market packaging. A deeper study should be made to explore the possibility of using these food containers more years and see if the 250 ml is viable in a longer period.
Last but not least it is shown in the flowchart that the most pollutive procedure is the washing procedure not the injection of plastic, so if food containers would be cleaned in an industrial dishwasher instead of being cleaned in a home washing machine then the results should be better when it comes to the new package.

## VIII. Annex

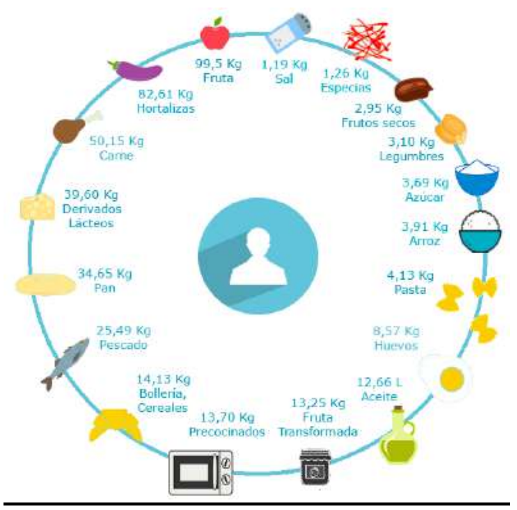


Figure 7: Percentage of the different types of food consumption per capita in a one year time

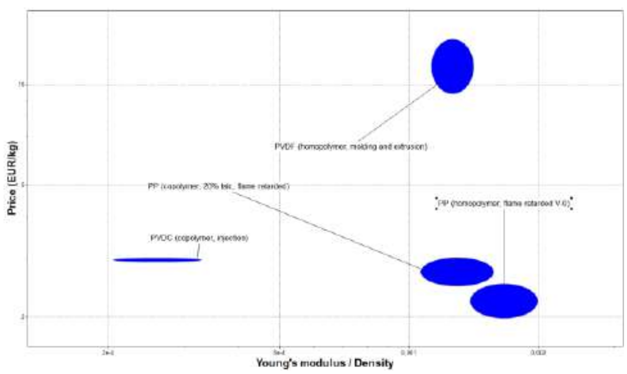


Figure 8: Graph of price and Young's modulus / Density of the choosing of the material

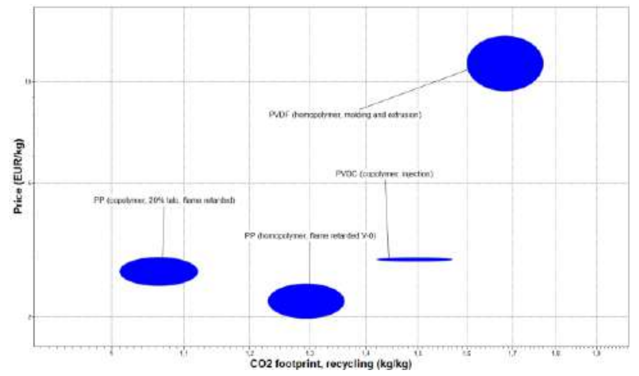


Figure 9: Graph of price and CO2 footprint of the choosing of the material

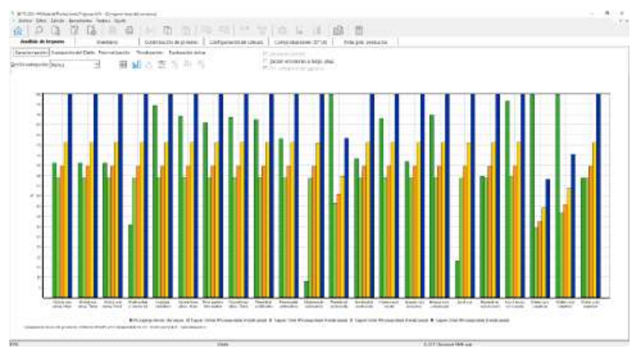

Figure 10: Impact analysis characterization for two years of the 1 litre food container, 750 ml food container, 500 ml food container, 250 ml food container and the market packaging

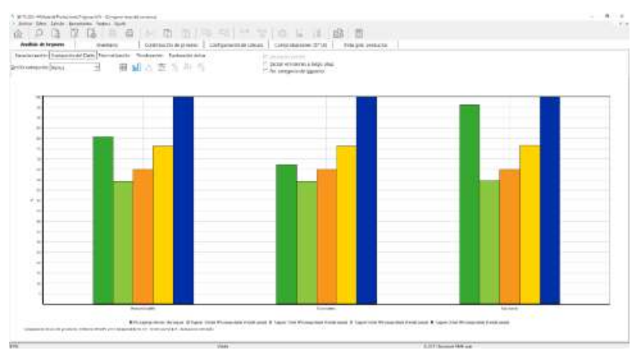

Figure 11: Impact analysis damage evaluation in percentage for two years of the 1 litre food container, 750 ml food container, 500 ml food container, 250 ml food container and the market packaging

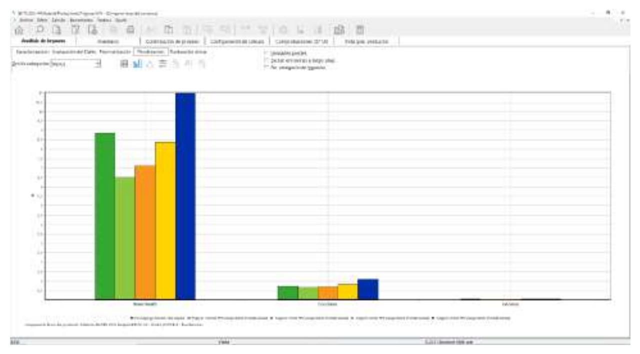

Figure 12: Impact analysis ponderated for two years of the 1 litre food container, 750 ml food container, 500 ml food container, 250 ml food container and the market packaging

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Water Pollution Monitoring and Automatic Microplastic Sampler

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***Abstract*— The distribution, quality and quantity of drinking water will become scarcer in the future. It is therefore important that new innovations related to water conservation and harvest technology are being produced. But before real action can be taken to reduce the pollution of rivers, lakes or the sea, it is important to document the current level of pollution. The last decade microplastics became an increasing polluter. The impact of microplastics is still not well-known. Therefore, creating a device that allows for large-scale and high-density research into this pollutant is useful. Along with other parameters that have a large impact on the quality of water. Since the best understanding can only be reached when everything is put into context. The result of this project is a device capable of producing an array of samples for research instances for different parameters related to water quality.**

***Research question— How can the sampling process for microplastics and water quality be simplified?***

***Keywords— Microplastics, water, quality, sampling, samples, sensors***

## I. Introduction

The summer of 2021 remembered the western European citizens of the importance of water management. The flooding caused by huge rainfall cost the life of 217 citizens whilst a 158 remain missing till this day [1]. This shined a light on a pressing problem that is caused by the upcoming climate change. The availability of water is guided by larger extremes where periods of draught are followed by extreme rainfall [2]. This phenome endangers the water availability for upcoming generations where these peaks in water availability and water scarcity emphasizes the need for water management. Besides the large fluctuations in the available quantity of water, the quality of the water in the natural bodies of water is deteriorating [3]. The increasingly important nature of this problem made it perfect for the I2E2 project organised by Fontys Engineering and ECAM. The I2E2 project tackles contemporary problems where the applicants are challenged to engineer solutions for these problems. Therefore, this project is conducted by a team of students from Fontys and ECAM. Within 20 weeks the team must determine and realise a technical design within this problem areas. At the start the following project definition is given:

### A. Problem definition

Clean water is likely to become a scarce commodity in the future. At the same time, it is projected that the cost of clean water for domestic and commercial use will continue to increase, especially for environments where water is scarce. These costs for drinking water are currently low in comparison to the value for mankind. Currently a lot of business cases are financial not viable due to these low costs. Nevertheless, due to the high value of clean drinking water and the forecast for upcoming water scarcity this remains an important research area. This makes water conservation and harvesting a key challenge in households and commercially. It is therefore important to continue to innovate in water conservation and harvesting technologies within the built environment.

## II. Background of the project

The goal within this project is to propose an innovative concept in water conservation & harvesting technologies within the built environment; key attributes of these concepts must include cost effectiveness, public acceptance, efficiency and modularity.

This is a broad description and within literature research several possible problem areas were determined. These topics consisted of the following general guides:

- Grey water collection:
  - In this application rainwater is collected from roofs. To decrease the peak stresses upon the sewer systems.
- Grey water reuse:
  - In this application water is collected after being used in relative clean applications (shower, sink etc.). Afterwards it is cleaned or used for flushing the toilet.
- Creating awareness:
  - Giving a better overview of water usage in households by designing a smart water meter or measuring usages per device.
- Monitoring water quality:
  - Automating water quality monitoring whilst getting a better insight of water quality in natural water bodies.

These different topics were researched and investigated by stakeholder analysis. This is described in [4], [5]. After this report a contemporary problem was determined by the research process. The monitoring of water quality in rivers, where microplastic sampling was one of the main focal points. This is mainly for the following reasons:

- Microplastics have been identified as an upcoming concern by the WHO [3].
- The sampling of microplastics is currently a labour-intensive process [6].
- Monitoring water quality values is not yet done at a large scale [6].
- The process of collecting these values is not off grid [7].

However, microplastics are not the only variable that impacts water quality. It is therefore a good opportunity to not only focus on microplastics but an as wide as possible spectrum of parameters related to water quality. Since any device that collects samples for microplastics will have to be placed in or near water, the addition of sensors for the further examination of the water quality is a natural next step. These values combined results in the following research question: How can the sampling process for microplastic and water quality be automated?

To answer the research question the paper will be organised as follows; Section 3 discusses the approach and theoretical background for microplastic sampling and water quality control. Thereafter section 4 describes the technical design split up between the mechanical and electrical elements. In section 5 the methodology for design verification is discussed. Lastly the conclusion for the research question is given.

## III. Approach and theoretical backgrounds

### A. What is the measuring process for microplastics?

Determining the amount of microplastics in a given body of water is not as straight forward as using a sensor to measure the concentration. Microplastics are defined as plastic particles smaller than 5.0 mm in size. There are two types of microplastics that enter a body of water in different ways: primary and secondary microplastics. Primary microplastics consist of raw plastic materials, such as plastic pallets, scrubbers or microbeads. These particles enter a body of water via runoff from land. Secondary microplastics come from the degradation of lager plastic pieces that have entered a body of water. Whether microplastics are primary or secondary does not matter, they have the same polluting effect on the environment and can be detected via the same methods.

#### 1) Analysis method for water samples using filtration

Microplastics within a water sample are pieces of suspended debris. These are collected form the surface layer of the water. This collection happens by making use of a floating device called the manta, see Fig.1 from [6]. This device has a rectangular intake box, with floating and stabilising wings on the side, allowing it to remain on the surface layer of the water. Attached to the intake box is a conical shaped net, the point of which is attached to a filter. This filter contains sieves with sizes ranging between 5.6 mm and/or 0.3 mm. Once the sample is collected, the sieved material is dried in order to determine the amount of solid mass. Next the sample is subjected to wet peroxide oxidation (WPO) in the presence of a Fe(II) catalyst, this digests labile organic matter but leaves the plastic debris unaltered. The sample is then subjected to density separation in NaCl(aq) to isolate the present plastic debris through flotation. The floating solids are separated using a density separator and are then collected using a 0.3 mm filter. Lastly, the sample is air-dried, the plastic material is removed, by making use of a microscope, and weighed to determine the concentration [6].

*2) Analysis method for water samples using sedimentation*

A sample is taken by pumping water through a sedimentation trap. This a box with an interior structure that slows the water down enough for the suspended debris within to settle at the bottom of the box while the water leaves at the other end. This pump allows the water to be pumped with a constant water flow. This allows for better comparison between different locations, where the natural flow of the water can vary significantly. The input of the pumps is also covered with a sieve in order to prevent larger debris from entering it. Once the sample is collected and analysed using a GC-MS (Gas Chromatography-Mass Spectrometry) method. Firstly the sample is heated to the point that all organic matter within is burned away, leaving only the plastic material. The plastic material is then vaporised after which the molecules can be analysed. The result of this analysis is the present mass of microplastics within the sample [7], [8].

*3) Sampling and measuring*

In the before mentioned methods for analysis of microplastic two sampling methods have been discussed. The method for taking a sample is not intrinsically linked to the method of analysis. This means that a sampling method making use of filters can be used in conjunction with the GC-MS method. Similarly, a sedimentation sampling method can be used in conjunction with the WPO method.

*4) Market research*

After the general sample collection methodology determined market research is conducted into the possible solutions that are already available. Here special focus is applied to the different type of microplastic devices. These devices are researched, the researched systems have all been used in the Netherlands. Afterwards, their strong point and weaknesses are given in [9]. These different solutions are determined through literature research [5] and stakeholder interviews [4]. These solutions are all ranked to their specific strengths and market share in a Boston matrix (BCG matrix). This determines the market share of the different techniques. Here is seen that filtration has the current biggest market share, this is mainly due to ease of use and high quality of sample. The sedimentation is an upcoming technique, it has less versatility but is able to process large volumes of water. Between these characteristics there is a market share for a system with high versatility and sample quality.

## *B. Measuring water quality*

Currently the main way the quality of any given body of water can be measured requires a large-scale sampling process. This varies with each parameter that is being measured, however within this project it is assumed that an array of parameters, at least larger than one, is desired to be examined. Therefore, when a more complete assessment of the water quality of a body of water is to be made, several parameters will have to be measured at once. This means that multiple samples will have to be taken, each of which will have to be studied individually within a lab or a surveillance station, which in turn will have to be established first.

# IV. DESIGN/RESEARCH MAIN RESULTS

## *A. Mechanical design choices*

*1) The Buoy*

The device is composed of an anchored buoy which houses a whole set of electronic devices. These include a sensor which gathers data about the water quality that are stored on a memory card, which can be collected along with the microplastic samples produced by the microplastic sampler that is also housed within the buoy.

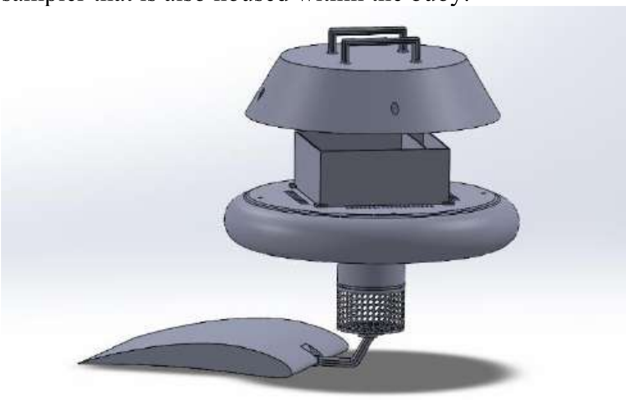

*Figure 1: Buoy design.*

The Buoy is made of three parts that are connected:

The first one is the housing that contains the microplastic sampler and the electronics dedicated to the water quality monitoring and contains the water exhaust needed for directing the water circulating through the sampler.

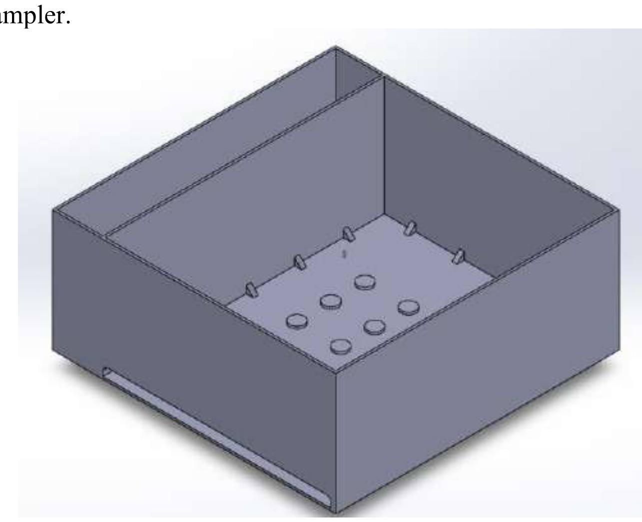

*Figure 2 Housing box design*

The whole system is protected by the hood of the buoy which is bolted to the mainframe of the buoy and contains a handle to be easily picked up from the water.

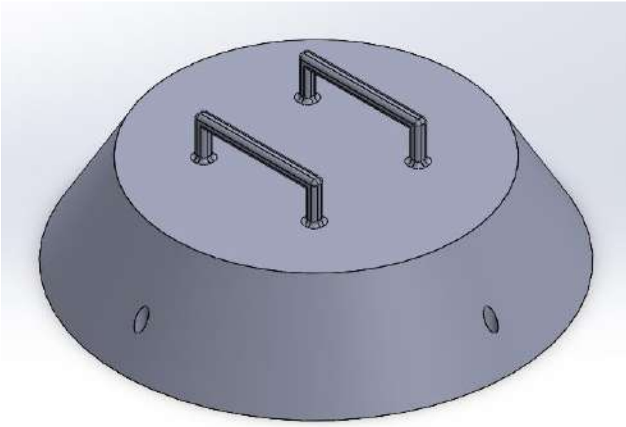

*Figure 3 Hood design*

The second part is the frame of the buoy which serves multiple purposes, the main one is to serve as a flotation device for the micro-sampling box and also serves the role of a hub for all the other parts such as the sensor cabinet underneath and the micro-sampling box up top and finally contains the anchor point.

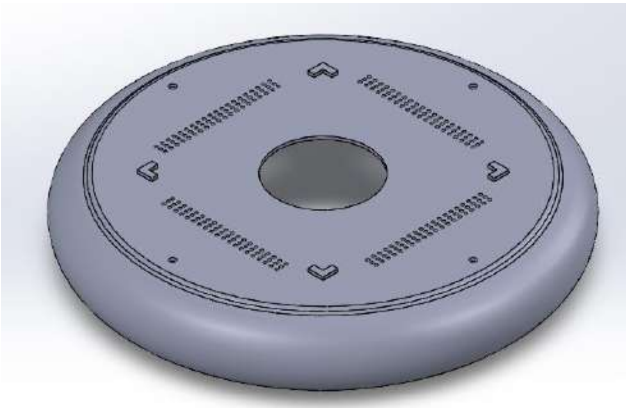

*Figure 4 Buoy mainframe*

The third part id the sensor cabinet which will hold all the sensors described previously and protect them from any debris or eventual damage. It is composed of an upper cylindrical sealed part where the electronic parts of the sensors will be placed, and a lower screened and therefore submerged part where the probe parts of the sensors will be placed. The two parts will be hermetically linked to avoid any presence of water in the upper part.

*Figure 5 Sensor cabinet*

The last part is the wing of the buoy that keeps the device as flat and steady as possible to prevent any miscalculations in the micro-sampling process. The surface and profile of this wing has been calculated and designed to counter the effect of the current on the buoy and keep the system in horizontal equilibrium.

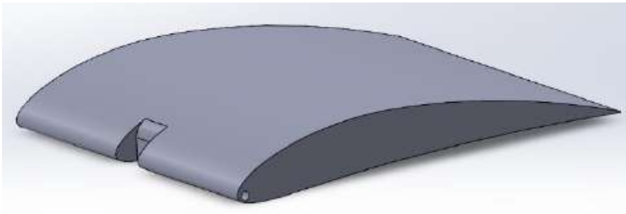

*Figure 6 Wing design*

The entire device is powered by a battery, which in turn is charged by a solar panel. This allows the device to operate without being connected to the power grid.

*2) The Sample unit*

In order to design the sampling unit, the morphological chart and Kesselring methods where applied. This allows for an overview of design choices, out of which the most optimal design can be chosen.

The first step was to break down each separate function of the system. In order to produce several different solutions for each function. All these solutions were plotted within a morphological chart against the functions. Then these solutions where combined into three different concepts, these concepts where then tested against the requirements using the Kesselring method. The result of these steps is a design that fulfils all the requirements.

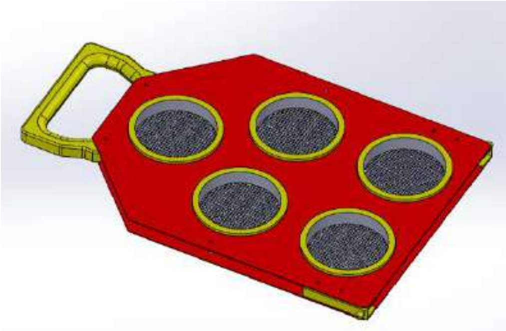

*Figure 7: Sampling tray.*

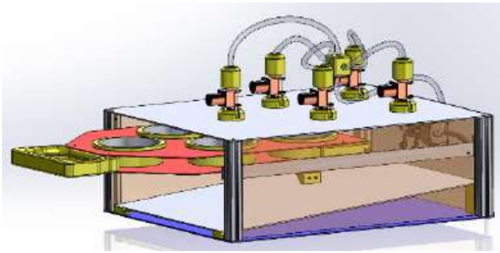

*Figure 8: Sampling box.*

The chosen design is the most optimal solution compared to the others because it has a low mechanical complexity and still able to have a consistent sampling process. This characteristic allows the device can be relatively low cost while require less frequent maintenance. Within this solution the sampling method is filtration. This method is selected because it delivers the most accurate samples. And gives the researcher the capability to test for different microplastic sample sizes by using different mesh sizes in the filter. This type of filtration is linked to a pump to ensure that the system can be implemented in every location. In addition, the water flow is constant for each system and makes the measurements comparable for each situation.

The sample unit consist of two components: the sampling tray, seen in Figure 7, and the sampling box, seen in Figure 8. The sampling tray is a module that can contain up to five stainless steel sieves, which can be quickly inserted into the sampling box. The sampling box is a module that contains a pump, five electrical water valves and a tilted plate that directs the water to the exit. The pump directs the river/lake water onto the sieves with a consistent flowrate. The electrical valves control which sieves collects the sample, this allows the device to collect samples over the course of several days. The valves enable the system to have less moving parts. Therefore, the filters can stay in a fixed position during operation. This increases the reliability of the system and makes exchanging the filters easier. The different valves allow the researchers to study the change in microplastic concentration in a more efficient way, since it allows for a data set over a longer period of time. Finally, the tilted plate directs the outflow water back to the river/lake with a enough distance away from the inlet of the pump to prevent contamination of the samples.

This sampling unit will be implemented within the buoy so that the intake pipe of the pump on the sampling box can reach into the river water.

### *B. Electrical design choices*

#### *1) The Sensors*

Since the device will be submerged in the water and help measure its microplastic concentration, it felt natural to be interested in gauging other water quality parameters which could pique the interest of municipality or water quality assessing organisms.

The choice was made to use sensors that could be used directly within the buoy instead of the usual sampling method widely used nowadays. Naturally, the measurements made this way will lack in precision however their sheer number as well as their ease of accessibility and cost effectiveness will provide for a new kind of water surveillance technology.

In order to provide the most relevant data as possible, the SDEA (Syndicat des Eaux et de l'Assainissement d'Alsace Moselle) [10] was contacted and asked which sensors and parameters should be prioritised. After exchanging a few mails, the choice of the sensors was made according to their feedback. Those are:

- Thermometer: Even though not directly linked to water quality itself, temperature is an interesting parameter to monitor since warmer waters tend to help the development of micro-organisms. Furthermore, as we can already see the consequences on climate change, this will help to assess their evolution in the riverbed.
- Conducti-meter: The conductivity of a water body gives a good indication of its ionic concentration thus of its mineral charge. A river featuring an excessive conductivity is considered of poor water quality.
- pH-meter: pH is an indicator of the acid-base equilibrium. Water suited for consumption has a pH between 6.5 and 9.
- Turbidity sensor: Turbidity corresponds to the concentration of trouble material in a liquid. In rivers, those materials are often mud particles, but a high turbidity can also betray the presence of a high concentration in bacteria or micro-algae.
- Nitrate concentration sensor: Nitrate concentration in a water body is a health parameter as well. It is an efficient indicator of agricultural (pesticides and fertilizer) as well as urban (leakage in sewer systems) or industrial pollution.
- Chlorine concentration sensor: Chlorine are natural elements found in water body due to dissolved salts. The evolution of its concentration could mean a change in the riverbed or source. Water containing a high concentration of chlorine also increase the risk of cardiovascular diseases.
- ORP (Oxidation-Reduction Potential) sensor: ORP is a tool used widely to gauge water quality.

It combines some of the already assessed parameters but gives a better idea of the overall quality of the river water.

The results of these sensors will be gathered and sent wirelessly to a dedicated computer which will compile said data to help monitor the evolution of the different studied parameters.

The sensors will not have to operate 24/7, instead they will be activated once every specified time interval. The microcontroller that is in charge of the data measurement will operate in sleep mode. Thereby, the overall system will consume as less energy as possible. The system will "wake up" after a certain amount of time (data gathering frequency, define by the user) in order to gather all the sensors data, before going back to sleep. This will allow for the conservation of the used energy of the entire system and the users will have the opportunity to see the evolution of the different parameters of the water (stating possible peaks of chemicals, see recurrency issues, or just monitor the constants).

The data gathered by the sensors will also be stored on a SD memory card which can be collected alongside the microplastic samples. This SD memory solution is aimed to be improved into a system using Internet of Things.

The goal of such an amelioration is the creation of a network of such buoys in the prospect of assessing the water quality and microplastic concentration along a whole riverbed. In addition to the monitoring of these parameters over time, an IOT enhancement will also enable municipalities and water quality measurement organisms to see their evolution geographically. All the data would be sent to a datacentre in order to be treated and assigned each point along the river. One of the applications of such a network would be the detection of industrial spillage for example. Detecting a peak in nitrates on a buoy but not on the one upstream helps the localisation of the issue and its faster and easier solving as well as the prevention of such issues.

Such a system would thus be mainly autonomous, requiring little human intervention when it comes to the monitoring of the water quality besides the retrieving of the microplastic filters. The interconnected buoy providing a whole city or even a region with an efficient water quality assessing grid at its disposal

*2) The Sampling unit*

To create an autonomous system able to carry out operation with as little as possible required infrastructure the system needs to generate its own power. The system power will be provided by a solar panel which will charge an installed battery when power production exceeds consumption. The system will therefor be able to operate without the need of a connection to the power grid. With the currently selected battery capacity and solar panel, the system is able to do 2 samples a day with 1 hour of sunlight a day. If more samples need to be produced this can easily be achieved by increasing battery capacity and the installation of a second solar panel.

The sampling process chosen for the system is by pumping water through filters. As mentioned previously a total of five samples are available within the system. The selection of which filters will be used is done by using valves positioned above all filters. A microcontroller will be able to control the opening of the valves and the starting of the pump. After enough water has been pumped through the selected filter the valve will close again and the pump will be stopped. The valves selected for this process are bi-stable to keep power consumption low.

By featuring a remote connection on the system, the system can be monitored and controlled without needing a physical connection. The system is able to send reminders when clean filters need to be placed or when errors occur. It also allows for the remote monitoring of the sensors installed within the system as explained at chapter IV.B.1). Using this remote connection certain parameters can also be programmed. For example, the interval in which filtering needs to be done can be setup, but also the required litres of water filtered to complete a sample.

## V. Verification results

In order to ensure that a prototype works according to the user and system requirements set at the beginning of the project. These requirements, along side the project boundaries and the desired project result, can be found in the plan of approach [11]. The test plan needs to test the device on all factors, if all tests have a positive result, the system is ready for use.

When all project boundaries and user requirements are met, the project result is achieved. Based on the test plan, feedback can be given on the plan of approach and the main & sub questions.

To test the product, several tests have been set up, divided in categories: mechanical, electrical, software and general.

Mechanical tests cover all the static parts, such as those which are lasered and bend, but they also cover all connections (nuts, bolts and screws). These parts are examined individually but also in combination which each other.

All parts with an electrical component shall undergo the electrical test. These parts include: cables, connectors, motors, relays and sensors.

The general test is the most important one to ensure that the product meets the requirements. In this general test, all subsections (mechanic, electrical and software) are tested in combination with each other.

During the course of this project a prototype was made, dimensions and materials may vary. The purpose of the prototype is to have a "tangible" model to test the new product concept, service or process. The purpose of a prototype is to have a tangible model of the solutions to the problems already defined and discussed by the designers during the concept/idea phase.

If the tests are successful and have been carried out the specific numbers of times, the probability of failure is virtually zero.

## VI. Conclusion

This paper presents the research into water quality measurements where the following research question is stated: *How can the sampling process for microplastics and water quality be simplified?* To answer this question firstly an analysis of the sampling methodology and water quality measurements is made. This analysis determined that sampling by filtration is a better fit for microplastic sampling due to the following benefits: The difference in microplastic size that can be detected; the capability of samples with different volumes and the accuracy of the system. This filtration system is linked to a pump to allow different sample volumes whilst keeping the flow rate steady. This makes the system applicable in all bodies of water, even in lakes. The changing of the filters is done by a simple linear sliding mechanism. This keeps the complexity of the system low and makes operating easy. To change the location of the water flow within the system, valves are used. These valves are chosen because they have low power consumption due to the bi-stable control. Whilst being a reliable solution, because it requires fewer moving parts within the filter exchange system. For the water quality measurement SDEA was contacted. From here the necessary values were determined to measure water quality. This resulted in seven different sensors, these sensors are installed in the device and collect the required data on pre- determined intervals. The data is thereafter remotely sent to a database whilst also being stored locally. The measurements are processed in intervals to keep power consumption low. Lastly all the separate elements are combined in a buoy. This device is designed to have a central compartment. Here the electronical components are stored and the microplastic sampling unit is placed. The inlet of the pump is protected by a rotating grid consisting of angled fins. This generates the rotation and makes sure that if debris gets stuck in the fins the rotation removes it. The power storage is also stored within the centre of the device where the top of the buoy has room for several solar panels to replenish the power. To keep the buoy fixed in the desired location an anchor is used.

The combination of these elements creates a design of a self-sufficient system which can operate off the grid due to a battery combined with solar panels. This enables the system to collect samples at places that where previously difficult to access. The system is able to collect different samples volumes orientated towards different microplastic sizes. Whilst keeping the sample quality at a high standard. The only labour required for the sample process is to collect the samples at a preferred moment. The water quality measurements are fully automated and sent at intervals toward the cloud. These elements are all combined in a buoy where a grid system is used to keep the water intake clean. This device automates the microplastics sampling and water quality measurements. Therefore, succeeding in fulfilling the research question.

To verify the design all the elements need to be tested accordingly to the test plan. Afterwards the conclusion is given if the design meets all the demands. This test determines if the device operates as designed.

## Discussion

After this research the results suggest that there is a market for an automated microplastic sampling device. The sampling of microplastic has increased over the past decade and research is demanded. There are several competitors within the market but not yet a market leader. The generated product has special features which make the sample quality and diversification a strong suit for the envisioned design. To check how these strong suits are valued by microplastic researchers an investigation with a leading research facility needs to be conducted. Besides this, the design needs to be produced and validated according to the test plan. Where special focus needs to be applied to combing the systems together and creating a sturdy, reliable system.

## Acknowledgments

First, we want to thank our tutor Mr. Hans Smaal for his enthusiasm and advice. Also, we want to thank Mr. Hay Geraedts and his European colleagues for organizing this “International Innovation Engineering & Entrepreneurship Project”. We would like to thank Mr. Turko (ECAM) for his diligence as well as his comprehension towards our project as well as Mr. Sire (ECAM) for his insight and the experience he shared with us for the patenting part. A special thanks to Mr. Mossmann (ECAM) as well who was kind enough to lend us his own hardware so we could train on it while waiting for our sensor order as well as Mr. Di Domenico for his professionalism and understanding in the organisation of this collaboration.

Next, we want to thank our stakeholders for the time they took to help us with finding a need for innovation. Especially, Maarten Fleuren of Vitens, a Dutch drinking water company. Of course, we want to thank our families and friends for their support. Also, thank you to everyone who was involved in the project in any possible way for their advice, support and knowledge. Lastly, we want to thank each other for the goodtime we had during the project.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Designing a retractable hydrofoil

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***Abstract*— This paper cant go in deep details because the project has an NDA. The assignment was designing a retractable hydrofoil in a surfboard. By using different design methods, a design for the concept and the main mechanism behind it have been made. This concept will make hydrofoiling more universal and make it possible to pass shallow waters on this hydrofoil board. The concept will also make it safer to hydrofoil and easier to learn. For the next phase in the project the concept will be tested and validated to proof our concept.**

***Keywords—Hydrofoil, Innovation, Retractable***

## I. PREFACE

All authors of this paper are fourth-year students at Fontys University of Applied Sciences. These students are in their differentiation phase where they are deepening their knowledge in innovative engineering. The authors are all from the engineering department of the college and form a project group called Innosurf inc. with the objective of designing an innovation. In order to achieve this and for the development of interdisciplinary and intercultural skills, four contributors are involved in the project. Two of the contributors are from the business department of Fontys UAS and support this project as second-year students for self-development and to complete the honoured program they follow. The other contributors are from the engineering department of Ulm University of Applied Sciences, they are also following this project as fourth-year students like the authors of the report.

All the students involved had a choice of about ten possible innovations design ideas. The main reasons for choosing to design an innovative hydrofoil are the attractive technical complexity and the amount of engineering involved. Apart from that, it is an attractive product for this target group and using it has been experienced as very entertainment. It is a challenging project with plenty of room for creativity, resulting in a very impressive end result.

## II. INTRODUCTION

The hydrofoil project is start up by Peter Kooren, owner of The Blue Compass located in Haarlem. The Blue Compass is a start-up since 2020. The company creates electrically driven water sport equipment and is currently busy with a project called ‘Seatfoil’. This project is a product development of an electrically driven hydrofoil surfboard (e-foil), and a prototype has been made already. This prototype has a static hydrofoil.

The initiative of Peter Kooren is to take this prototype to the next level in addition to the already existing board. The main goal: To create an electric hydrofoil that is ‘idiot proof’, safe and easy to operate without a lot of board experience[1], so everyone could learn fast how to operate the e-foil safely and at as many places possible. This project is the start to create the hydrofoil board Peter wishes.

The vision Peter has for the new e-foil has quite some engineering to do. For this project, the main goals will be:

- The 1st goal is to create an electrically driven hydrofoil that can be used in shallow waters.
- The 2nd goal is to make the boards safer. The ultimate goal is to be safe enough, so no helmet is required when using the Seatfoil.
- The 3rd goal is to make the boards easier to use. To decrease the learning curve.

This project, submitted by The Blue Compass, has been picked up by Hay Geraedts. Hay is a teacher at Fontys University of Applied Sciences (Fontys UAS) located in Eindhoven in The Netherlands and, together with Ercan Sengil, are the two tutors from Fontys UAS to coordinate the project.

The project team consists of seven engineering students from Fontys UAS (which are mentioned at the begin of this document), as well as two engineering students from the university of Ulm. There will also be two business students from Fontys UAS to help create a well organised business plan.

## III. Background information

An E-foil can be seen as an electrically powered surfboard. A mast and wings attached to the surfboard allow you to rise out of the water at a certain speed. An E-foil 'flies' because the water that flows over the top of the wing has a higher speed than the water that passes the bottom of the wing. This causes the foil to come out of the water. And therefore the board literally floats above the water. With the use of a hand controller to accelerate, to see how fast you are going and how much battery is left. The great thing about E-foiling is that there is no need for wind or waves.

Hydro foiling has been growing in popularity in the past decade. It even made its entry in the Olympics with kiteboarding. But with the growing popularity of hydro foiling and e-foiling the unknown problems have surfaced. With the main problems being safety and usability. When a hydrofoiler falls of the board the foil can get out of the water and hit the user or people in its surroundings, causing severe injuries. Due to the safety issue, the places where people are allowed to hydrofoil are getting less and less. And with a depth of around 70cm, the foil isn't able to go through shallow waters. In order for people to keep using and enjoying e-foils these problems have to be solved.

## IV. Problem definition

The Challenge that the company (referred to The Blue Compass) takes on is to design an innovative solution for the existing seatfoil. By accomplishing this challenge, a solution is created for the next problem: Sometimes people want to ride a surfboard with an electrical driven propeller. A hydrofoil under the board gives people extra thrill when the board is, due to the velocity of the foil in the water, lifted out of the water. However, in two cases this is giving problems. In the one case when surfing in shallow water the hydrofoil hits the ground. Secondly, in a hazardous situation when the person on the board is falling off.
This leads to the following problem definition: The safety of the electrical hydrofoil must be improved, and it must be made possible to pass through shallow water.

## V. Objective

The main goals have shortly been mentioned before, but, to get a clear picture of what the main objective will be it has been developed using the SMART approach, this method has been applied to meet the following principles:

- **S**pecific, to design an innovation that improves the safety of electric hydrofoiling and that makes it possible to pass through shallow water
- **M**easurable, to improve safety to such an extent that protective accessory for the user become superfluous, and to make it possible for the hydrofoil to pass through shallow waters of 0.335 metres in depth.
- **A**cceptable, to make e-foiling more accessible to a wider public by making it safer and by making it possible in more locations because of the possibility to pass shallow water.
- **R**ealistic, the target remains attainable and yet challenging due to a good differentiation of wishes and requirements. The functions must be fulfilled but not, for example, fully automatically, although that would be desirable.
- **T**ime-based, the objective(s) are time-bound to 1 school semester, which is approximately 20 working weeks.

## VI. Approach and theoritical background

After completing the problem phase and defining the objectives, concepts are drawn up. Before these concepts are drawn up, various research studies are carried out. Aspects were also investigated during and after the concept phases. Noteworthy research can be summarized as follows: business plan, patent research and material research.

For the business plan, research was done into what already exists in the market (competition) and how big the current market is, among other things. Such as the stakeholders and organization in the form of key partners, activities and recourse.

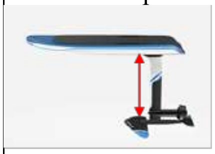
Patent research has been carried out to inspire concepts, also to exclude possibilities of applying for creating potential patents. The aspects focused on in this research and its results are covered by the NDA.

The material research was carried out using the CES Edu pack program, which is a database of all possible materials that can be filtered according to their properties. The choice of material took into account shape, stiffness, strength, weight, durability, price and resistance to water. The outcome for the mast/hydrofoil itself is carbon fibre.

## VII. Concept selection

For the project, the team needs to design an extendable e-foil. Before starting to design a specific extendable e-foil, all feasible options should be considered. There are three ways in which the extendable e-foil can adjust its height. The three options are showed in Table 1.

*Table 1 Design Options*

| Slide to the front | Slide up | Slide to the back |
|---|---|---|
|  |  |  |

A good design choice must be substantiated. A morphological map was used to substantiate the best design choice. From a morphological map, the best design choice emerges; in this case, the Slide up method emerged as the best choice. Because of an NDA, this paper can’t go more into details about the morphological map.

The next step after setting up the morphological chart and making concepts out of it, is deciding the best concept. This decision has been made by making a Kesselring-chart. With this chart the concepts are compared with the requirements that have been set up. The first step is identifying the requirements and deciding if they are realisation or function requirements. This Kesselring-chart can’t be showed because of the NDA, but the best method is a vertical retracting concept. There is chosen for the electric version where the whole hydrofoil is going through the board. The hydrofoil moves up by using an electric motor.

## VIII. DETAILED DESIGN

After choosing the main concept the next step is choosing a mechanism to apply the main concept. Similar to the main concept a morphological chart has been set up. With this morphological chart concepts can be designed. The morphological chart is divided in three different functions drive, guidance and lock system. For each function there are 3 methods to apply them.

As a result of this morphological chart 5 concepts have been made of a mechanism used in the main concept. To make a choice out of these different concepts a spider diagram has been made. For this the first step is setting up a table where different specifications are graded for each concept. The table contains the following specifications:

- Costs
- Durability
- Play
- Friction
- Producibility
- Volume
- Force
- Speed
- Backlash

These specifications have different weight factors, to factor in the importance of certain specifications. Every concept from A to E gets graded on these specifications. After the grading, it will be displayed in a spider diagram which will give the best solution. The final concept will be concept A because this mechanism fits the best in our design when looking at certain specifications.

## IX. RESULTS ANALYSE

The goal of the project is to design an innovative solution for the existing Seatfoil. In the current concept of a hydrofoil there are two main problems that users face. One being the safety hazard of the hydrofoil jumping out of the water and hitting users or its surroundings. And the problem of the hydrofoil not being able to pass through shallow water. In this paper the details of the final concept and the choices made are given. As a result of the research done one concept is selected as the best solutions to the problems. To get to this concept first a main concept had to be chosen and after this a more detailed concept has been made.

The design method used to create these concepts is partly described in the paper. The morphological map is mentioned several times, as well as the Kesselring method and the spider diagram. These design tools have been used in a structured way according to Kroonenberg's design method. The Kroonenberg method is a methodical design process that includes the tools mentioned. The method simplifies the process and divides it into different phases (problem - method defining - selection - shaping) that work from abstract to concrete and from rough to fine (work breakdown structure). By applying this method, we strived for a process that was as efficient as possible and in which all the steps taken were substantiated and linked back to the functions, requirements and wishes.

By following the steps of the Kroonenberg method, the main concept emerges that is not yet fully concrete and finely worked out. To achieve your goals, the linking back and definition of your requirements in the form of functions and realisations are the key. The following requirements have been applied with different weightings in order to achieve a valid evaluation of the different possible concepts:

- Be able to pass through shallow waters of 0.335 metres in depth.
- Be waterproof according to the IP68 standard.
- Be in the limits of what the customer is willing to pay.
- Be hydrodynamically shaped.
- Be light weighted, i.e. under 50,00 kg.
- Be easy to use so that an inexperienced person can learn it within 15 minutes.
- Be automatically adaptable system to perform the retraction function depending on the water depth.
- Be sustainable design consisting of durable material.

The final choice scores the best in functionality. Another concept scores higher on realization because it is realistically more achievable, also is this option cheaper and less difficult to produce. However, the final choice will be a much safer and also has the potential to be produced at an attractive price without difficulty

After the main concept was selected the next step was to go more into the details. The next question to be answered was: ”How can we realize the main concept into a working proof-of-concept?”. In order to get to the best solution, the detailed concept should be tested to its own specifications regarding the working of the concept. These specifications are discussed in the detailed design. From these specifications a spider web has been created where it becomes clear which concept was the best suitable option.

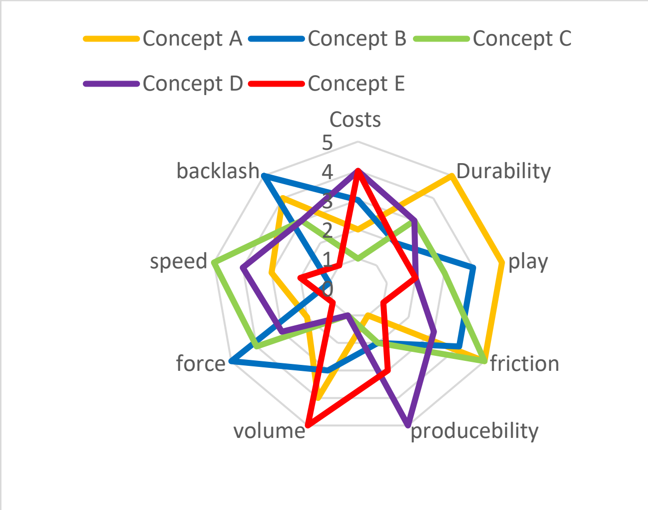



*Figure 1 Spider diagram of detailed design options*

When just looking at the total scores concept A, B, C and D have gotten similar scores. But not every specification is considered equally important to the operation of the concept. So, if we apply this importance to the different specifications, concept A comes out as the best suitable concept for this project. It scores the highest in durability, play, and friction and also scores well on backlash, and volume. Concept A however scores the lowest on producibility, but this can be improved in the future.

Because of the structured way of working and the methods used to support the choices made in this project. The most desirable concept has been selected. The concept solves the problems regarding the hydrofoil and at the same time also takes into account other aspects that are important for the functioning of the product. Although the selected concept is the best suitable option it also comes with its limitations. Because of the chosen way of moving the hydrofoil the board has to be altered in a way to fit the newly designed hydrofoil.

## X. Conclusion

The full project cannot be concluded yet but for the phase the project has gone through a conclusion can be drawn. The goal of this project was designing a hydrofoil board that will be able to pass shallow waters and be safer to foil on. Up to this point in the project the design phase has been completed and concepts have been made. These concepts have been made using the Kroonenberg methods to fit the criteria needed. There are two concepts for the final design. A concept for the method in retracting the hydrofoil and a concept for the mechanism behind it. The final concept for the full design is the hydrofoil going through the board. This concept is determent to be best fitted as the solution for the problem.

Going further with this project the focus will be put on making a prototype out of the concept and do different tests to confirm safety an liability. With different tests the final concept can be validated and the project can be completed.


## Acknowledgements

The assignment in this paper is the result of a collaboration with the company: The Blue Compass. We would like to thank The Blue Compass, but especially Peter Kooren for this cooperation. At the start of the school year, Peter Kooren explained his concept and his vision. After this, he allowed us to bring our own ideas about possible concepts in full confidence. In this, he gave us the necessary knowledge and information when needed. The intermediary who has also ensured this cooperation is our mission mentor Hay Geraedts. Hay Geraedts learned us to work 'Fast and Sharp' in a project. In addition, he watched our progress on a weekly basis and guided us where necessary.

Besides Peter Kooren and Hay Geraedts, there are also students from other universities with whom we worked on the project. We would like to thank Charles Manuel, Juliette Wulms, Luca Pfuhler and Linda Ostertag.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# How can the harmfull effects of plastic and aluminum waste be reduced using innovative recycling?

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***Abstract*— There are a lot of things that cause pollution on earth. Plastic waste is one of the most causes of pollution. Each plastic bottle takes over 100 years to decompose, and each aluminum can take 200-500 years to decompose. So, how can we get rid of plastic waste and aluminum cans using innovative recycling?**

***Keywords—Environment, waste, recycling, innovation.***

## I. Introduction

What is responsible for climate change? Plastic waste and aluminium waste are responsible. If so, how can the harmful effects of plastic waste and aluminium cans be reduced?

According to a report published in May 2019 called "Plastic & Climate: The Hidden Costs of a Plastic Planet", plastics emanate as fossil fuel. So, they exhale greenhouse gases [1]. This means plastic waste is one of the main causes of climate change. Due to the harmful effect that plastic waste has on the environment, people on earth must be a part of the journey to reduce the amount of plastic waste produced, whether it be plastic bottles or any type of plastic. As a result of reducing the amount of plastic waste, the planet will breathe again, and the environment will become cleaner. Although the recycling bins can be found easily, an insufficient percentage of plastic waste, and aluminium waste can be found in them compared to the amount that is needed to be recycled. this planet. This research technical paper is set out to answer the following question: how to reduce aluminium cans and plastic waste's harmful effects by using innovative recycling? From that question, an idea came into the mind of group 4 from the semester 7 project to design a machine that could receive plastic waste and aluminium cans and give points regarding how much weight of was inserted into the machine. From these points, free parking, discounts, and toys for children are given as well. The idea should be interesting to the user, the owner of the machine, the government, which is working to increase sustainability, and to the recycling companies as well.

The following sections of this paper are going to cover the background of the project, approach, design research, and the verification of the results related to the plastic waste and aluminium cans recycling machine. At the end of this paper, a conclusion is presented with the answer to the main question.

## II. BACKGROUND

The project starts without any assignments given. The group had to come up with an assignment and improve it. Since all the new innovations are focusing on sustainability, the idea of making a machine that exchanges plastic waste and aluminum cans for points, which can be used as parking tickets, to get discounts, or to get small gifts for kids. The main idea behind the machine is to reduce the amount of plastic waste and aluminum cans in the Dutch environment because of its bad effect on the earth. The machine is responsible for encouraging people to get rid of their plastic and aluminum waste in the right place and saving them some euros, which they can use to pay for parking.

## III. APPROUCH

At the beginning of the project, the group members held a meeting to discuss how to find a good, challenging assignment that suits the complexity level of the P7 project. The output of the meeting was that every member of the group had to come up with an innovative idea for the project, and the suitable one was chosen. Regarding the complexity level and the different engineering departments in the task of Cash 4 Trash, the task has been chosen as an assignment to improve for the P7 project for group number 4. There are approaches to the design of the machine that is divided into 3 parts: AI, mechanical, and electrical, which are going to be described in detail in the section of design and research in this paper.

To approach the product side of the project, a course of production innovation has been followed by the team members. Before starting work on the project, patent research has been done to make sure the idea is patentable and not a copy of an existing idea. From the patent research, the green light is given to start working on the Cash 4 Trash machine. Sustainablity was also taken into account when working on the idea of this project.

However, the business side is important as well as the product. A business innovation course has been followed to get into the business side of the project. Three business canvases have been done to make the picture of the business clear if anyone is willing to invest in this product.

## IV. DESIGN AND RESEARCH

During this project, they have been working on a "cash 4 trash" trash bin. As already mentioned, the purpose of this trash bin is to collect plastic waste and metal cans in the environment to keep the streets clean. During the previous period, there has been work done on the design of every component of this machine, combining all of these components into a single machine. Together with the electrical part of the machine and the AI program that can recognize the different kinds of waste, the designed machine is able to give a kind of "reward" to the user for keeping the environment as clean as possible by using the trash for cash trash bin. Before the start of the final design, a concept design has to be made. The concept design is an important part of the project because this way it is easy to compare different possibilities with each other and take out the best one. During different meetings and discussions, three different concepts came together and were put into a morphological overview where different functions are mentioned.

After the three different concepts have been chosen, different requirements for the cash for trash have been set up. The 13 different requirements can be divided into functional or manufacturing requirements and fixed, variable, or wish requirements. This is necessary for the Kesselring method that is explained later on. For the next step of the concept design, the Kesselring method comes into use. With the help of the Kesselring method, the best concept out of the three different concepts can be chosen. With the help of the functional requirements, the manufacturing requirements, weighting factors for each requirement, and the outcome of the Kesselring method, a Kesselring diagram is put to use and generates the best concept to use. In this Kesselring diagram, the outcome of the Kesselring method is plotted. The concept with the highest overall score is considered the best concept to use in the designing stage. After these design models were made, the team came to a conclusion on how to design the machine.

Whenever garbage is thrown into our machine, we want to be able to classify this garbage. This could be useful information for the customer to know. If we could tell the customer what street waste is found most commonly in the streets, they could think of things to prevent this waste from reaching the street at all. Besides that, different amounts of credits can be given to users that hand in different amounts of waste. For instance, a used cigarette would give you fewer credits than a plastic bottle. So here we have our problem: how are we going to classify different types of waste and what characteristics can be used for classification? First, a decision has to be made on what characteristics to use for classification. The answer to this question is to use weight and pictures. Our machine will contain a scale at the location where the trash is being put. An artificial intelligence program will use this as an input for the model to help classify the type of waste. Also, a picture of the waste will be made.

Using convolutional neural networks, this picture will also be used as an input for our model.

A code for garbage classification has been made. How does the artificial intelligence program really work? In our solution, there will be two software components. In the first module, a convolutional neural network (CNN) that can classify a picture of a garbage item will be trained. This module will be used centrally by our data scientists; they will provide this module with large sets of pictures of garbage items and use supervised learning to train the CNN. The second module will classify garbage items that were collected and compute the credits to be given to the collector. This module will be present in our Dropboxes. It runs the CNN that was created by our data scientists.

There are a few classes defined at the beginning of this project. These classes are based on the most common waste found on the street. The machine will try to classify our waste into one of these categories. After our model has received a picture and weight of some new waste that has been put into the machine, the model will give back percentages for each class. These percentages tell us the probability of the waste being in that category. If none of the categories is more than 50% or at least 10% higher than the second highest percentage, we classify the waste as undefined. After a few months of time, we can look through all the pictures made by our machine to see if we 'guessed' the classes right. For instance, if we conclude that there is a certain type of waste being seen a lot in the undefined class that doesn't have its own class, we could decide to make a new class for this waste. The goal is to eventually have nothing classified as undefined and to get the credit scores of our users as good as possible. We have been using Matlab as a programming language. With Matlab, a program has been developed that uses supervised learning to train a Convolutional Neural Network (CNN) that is based on Alexnet. Alexnet is a well-known CNN that already has many pre-trained convolutional neural network layers to classify pictures of a thousand different types of objects. Alexnet is often used in combination with "transfer learning" to reshape it such that it can recognize other types of objects. In our case, Alexnet has to be programmed to recognize different types of garbage: drink cans, plastic lids, candy bars, boxes, etc. In transfer learning, you "retrain" some of the last layers of Alexnet by feeding it with pictures and also providing the class with those pictures. This is called supervised learning. Using "back propagation," Alexnet will modify the last layers such that it can classify our type of garbage objects.

Once the CNN has been trained to recognize our garbage types, the machine can save the CNN to a file and re-use it in our Credits Computation module that runs in our drop boxes.

When the trash has been categorized, it needs to be collected in some sort of bin. In the mechanical design, two trash bins on each side of the main machine have been designed. The reason why the design was made with two trash bins is because the machine has the possibility to separate plastic waste from metal cans. In this way, metal cans can go to the trash bin on one side of the machine, the part that the users see and interact with, and plastic waste can go to the other side of the machine. Besides that, the machines use two trash bins. There is one other special thing going on with the trash bins. They are almost fully placed under the ground and connected to the main machine that is mostly on top of the ground. In this way, the big trash bins will not take up a lot of space. The second "main" part of the machine is the machine itself, which is mostly on top of the ground. The machine itself consists of a hole with a space behind it where the waste is placed. A cylinder is connected to both sides of this space. In this room, the camera and scale will be placed for the artificial intelligence to do its work.

The order in which the machines work is as follows: The waste is placed in the machine and the door is closed. The waste is then weighed and photographed, allowing the artificial intelligence system to determine which waste it is. The AI system is able to determine what kind of waste is placed in the machine and decides if it is allowed or not, and on which side the waste should be placed. After the AI system decides what kind of waste is placed in the machine, two cylinders from each side of the machine will compress the waste and make it as small as possible so it does not take up too much space inside the earlier mentioned trash bins. Together with the cylinders, there is also a system in the compressing stage that allows the machine to compress bottles filled with air and closed with a cap. If the air-filled bottles are compressed without first making a hole in them, they will explode. This would first of all scare the user of the machine and, second of all, possibly damage the machine itself. Besides air, it is also possible that there is still a lot of liquid in a bottle. This problem will also be detected by the AI system, which will refuse to compress the bottle. After the waste is compressed, one of the two cylinders will push the waste from the table onto the side it has to go to (one side for plastic waste and one side for metal cans). The machine will guide the waste with the help of a slide to the correct underground trash bin.

Besides the working of the machine itself, there is also a whole technical aspect to the trash bins because they are not the average trash bins that everybody can see in the environment. The trash bins from the cash for trash project are inspired by the glass containers in the Netherlands that are also placed under the ground. The trash bins that are used in the project have an inside volume of approximately 1 cubic meter.

The trash bins consist of a construction in the form of a collection bin with 2 folding doors at the bottom. On top of the trash bin, there are three hooks with which the trash bin can be lifted and opened. The middle hook is needed to lift the heavy trash bin out of the ground. The other two hooks are used to open and close the swing-away doors when emptying the bins. Between the eyes and the swing-away doors is a mechanism with chains to connect the two.

The order in which the trash bin is emptied is as follows: The trash bin is hooked up to the three lifting hooks of a truck that is used to come and empty the trash bins. After the trash bin is connected to the truck, the crane on the truck will lift out and disconnect the trash bin from the machine itself. When lifting the trash bin on the middle hook, the other two hooks that are connected to the swing-away doors are held under tension because, otherwise, the swing-away doors will open and the trash will come out before the bin is placed above the truck. When the crane puts the trash bin above the truck, the crane will then lower the two eyes of the swing-away doors, and the swing-away doors will open. When the trash bin is emptied, the swing-away doors can be closed again and the trash bin can be placed back on the ground next to the machine.

Last but not least, we can conclude that the design of the machine will help fix the problem of trash in the environment. But next to all the good parts of the design, there is also a place for improvement. For the next phase of the project, it would be nice to make a smaller version of the machine and the trash bins so that they can be placed above the ground so that, for example, it could be used with an existing trash bin so that no other type of truck has to be used. This is also easier to use for smaller spaces or, for example, where a truck with a crane cannot be used. as well as for less congested environments.

The electrical system was designed to merge the AI and the mechanical design into a working system. The electrical system had to consist of several subsystems. It is not only about the inner power network but also the interface with which the users can operate the machine and the credit system. For the internal electrical circuit, a power supply has been designed that can transform all the necessary voltages. This is done using a transformer that first converts the high alternating voltage (230 VAC) to a low alternating voltage (9 VAC). Because the machine is connected to the national grid, safety also had to be taken into account. A fuse has been added for this, and all metal panels of the machine will be grounded. This is due to a short circuit, but also since the machine will be outside and may have to deal with lightning strikes. A so-called diode bridge is used to convert the alternating voltage to direct voltage. The rest of the power supply consists of Integrated Circuits that generate the desired DC voltage for the subgroups of the machine. One of these subgroups is the User Interface. The User Interface is a system that allows the user to give the necessary inputs to the machine and the machine to give outputs to the user. A User Interface in the form of a touchscreen has been chosen. The touchscreen we chose has its own processor. A so-called diode bridge is used to convert the alternating voltage to direct voltage. The rest of the power supply consists of Integrated Circuits that generate the desired DC voltage for the subgroups of the machine. One of these subgroups is the User Interface. The User Interface is a system that allows the user to give the necessary inputs to the machine and the machine to give outputs to the user. A User Interface in the form of a touchscreen has been chosen. The touchscreen we chose has its own processor. A so-called diode bridge is used to convert the alternating voltage to direct voltage. The rest of the power supply consists of Integrated Circuits that generate the desired DC voltage for the subgroups of the machine. One of these subgroups is the User Interface. The User Interface is a system that allows the user to give the necessary inputs to the machine and the machine to give outputs to the user. A User Interface in the form of a touchscreen has been chosen. The touchscreen we chose has its own processor. By this, The User Interface is a system that allows the user to give the necessary inputs to the machine and the machine to give outputs to the user. A User Interface in the form of a touchscreen has been chosen. The touchscreen we chose has its own processor. By this, The User Interface is a system that allows the user to give the necessary inputs to the machine and the machine to give outputs to the user. A User Interface in the form of a touchscreen has been chosen. The touchscreen we chose has its own processor. By linking this with its own software, it is possible to create its own graphic user interface. The processor also provides a serial data communication port. Using this connection, the touchscreen can be connected to the master microcontroller, namely an Arduino MEGA. The Arduino MEGA will control the entire system.

After the trash has been collected and properly separated into one of the bins, credits that have been assigned by the artificial intelligence need to be given to the user. After trying different ways to hand out credits, the conclusion states that radio frequency identification devices (RFID) would be the best solution. Every person carries a card that has an RFID chip in it. By adding an RFID transmitter/receiver, the machine can communicate with cards. When a new user wants to make use of the machine, they simply take a card that they have with them and scan it against the machine. The RFID receiver/transmitter will collect the unique digital identification and add an account to it as well as the received credits for the waste. Whenever this user disposes of waste again at a machine, they can use the same card and credits will be assigned to their account. The RFID transmitter/receiver are also controlled by the master controller, the Arduino MEGA.

## V. VERTIFICATION OF THE RESULTS

Our developed machine for recognizing trash works perfectly as a proof of concept. The code has been tested with small data sets of pictures; for each class, there are 15 pictures. In the future, we still expect to expand a lot of things. We will have a better idea of the types of trash that have been put into the machine after it has been used for a few months. Also, we want to expand the train data sets that right now only contain 15 pictures. An idea we have is that whenever a type of waste is classified correctly, we could add the picture of this waste to the category it belongs in. In this way, the data sets of pictures will get bigger and bigger with time, which will make the accuracy of our model only better. We don't see any errors and are certain the concept of the machine works for what we want to do with it. The next step is to implement it in the machine and put trash in the machine. Then errors or faults could occur. It is expected that these are easy to fix since the code we use is not extremely complex for a mathematician/engineer.

## VI. CONCLUSION

The main question of this paper is how can we reduce the harmful effects of plastic waste and aluminum cans using innovative recycling? This question is very important to be answered according to the huge amount of plastic waste and aluminum cans in the environment that are thrown away and do not get recycled. The main reason for the issue is human. There are specific places to put the empty plastic waste, but people do not do that. They are aware of the major bad effects of plastic bottles and aluminum cans on the environment, but nothing is motivating them to throw their plastic waste in a different place that has been made specifically for it.

Sustainable development is one of the biggest goals that the world is working on currently. Getting plastic waste and aluminum cans recycled reduces air, water, and earth pollution. People are the main tools to get our world cleaner and more sustainable by changing their habits.

The paper goes through the process of improving a machine that motivates people to separate their plastic waste and aluminum cans from their general waste to be recycled. The machine gives points according to the amount of waste that is inserted into this machine as a motivation. The points can be spent on free parking, getting discounts at some stores that support the machine, and by using the points, a toy for a child is given.

Answering the research question of this paper, the machine is going to play a good part in reducing the bad effects of plastic by giving people a good reason to put their plastic waste and aluminum cans in the machine to get points which they can use for more than one thing. It is a good motivation to make people do the work and help our environment survive and be sustainable.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Designing a Handheld Seaweed Cutter

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ABSTRACT:

This project discusses the development and production of a prototype for a seaweed cutting device. This device is designed to help with sustainable agriculture, and increase the efficiency and productivity of seaweed farms around the globe, hopefully helping to increase the competitiveness of this market in the future

Keywords: Sustainable agriculture, Seaweed, Mechanization

## I. INTRODUCTION

The world is a rapidly changing place, with a need to constantly develop for whatever situations may arise in the future. Entrepreneurship is devoted to the task of finding these developments and preparing for the future, solving problems that already exist, or may soon come to exist is the core of this task, making up nearly the entirety of what innovation is. One such looming problem is the potentiality of food shortages and population growth in the coming decades. Seaweed farming is seen as a solution to this problem in some circles, however the industry is dominated by large players using damaging heavy machinery, and small players using hedge clippers and small scale tools. This project aims to benefit these small players, focusing on Rope-Based seaweed farming. The goal is to design a mechanism with which the manual cutting action can be removed, and to devise a device which can slide along the rope, cutting seaweed at a faster pace than otherwise possible.

## II. BACKGROUND OF THE CURRENT SITUATION

### A. Climate Change and Food Scarcity

In order to understand the inspiration for this project, a brief overview of climate change and food scarcity is required. While many know of the commonly stated points on food scarcity and climate change, some of the key points will be reiterated. Key crops could see their yields drop by nearly 30% [1], poorer and densely populated regions of the world could see their entire food production dry up as temperature rises [2], and potentially disastrous price increases [3]. These factors whether in isolation or combination spell disaster for potential food supply chains. Solutions must be found, and the seaweed farming industry is one such solution.

### B. The Current State of the Seaweed Industry

In the seaweed farming space, the primary "standard" at this time is dependent upon the actual method of seaweed farming that a given business partakes in. The form that this team is focusing on is floating cultivation, in which floating ropes sit on the surface of the water, with seaweed growing down from them. These ropes are then lifted out of the water in sections, with every researched operation then cutting from these ropes by hand with hedge clippers. Within this type of farming, the primary competition is the manual cutting process, and the group's device must be faster and more economical than this process. However, there are many methods of seaweed farming outside of this rope based farming (shown in Figure 1), and it is these methods that act as greater competition.

*Figure 1:Rope based seaweed farming [4]*

The most prolific method discovered was the so-called "Norwegian comb", which operates through 'raking' the seafloor as a large metal device is pulled along the seafloor by a boat, uprooting and harvesting large amounts of seaweed. This metal piece is then lifted out of the water, with the seaweed then pulled off it. This method comes with numerous ecological problems, however, destroying the ecosystems it is used in, leaving a destroyed habitat behind it [5]. Furthermore, the equipment to develop such an operation is more involved and expensive than that which is used in rope-grown seaweed. Norwegian combs and other entirely different farming methods aside, there is no known competition for rope-based farming in this specific field of seaweed farming outside of the hedge clippers and manual work done as of now, which is one of the reasons this project was appealing to the group.

## III. The Device

With this background information and motivation, the task then fell to developing the product and its concept. Many iterations were devised, and many concepts were pitched, thus a detailed process had to be used in order to ensure the most effective design was chosen.

### *A. The Decision process*

While not fully relevant for a symposium such as this, the decision process and its components will be briefly described for clarity.

- The initial step was to establish user requirements. This was done through the market research shown above, and calling various seaweed companies. While the response from companies was limited, the data received combined with the actual research done by the team allowed for an acceptable set of user requirements to be developed for a prototype.
- The next stage was to design a morphological chart, in which every possible component for every possible function of the device was put in. Various combinations of these were then used to produce designs used in the next step.
- Following this, the designs were put into a Kesselring diagram. The Kesselring diagram breaks each function and requirement of the device into its own category. These categories are given a weight (or importance) and each design is given a score in each category based on its theoretical performance in that category. Using this method, a final design was arrived on, shown in Figure 2.

### *B. Design of the Device*

The final device, arrived at via this method, is shown in Figure 3. It operates based on 4 primary components, each of which is designed to fulfill its purpose in an affordable and light configuration. The first component is the saddle, which rests on top of the seaweed and slides along it. Due to the inherently slick nature of seaweed, as well as the variable width and topography of the seaweed over the rope, it was determined that a sliding mechanism such as this would be more effective. This is shown in figure, with the arm that attaches it to the box shown as well. It’s manufactured via additive manufacturing, as the shape required is not feasible to make from steal for a prototype, and the weight factor is relevant.

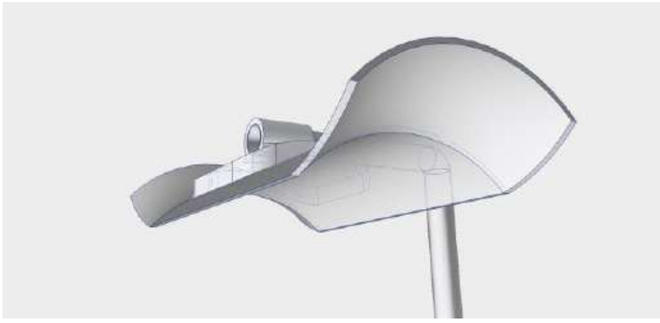

*Figure 3: The saddle.*

Following the saddle is the box, the central component from which all others are based. For the prototype’s sake, this device uses the internals of a hedge clipper, but the concept is the same. It contains the electronics and mechanical components for the actual cutting mechanism, which can be seen protruding from the front. It contains the battery, actuation mechanism, motor, and gearing. The interior of the box is designed to hold all of these components in place, and is shown in Figure 4. As with the saddle, this is manufactured from plastic in order to minimize weight and maximize ease of manufacturing.

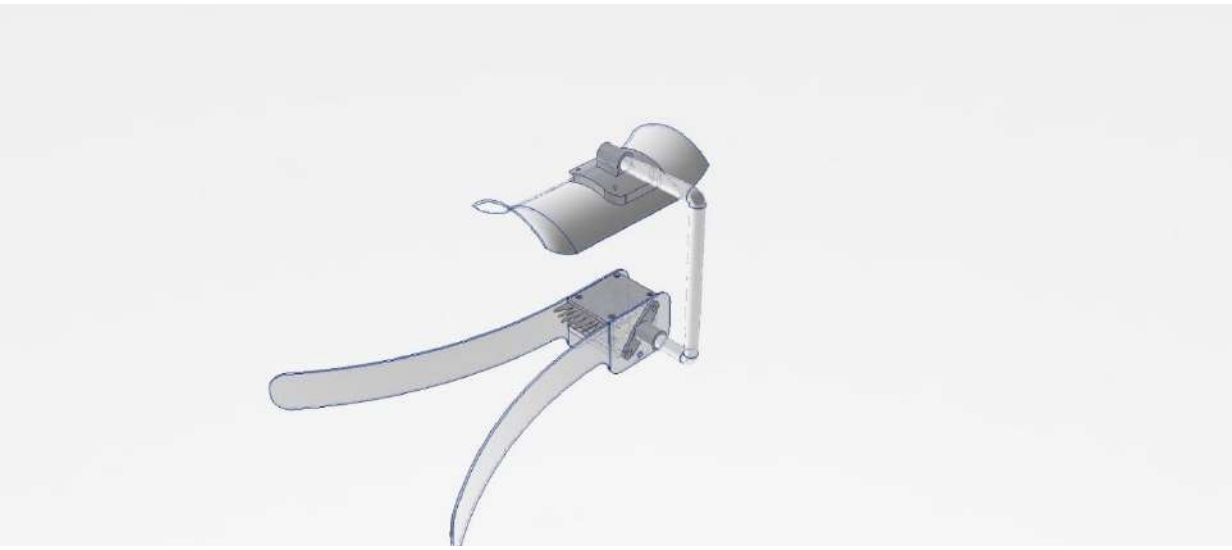

*Figure 2: The cutter.*

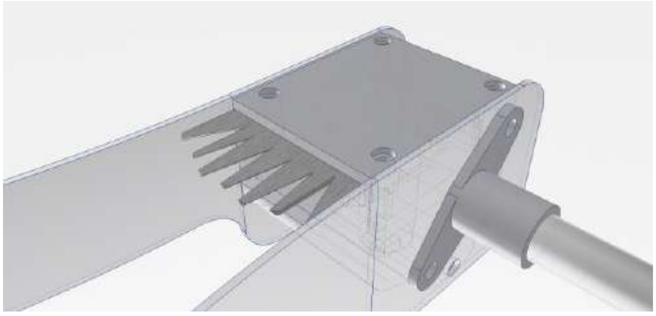

*Figure 4: The box and cutter.*

Protruding from the front of the box are two flat panels(Figure 5), acting as guides for the seaweed into the device. In order to maintain structural integrity, these are made from steel. Steel, while heavy, is stronger than aluminum and often easier to work with. With the length of these protrusions taken into consideration, the increased strength makes sense for this application. Additionally, a simple bend of steel is a simple manufacturing process.

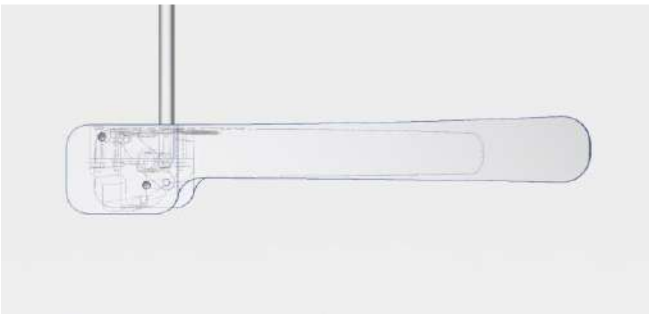

*Figure 5: The guides.*

The final major component is the handle (Figure 6). There are two of them, the first being taken from the hedge clipper and containing the actuation device, and the second being a grip point on the support beam itself. The handle from the original clipper was used as its interior components contained a mechanical safety and proper molding for the electronics. In the final product, this will be a custom part (along with all other hedge clipper parts), but for the prototype phase these parts will be used.

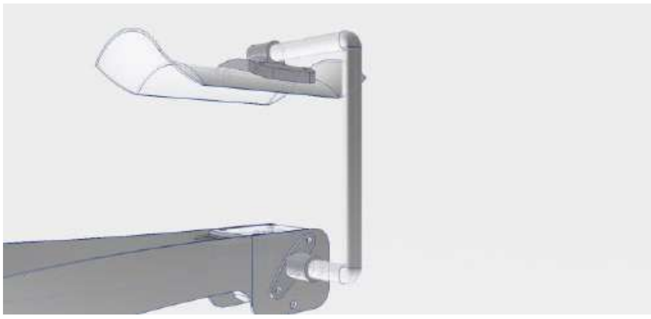

*Figure 6: The support-based handle will be attached here. The actuating handle is not included in the current CAD model, as it must be designed from scratch in the full development phase.*

## IV. Further Work and Investment

In order to further develop this project, a few things will be needed from both the engineering team and from external investors and partners. Plans for both are shown below. Ideally, both of these can be accomplished over a reasonable amount of time, and with further development eventually lead to a fully fledged business

### A. Internal progress

As a further plan regarding internal progress on this project, development on the device itself must continue. While the current prototype is sufficient for demonstration on the overall concept of the device, it's not yet a commercial product. The steps required are clear and attainable however, and when combined with the external factors required, can lead to a successful product launch.

- The device needs to be appropriately balanced to ensure optimal operation with minimal rocking forwards and backwards on the rope.
- The cutting mechanism and the handle actuation mechanism must be designed from scratch in order to ensure the design is wholly in-house and manufacturable without licensing.
- Manufacturing processes and materials must be solidified into a final set of specifications. Currently the materials work to do their job, but the manufacturing of a prototype is entirely different from mass production of a device such as this.
- Waterproofing can always be improved, and with the redesign of the internal mechanism, handle, and material choices; the waterproofing can be solidified to the maximum extent possible.

### B. External Progress

With the above requirements solidified, a tandem step is to acquire investment for such a product. While the device itself is functional as is, the further development with the product and the infrastructure around it must be funded in order to ensure market-readiness. A detailed funding plan is available, however the initial year will require the raising of funds. These will come from three sources, the students' own pockets, investors, and a bank loan.

large amounts are very difficult to obtain for start-ups such as Einnovation. However, the company will not need a large initial capital, so financing by the bank remains a possibility. The advantage of a bank loan is the fact that the interest is many times lower than when money will be provided via crowdfunding. Due to crowdfunding, an interest of 6-8% has to be paid quickly. In contrast to the bank loan of about 2-5% on average. Currently, the plan is to take 10,000 Euros of the bank's money (as it was assumed that this would be the biggest amount a bank would be willing to lend to inexperienced students), and to ply for 120,000 Euros of investment from private investors in other fields. A remaining 20,000 Euros will come from the team's own pockets to ensure personal liability in the venture.

### C. Further Plans

If this funding secured, and the product brought to market, then the company formed around this device would work to further develop solutions for the seaweed market. As integrated solutions would allow for more efficient and useful seaweed farming (thus furthering the team's goals of helping to support sustainable farming and stave off food crises), solutions such as hydraulic rope lifts, dedicated growing ropes/buoys, and even a boat-based system could be developed over time to further solidify the functionality of seaweed farms and establish a foothold in this rapidly emerging market

Further value opportunities for this company to provide are shown below, along with current ones:

1. Cost reduction: The cost can be reduced for the harvesting process. It can also be decreased by decreasing the number of the workers.

2. Customization: Einnovation is willing to design customized products depending on the demand of the customer.

3. Time reduction: The seaweed cutter should be able to harvesting the seaweed faster than the normal ways of harvesting depending on scissors or hedge trimmers.

4. Employee reduction: The product designed and created by Einnovation also aims to decrease the number of the employees responsible for the harvesting process of the seaweed.

5. Sustainability: Einnovation puts sustainability as one of the top priorities to be achieved while providing the customers with products. This is achieved by creating a product that doesn't harm the environment or the individuals using it. The company is also focusing on using less amount of materials needed through part design.

## ACKNOWLEDGMENT

Thanks are afforded to all Fontys staff, but especially to Maarten Haasnoot and Hay Geraedts. Both of them have been exceptionally helpful in the development and thought process of this project as a whole, and it likely would not exist as it does without them.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Topology optimization of a solar panel mounting system

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**Abstract— This paper is written during S7 project of Fontys University of Applied Sciences with combined disciplines of Fontys Engineering. The main purpose of this paper is to find an answer to the following research** [redacted] **This paper provides a guide on how topology optimization can be applied to optimize a solar panel mounting system. The original solar panel mounting system started out with is a concept provided by We Fabricate. The research consists of a literature review and the results were obtained with help of the SIEMENS NX software package. Important to mention is that original design provided by We Fabricate did not meet the NEN-norms which allowed it to be a lot lighter than a profile that would meet the NEN-norms. The topologically optimized profile shows between 868% and 328% less deflection, depending on the roof angle, and is 66% heavier compared to the profile of We Fabricate B.V. This sounds negative but the (non-optimized) profile designed by We Fabricate was a not yet valid design.**

*Keywords— Topology optimization, PA panels, mounting system, load cases*

## I. Introduction

Topology optimizaton is a principle that has been used for many years already, mainly by mechanical and civil engineers. According to ScienceDirect, topology optimization is a mathematical approach which spatially optimizes the distribution of material within a defined domain, by fulfilling given constraints previously established and minimizing a predefined cost function. This essentially means that it is a method to define the ideal shape for a certain situation with certain conditions and restrictions [1]. In practice this is mostly done with software programs that will do the math for you.

Although the software has been around for quite some time, it has not been standardized in most industries yet. The goal of this project is to apply topology optimization to a structure that already exists, thereby providing innovation to a certain industry. During this project it has been used to minimise the amount of material needed while keeping its structural integrity.

The structure that was chosen for the application of topology optimization is a solar panel mounting system. The research question therefore becomes: "How can the solar panel mounting system be made lighter using topology optimization?,,

By designing a lighter system, the material cost and installation times will be reduced. The mounting system will therefore become cheaper, making solar energy financially more attractive to the average consumer.

The paper is organized as follows: an introduction, followed by an explanation of the (non-optimized) mounting system designed by We Fabricate, a draft of the forces the system is exposed to (following the Dutch NEN norms), a derivation of the constraints Andy building volume for usage in NX, a redesign based on a topology optimization simulation, and finally a validation and conclusion



This project was an initiative from Fontys University of applied sciences & We Fabricate

## II. Original Design Mounting system

[redacted]

## III. Formulating loadcases according to Eurocodes

In order to perform a topology optimization, the software in question needs to know the forces that the structure needs to withstand. One requirement of our system is that it is going to meet the norm for our system. For solar panel mounting systems in the Netherlands this is the norm NEN 7250 (Solar energy systems - Integration in roofs and facades - Architectural aspects). In this norm there are references to the Eurocodes for wind load (EN 1991-1-4) and snow load (EN 1991-1-3). From these Eurocodes, supplemented by NEN 7250 for area specific factors, wind and snow loads are [redacted]

### *A. Wind load*

The wind load can be obtained from the Eurocode described in NEN 1991-1-4. This Eurocode describes the wind load on various structures. To calculate the wind load, a formula (1) was used from a research paper [2] co-written by one of the scientists who helped to create the NEN 1991-1-4.

$$W_{wind} = \gamma_w * q_p * C_{p,net} * C_s * C_d \left[{}^{N}/_{m^2}\right] \quad (1)$$

Where:

$\gamma_w: safety\ factor\ for\ wind\ load = 1{,}5\ [-]$

$q_p: air\ pressure = 1466\ \left[{}^{N}/_{m^2}\right]$

$C_{p,net}: net\ pressure\ coefficient\ 1\ [-]$

$C_s: structural\ size\ coefficient\ 1\ [-]$

$C_d: structural\ dynamic\ coefficient = 1\ [-]$

The air pressure for our situation is derived from the online calculator [3]. The net air pressure coefficient for this situation is -0.5 and +0.7, because it is assumed the solar panels are in the safer zones on the roof and the distance between the solar panel and the roof is maximal 300 [mm]. The structural size coefficient is 1, because we assume our mounting system is not mounted above 15 [m] height. [redacted]

### *B. Snow load*

According to Eurocodes 1991-1-3 the formula for snow-load is:

$$S = s_k * \mu * C_t * C_e\ [{}^{kN}/_{m^2}] \quad (2)$$

Where,

$s_k = caracteristic\ snowload\ on\ flat\ ground = 0{,}7\ [{}^{kN}/_{m^2}]$

$\mu = coefficient\ for\ the\ form\ of\ snow = 1.6\ for\ 60°\ and\ 0.93\ for\ 5°$

$C_t = thermical\ coefficient = 1$

$C_e = exposure\ coefficient = 1$

The coefficient for the form of snow depends on factors like how the wind accumulates the snow and is therefore dependent on the roof angle, that is between 5° and 60° in this situation. The thermal coefficient in this situation is 1, because a reasonably well isolated roof is assumed. Extreme [redacted]

### *C. Incidental loads and dead weight*

During installation of the solar panels, solar panel installers are standing on the solar panels. The weight of the installer is taken as maximum load of the incidental loads. The maximum weight of the installer that is taken into account is [redacted]



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[redacted]

*E. Overview of loadcases*

In table 1, an overview of all loads that are mentioned in this chapter are given:

*Table 1: overview load cases*

[redacted]

Visual display:


In the most critical situations, the load on the solar panel is a combined load of for instance wind, snow and dead weight. All the critical situations with their summed loads are shown in Table 2:

*Table 2: critical situations*

[redacted]

In table 2 it could be noticed that the forces marked in red are the highest in their direction. In the topology optimization could all forces be included, but this is highly inefficient and unnecessary. When the stresses and deflections in the most critical situation are acceptable, the other situations are also acceptable. Then another important assumption is made. The highest loads at the lowest and highest roof angle are combined. It is assumed that all angles in between are therefore also covered, because their x and y are never higher than that of the highest component of the lowest or highest roof angle. For instance, snow loads exert a maximum force parallel to the roof if the roof angle is 60°, whereas a maximum force perpendicular to the roof is obtained if the roof angle is 5°. In the optimisation both of these force components are combined. The resultants of these components are obviously too high, but it will ensure the profile can withstand the forces at all roof angles. This results in the final load cases that go into the topology optimization, shown in Table 3:

*Table 3: load cases topology optimization*

[redacted]

*Figure 3: Visualization how forces attach*

## IV. Determining Simulation constraints

[redacted]

[redacted]

## V. Determining Simulation Building Volume

For topology optimization it is necessary to define a volume wherein redundant material can be taken away. This can be done in NX by placing geometries in a space that defines those volumes. This way a designer can force the material into a direction and have some control in this computer-generated process.

Some assumptions need to be made at first, because no dimensions are known or specified. A small volume is desirable, because this way there is as little as possible height between solar panel and roof. This will also result in less critical upward wind forces, as is stated in chapter IIIA Wind load.

On the other hand, topology optimization reaches its full benefit, when it gets more freedom and so on a big building volume. What is known, is the ratio between height and width. For an I-beam this is 1.5 to 2. For this case 1.5 is picked because transverse forces need also be dealt with.

To determine the volume, it needs to be optimized and scaled to find the right height and width, that can cope with deflection and stresses as a result of being subjected to the forces from chapter 3.

[redacted]

*Figure 5: Building volume topology optimization*

## VI. Implemeting Topology Optimization

[redacted]

[redacted]

So, the simplification of the 8 load cases results into 2 key load cases. Since these however have to engage at 25 points and have to be mirrored due to symmetry, 100 load cases can finally be distinguished. Within each load case, 1 force that has 2 components and 3 moments. The result of this simulation can be seen in Figure 7 below:

[redacted]

*Figure 7: Topology optimization with 100 load cases*

The result of the simulation shows that a lot is being built at the top and bottom of the building volume. This is to absorb the moment of the largest component of the force perpendicular to the roof. Furthermore, the upper and lower parts of the building volume are connected with organic tension and compression beams, which form a truss structure with many triangular shapes.

## VII. Redesign Topology Optimiztion

[redacted]

[redacted]

*Figure 8: Redesign of the topology optimized profile*

## VIII. Validating redesign using Finite Element Method

[redacted]

In Table 4 the simulation results are shown for the simulations mentioned above.

[redacted] The table above shows that the profile also meets the requirements for the most critical situations. The deflections are acceptable,

## IX. Comparison with original profile

[redacted]

*Figure 10: Deflection original profile 'wrong' orientation*

[redacted]

*Figure 11: Deflection original profile 'right' orientation*

[redacted]

*Figure 12: deflection redesign*

It follows from the above figures that the optimized profile deflects 868% less than the original profile in the 'wrong' direction and 328% less compared to the simulations of the original profile in the 'right' direction. It should be mentioned that the optimized model is 66% heavier. This is the minimum mass to comply with the NEN standards, while the original design does not meet the requirements.

## X. Business

### A. Introduction

Next to the technical part, the project also consists of a business part. It has been checked whether there is a business case to start a company. This is done by creating three kinds of business models, doing market research and getting financial data. The research is done by the use of marketing models like SWOT and Five Forces. In the following subsections, the three canvas models are summarized and explained. For further information, reference is made to the full document.

### *B. Lean Canvas*

The first one is the lean canvas. The lean canvas is created to test if the idea is worth it as a start-up. In the lean canvas the problem of our possible customer and the idea to solve this problem are explained. Next the unique value proposition, which consists of lowering the price, lowering the carbon footprint and increasing the quality is explained and motivated. Another important part is the revenue stream. The revenue stream explains the way of earning money. Our revenue stream will be created by selling the profiles to a distributor/re-saler or installation company of solar panels. Why the system is not directly sold to an end-user is explained in the model. The lean canvas occurs during the first year of the startup. At this point the first profiles are taken in production and being sold to our customers.

### *C. Business model*

The second model shows the strong and weak points of a company. The difference with the lean canvas is that it's not focused on a startup anymore. Some chapters stay the same, some change. For example the key activities. After the startup phase the technical activities are to improve the profile. In the key partner section, the partners are analysed. Conclusion about this is that there are multiple partners available. This is important because when there is only one partner for supplying the raw material, or selling the profiles, the price can be determined by them. Other important aspects, described in the business model, are the customer relationships and the needed resources for the company. The business model occurs directly after the startup phase. At this point the production is optimal running and the improvements are implemented.

### *D. Scale up Canvas*

[redacted]

## XI. Conclusion

The newly designed and topologically optimized profile has shown that the deflection of the optimized profile deflects 868% less than the original profile in the 'wrong' direction and 328% less compared to the simulations of the original profile in the 'right' direction. This comes at the cost of being 66% heavier. This sounds negatively but it is optimized for its use and according the NEN norms, which the profile of We Fabricate was not.

## XII. Recommendations

[redacted]


## Acknowledgment

We would like to thank the tutor of the project Florian Kats for the supervision of the process. We would also like to thank Fontys for supplying us with SIEMENS NX and providing us with time to do this project. We also like to thank We Fabricate for sparring with us for a project idea and providing us with feedback, knowledge and information.


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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Recycling End-of-Life couches

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*Abstract* — **For many years, environmental consciousness is increasingly becoming a major concern for both manufacturers and consumers. It is widely acknowledged that the most ecological way to treat worn-out products like furniture items is by recycling, for which disassembly is critically important. This paper presents a review of recent research on the replacement and development of an automated process which purpose is to disassemble couches in multiple parts that, in a later stage, will be sorted based on their materials like wood, textile, etc. The absolute goal is to produce 100% clean material streams coming from the disassembled couches which can be recycled and reused for future products. This automated system represents an efficient and cost-effective way to get rid of both manual labor and incineration that nowadays are commonly used to recycle unwanted pieces of furniture. The process of disassembling a couch is done in several steps which involve the use of different innovative solutions like robot arms, vacuum removal, hydraulic pressure, etc. The working principle of the entire disassembly system including the different methods used to remove all the parts of a couch (armrest, textile, foam, frame) is presented in detail in the research paper below.**

**Keywords - Couch, Furniture, Upholstered Furniture, Booth, End-of-Life, End of Life, Disassembly, waste-streams, waste streams Automated Process, Recycl,**

## I. INTRODUCTION

Yearly, 22 million pieces of furniture are thrown away in the UK alone [1]. This is around 1,6 million tons of bulky waste. Much of this furniture goes to landfills or is incinerated which is a poor use of the valuable materials of which they are made and increases the demand for new materials many of which are not sustainable in the first place and have negative effects during production.
This research paper investigates a method to recycle one type of this bulky waste, namely couches. Nowadays couches are not suitable for reuse of mostly landfilled, incinerated, or sent to waste to energy facilities [2] a poor use of the materials used to produce these couches. The problem, in this case, is that there are no existing, efficient ways to separate the materials contained within a couch and to recycle or reuse these. [2] The goal of this paper is to outline ways to separate and sort a couch into clean waste streams to achieve a high recycling rate. With this in mind the following main research question was formed:
***'What is a more effective and viable to separate a couch into clean waste streams that can be recycled?'***
To answer this question the following two background questions were investigated:

- What are couches made of?
- How is a couch constructed?

After that the main question is broken down into several sub-questions (See: Sub *questions*) which will be defined after the background information, to give a transparent overview of the problem.

These sub-questions are a result of the investigation into the two background questions in the Problem definition. And represent functions that are required to achieve the main question.

Beyond the main question of how to recycle a couch, a conclusion is drawn with regards to how to apply the solutions found to recycle and reduce other forms of bulky waste.

## II. BACKGROUND

Because of the problem that disposing of these sofas presents, various parties were interested in finding a solution to this problem. In particular, this problem was presented by Renewi and Ikea[1]. For Renewi this problem fits into their overall mission to recycle as much waste as possible and particularly their "mission 75" of increasing their recycling rate up to 75% by the year 2025 [3]. Ikea is interested in becoming more responsible for its end-of-life products [4]. Renewi and Ikea had also previously collaborated with the company Retour Matras to recycle mattresses and as a result of this success, they are looking to expand upon this success.
The problem that they came up with was that there was no effective way to recycle couches. Renewi had tried one test where they put a couch through one of their existing shredders and put the resulting waste through an existing sorting line meant for construction. The results of this test were poor with only the metal parts and a small part of the wood being recoverable. The textiles and polyurethane foam from the shredded couches were contaminated with wooden splinters that could not be removed. Ikea themselves had conducted several studies via student teams with the main conclusion being that a couch could be disassembled manually and that this would result in a net profit through both materials which could then be sold and diverting waste from landfills. However, these studies also concluded that labor was the major factor preventing this technique from being more widely adopted. Only when labor was not considered or was free either through volunteering or subsidies was this manual process a viable option. In addition to these two parties, Cure Afvalbeheer set up a dismantling hall with the aim of seeing if they could refine the manual process to be more cost-effective when done at scale at a dedicated facility. The setup was partly effective in that was more cost-effective and processed furniture waste from 4 cities resulting in most of the wood being recycled in addition to metal and some plastic. In addition, workers at the dismantling hall said that the waste they did have was no longer considered "bulky waste" but was considered "fine waste" and that this waste was cheaper to dispose of. This waste mainly consisted of polyurethane foam, fabric, plastic, composite materials, often glued together, and generally waste that would take too long to dismantle. This waste mainly light materials that were cheap to dispose of since disposal is paid for by weight. Despite this relative success in recycling materials, the project did not achieve the goal of being cost-effective in that it relied mainly on subsidized social labor. In addition to this, it is difficult for the dismantling hall to find and retain labor making this a difficult process to scale. Given all this previous background work done IKEA and Renewi set up six criteria points that they were looking for. The criteria given were: Economically Feasibility, scalable, technical feasibility, high recycling rate and temporal feasibility.

The main derived sub-questions would then be:

- What is the best method for armrest removal?
- What is the best method for fabric cutting?
- What is the best method for fabric removal?
- What is the best method for foam removal?

*Sub questions*

***[1] IKEA is used to refer to the IngKa group which holds 367 of the 422 Ikea franchises worldwide. However it is not directly involved in manufacturing***

## III. PROBLEM DEFINITION

The problem was that the old furniture sold by Ikea did not fit any existing recycling or waste processing plants. These products like couches, sofa chairs, chairs, and other civic furniture, were a problem to process due to the normalized shredding method not being applicable here. The main issue was that due to this shredding of the couches e.g., almost all the wood was contaminated with textiles, wool, etc. This would all then be put into the incinerator, which would negate the whole idea of recycling.
Keeping the six criteria points in mind this paper will focus on researching the practical difficulties of recycling these couches and attempt to find solutions to these problems. This attempt could mean multiple things; ranging from a concept idea to a recommendation to change up the way that Ikea produces their furniture.

## IV. RESEARCH AND POSSIBLE SOLUTIONS

### 1. Sofa Materials

After researching couches, it was evident that the most common materials that these sofas were made of were a frame usually consisting of wood. Springs are usually made of metal for the seating section of the couch and nylon for the backrest and cushions. The cushioning was almost always a polyurethane foam with a fabric covering. This fabric varied but the most common materials were nylon, denim or canvas, leather, etc. actual leather was also used in higher-end couches as well. Besides these main components, various fasteners were also used namely staples to attach the fabric/cushioning to the frame or in some cases Velcro. Plastic clips to hold the springs in place in cases of metal or staples for nylon strips. Lastly, various types of screws and bolts were used to attach the different parts of the frame. There were also miscellaneous other parts used such as the legs which were most often either wood, plastic, metal, or a composite of these different materials. The overall composition of these materials and the amount used varied per couch but these were namely the materials used.

Upon investigating these different materials, it was found that the metal was the most easily recycled material recoverable even in the case of shredding, followed by wood which when recovered could be reused in plywood at about 70% with the rest going to waste to energy plants. Thus looking into ways to substitute or recycle these materials was deemed less relevant.

The fabric and polyurethane foam were a bit more difficult to recover with these materials being thrown out in the case of manual recovery due mainly to the difficulty of separating these materials and their lightweight. Recycling options do exist for the fabric such as recycled felt [5] or denim [6] also with so many different materials used there are a lot of alternatives to anyone material such as denim which is made of cotton as opposed to nylon from hydrocarbons. Polyurethane proved to be a more difficult material to recycle. These foams are made from hydrocarbons and are not biodegradable or easily recycled Currently these foams are either landfilled, incinerated or used in waste to energy facilities. Some foam is reused in terms of bonded foam but there is insufficient demand for this material and the quality and price for this material often does not make it a feasible option to be used at the scale required. In addition, the main alternative to polyurethane is natural latex which suffers from its own issues namely price, land use and disease. [7]. However, upon discussion with the clients, it was apparent that this issue was being that a recycling solution was being investigated that would solve these issues. [8]. Overall looking at the materials was deemed infeasible due to research already being, the time available for this project, and the available expertise.

### 2. Sofa Construction

Through multiple visits to the dismantling hall at Cure as well and other background research, it was found that couches had a fairly standard construction. Beyond what was mentioned in **Sofa Materials** couches were mainly put together in sections with the armrests being bolted or screwed onto the main body of the couch (*see figure 1*). The legs of the couch were often screwed onto the bottom of the seating area or were extensions of the frame. Finally, in some of the simplest couches, the seating section and the backrest were separate pieces and bolted or screwed together. In some cases, there was also the glue that attached the foam cushioning to the wooden section though this was not always the case. The bolts holding the entire couch together were usually accessible from under the couch which could be accessed by cutting the thin fabric bottom of the couch off. This construction varied from couch to couch with some of the more expensive couches having frames that were one piece but overall, this overall construction was typical for most couches that were looked at.

To further investigate the couches construction a typical couch was defined as consisting of a mid-section with a seating section and backrest in one wooden frame. The armrests for the couch were screwed or bolted to this mid-section. The bottom fabric of this couch could easily be cut off exposing these fasteners. The legs of the couch could also easily be screwed off (*Figure 1: Cross-section basic couch*). Finally, the cushioning of the couch was made of polyurethane foam that was either not glued or the glue could easily be removed or dissolved, and the fabric was stapled to the mid-section frame and the armrests using staples. Of course, this definition does not apply to all couches leaving out categories such as sectionals and booths.

However, it does provide for a workable definition. The materials of the couch were those mentioned in **Sofa Materials**. Further details on exactly how each section is constructed is given in the following sections.

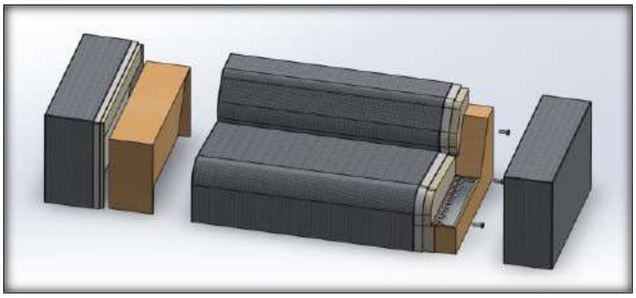

*Figure 1: Cross-section basic couch*

Looking at the overall construction of the couch defined, the current manual disassembly methods used and contrasting this to the alternative methods available namely shredding it was determined that the best use of time and expertise would be to find ways to automate this disassembly process. Improving this manual process was looked at and there was room for improvement however upon consultation with the clients it was determined that this would only deliver marginal improvements and would not fulfill the given criteria. Therefore, the process was looked at again to see where automation would be most effective in terms of time to design, and investment required. After consulting operators at the Cure dismantling facility and observing their ways of working it was estimated that most of the time was spent on cutting the fabric off the couch, since this step was also fairly repetitive it was decided that this would be the focus of our research. The overall new process flow after automation is shown in *Figure 22: Planned process flow to disassemble a couch*

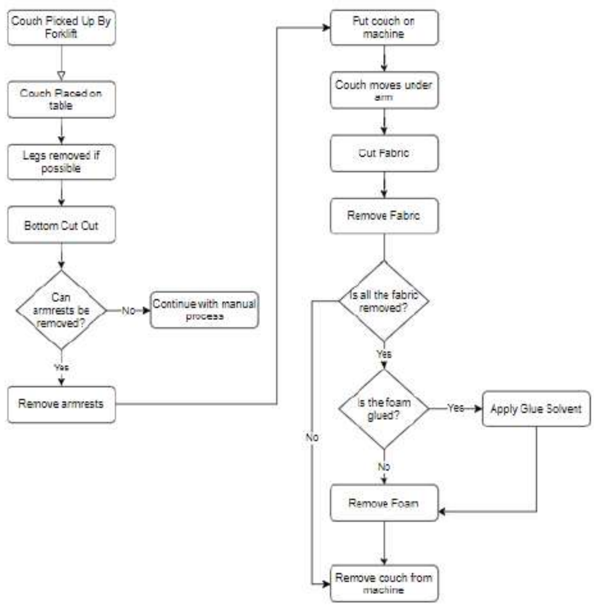


*Figure 22: Planned process flow to disassemble a couch*

## 1. Methods for armrest removal

In part, an answer will be sought after to the sub-question: 'What is the best method to remove the armrests?' The removal of the armrests is an essential first step to compartmentalizing the couch for easier processing. The armrests are a blockade when it comes to processing the main body, so they have to be removed first. Before the removal of the armrests, the legs of the couch are removed including the black bottom fabric, this will be done manually. This is due to the ease of processing after the legs have been removed. In the experience of manual laborers at the moment, working without the legs makes for an easier workable couch.

For the ideation, multiple concepts for the removal of the armrests were produced to compare and test.

The first concept at hand is pushing off the armrests due to applied force. In this concept, there will be an hydraulic press that will apply force from the center of the couch to the side to push the armrests from the inside. The couch will be in a fixed position. This concept will generate clean streams of waste because there will be no sawdust and a limited number of splinters that will contaminate the foam and the fabric. Using a 3D-CAD model of the couch which was created, it was calculated that the press would need to push on the armrests with a force of at least one thousand Newtons. This calculation has some uncertainties like material properties. This solution can be used for more types of couches. This means that the internals of the couch can be bolted or glued. The second solution thought of was the cutting concept. In this concept, there will be an automated saw that will come down and cut through the armrest of the couch vertically to separate the armrest of the main part. This also gave a completely automated process. The saw generated sawdust and splinters, the sawdust and splinters contaminated the fabric and the foam of the couch. Due to the contaminated fabric and foam, there will not be a clean waste stream, therefore this option could not be used. The last concept was the manual removal of the armrests. This method is already used at the dismantling hall. With the manual removal, the bolts that keep the couch together will be removed manually by an employee. A simple IKEA couch took approximately two minutes to take the bolts out of the couch and remove the armrest. Some couches however are made of a single frame and would require breaking the actual wood of the frame this possibility was investigated through a mechanical stress analysis to see how a couch would break. It was found therefore that this was possible however it was deemed that first automating the fabric cutting would be a more cost-effective option since the manual process does not take much time. However, later once cutting has been automated this would be a good candidate for further investigation. This would help further automate the process and make it more cost-effective.

## 2. Methods for fabric cutting

Separating the foam and fabric from the wood is one of the most important steps; the effectivity of separating the foam and fabric is directly proportional to the effectivity of the system since every unremoved piece of fabric affects the purity of the wood. Thus the importance of researching and testing definite methods of cutting to determine the best method of cutting the fabric off of the wood. Moreover, the fabric cutting and removing is the part to focus on to increase the efficiency of the entire system as a whole as this part of the process takes up the most time relative to the other processes e.g. the armrest removal. If an efficient development has to take place with an automated system; this is the place to innovate upon.

During the research phase, multiple cutting methods were investigated. As a starter, the basic idea was automating the current methods used to disassemble a couch. Resulting in the first concept which is using a knife on a robotic arm to cut through the fabric. This is the simplest and most used technique now for the manual way. This technique has some flexibility when it comes to what type of knives or cutting tools are used and has some advantages regarding scalability.

The second cutting concept was driven by the current way of shaping foam, which is wire cutting. Wire cutting is a way of cutting where electricity is used to create a potential difference on a thin wire, creating the cutting tool. During testing, it was discovered that this method gives the cleanest cut. However, it can be unreliable when used on an old couch since any irregularity in the wood combined with a big force can cause damage to the hot wire. Another disadvantage of wire cutting is the amount of time needed in comparison to other technics.

To avoid any damage to the cutting tool a new technique was researched, such as laser cutting. This method is good to scrape off all the fabric parts that are attached to the wood, leaving the wood almost all cleaned up. While laser cutting sounds like a good choice it's not. During laser cutting, the laser cutter doesn't cut in a straight line, instead, it makes a general burn in the fabric that can't be controlled. The burning creates toxic fumes. The fumes can also damage the lens, which is the most important and delicate part of the laser cutter.

Water cutting on the other hand is promising and shows great potential. Water Cutting with a water jet is a method of engineering for cutting objects using energy from high speed, high density, ultra-high-pressure water [9]. Testing showed that water cutting can cut real clean throw fabric, foam, and wood. Further, since every material needs a different pressure to penetrate and cut throw, water cutting can cut throw only fabric and foam without cutting throw the wood [10]. Testing and research also show that during cutting the workpiece shouldn't get wet by much. Although the amount of water used varies based on the cutting rate, type of material, and other variables.
In a conclusion, through testing and criteria matching, the "knife" cutting concept has been brought forward as the main technique to go with. Due to its reliability, scalability, and implementation prominence compared with the rest of the options.

### 3. Methods for fabric and foam removal

The main problem with the fabric and foam removal was that the way the couches were assembled, staples and other types of fastening were used to hold the fabric tightly to the wooden frame. This made sure the manual dismantling was never worth the time it took to carefully get rid of these fasteners, than to just take the loss and cut around the fasteners, leaving a bit of polluted wood-with-fabric material. Here comes into play the automation part of this process, where an accurate and precise machine could increase the effectivity and decrease the amount of fabric pollution on the wooden frame.

While there are many ways to automate foam and fabric removal. The two main ways that were researched and tested were, using a gripper and using a vacuum.
For both solutions, a robotic arm would be used to move the gripper to its desired location.
The gripper would be located on top of the robotic arm and will move around the couch to access the fabric or foam. The robotic arm will pull the fabric up and place it in a specific bin. After all the fabric has been removed the gripper will do the same for the foam.
As mentioned before to remove the textile and the foam of the couch, a vacuum lifter could be used. This technology can grip and lift the materials that needs to be taken apart.
The vacuum lifter would use suction cups to attach to the object that needs to be lifted. A pump would create a vacuum between the suction cup and the part to be lifted and store this vacuum in a chamber dedicated for this purpose. When the robot arm raises the cup, atmospheric pressure holds the textile/foam against the cup by atmospheric pressure. The volume inside the suction cup is at a much lower pressure and therefore has less force pushing down on the piece of material. The atmospheric pressure on the other surfaces of the workpiece is stronger, which pushes the workpiece up against the cup. This is what keeps it held up.
A vacuum lifter can suck an effective air volume in a very small amount of time which makes the process of removing textile/foam very fast.
Surprisingly, the vacuuming option was the best of these concepts, scoring enough points in the criteria management to outrank the gripper, manual or automatic.

### 4. Future expansion on the system

As has been noted in earlier passages, this method for disassembling couches can be expanded upon and scaled to refine the way many types of furniture are recycled. This will change the way furniture is used as well as the way they are made since manufacturers will know that their products can be recycled at the end of life.
The first thing that can be expanded is diversifying the definition of couches that can be put in the system. Upholstered furniture such as restaurant booths and car seats could easily be processed with relatively little additional work. Software such as databases and AI could be coupled with data on recycling rates on where to cut materials to make the system even more effective At the moment, the system can be seen as a hard-coded process,

which can only handle certain types of couches, but more soft-coding would add a lot of value to this process. It would perhaps even be possible to have vision control and AI identify couches that are good candidates for resale or reupholstering reducing the number of couches that need to be recycled in the first place

Beyond this, if the system were to scale up it would be possible to create an ecosystem around such a process. It would change supply chains in that furniture waste would need to be separated from other bulky waste. As well it could change how furniture is designed, optimizing for reuse or recyclability. Overall, the main question of this paper ***'What is more effective to separate a couch into clean waste streams that can be recycled?'*** could itself be a sub-question on how to reduce and recycle materials overall.

## V. Conclusion

Recycling reduces the land use required for additional materials, reduces pollution created when acquiring these new materials, and disposing of the old ones. It is also cost-effective in that it utilizes finite resources more efficiently

To reach the main goal background research was done and the main question was subsequently broken down into several sub-questions to create an overall concept.

This concept was to first step is to remove the armrests to ease the process. For now, this would be done manually later on a press will be used to apply force and separate the couch. After removing the armrests, the textile should be removed this step is the best initial candidate for automatization. This step is realized with the help of a robotic arm which has attached a knife at the top. The robotic arm cuts the couch according to set programming such as at edges or corners. Thus, replicating the steps done by a human but through more hardcoded logic After that this fabric and the foam cushioning could then be removed via a suction gripper. With these steps done the main question: ***'What is a more effective method to separate a couch into clean waste streams that can be recycled?'*** has been answered. The methods outlined are an effective way that couches could be recycled, and the methods outlined here would be effective for a range of bulky waste beyond just couches and could help significantly reduce waste.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# PC reinforced ABS filaments for FDM printing

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*Abstract*— **An investigation and selection of a material combination for manufacturing 3D printing filaments, combining two different plastics to improve one or more properties of the single materials, is leading in this paper. To the best of our knowledge and confirmed by the result of a patent search, a product or something similar does not exist. Nowadays there is not such a product yet and further realization, possibilities and limitations of the product were researched. Furthermore, the team focused on researching the possible manufacturing methods of the filament and contacting companies for help or sponsorship. To find the properties of the materials the team spent time on producing the filament at a small scale to perform tests and researched the possibilities to produce the filament on a large scale. A Polycarbonate (PC) core and an Acrylonitrile Butadiene Styrene (ABS) layer were chosen to be further developed. This combination was chosen to achieve better mechanical properties with the dual filament than with ABS or PC alone. Additionally, due to the high cost of PC, the new filament would be more affordable. The next reason is that the flow temperature of these materials is within a range that allows the materials to be printed together. This filament can contribute to the market of safety products, automotive industry, and to every small-scale application of people who possess 3D-printer at home.**

***Keywords — Extrusion, Filament, Plastic, 3D printing***

## I. INTRODUCTION

This project is an innovative assignment given by Fontys and EUSS University of Barcelona to a group of fourth-year mechanical and mechatronics engineering students from both universities. This project is part of the subjects “Innovation Engineering” and ”Advanced Mechanical Production Methods” of the Dutch and Spanish students respectively as part of their Innovation Engineering project. This paper is based on a paper developed by the US military in which a large cylindrical pre-form is used to be extruded into a dual material filament. The pre-form is a cylinder with a 5-point star PC core surrounded by ABS and produced by traditional Fused filament fabrication (FFF) printing. This pre-form is then extruded from 2.50 centimetres to the targeted diameter of 1.75 mm. This production method is not commercially available, as it is expensive, and the scientific research facilities are used for this military application are not available to the public. Therefore, the EUSS challenged Fontys students to develop and manufacture 3D printing dual-material filament that consists of a PC core and ABS around the PC. The end goals are making the filament available to the public, and to test the material to see if it has better properties than those two materials individually. EUSS University of Barcelona presented their requirements for the project and provided Fontys students with past research and testing results, as well as with the paper of the US Army research. The main conclusion of this research is that there is a manner to 3D print the new filament. Besides the way that is described in the US Army paper. [1] The focus of this paper is to present the reason and findings of the project and to show the properties comparison between the materials to see how this new material will be useful, and what the market possibilities are with it. Furthermore, the goal is to present the manufacturing method with which the filament will be made, together with some alternative methods. The manufacturing guide of the chosen method of filament production will then be finally presented.

## II. MATERIAL PROPERTIES

ABS has a long history in the 3D printing world. This material was one of the first plastics to be used with industrial 3D printers. Many years later, ABS is still a very popular material thanks to its low cost and good mechanical properties. ABS is known for its toughness and impact resistance, allowing you to print durable parts that will hold up to extra usage and wear. The pros of the ABS material are its very low cost of 1.5 euros per kilogram, good heat and wear resistance, and a long lifecycle in comparison with other printable plastics. On the other hand, the cons are heavy warping, and parts tend to shrink. ABS has a melting temperature of around 200 degrees Celsius, it is therefore recommended that the extrusion temperature be between 230 and 260 degrees Celsius. The application of ABS is to produce toys, such as LEGO, but it can also be used for electrical enclosures, sports equipment, and parts for the automotive industry. [2]

PC is an amorphous material which is hard and rigid. It is clear with excellent clarity and has similar properties to acrylic. In the 3D printing world, it is known for its high impact resistance and transparency. It also has high tensile and yield strength, which makes it resistant to impact and fracture, and further providing safety and comfort in applications that demand high reliability and performance. The cost of PC is 3 euros per kilogram, which by itself might not be too expensive but in comparison to other plastics it is. The downside of PC material is that it is not as easy to print as ABS, due to its high extrusion and built plate temperature, but nevertheless printing with PC allows complex and heat resistant parts to be produced. Its melting temperature is between 270 and 320 degrees Celsius. Furthermore, it absorbs moisture, and it is prone to warping. The products that are mostly made with PC are optics, protective screens, or decorative objects. [3]


*Figure 1 Material prefab*

The filament that will be the final product will consist of PC core, with an ABS layer around this core. The ratio of ABS – PC will be 84% to 16%. The creation of this filament will contribute to the improvement of the 3D printing world and would be an interesting new product on the market that many 3D printing hobbyists would like to have in their collection for usage to create products for personal applications or fun purposes. This dual material filament provides unique product properties that are better than those obtained by two materials individually in terms of mechanical properties and economic feasibility. The pros of the filament are that it will provide better strength than ABS alone, because of the PC core inside the ABS layer. Also, by having a higher ratio of ABS than PC in the filament, the printing process would be much easier as the PC is very hard to print and many problems can occur, which is not the case with ABS. Finally, the filament will have a more affordable price due to the usage of the ABS layer around the PC core, without losing much of its strength, which will be validated by the performance of the tensile tests. This dual material PC-ABS filament is suitable for safety applications, automotive industry and can attract any 3D printing fanatic.

## III. PROCES

The idea of the material came from a paper derived from a project concluded within the US military [1]. In which a rod was printed and extruded. This rod or prefab was made on a 3D printer and allowed the PC reinforcement to hold different shapes. To start, the prefab was recreated. Three different iterations were made of the prefab. It was soon concluded this technique came with many difficulties. The final iteration almost proved fully successful. However, after consideration, it was decided this was not a valid way of creating the filament. With more attempts the prefab would have been able to be produced, yet the next step in this process would cause more problems. The prefab would have to be inserted into a machine and slowly heated. The softened material would then be slowly extruded into a 3D printing filament roll. This machine would have to be produced, which fell outside the scope of the project. Producing the material in this matter would still leave the sizes of the rolls too small for a commercial application. A new technique had to be found to both produce and test the material.

**Producing the testing material**

The technique used to develop the dual material filament consisted of printing a coil (spiral-roll) of filament – see figure 2 – directly using a dual extruder 3D printer. A dual extruder is 2 way filament extruder with different colours or types of filament what can be printed at the same time. This way of printing we used it as a co-extrusion method to get a core of PC with an outside layer of ABS. This way, the filament containing both materials could be produced. Moreover, this technique has been developed as a consequence of a thorough creative process.

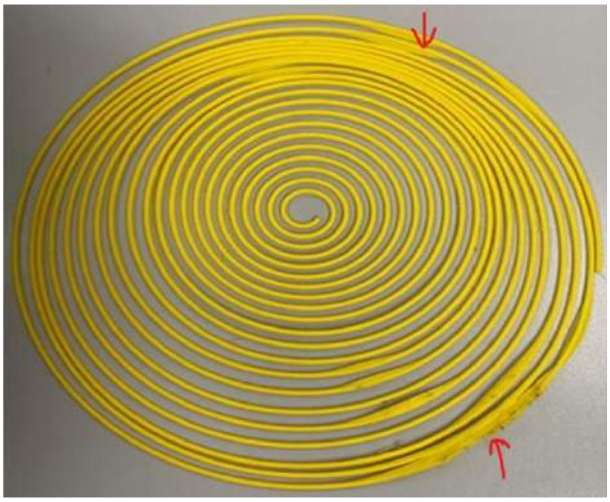

*Figure 2 Dual material filament deformed (see red arrows) due to an insufficient adhesion to the printed bed.*

Two cross sections of the filament can be seen in figure 3 [4]. On the left the schematic showing the layering during the 3D printing process. This cross section clearly shows how the PC was incorporated within the ABS. A layer of PC is put down onto layers of ABS. After layering the ABS around the PC, the ABS is put on top of the PC. The right cross section was made of the finished filament, after being treated with the heat break. This treatment changed the layer composition and Deformed the circular shape of the PC.

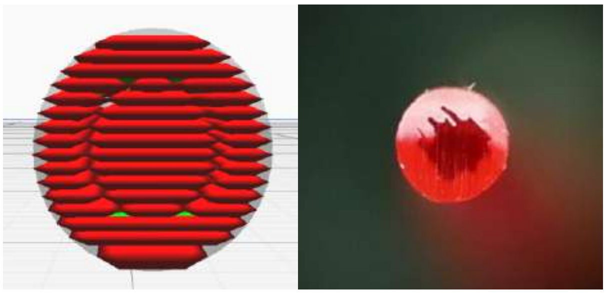

*Figure 3 Cross section of the PC and ABS*

First, the design of the inner part of the filament was noticeably constrained due to the lack of precision of the printer with such small details. However, designing the inner part in a simple geometry – such as a cylinder – instead of a five-pointed star, enabled the production of a usable spiral-roll of dual material filament. The same cylindrical geometry was implemented in the external part of the filament.

Second, the length of the filament was constrained by the 3D printer. The bigger the print surface is, the longer the filament can be. Although having the size constraint, there is worked out a way to print as much filament as possible. That was achieved by increasing the number of revolutions of the coil while reducing the space between each revolution. Moreover, by printing the PC with the right extruder, the printable area – and the longitude of the filament – increased noticeably.

Third, one of the main issues of FDM 3D printing is tackled, lifting, which is a phenomenon that causes the corners of 3D prints to lift off the platform and deform. This phenomenon was caused by the contraction of the plastics when the material suffers high changes in temperature. The solution was to increase the temperature of the 3D printer's bed up to the maximum that the printer allowed, which was 110 degrees Celsius, and to increase the initial layer height to 0.2 mm. That way, the temperature change that the plastic experimented was not as high as to produce the lifting phenomenon. The final filament outer shape was approximately cylindrical.

Finally, in order to eliminate some of the inevitable imperfections present in the filament after its printing — see figure 2 – the team thought of passing the filament through a heat-breaker, which is a precision machined piece that is used inside the 3D printer and ensures the filament will be the correct diameter and not clog the printer . By doing this, most of those imperfections could be eliminated and the filament could now be ready to be used.

Although printing the dual-material filament right away with a dual extruder 3D printer was – as has been discussed – not a feasible technique for upscaling, it was sufficient for the students at Fontys and EUSS. This is the best way to research dual material filaments because the only necessary equipment is a dual extruder 3D printer. Some other techniques require a bigger – and more expensive – investment in machinery to develop the research.

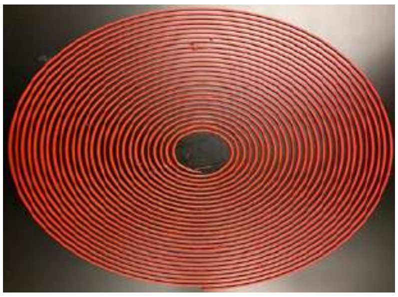

*Figure 4 Dual filament with observable imperfections that can be eliminated by passing the filament through a heat-breaker*

Now a technique was defined to create the filament with a diameter of 1.75 mm. To test the material more thoroughly the material would also have to be tested when made with a diameter of 2.85 mm. For this, the design of the spiral-roll was adjusted to meet the new requirements and then printed. The test to compare the filaments is the geometrical accuracy and material properties if they are the same and having the same ratio PC ABS in the filament.

As has been discussed in the section "Producing the testing material," the 3D printer plays the main role in the production of the dual-material filament. At Barcelona, the printer used was a Raise3D Pro2 Plus, which fulfils the requirements that the team believed a printer should meet to print the dual material filament – see table 2. This printer features a dual extruder that is capable of printing two different materials at once. The dual extruder method is working like setting two materials in the slicing program that one part will be printed by the first nozzle and the second part will be printed by the second nozzle. The task of printing with PC was attributed to the second extruder. This enabled the machine to reach the outermost parts of the bed so the filament could be as long as possible. The diameter of the right (PC) and left (ABS) nozzles – also known as first and second nozzle, respectively – was 0.2mm and 0.4mm respectively. The extruder temperatures were 280 degrees Celsius for PC and 250 degrees Celsius for ABS. Moreover, the initial layer height was 0.2mm and the height of the other layers was 0.15mm. This difference in layer heights helped reduce the lifting discussed in the previous section. Lifting was also avoided by setting the bed temperature to 110 degrees Celsius and using a PEI bed. Because of the higher bed temperature the lifting doesn't work because of melting to the bed is on a higher temperature. Table 1 shows all these data in a more concise form. With these data, anyone with access to a Raise3D Pro2 Plus or similar printer can replicate the research the team has done. In the case of using another printer, the requirements of the machine are exposed in Table 2.

| Printer configuration | |
|---|---|
| Nozzle diameter | PC: 0.2 mm & ABS: 0.4 mm |
| Extruder temperatures | PC: 280 ºC & ABS: 250 ºC |
| Initial layer height | 0.2 mm |
| Layer height | 0.15 mm |
| Bed temperature | 110 ºC |
| Shells | 10 |
| Infill | 100 |
| Print bed material | PEI |

*Table 1: data used in the configuration of the Raise3D Pro 2 Plus*

| **Printer requirements** | |
|---|---|
| Dual material | Required |
| Bed size (for dual material) | 280 x 305 mm |
| Enclosed build plate | Recommended |
| Filament size | 1.75 mm |

*Table 2: printer requirements for the printing of the dual material filament*

The printed roll, after some slight adhesion problems on the print bed, was successfully printed with a diameter of 2.85 mm. The adhesion problem where coming from a small surface to the print bed and this made the sticking to the bed not consistent through the hole print of the filament. After some testing an observation was made, the radius of the filament was not consistently sized or shaped. This led to the filament having a diameter of nearly 3 mm when measured at a different position of the filament roll. Because of this inconsistent of the printer the size of the filament needed to be smaller. To counteract this the design was adjusted to print the roll with a diameter of 2.6 mm. With this adjustment in size this new diameter should prevent the roll from having a diameter over 2.85 mm. To facilitate the lack of material, as a smaller diameter means less material, the flow speed of the material during the printing process could be increased.

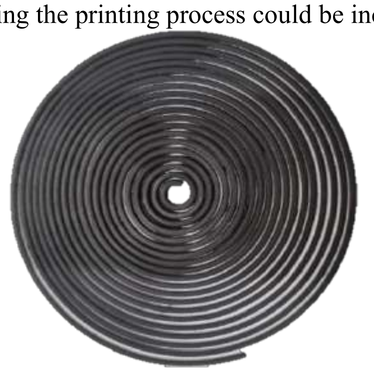

*Figure 5 Testing filament 2.85mm*

To test the printability of the material a standardized design was used. This design, shown in figure 6, depicts a cube with letters on three of its sides. Its small size provides ease of printing, yet the letters can give a clear definition of the printing quality. The filament with a 2.85 mm diameter, due to its irregular size, led to the cubes not being printed correctly. The oversized material kept getting stuck in the printer which caused the printer to abort the print. From this point onward only the 2.6 mm diameter filament was used. The cubes initially were fully printed. The first attempts showed deformations around the letters. This sort of warping was most likely an effect of the material being overheated which caused shifting of the layers. After adjusting the settings, the warping had indeed diminished. With the correct print settings defined the next step could be taken.

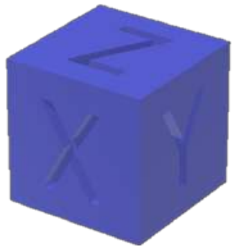


*Figure 6 calibration cube*


*Figure 7 One side of the printed test cubes. on the left the finalized cubes, on the right the first attempt*

Now that the material could be printed with its qualities could be tested. The first tests would be to test the tensile strength of the material. The printing of these objects was rather simple.
In total ten of these were printed with the filament. Five of these were printed with an infill of 20%, the other five with 50%. These were later used in tensile strength tests.

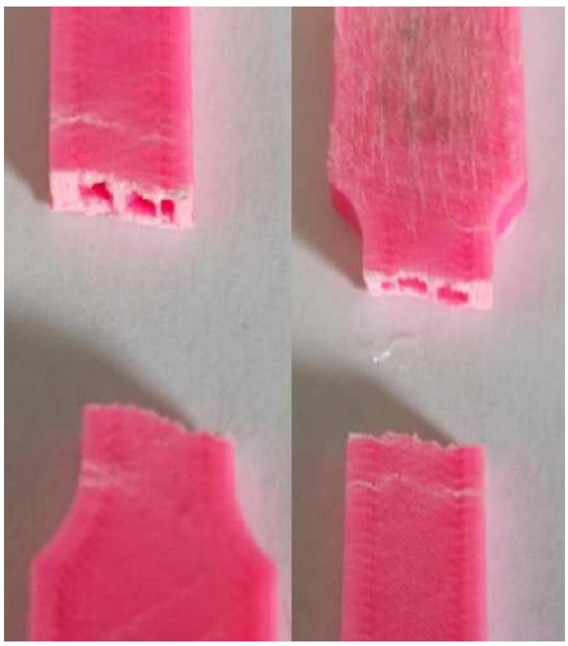

*Figure 8 Test bars from tensile test. On the left 20% infill of ABS-PC, on the right 50% infill of ABS-PC.*

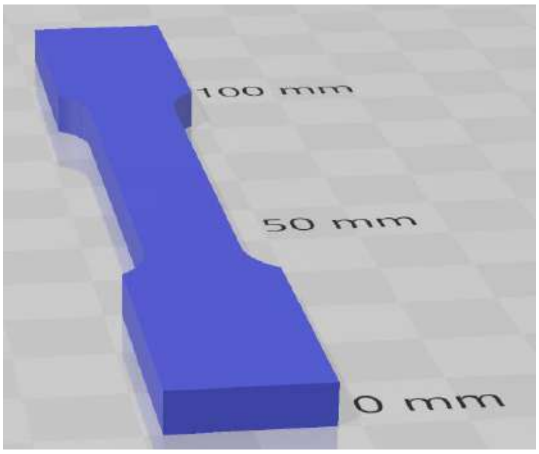


*Figure 9 Tensile-strength testing object*

## IV. TENSILE STRENGTH TESTS

The tensile tests are conducted to discover the difference between several 3D-printing materials. These materials are standard ABS, PC, and ABS/PC blend, and a self-produced material of ABS with a reinforced core of PC. The results will conclude if the developed filament has better properties in comparison to its direct counterparts.

In comparison to the standard PC and ABS, the developed material is expected to have properties that sit in-between. Its tensile strength should be higher than ABS, since it is reinforced with PC, yet lower than PC on its own, since it does not consist of pure PC. In comparison to the blended material the self-developed material is expected to have a higher tensile strength. The PC core will be fully loaded on tensile stress and thus should increase the maximum allowed stress. In the mixed material the PC is 'weakened' by being combined with ABS.

For each of the materials ten test objects will be printed. Each material will have five test objects with an infill of 20%, with the other five at 50%. Each test object will have a layer height of 0.2 mm, two walls of 0.8 mm and four top and bottom layers. Before and after conducting the test, the testing objects will be measured at set locations.

From all the tensile tests done the results have been compiled together and are shown in Figures 10 and 11 below. Based on the findings, the hypothesis for the 50% infill tests seems to be correct, showing an ultimate tensile strength (UTS) that is between the UTS of both the ABS and PC tests. However, based on the results for the 20% infill this hypothesis does not seem to hold, showing the UTS of the Self-Developed filament to be almost equal to the one of ABS, with PC towering above them both. This is most likely because the ABS 20% infill results had multiple invalid and uncertain tests. Three of the thirty test were invalid due to human errors during the test procedure. This is 10 percent of the test specimens. Differences between the 20% and 50% infill is that the amount of PC in the 20% infill specimen is less in comparison with the 50% infill specimen. What leads to more strength of the 50% infill specimen.

Making use of the stress-strain curves that have been obtained from the tensile tests, the Young's Modulus can be calculated. This mechanical property measures the stiffness (both tensile and compressive) of the material along the length of it. The calculations have been done by the tensile test machine through the ratio of the stress over the strain, which is equal to the slope of the curve. In Figures 10 and 11 the average Young's Moduli of the testing samples can be seen on the horizontal axes.

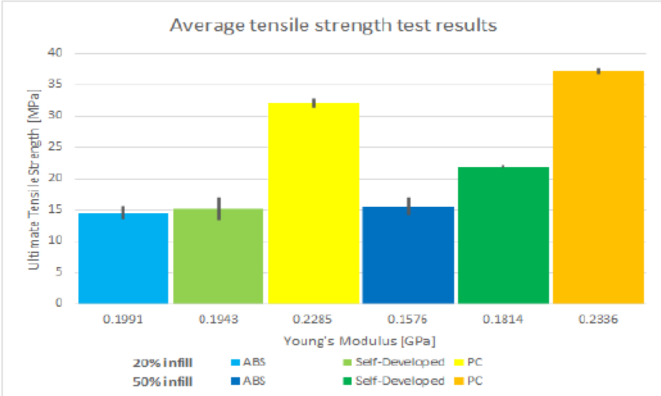


*Figure 10 Average tensile test results with ultimate tensile strength in MPa and Young's Modulus in GPa.*

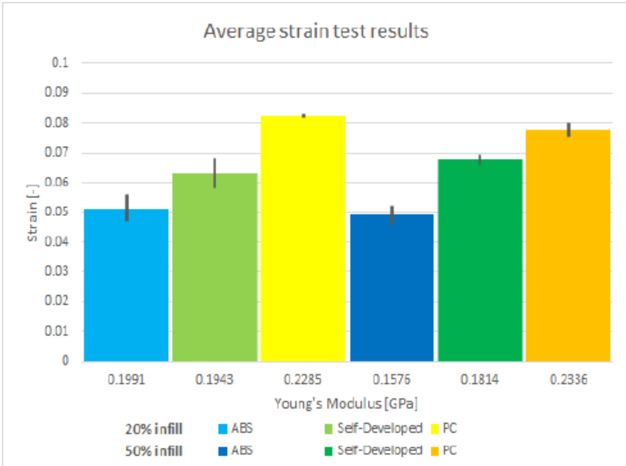


*Figure 11 Average strain test results with strain and Young's Modulus in GPa.*

The average strain result is 0.0651 [-]. The strain results of the developed material are even better than the strength results. The Youngs modulus of the filament is very low. The modulus of ABS with full density is in the 1-2 [GPa]. This specimen are not full density but despite that, the Youngs modulus is lower than expected. The 50% infill results do show increased strength in the Self-Developed filament compared to using pure ABS as expected.

## V. MANUFACTURING ON A LARGER SCALE

One of the best possible way to extrude a non-blended dual material filament on a commercially viable scale, is a technique called co-extrusion. In co-extrusion two materials are extruded through one singular mould, resulting into a single solid. Currently co-extrusion for filament is done with a technique that allows a fifty-fifty division of materials. A schematic of this process can be seen in the figure below. This technique is used to combine two colours of a single material, instead of two different materials. The two colours result into colourful patterns when used in a print. This technique of filament extrusion was invented in 2020 and the filament has been sold since 2021. [5]

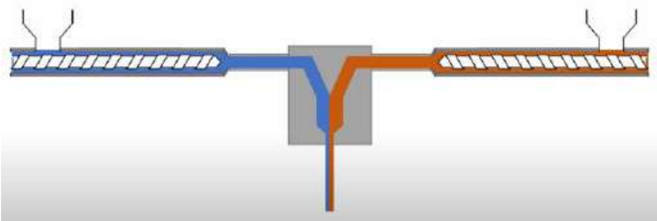

*Figure 12* Co-extrusion method 1

This way of co-extrusion is a way that is already been used for tools, automotive industry, medical industry and many more industries for combining materials. The benefit of co-extrusion is that is relative cheap to combine two or more materials with different properties. This way the material is stronger and easier to use in the industry. This way of combining different materials could never be done by 3D printing because of the nozzle can only held one temperature. The way of co-extrusion for 3D-filament nowadays is only used to combine colours of filaments. Instead of different colours two different materials should also be combined this way. For the PC reinforced ABS filament a change needs to be made to the existing co-extrusion technique.

The figure below shows a schematic of a modified version of co-extrusion. With this technique the PC could be extruded within the ABS. It could also allow the PC to be shaped in different patterns that could modify the mechanical properties of the filament and the ratio of PC to ABS to be changed. Because the materials will be inserted as pallets additives could also be used to change some of the properties and further enhance the percentage of the PC This technique should enable the desired filament to be created on a large scale. In the string of the filament the place of PC is not known, which can be considered as a problem for determining the amount of PC used. By the way of co-extrusion, the place of PC is fixed so the amount is fixed as well.

The adhesion between the materials will be expected with a part of PC and ABS which aren't combined in each other. This chemical side of the adhesion between the materials is not part of the scope in this project for now.

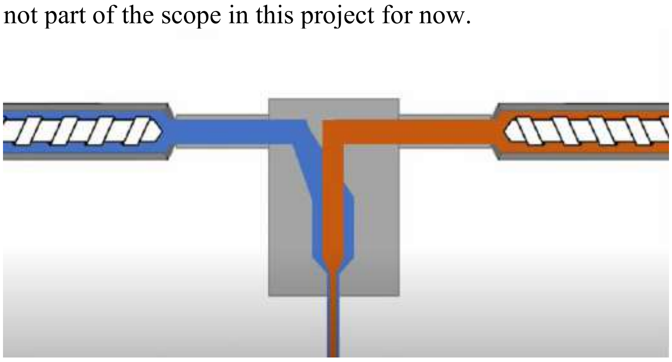

*Figure 13 Co-extrusion method 2*

Co-extrusion can produce unlimited length of filament, as the extruded filament can be wound up on a spool indefinitely. This enables the material to be produced on a large scale.

Currently, blended PC-ABS is mainly used in the automotive industry because it is a light material and quite robust. Creating a stronger material should increase the interest of anyone interested in this new material.

## VI. FUTURE DEVELOPMENT

This approach needs further development to optimize the filament and material properties. We have identified three points as described below. These have not been developed yet due to several restraints such as timing and to the COVID pandemic.

First, according to the US Military paper [1], once the test sample is printed with the dual material filament, if it undergoes a thermal treatment the properties of the sample increase noticeably. The reason behind this improvement is that by increasing the temperature of the test sample, the two plastics can fuse together. Thus, improving the mechanical properties of the final test sample, or adhesion between the materials.

Secondly, more testing can be performed. If more test samples are tested, more information can be obtained. This additional testing can assess whether the production of the dual material filament is efficient enough or if it should be improved by developing more production methods. One of the examples is to compare the dual material filament to the blend of these materials.

Finally, the development of more production methods can be a real breakthrough. Nowadays, the most obvious way to produce this dual material filament is by co-extrusion – as has been discussed – but some new techniques can be developed to increase productivity and reduce production costs.
Co-extrusion method 2 is how the future will be look like to make the filament. This the most likely how this filament will be produced. The production costs are way cheaper than the way of printing a test sample every time like we did for testing our materials.

## VII. CONCLUSION

Inventive ideas were generated to produce a dual material non blended 3D-printing filament that would have better properties than those two materials separately. The material combination for the filament that was used is PC-ABS, where there is a PC core within a layer of ABS. That way, the filament will be provided by better strength due to the PC core, and it would be much cheaper and easier to print due to the outer layer of ABS. The filament was then directly printed at a small scale to perform the tensile test and compare the samples of the dual material filament to the ABS and PC samples. The tests with the 50% infill have shown exactly what was expected, that the PC-ABS filament had better strength than ABS, but lower than the PC. However, the direct printing of a filament is not the solution to produce this filament because this process is slow and not perfect. So, if this filament will be manufactured on a large scale, the best way to do so would be with the process of co-extrusion, where the combination of the two materials has a positive effect on the mechanical properties. This method will combine two materials into one solid, by adding those at the same time until it becomes one. The estimated price for one roll of this filament would be approximately 45 euros, and the filament would be used in safety applications, in the automotive industry and would most definitely get the attention from every 3D-printing fanatic.

## VIII. ACKNOWLEDGMENT

This paper was written during semester seven of the Innovation Engineering differentiation at Fontys University of Applied Sciences and Escola Universitària Salesiana de Sarrià. Credits must be given to teachers from Innovation Engineering, Abigail Albuerque de Souza Daneluz, Hay Geraedts, Johan van Gerwen, Maarten Haasnoot, Bert Huis in 't Veld and Pablo Sevilla Sánchez for walking us through the product innovation and business innovation course and supporting the group of students during the project. Besides these important people, the students also thank Leandro Di Domenico for organising the ECAM symposium. The students are thankful to the teachers for looking for things that already exist but can also be innovated and for learning to critically look at products and the manner of communication with one another and apply the use of innovation principles.

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# Fireworks replacing AI pathfinding based drones


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## Abstract

Drone can be used in a variety of different applications which all require different solutions. For the implementation to replace fireworks, major aspects which were focussed on by the team are the lightweight mass, compact format, affordability, and use-case implementation of the drone. This paper gives an insight in several aspects of the development of such a drone. Topics to be featured are the designing, selection of hardware components and the integration of the software AI. A more detailed description is also given about functions like the pathfinding and collision detection, performed by the software AI.



### Keywords

Innovation, Engineering, Drones, Software AI, Swarming, STEVAL-FCU001V1, MATLAB

# Introduction

Every year around new year there is a returning discussion about the private use of fireworks. Whether to forbid individuals from buying and using them, or not. For the people who are against fireworks, there are three main arguments to be made. First up, the damage caused using fireworks costs a lot. During the celebration of New Year's Eve 2018-2019, the total cost of damages is around 12.9million euros, according to just the private insurances [1]. In the timespan of nine years, 158 people lost one of their eyes in firework accidents. According to the OVV (Dutch research council for safety), the yearly medical cost for a person who lost their eye is 12.500 euros. The average age out of the 158 people who lost an eye, were 20-years-olds. With a Dutch life expectancy of 88 years, the costs for just this medical care alone accumulates to 134.3 million euros [2]. This is still only taken into account one of the possible injuries. This results in a much higher price tag every year.

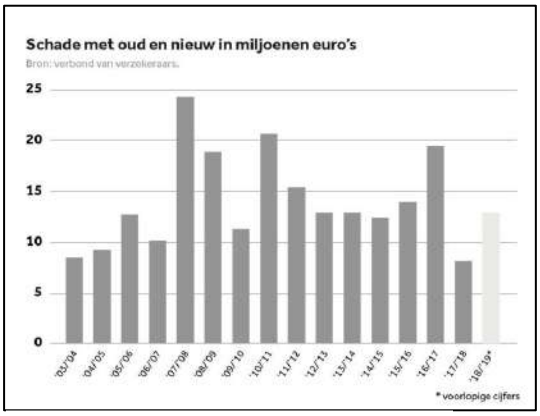


*Figure 1: Damages from fireworks in euro's*

Besides the financial aspect, another argument for banning the use of them is the added pressure on the medical sector. With the effects of the currently ongoing covid-19 pandemic, this has become a larger issue. During New Year's Eve 2019-2020, there have been over 1200 instances where people had to seek medical attention after being involved in a firework accident. Out of these, nearly 400 cases ended up in the emergency room [3]. During the following New Year's Eve of 2020-2021, this number decreased to a total amount of around 380 in total. The main cause behind this occurrence is the temporary ban on private use of fireworks. This was put in place beforehand by the national government in order to, successfully, help relieve the pressure on the health sector. This shows that by banning the private use of fireworks during New Year's Eve, the impact on the healthcare will be reduced.

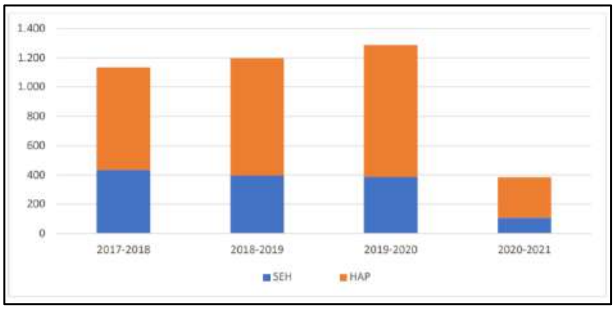


*Figure 2: Cases of first aid*

The third main argument against the use of fireworks is the environmental impact. Fireworks are a single-use product, meaning that the product is neither reusable, nor recyclable. This is clearly visible by all the remaining debris of the fireworks, littering the streets on New Year's Day. Sometimes this waste also ends up in nature. This waste contains micro-dust, which inflicts damage to the environment and can be harmful to the natural flora and fauna [4]. Not just the remains from the fireworks create micro-dust, it is also something that gets released when initially lighting the fireworks. Each year around 250.000 kilograms of micro-dust gets send in the air [5]. By replace fireworks with multi-purpose drones to create shows, the impact on the environment can be reduced.

The previously mentioned reasons are the three main arguments against the private use of fireworks. Besides these three, there also other arguments like the CO2 pollution [6] and the harmful impact on pets and other animals [7]. Concluding the arguments, there definitely is a need to replace the traditional use of fireworks. This paper will give a solution which obviates all the before-mentioned problems.

## Design/research main results

The drone has been designed in separate modules: the frame design, the flight computer, the software AI algorithm and the electrical hardware. The performed project is a continuation of the work performed by a previous project team in years before. Part of the performed research has been carried out to ensure the previously established results for; the design of frame, the implementation of the flight controller, motors and propellers, and modification of the software AI program.

# Method

## Drone algorithm

Pathfinding is an algorithm in which the computer determines a route that an object must take, to go from a starting location to the final target location. In this project, drones will fly autonomously from a random assigned starting location to a specific set target location. At this final location the swarm of drones together will form a shape. In order to perform this manoeuvre, a pathfinding algorithm is required to guide the drones. While traversing the determined route to the final set location, it is important that the drones do not collide with each other. Alongside this, the drones need to reach the location at which the show will take place, perform the show itself, and return to the initial starting location, all before the battery runs out. The programmed software algorithm which is described is developed using the program MATLAB [8].

The developed algorithm takes the individual starting locations of all active drone and the predetermined height of the show as an input. Using these values, the program calculates the route each individual drone needs to fly. This can be separated into different parts: calculating the target locations, assigning the target locations and calculate the pathing of each drone. In order to calculate the target locations, the central point, around which all drones come together, is determined. This is done to balance the flight time of all the drones, so that it doesn't occur that some drones have to travel a multiple of the distance of other drones need to travel. The equation which is used for this operation depends on the number of active drones. If the number of active drones is smaller than 900, the position of the centre is calculated by taking the mean of the starting locations. The reasoning for this is the use of the Central Limit Theorem. This theory describes that, even though samples of a population may not be Normally Distributed, if you take 30 sets of at least 30 samples, these will individually be Normally Distributed. This allows to give a more accurate centre position for the drones. In the x-, y- and z-axis the equation goes as follows, for *n* number of drones (*D*). The calculated value for *C* describes the position of the centre ($C_x$ is the x-coordinate and $C_y$ is the y-coordinate). $C_z$ is not calculate, since the height is a pre-given value as one of the input values.

*Equation 1:*
*X-coordinate of Centre position*

$$C_x = \frac{\sum_{i=1}^{n} D_{n_x}}{n}$$

*Equation 2:*
*Y-coordinate of Centre position*

$$C_y = \frac{\sum_{i=1}^{n} D_{n_y}}{n}$$

If the number of drones is 900 or greater, the position of the centre is calculated in a different way. First the drones will be divided into different groups. The grouping is performed randomly, independent of the starting location. The drones are be divided into 30 groups, where the size of the groups is dependent on the total number of active drones. For every group, the mean will be calculated using the same equations as if the total amount of drones were less than 900 (using Equation 1 and 2). Afterwards, the position of the centre is calculated, by calculating the mean of the previously calculated means of the separate 30 groups.

For every possible shape, the target locations of the drones will be different, therefor the target locations are calculated independently per shape. Regardless of the final figure, in every situation the position of the centre is calculated as described previously. The results from the Centrepoint calculations are transformed to the target locations accordingly, this way the centre (*C*) will be the centre of the intended final figure. The output for every figure is the only value which is the same; an equal amount of target locations as the number of active drones, containing the x-, y- and z-coordinates, and the angle of the target location to the origin. This angle is calculated in the x- and y-axis, since the height is the same for every target and will later be used to assign the target locations to the drones.

The algorithm also optimizes to reduce the flight time of the drones when assigning the target location. This is done by assigning the drones to the closest, not yet assigned, target location. The target height of all drones is the same, therefor the algorithm only takes the x- and y-axis into consideration (when assigning the target locations). In order to reduce the number of collisions between the drones and the distance travelled, the drones and target locations will be sorted by the angle and assigned in order.

Now that the drones have been assigned a target location, the routes are left to be determined. The path each drone has to fly is tracked by its position. Every time the drone moves one timestep, the current position is added to a vector. The drones will first be flying upwards, until the targeted height has been reached. This manoeuvre is performed in order to prevent the drone from colliding with other obstacles, such as buildings and trees. It is assumed the drone takes-off with an unobstructed view towards the sky. This makes it obsolete for additional sensors to be installed, simplifying the hardware of the drone. When the target height has been reached, the drone will start flying towards its target. The direction each of the drones will manoeuvre towards is calculated based on the current position of the drone and its target location, using the following equation:

*Equation 3: X-vector of path*

$$M_x = \frac{T_x - P_x}{|T_x - P_x|}$$

*Equation 4: Y-vector of path*

$$M_y = \frac{T_y - P_y}{|T_y - P_y|}$$

The calculated value for *M* is a vector of the direction in which the drone needs to manoeuvre. The value for *T* is the coordinate of the target location and the value for *P* is the current position of the drone. The value of *M* can only be -1, 1, or not a number (NaN). If *M* is NaN, it means that the target location has been reached and the drone no longer needs to manoeuvre in that direction. After the direction has been calculated, the algorithm will check if there are other drones located in a certain radius. In the case that other drones are present, only one of the drones will continue to move, while the other drones will stay at their current position. After the single-moving drone has left the area, another drone will start moving. This process will keep repeating until the area is emptied. This action is performed in order to prevent drones, which will otherwise cross each other's paths, from colliding. After every drone has moved in a single timestep, the current position of all drones will be updated. This process will be repeated until every drone has reached their desired target location.

## Drone electrical hardware

The electrical hardware design of the drone is based on the STEVAL-FCU001V1 controller. This is a development board which has enables the project team to rapidly develop a working prototype. The development board is based on a STM32F401. The STM32 is a well-known microcontroller (MCU) in the industry, there is a lot of helpful documentation about it and good support on the software side. The design of the STEVAL development board can be divided into different sub circuits.

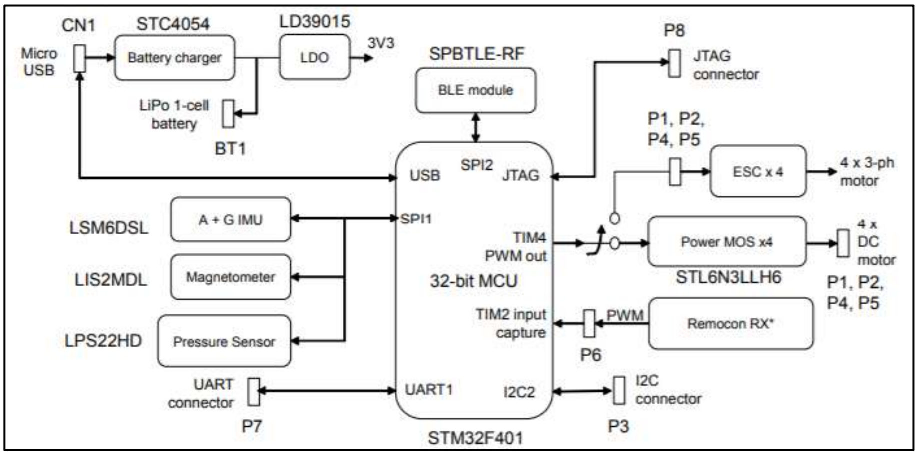


*Figure 3 STEVAL-FCU001V1*

The most important circuit is the STM32/32-bit MCU block. This block performs the interfacing with all the other circuits and will run the flight software, which enables the drone to fly. The MCU interfaces with different several peripherals via the SPI1 bus. These peripherals are sensors which are necessary for the drone to perform stable and controlled flight manoeuvres. The 3 main sensors which are used are; the Inertia Measurement Unit (IMU), the Magnetometer and the Pressure sensor. By measuring the inertia and acceleration of the drone over the movement axis, the software is able correct for unbalance and control movement via the motors. The magnetometer detects the magnetic field of the Earth. This way the drone can calculate its orientation related to the field of the Earth. Using this, the drone is able to navigation when flying towards or away from the swarm of drones. With the use of the pressure sensor, the drone can determine the flight altitude, the altitude is an important variable when a drone needs to fly in swarm formation, since the software pathfinding AI requires this information to calculate the manoeuvre direction for the drone.

The electronic hardware of the drone will be communicating with the software AI on the main computer. Even though the communication to the PCB (Printed circuit board) is setup in the software on the development board, it is only a half-duplex style communication. It is not possible to communicate the measurements back to the flight computer on the ground. Since the development board has no build-in GPS, it has been added separately to the drone. Having a GPS location is necessary to perform the swarming in formation by the drones. The added GPS module is interfaced via the UART1 port on the development board. The GPS module receives the exact time and location via the EU Galileo satellites, which are moving in orbit around Earth.

Currently, controlling the drone is performed via a Bluetooth module. Via the Bluetooth module, the information to control the drone is send directly to the controller of the drone from an external Bluetooth device, like a smartphone or computer. With future development, this will rather be performed by the external remote control signals header on the development board.

For controlling the motor on the drone, there are two options build into the development board, the project team can take advantage of. The first one is by using larger and higher voltage motors, which can be used by implementing External Speed Controllers (ESC) into the design. These controllers convert the PWM (Pulse width modulation) signal, coming from the STM32 to a 3-phase ac signal so that brushless motors can be implemented. However, since the drone is designed to have a lightweight mass, future development of the drone will use the MOSFET circuit, which is built onto the development board in order to power low-voltage, dc-coreless motors. Making use of the low-voltage motors, it is also possible to use the on-board battery charger. Since the battery charger circuit is designed to charge a 1-cell lithium-polymer battery. The use of the development board is only being done during the initial prototyping stages. With future development, the drone will be designed with a single-PCB design.

## Software of drone

To control the movement of the drone, two separate processes are being performed. The first one is for the stabilisation of the drone. To keep a drone in the air this process is necessarily. Would this process fail then the drone will become unstable, and in the worst case the drone would crash. Therefore, the stabilisation process is a process that is always running in the background. Besides the stabilization process there is also the process of user input. In this case the user input will be generated by the pathfinding software AI. The software AI calculates which route every drone needs to manoeuvre. From one central main computer, this data is communicated to every individual drone. To calculate the correct path for each drone there will also be a feedback-loop put into place from the drones. Each drone will have a GPS location module on board. The data gathered from this module is crucial for the process, in order to keep the current data, with which the software AI is calculating up-to-date. In order that if something changes in the manoeuvre of a drone, the pathfinding software can recalculate the route it should perform.

In figure 4, the software process is displayed with the corresponding signals. These are further described in table 1.

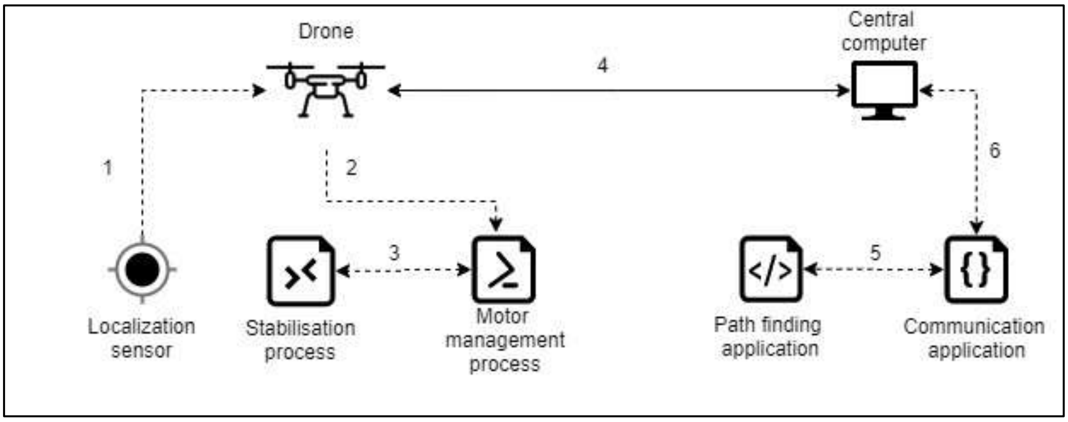


*Figure 4: Software process*

## Drone Flight computer (Central computer)

The flight computer is the outer loop control of a drone that generates angle or rate commands to get the drone from one point to another using pathfinding software AI. It requests the required data from the flight controller in order to get the drone's position in a space, in order to direct the drone to the desired destination successfully. The flight computer is the decision-making brain of the drone which determines the specific task it should be carrying out. The drone's flight computer for this project is the ST_BLE_DRONE app, which is designed to be used in conjunction with the STEVAL-FCU001V1 (flight controller) or STEVAL-DRONE01 evaluation boards. It is available for Android and iOS devices, and imitates a drone's flight computer or remote controller by connecting to the drone via Bluetooth, using the BlueST protocol [9].

This flight computer or ST_BLE_DRONE provides an easy-to-use interface to replicate the remote-control functionality on the smartphone, tablet or computer through an emulator. Downloaded the app from Google Play or Apple store, it can be used on smartphone/tablet Bluetooth, and computer via an emulator.

Keys Features

- Access to pilot settings and flight parameters
- Based on BlueST-SDK library
- Automatic detection of the STEVAL-FCU001V1(flight controller) via BLE
- Complete source code

While performing tests during the prototype stage, the ST_BLE_DRONE app was used to generate data for stabilizing the drone.

## Frame design and manufacturing

The frame of the drone is the part where all of the components of the drone are attached to. A number of factors e.g., the number of rotors, shape of the frame and materials have been researched to find the most suitable design for the frame of the drone. It is also important that the weight is kept at a minimum, in order to increase the lifting ability and prolong the flight time. The requirement is to have a drone that is not heavier than 250 grams [10] and with the limited open-source flight controllers with integrated Electronic Speed Controller (ESC), a quadcopter configuration is chosen for this project. This is the most suitable configuration, due to the stable design compared to a tri-copter and its lighter design compared to a hexa-copter, because of the needed amount of material. The shape of the frame is cross shaped which is compatible with the integrated control software of the selected flight controller. When deciding what material to use for the frame, sustainability of the frame has been a consideration. A comparison has been made to decide a material which is not only easy to produce and rugged, but also biodegradable. Since the drones will be mass produced, plastic is the most suitable material for ease of production. Therefore, two kinds of plastics have been considered to use. These are Polylactic Acid (PLA) and Polyethylene Terephthalate Glycol (PETG).

PLA is a plant-based, more specifically; corn-starch, thermoplastic which requires low energy and temperature for extrusion, while PETG is an oil-based polymer which has good formability and is water resistance. While PETG is not biodegradable, it is fully recyclable. Both plastics are compatible with production method of injection molding and fused deposition modeling (FDM) in additive manufacturing (AM). In Table 2 it shows that PLA is a more favourable choice over PETG, due to the better properties in strength and sustainability, but with having the disadvantage of having a lower impact resistance compared to PETG.

*Table 21. Mechanical properties of PLA and PETG*

| Properties | PLA | PETG |
|---|---|---|
| Density (g/cm$^3$) | 1.25 | 1.23 |
| Tensile strength (MPa) | 65 | 49 |
| Flexural strength (MPa) | 97 | 70 |
| Izod impact strength (kJ/m$^2$) | 4 | 7.6 |
| Recyclability | Yes | Yes |
| Biodegradability | Yes | No |
| Fume toxicity | Very low | Very low |

As for the production method, two methods are viable for mass manufacturing the frame of the drone. These methods are injection molding and additive manufacturing via FDM i.e., 3D-printing. The advantages of 3D-printing are low entry costs and fast turnaround times which makes it good for frequent design changes. However, the production speed is not as high as injection molding, and it needs post-processing after the print. The injection molding method requires a much higher entry cost and is very limited in design capabilities, but it can produce in large numbers cost-effectively. In the stage of designing the frame for prototyping with 3D-printed frames, it is designed to make printing easier without supports and using the least amount of material to minimize weight and printing time.

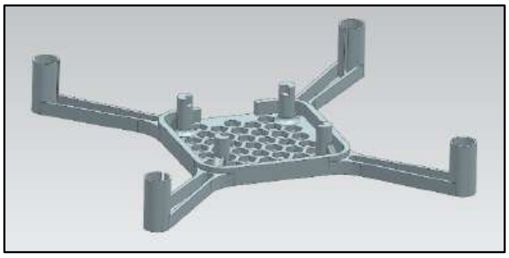

*Figure 5. Prototype frame model for printing with no supports needed.*

### *Motors and propellers*

A set of motors and propellers is needed to make the quadcopter lift and fly. Generally, there are two types of motors for quadcopters, brushed and brushless DC motors. It is known that the brushless DC motors has better features compared to the brushed DC for most cases. However, in this case, with the selected flight controller there are not external ESC's which are needed for brushless DC motors. Therefore, coreless DC motors are used for the mini quadcopter of this project, because these motors do not require external ESC's. Next, the propeller needs to be selected. The properties of the propellers are measured by the diameter and the pitch. There are also more bladed propellers which will provide more thrust at the cost of weight. So, with the correct propeller chosen, enough lift can be generated without overheating the motors.

### *Thrust and weight analysis*

The lifting force that is generated by the propellers is called the thrust. This thrust is calculated with the equation from an article written by Gabriel Staple [11] where he derived a theoretical static thrust equation into an empirical corrected static thrust Equation 5 whereas only the known values of a two-blade propeller is needed.

*Equation 5: Thrust force*

$$F = 4.392399 \cdot 10^{-8} \cdot RPM \frac{D^{3.5}}{\sqrt{pitch}} (4.23333 \cdot 10^{4} \cdot RPM \cdot pitch)$$

Here, $F$ = thrust (N)

RPM = prop. rev./min.

D = prop. diameter (in.)

pitch = prop. pitch (in.)

Next, the maximum mass that the quadcopter can lift can be calculated by using Equation 6. By using the calculated values obtained from these equations, the final selection of the components can be selected.

*Equation 6: Maximum mass of the drone* $$m = \frac{F}{g}$$

Here, m = mass (g)
g = gravitational acceleration (m/s$^2$)

# Testing the algorithm

## Correct centre

To check if the calculated position of the centre is a correct value, the value for the centre has been visually checked to verify if it roughly seems to be in a central point for all drones. The simulation has been run for multiple times, and in every case the centre was observed to be in a correct position for the drones. The tests have also been performed on different sample sizes for the drones. The results of this test concluded that in all of the performed simulations, a correct position for the centre for the drones was calculated, while using the algorithm as described previously.

## Target Reached

To test if the target is reached, a counter is used to keep track of how many drones have reached the target location. Every time a drone gets to its destination, the counter goes up by one. When the number of drones and the sum of the counter are the same, all drones have reached their target location.

## Different starting positions

For the test of different starting positions, random starting locations are used. When using different starting locations, it can be assumed that the algorithm works for every different location.

## Distance in range

To check if the distance is in range, simulations were performed with a maximum time of 5 minutes. If the drone reaches the target within the time, the distance is in range. This worked in multiple simulations with different numbers of drones and different starting positions (as described before).

## Drone collisions

When testing whether the algorithm prevents the drones from colliding, specific situations have been simulated. The simulations will take place in the (x, y)-plane using different number of drones. The collision tests are only done in the x- and y-axis, because the algorithm is programmed to first move to the target height and only when the target height has been reached will the drones start moving in the x- and y-axis. An example of a simulation using three drones, with starting positions: (-10, 10), (-10, 0), (-10, -10) and target locations: (10, -10), (10, 0), (10, 10) respectively. In this simulation, the drones will cross in the centre (0, 0) at the same time and thus collide. However, the algorithm works as expected and prevents the drones from colliding, instead the drones cross the centre one at a time and afterwards move towards their target locations.

# Conclusion

The first prototype of the drone is built by the use of a 3d printed frame, STEVAL-FCU001V1 development board, 3.7V dc motors and a GPS sensor. The path finding software is completed and tested. Both parts work independently, the integration of both systems still need to take place. The drone currently operates manually and the path finding software is visualized trough a simulation. For the future another project group will continue this work and hopefully successful create a submerging between the two separate parts.

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# Electrical Steps and Smart Mobility

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***Abstract*—Mobility between Fontys campuses is for the most part done either by foot, public transportation, or bike. Leading to a lack of mobility between campuses for people who attend Fontys in Eindhoven but do not live in Eindhoven, most of these people do not have an efficient way of getting from the train station to the TU/e campus and other campus. While attacking this problem we also need to make sure that what we do designing can be smart, sustainable, and environmentally friendly. These electrical kick scooter will be addressed as steps or e-steps going forward. With these challenges at the forefront, the designing of an electrical kick scooter was the most viable option, but not only designing the step but also a smart docking station. The docking station will act as a charging station and a reliable anti-thief mechanism. By taking the Dutch regulations into account, the step needed to be redesigned and a custom docking station must be created to satisfy our requirements. In the following paper the step will be expanded upon how it was redesigned, how the docking station was designed and how it works and the results of this, in this system an application will also be implemented. To design this system the V model was decided upon. On the side of the V-model there will be a marketing and financial plan and marketing researched done to fully understand how profitable and how viable such system can be for campus to campus smart mobility and station to campus mobility.***

***Keywords*— innovation, smart mobility, electrical kick scooter, steps**

## I. Introduction

With the everchanging climate and governmental regulations smart solutions for mobility are becoming more and more of a necessity. To solve problems like these the need of innovative solutions is increasing.

In Eindhoven, traveling between the campuses can take up to an hour and this time could be used in a more productive way. To provide students and employees with an affordable solution to travel that saves time and is also environmentally friendly, the team is working on a system to system that solves the issue of traveling between the TU/e and Fontys campuses and the central train station in Eindhoven. This system will consist of electrical kick scooters, docking stations and an application.

Firstly, it would increase mobility from the station to the campus instantly for whomever choses the E-step also the mobility between buildings in the campus itself by not having to walk for example 20 minutes from the Auditorium to the flux building or even to the Paviljoen building which is far from every building on campus to not say the station which would be a 30-to-40-minute walk.

Not only is this time consuming but also tiresome, and here would be the second justification this project would severely impact the time every person could win to use this time more effectively. Considering that public transportation does not have ideal times of arrival for student, allot of students come from different cities across the Netherlands and most of them need to leave home earlier than they should because they need to take an earlier train just to be on time. They need to walk 15-to-25 minutes, with the E-step we take those 15 to 25 minutes to 10 minutes and allowing students to get not only up to 10 minutes for the walk but also extra time of sleep because they don't need to take a train earlier which can lead to students being more rested and more awake in lectures. When going back home they would win time as well not only up to 15 minutes but also getting to their train and not needing to wait for the next train because walking would be impossible to get to their train. This would gain from 15 to 45 minutes of useful time gained.

If we take these into account per person could gain between an hour and two hours per person per day, considering this and just hypothetically speaking 100 people using this service could lead to 100 to 200 hours of gained time per day.

What also should be considered would be specifically for Fontys student on the TU/e campus most of them if not all don't walk through the TU/e campus but walks on the outside of the campus on the bike lane, this is not safe and could lead to accidents with this project we would be part of the traffic and would lower the risk of the pedestrians. We would increase the safety on pedestrians within the campus.

Implementing the use of electric kick scooters not only cuts down on the traveling time, but possibly gives a chance for commuters that would use their personal car to choose public transport and then the electric kick scooters instead, therefore cutting down on the $CO_2$ emissions.

Currently our direct competitors are Felyx and GoSharing, Felyx only has scooters for ride sharing and does not offer any sustainable options. On the other hand, GoSharing does have scooters and also electrical bikes and bikes for renting. The biggest problem GoSharing has encountered by growing so rapidly is how esthetically unpleasant so many scooters have become when parked close to each other. There are areas like the TU/e Campus that have stopped GOSharing from parking in their terrain because all the scooters can become a hazard for everyone in campus. Hence were Estep comes in, we will have docking station and will not be a hazard for anyine on campus and also the escooter is more environmentally friendly than the scooters offered by GoSharing. .Felyx does not have a close enough parking space for it to increase smart mobility on campus itself. The estep would have more accessible docking station, it can work with your student card and will not be a hazard for anyone on campus.

## II. Background of the project

The TU/e campus and the Fontys campus are very widespread across Eindhoven, the TU/e campus is widespread, there is the Rachelsmolen campus across the street, but there is also a part on Strijp S and even in Helmond. On a regular basis students and teachers travel about 15-20 minutes from their station of arrival to the education building and if they need to travel during this day, the traveling time can take up to an hour. On any day this would mean that the traveling time ranges between half an hour and 3 hours, which is time that could be spend in a lot more useful way. These long traveling times cause the need for other ways of traveling, like shared electrical scooters, busses and trains or even cars to get from one place to another, which are both expensive and bad for the environment. Furthermore, cars and scooters need a lot of place to be parked, which could be used more wisely as well and would be safer for the students around campus.

To solve this traveling issue the step was come up with, an electrical kick scooter that will be to use for students and employees of the universities in Eindhoven. Electrical kick scooters are a new innovative way of traveling with low environmental impact. It works similar to the kick scooters that were used as kids, but these have a electrical battery to make it faster and less tiring. These steps therefore speed up the traveling time and make the use of less environmental friendly traveling options superfluous.

Currently in the Netherlands they can only be used if one owns them, and there are no rental services yet. This comes from the fact that there are no regulations on these steps yet, which are meant to be made in the coming two years.

For new businesses it is important that the ideas that are brought to the market are innovative and that they amount to making the world a smarter and environmental friendly place. This gives a company a big advantage over the current existing ones. This is also caused by the fact that innovations are always made for a specific group of people in need.

## III. Approach

To solve the problem of the difficult traveling, a system will be set up. The process of making this system will consist of multiple parts and will be following the V-model approach as can be seen in Figure 1 V-Model.

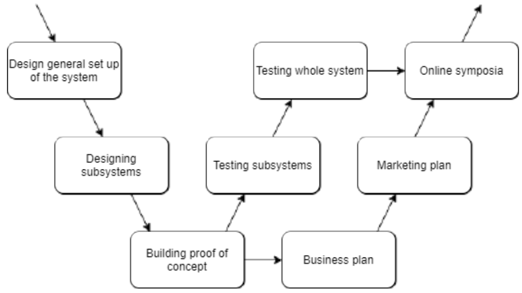



*Figure 1 V-Model*

From the potential users it was found that a lot of them are interested in using the system, especially at the beginning and end of their day. Research on getting a patent for the product was also done, at which it turned out that the idea cannot be patented as the separate parts are already patented; this includes the docking station [4], the nfc communication [5], the application [6] and the system between it [7].

After the research the design process will start. This means that first it will be focused on designing the general set up of the system. This includes deciding what components the system will consist of and how they will be connected together. This also includes deciding on the general functionality of the different components. This also includes a survey under the potential users of the system on what is important for them and under what conditions they would use the system. This step resulted in a system consisting of an application, a docking station with RFID scanner and the electrical steps.

After this the designing of the subsystems will be done in detail. This will include material choices, component choices but also the way the systems will look and connect to each other physically. After designing these separate parts these will be tested on functionality. For this designs will be made in drawing programs

The final part of the model will consist of building the proof of concept and testing its functionality. This will be to see if the product designed will work and can be used as desired.

As the first proof of concept is created, the project will also go into the marketing phase. This means that first a business plan consisting of canvases, balance sheets and cashflow analysis will be set up. After this also the marketing plan will be constructed, where market research will be done and the way to advertise the system will be looked into.

Finally, to make sure that people know about the project and possible investors would be attracted to the project, two symposiums will be attended where the project will be presented. Also a video will be made and a poster.

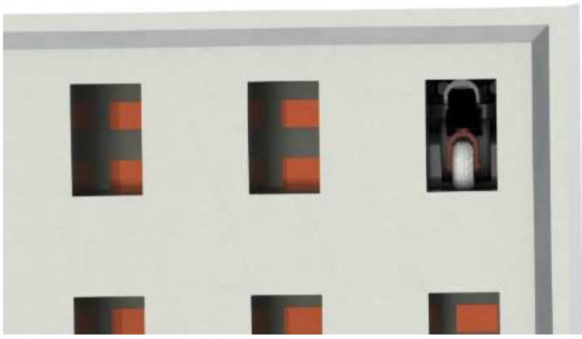
## IV. Design

The step in Figure 2 The Foldable Electrical Step is the concept drawn to visualize what the inventive step would roughly look like. As shown, the step can be folded in three points. These pivot points allow the step to be very compact. This results in a small storage space for each step. The step has a main hinge that allows to fold in one way and prevents it from bending the other way. Currently fully powered scooters are not allowed in the Netherlands. For this reason, the step only provides assistance when kicking.

If the step only provides assistance when the user is kicking, then the scooter meets the electric bicycle regulations and can therefore be used on the road. If the user is going 25 km/h the step will stop providing assistance. The step has two batteries which can be charged in the docking station. When the step is folded the charging, ports become visible.

They are placed in the back which makes it easier to invent a docking station. For the most they will be made out of aluminum. Aluminum is a strong and lightweight material. Lightness is a key aspect because the user has to be able to put the step back into the docking station. Brakes are also needed for safe use; these will consist of a motor brake and a mechanical disc brake. The steering column is adjustable in height to make the step more ergonomic for different sized users.

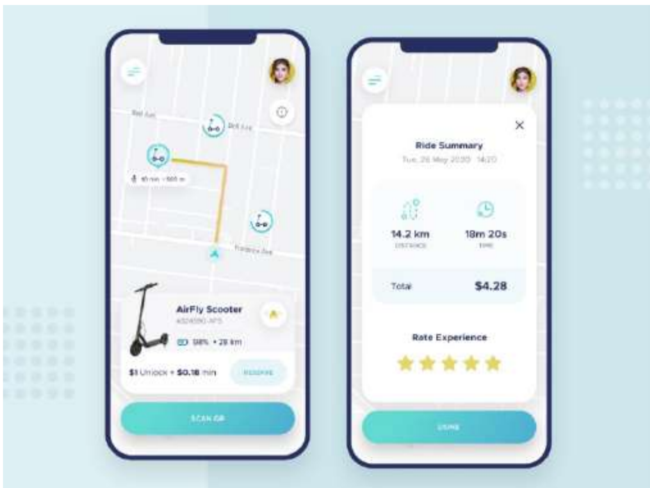
The docking station is designed in a way that it can store many steps in a relatively small area.



As is shown in Figure 3 The Docking Station above the step will fit in a very small chamber. If the step is placed all the way to the back the charging ports will connect to the copper plates and therefore the scooter will begin to charge. On the side of the docking station is a screen and a card reader. The card reader and the screen will show which scooter will be available for use.

These docking stations can be placed near crowded places like the train station. All docking stations are interconnected, making it possible to return the step to a different docking station than the one it was retrieved from. The docking station does not take up a lot of space because it is about the size of a clothes cabinet. The docking station will be made from some type of stainless steel. This material is strong and relatively weather resistant as well, therefore the docking station can hold a lot of steps at the same time and be resistant to the elements. The docking stations must be weatherproof.

To let the users of the system, interact with it an application will be created. Using this app, of which an impression can be found in Figure 4 The Application, the users of the system have an interface on their smartphone which can be used to find locations of docking stations and the steps themselves. The app is used also for booking the step, seeing previous activity and also the invoices.




The app is intended to be available both for android and iOS (iPhone) users, this means it needs to be a hybrid app, meaning the app is programmed for both platforms. Thee app is made taking into account trends that are important both for the users of the app and also the company itself. Most important ones of these trends are mentioned below:

- Simplicity - people have short attentions spans, if the application is difficult to navigate people will lose their interest quickly. If the information is not easily accessible, they might become frustrated and possibly even use a competitors application. The application must have clear information and must be clutter free.
- Speed - quickly loading application is vital, but for the costumers that are not subscribed there will be the option to assist an add to gain either points or discounts that can be used later when purchasing the product. Apart from this speed will be achieved by selecting the appropriate set of graphics and making sure the app does not fetch large tables and databases.
- User feedback - while trying to provide the perfect application the first time around, it is bound to have some issues. Giving the option to receive feedback from the users is a good way to best understand what the user is expecting of the application. This way the feedback can be filtered into the progress and development of the application. Placing a feedback button in the application enables the client to tell what they think would improve it.
- Security - internet security is an ever-increasing concern between users of applications. As the option to save a profile with payment methods and other user details will be provided, securely storing data in servers must be ensured. With sensitive data being stored in servers any types of these attempts must be prevented:
    - Placing of malware into the application or into the user devices where data can be stolen or manipulated.
    - Interception of sensitive information traveling through the network.
    - Stealing of costumer data, for example, for identity theft or fraud.
    - Stealing private assets.

Implementing these trends will lead to a better-quality app with the correct number of features. This ensures that user requirements are met, and the user is also kept satisfied. This also ensures the maximum possible amount of profit.

## V. Verification Result

As part of the verification for the viability of this service a survey for the students and employers of Fontys University of Applied Sciences was conducted. This survey has been set up and distributed online using Qualtrics software. [8]

This survey has been answered by 136 people, of whom 100 are students and the rest are Fontys academic staff. More than half of the respondents answered that Eindhoven central station is their arrival destination, therefore this is one of the most important places where the E-step sharing service should be provided.

From this survey, of which the full information can be found in the full project report [9], it can be concluded that 75% of the responders would be interested in using a step if it was available. The current problem with Felyx and GO sharing scooters is the low availability and the fact that the price is not affordable for students.

Another part of the verification is the cash flow statement which can be seen in Figure 5 Cash Flow Statement below.

**ESTEP**
**Cash Flow Statement**

| | |
|---|---|
| For the Year Ending | 31/12/2021 |
| Cash at Beginning of Year | 15,700 |
| **Operations** | |
| Cash receipts from | |
| Customers | 693,200 |
| Other Operations | |
| Cash paid for | |
| Inventory purchases | -264,000 |
| General operating and administrative expenses | -112,000 |
| Wage expenses | -123,000 |
| Interest | -13,500 |
| Income taxes | -32,800 |
| Net Cash Flow from Operations | 147,900 |
| **Investing Activities** | |
| Cash receipts from | |
| Sale of property and equipment | 33,600 |
| Collection of principal on loans | |
| Sale of investment securities | |
| Cash paid for | |
| Purchase of property and equipment | -75,000 |
| Making loans to other entities | 0 |
| Purchase of investment securities | |
| Net Cash Flow from Investing Activities | -41,400 |
| **Financing Activities** | |
| Cash receipts from | |
| Issuance of stock | 0 |
| Borrowing | 0 |
| Cash paid for | |
| Repurchase of stock (treasury stock) | 0 |
| Repayment of loans | -34,000 |
| Dividends | 0 |
| Net Cash Flow from Financing Activities | -34,000 |
| Net Increase in Cash | **72,500** |
| Cash at End of Year | 88,200 |

*Figure 5 Cash Flow Statement*

This shows what are the main cash inflows and outflows during the 1st year of operation including the startup costs and buying all the necessary equipment.

As it is a startup the team has decided not to take any salary for the first year and rather invest this money back into the company. This choice leads to a positive net amount of cash already at the end of first year, meaning the company has more cash resources and will grow quicker.

From this predicted cash flow statement for the 1st year, the startup idea is reasonable and viable and as said before will also bring profit.

The predicted cash flow for the next 3 years can be seen in Figure 6 3 – Year Cash flow below. This shows that the business is still viable after 3 years with the profit increasing each year.

Both cashflow statements are with a positive net outcome, however these are predictions, and some external factors might affect this analysis. Usually this might not post a large treat, but the current situation in the world and students as well as teachers working from home could render this service not needed. Therefore, it is very important that the predicted profit margins are large to account for many possible setbacks.

ESTEP
**3-Year Cash Flow**

| | | | |
|---|---|---|---|
| For the Year Ending | 31/12/2021 | 31/12/2022 | 31/12/2023 |
| Cash at Beginning of Year | 45,359 | 49,035 | 70,477 |
| Cash at End of Year | 49,035 | 70,477 | 125,215 |

| **Operations** | **2021** | **2022** | **2023** |
|---|---|---|---|
| Cash receipts from | | | |
| Customers | 167,616 | 335,232 | 502,848 |
| Other operations | 60,000 | 80,000 | 110,000 |
| Cash paid for | | | |
| Inventory purchases | -25,845 | -30,000 | -50,000 |
| General operating and administrative expenses | -15,000 | -25,000 | -35,000 |
| Wage expenses | -2,080 | -10,000 | -20,000 |
| Interest | -17,500 | -15,750 | -14,000 |
| Income taxes | -112,670 | -205,540 | -303,360 |
| Net Cash Flow from Operations | 54,521 | 128,942 | 190,488 |
| **Investing Activities** | | | |
| Cash receipts from | | | |
| Sale of property and equipment | | | |
| Collection of principal on loans | | | |
| Sale of investment securities | | | |
| Cash paid for | | | |
| Purchase of property and equipment | -25,845 | -82,500 | -90,750 |
| Making loans to other entities | | | |
| Purchase of investment securities | | | |
| Net Cash Flow from Investing Activities | -25,845 | -82,500 | -90,750 |
| **Financing Activities** | | | |
| Cash receipts from | | | |
| Issuance of stock | | | |
| Borrowing | | | |
| Cash paid for | | | |
| Repurchase of stock (treasury stock) | | | |
| Repayment of loans | -25,000 | -25,000 | -25,000 |
| Dividends | | | -20,000 |
| Net Cash Flow from Financing Activities | -25,000 | -25,000 | -45,000 |
| Net Cash Flow | **3,676** | **21,442** | **54,738** |

*Figure 6 3 – Year Cash flow*

More about cash flow statements, business canvas and the business case in general can be found in the Smart Mobility - Business Case report. [10]

To see the market possibilities of the system a swot analysis was done, from which a collection of strengths, weaknesses, opportunities and treats.

**Strengths:**

- To introduce an E-step usable in the Netherlands, by producing the E-steps within the company. Therefore, the competition cannot access them. Similar to what Citystep is doing. However, producing a more similar device towards the E-steps known worldwide.
- Having a familiar device with which costumers would already be familiar with from foreign countries
- Using an E-step, which provide more flexibility and agile handling in the streets comparing to a bicycle or a moped
- Integrating the use with the student card
- Initial start-up only for student (a specific target group)
- Using vandalism proof docking stations as the only parking method
- More affordable than competitors

**Weaknesses:**

- Being a start-up, therefore people do not know the brand and services provided yet. This can result in users not daring to use the product/service
- Having an unexperienced team within the company, that can result in mistakes and issues
- Using advertisement as revenue within the app. Even though costumers would only need to watch an advertisement when reserving the E-step in advance, the fact that adds are used can be irritating for the user
- Not being able to purchase an already existing E-step that would also be approved by the Dutch regulations

**Opportunities:**

- Increasing the use of E-scooters worldwide, many users would already be accustomed to the idea and device. There is not a service in Eindhoven or most of the cities in the Netherlands for an E-scooters yet, due the regulations
- GO sharing and Felyx being used in Eindhoven and other cities, users are also accustomed to the idea of using a rental vehicle. Go Sharing and Felyx being expensive and having a low availability for our first start-up, this results in an opportunity for this product
- People want to use more sustainable vehicles retaining the freedom of not using public transport. Electric cars are too expensive for many, and moving through a city using cars or public transport during rush hour is very time consuming
- People enjoy convenience, therefore when offering a reduction in traveling time and not having the need to walk. People tend to use the possibilities handed to them to reduce traveling time and having to put in less effort

**Threats**:

- COVID would have people working more from home, this would result in less people attending university
- Regulations changing for E-steps in the Netherlands would give larger companies the change of implementing their services, since these companies already have an established name and working app and service, it tends to be difficult to compete with
- GO sharing inventing an E-step that can be used in the Netherlands or having a partnership with Citysteps. If a well-known and used company such as GO sharing would be first to the market introducing an E-step.

## VI. Conclusion

To conclude, it is important to not only think about, but also implement smart mobility solutions for the city. Focusing on the Netherlands more specifically Eindhoven. One of these solutions is the introduction of electric kick scooters between the TU/e and Fontys campuses and the Eindhoven train station. This not only creates an environmentally friendly way of travel, but possibly cuts down on the use of personal cars in the city, while simultaneously making the city more connected and providing a business opportunity.

Can be concluded that not only is the kick assist scooter can be implemented in the Netherlands by changing the design of the scooter for the Dutch regulations. The step also is a more environmental friendlier option and will not clutter the city as much compared to the top competitors in the region this being Felyx and Go sharing. And in comparison, to Felyx and Go sharing, it will only be for student and employees use. With the E-step what is quite similar to a regular E-scooter, our users would be familiar with the device and use it more than our competitors. It is cheaper and more agile as well. The advantages of focusing on the educational terrains of Eindhoven adds an extra edge to the project by having a parking spot that is accessible to everybody of the TU/e and Rachelsmolen campus. Adding to that also the integration of the student card of either Fontys or TU/e makes it easier for not only student to use these steps but also teachers and maintenance workers of these terrains.

We can summaries by the business case that was made that people are interested in the idea but also in using this step to help with the mobility around the campus. Most students will be moving from Eindhoven central towards the campus and therefore our focus will be at them first. Going from out this point we can conclude from the cashflow, income statement and balance sheet that it would profitable and by reinvesting the profits, this project could be scaled up around the whole of the Netherlands at cities but also can be scaled up specifically for other big Universities that have a mobility problem within their different educational campuses. It is important to note that this project could be scaled up if nothing exceptional happens within regulations regarding E-scooters. If E-scooters would be allowed to way they are in foreign countries, there would be more competition with already known and working rental service.

ACKNOWLEDGMENT

We would like to express our gratitude to our project tutor Kennedy Aduda for coaching us throughout our project. He was a great help managing the project and helping us solve problems.

Furthermore we would like to thank our teachers Abi Albuquerque and Hay Geraedts for teaching us about product innovation and Maarten Haasnoot and Johan van Gerwen for teaching us about business innovation. We would also like to thank all the teachers and students that took the time to fill out the survey.

Lastly, we would also like to thank Kiona Basten for assisting us on the business parts of the project. She was a real help with seeing the project from another point of view and giving feedback

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Can Collector

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### *1.1 Abstract*

*The environment is suffering from pollution which causes unwanted consequences. Recycling is the most important solution that people should recognize and apply to save the environment and their lives; the main question of this technical paper is: How can the environment survive from pollution by recycling aluminum soda cans using the can compactor? The question will be answered through a set of project steps performed by a combination of Fontys and ECAM students. The answer is specified and will be by showing the steps and research to arrive at the final goal of the project.*

***Keywords—aluminum cans, innovation, collector, reward system***

## Introduction

The environment is one of the most focused aspects around the world. Rapid population increase, unsustainable resource usage, poverty, failing to include the environmental costs of commercial commodities in market prices, and attempting to manage and simplify nature with insufficient knowledge of how it works are the five primary causes of environmental problems, due to the previous causes, countries, governments, and organizations are working with a main target of helping the environment using different tips, methods, procedures, and innovations. The first rank solution is recycling, considering that this technical paper will discuss and focus on the importance of recycling and the way to increase recycling rate by implementing the recycling solution of cans collector machine.

Innovation plays a significant role in this issue, as the topics of this paper are connected to the innovation project (Cans collector), for that the paper is set out as follows, chapter 2 presents the background of the paper, chapters 3,4,5,6, and 7 include the following innovation project topics: Problem area, Research, Patent research, Design phase, financial plan, Proof of concept, and prototype.

***Problem area***

Recycling is a process in which materials from everyday waste are used and converted into new products. They include recyclable materials such as: glass, paper, plastic, and various metals. Recycling involves separating waste after collecting, treating recyclable waste, and manufacturing new products.

*1.2 Need to recycle*

The process of manufacturing products involves obtaining raw materials from different sources. These materials may be from forests or mines. They are usually transported to the place of manufacture" by land or sea, an energy-consuming process.

The process of purchasing and transporting raw materials causes pollution in addition to the use of scarce resources such as trees and fossil fuels. All this in turn leads to global warming by releasing gases and eroding the ozone layer that protects the Earth from harmful rays from the sun. Global warming is blamed for climate change and its catastrophic consequences, including off-season rainfall or drought, causing floods and famine.

*1.3 Recycling advantages*

Waste recycling reduces demand for raw materials. It also reduces the process of waste disposal by landfilling or burning it, thus helping to reduce pollution and global warming. Recycling is extremely useful because it not only reduces the amount of household waste sent to landfills and incinerators that in turn pollute the environment but is also a means of achieving sustainable development where it can help preserve the environment for future generations.

Recycling also reduces pollution by reducing the need to collect raw materials. If the materials used are not recycled, the manufacture of new products will be carried out using new raw materials from forests and the use of mining. Recycling thus helps preserve natural habitats. Recycling also provides energy as energy is used to extract raw materials as well as refinement, transportation, and construction.

*Main goal*

The main purpose of the innovation is to increase the recycling rates of aluminum in public buildings. This will be achieved by designing a machine which only accepts aluminum soda cans, the machine will reduce most of the size of the cans and store them for easy removal by staff. The user of the machine will get rewarded for using the machine.

*Performance requirements*

1. The system must operate with the power resources available at a ECAM cafeteria, (a single wall outlet, 230V 16A 50Hz)
2. The storage capacity of the system should be 400 empty soda cans, equal to the capacity of common soda vending machines.

*Geometry requirements*

3. The maximum dimensions of the machine are a width of 1m, a depth of 1m and a height of 2m.
4. The system can detect if the user throws in an empty aluminium can with a maximum diameter of 211mm and a height of 168mm, or something that does not match these parameters.
5. The system must be able to work with all can sizes up to a diameter of 211mm and a height of 168mm.

*Sound requirements*

6. The system must not exceed the 40-decibel limit, equal to the noise emission of a vending machine.

*Safety requirements*

7. The product must comply with the latest safety standards applicable for the machine equal to machine directive 2006/42/EG.

*Ergonomics requirements*

8. The product must be intuitive to operate.
9. The compacted cans should be removable in within 2 minutes.
10. The infeed of the cans should not be higher than 1,5m from the ground.

# Research

*Waste sorting rates in France and Europe*

As we can see, the sorting rate of aluminium is only 48% and is very low compared to other European countries like Germany for example where the aluminium is recycled up to 60%. These numbers are when focussed on aluminium recycling rates in its entirety.

But for aluminium cans, the number are a bit different. In fact, the rate of cans collected varies greatly from country to country; thus, in 2010, it went from 20% to 95%. The countries with a collection rate above 90% are Belgium, Finland, Germany, Switzerland and Norway. Countries that have opted for a depository strategy have an average collection rate of 87%. France is at a lower level, with a collection rate of 57%, which corresponds to the average of what is obtained in countries using a green point type waste recycling contribution system.

*Waste at ECAM*
At ECAM, there are four types of waste: plastic, paper, aluminium and remaining. The plastic and paper are properly sorted and recycled. However, currently the common garbage and the aluminium cans are both incinerated at the end. So, the aluminium is not recycled.

*Raw aluminium prices*
The price of raw aluminium has risen rapidly during 2021, this is due to a worldwide shortage of raw metals. A higher aluminium price has a positive effect on the profitability of the machine. It is assumed that the aluminium price will stay above 2 USD/kg in the coming years due to a growing demand of aluminium. We can also easily assume that this price should increase, as the world's aluminium reserves are only decreasing, thus increasing the value of the resource.

*Capacity of vending machines*
The most used vending machines at schools are Small Vendor Vendo 392 or similar machines. The capacity of such machines varies between 190 cans and 395 cans. These parameters have been researched due to the reason of placing the system next to the vending machine to at the same time empty the can machine and fill the aluminium can collector machine.

*Patent research*
The compacting of aluminum cans is not a new technique and has been patented in very many ways already since 1837, therefore it is almost impossible to patent the machine. However, most patents are already more than 20 years old and therefore, not valid anymore. The patent research is conducted by using Espacenet, an online search engine for patents developed by the European Patent Office (EPO). Espacenet uses search codes to classify different patents. The search code used in the patent research is "B30B9/321" and has the following description "Apparatus for consolidating metal, plastic and/or cardboard containers".

## Design phase

*Function block diagram*
Function 6 of the prototype is not depended on the other functions of the machine and will therefore, not be included in the morphological chart.

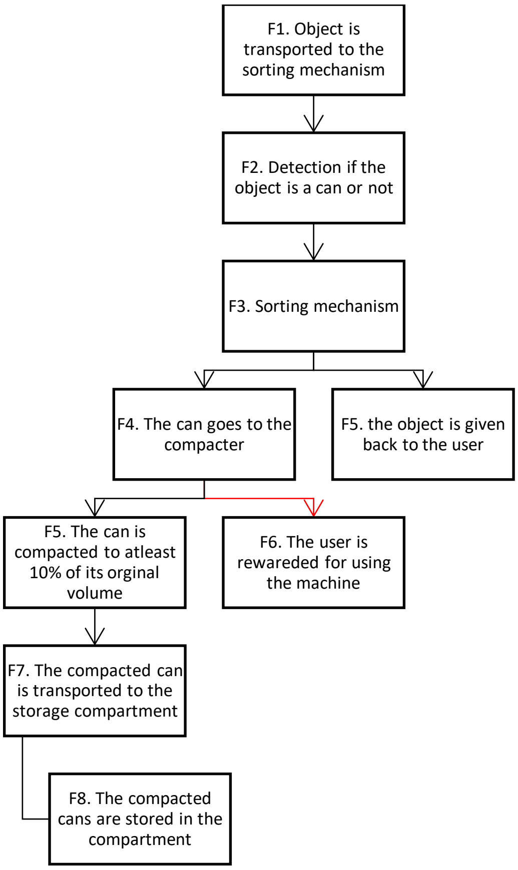


Figure 1, Function block diagram

*Concept creation*
The concepts can be created with the functions from the function block diagram. Numerous solutions are searched for every function. These are then put in a table where paths are drawn in to represent one concept and the solutions it uses for every function. Pictures are implemented in the table to give a better visualization of the concepts.
*Concept selection method*

The concept selection starts by determining the weighting factors of the requirements. Because, not all requirements are of as great of importance to the project. For example, safety should always be one of the top priorities to compile with regulations and is therefore of more importance than ergonomics of the machine. Each requirement is compared to the other requirements and gets a 1 if it is more important than the other requirement. In total there are 10 requirements so, the maximum score a requirement can get is 9. The requirements that score the highest get a weighing factor of 3 and lower scoring ones get a 2 or 1.

The next step is to grade all concepts on how well they match the set requirements by using a selection table and the concept that scores the highest is then further elaborated into a design. Below the selection table of the final concept can be found.

| Functional requirements | Weighting factor | Variant | | Ideal |
|---|---|---|---|---|
| | | **Concept 1** | **Concept 2** | |
| 1 | 3 | 15 | 15 | 15 |
| 2 | 1 | 3 | 4 | 5 |
| 3 | 2 | 4 | 6 | 10 |
| 4 | 2 | 6 | 10 | 10 |
| 5 | 2 | 4 | 4 | 10 |
| 6 | 1 | 1 | 4 | 5 |
| 7 | 3 | 8 | 13 | 15 |
| 8 | 3 | 12 | 14 | 15 |
| 9 | 1 | 3 | 3 | 5 |
| 10 | 2 | 2 | 4 | 10 |
| Total | | **58** | **77** | **100** |
| Total % | | **58%** | **77%** | **100%** |

*Table 1, Concept selection table*

*Final concept*

The final concept is concept 2 and it uses pipes to transport the cans, these will generate more noise but don't require electrical power to work, this makes the concept less complex. The barcodes on the cans are scanned to detect if an aluminium can is thrown in. a weight sensor checks if the can is empty as a full can will damage the compactor. A two-way valve is used to direct the can to the outfeed or compactor. A pneumatic actuator is then used to compact the can and afterwards the cans are stored in a waste bag.

| Function | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Solution | Pipe | Barcode and weight scanner | 2 valves | Pipe |
| Visualisation |  |  |  |  |
| | | | | |
| Function | **5** | **6** | **7** | **8** |
| Solution | Pipe | Pneumatic actuator | Funnel | Waste bag for metal |
| Visualisation |  |  |  |  |

*Table 2, Concept function-solution diagram*

## PROTOTYPE

*Figure 2, 3D renders of prototype*

The outside design of the prototype is simple and elegant, the case resembles an old jukebox, and its sizing is similar to a regular vending machine. The aim is that the machine is implementable in nearly any spot a vending machine would also fit. The machine will also be usable by wheelchair users as the entrance will not be placed any higher then 1,6 meters. At the top of the case, a slot is available for a led that should be used for the level of filling of the storage bag. Then there is the entrance for the cans that is relatively high on the system in order to keep the maximum amount of space to put the internal system and allowing the storage bag to be as big as possible. The next hole is made for the screen. It is lower than the intake hole for people to read it comfortably. Then a recess has been made for a notice on how to use the system. The notice should include the intake of the system and specify that it is made only for aluminum cans and that any other kind of material or object will be rejected by the next hole. The last facts about the casing are the hole in the back to let the powering wires go through the system, multiple plane surface to implement advertising and the ease to manufacture.

*Storage bag's doors*
The main idea for those doors is the possibility to open the door no matter which way the system is implemented. The hinges used are small and difficult to break, the doors itself have a key locking system to let only the maintenance and cleaning agents open the system. A high number of screws has been planned to make the system as sturdy as possible.

*Profiled frame*
The goal of the profiled frame is to hold the whole system and make it as stable as possible. The decision has been made to use it to fix components inside the system since it can be use as non-movable referential frame inside the system. It is also worth noting that the profiled frame is easily modular and thus can be used to add different layers to the system.

*Intermediate plate*
The aim of the intermediate plate is to create a splitting between the electronical part and the accessible part for the cleaning agents. Since the cleaning agent should not have access to the electronical part, a layer of security can be added to the whole system. Another utility is to provide a base frame for the compactor, so it does not move inside the system and to provide a fixation point to the level sensor for the state led explained in the casing.

*Internal conducts*
The conducts of the machine are designed to be able to carry all size of cans. So, it is adapted for the largest can (which is the standard model) and for the longest one (the 500ml can). The cans will be put in the machine either by the top of the bottom and they will slide in the conducts.
The first conduct is not horizontally disposed in order for the cans to slide with only a little amount of strength. This conduct will then be inclined by 20°. The special shape of the conduct is also required for the cans to be able to make a rotation in the pipe from a nearly horizontal position to a vertical position.
The second conduct is quite similar to a reversed Y with some modifications on the sides for allowing the cans and a special device to make their rotations in the conduct. This conduct will be used for the sorting of cans and will be openable on one face so that a sorting device can be put in place. One output of the conduct will be used as an ejecting branch for objects that will not be identified as cans while the other output will redirect the cans to the compactor.

*Stopping device*
The device that will be used in order to stop any object introduced in the machine while the sensors will determine if it is a can or not is quite simple. It consists in a V-shaped valve. In a waiting position, the valve is maintained in a completely vertical, ready to stop any object, and when the object is identified by the sensors as a can or not, this valve will rotate using a motor, obstructing one output to allow the object to slide in the other one.
This valve is designed in a way that even small objects will be stopped since the space between the valve and the face of the conduct is only of a few millimeters.

*Figure 3, 3D renders of internal conducts and compactor mechanism*

*Physical explanation and justification of our choice:*
To crush an object, a lot of strength is needed. In this case it was found that around 900N of force is needed if the force is in the axis of the can. Ideas were to crush from the side and fold it but came the problem of different can format. So, another idea was to add an angle to the receiving plate, to twist the force and un align both compression vectors so it would avoid the maximum intensity crushing point. After experimenting with this solution, it was found that with an angle of 10° the crushing force is almost divided by 2 (500N in peak).

It was found that the pressure needed in the chamber of the pneumatic actuator is around 7bar (based on an existing model) which deliver a force of around 2560N in peak (chamber at its lowest volume). This allows the system to deliver a constant force considering the chamber of the actuator will see it's volume change during the process so, the pressure will drop and having a pump capable of furnishing 7 bar of pressure is the best suited model for our system.

*Receiving a can:*
For a can to always land the same way we use a V shape receiving piece. Which will force the can to fall if the center of gravity isn't aligned with the two-contact point between the cylinder of the can and the V shape of the receiving piece. This system will be tilted with and angle of 15° To avoid that the can being stuck because of the chamfer on the bottom or top of the can.

This whole system is independent and can be disassembled easily to help the maintenance and prevent additional cost

## Proof of concept

The proof of concept is a simplified version of the prototype and only features the sensing and sorting mechanism. The design is fully 3D-printable for easy and fast manufacturing, it features two sensors and a servo which are explained in detail in the electrical design chapter. The dimensions of the proof of concept had a width of 200mm, a depth of 70mm and a height of 250mm.

*Figure 4, 3D-design of proof of concept*

## Electrical design of proof of concept

In this chapter, the development of the proof of concept will be explained. The component choices will be elaborated based in the requirements for the different modules. Below a block diagram of the proof of concept can be found.

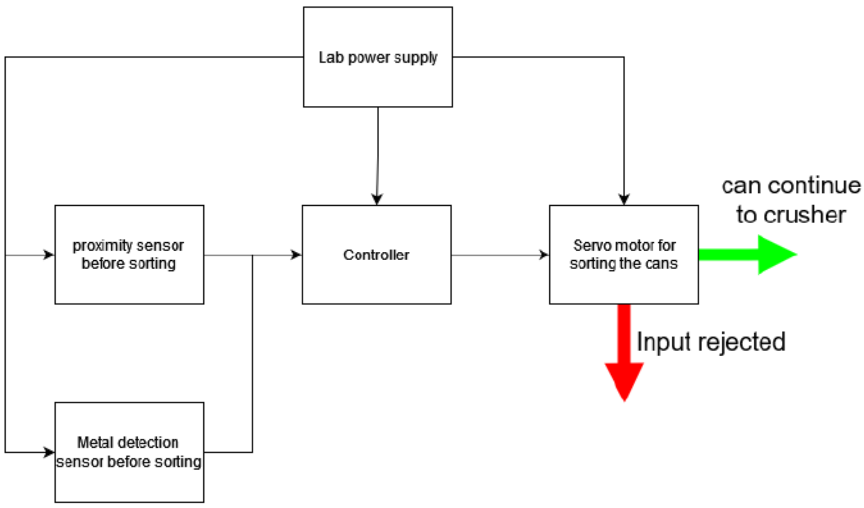


*Figure 5, electrical function block diagram*

*Controller*
For the proof of concept an Arduino nano was chosen as the main controller. One of the main advantages of the Arduino platform is that it operates on 5V. This is the default voltage on which many sensors operate, which makes it suitable for easy integration. It also has support for 14 digital I/O pins which can be used to read out the different sensors and drive the motors.

*Metal detecting sensor*

*Function of the module*
Because of the budget the sensor will detect if the input consists of any metal instead of only aluminium. This output will be communicated with the controller. Because the sensor operates on 12V the 12V signal first has to be lowered to a voltage accepted by the Arduino. This is done by a circuit with resistors. This controller will be communicating this again with the servo motor to move it in the right direction.

*Components*
Based on the requirements a sensor has been found. This is the E2EY sensor from manufacturer Omron. This is a proximity sensor which only detects aluminium. Due to the price of 238 euro this sensor will not be used for now but will be a very nice component when there is budget for in the future. For the proof of concept, the Omron M12 x 1 Inductive Proximity Sensor will be used. This one will do the same as the expensive sensor above. The only concession that needs to be done with this sensor is that this sensor also detects other metals. For the proof of concept this will be fine to show the function of it, but for making this into a real product the expensive sensor is highly recommended.

*Proximity sensor*
For the proximity sensor an infrared break beam sensor will be used. This sensor operates with a separate IR emitter and IR receiver. These two modules are pointed at each other such that the IR receiver always senses the IR-light emitted by the emitter. Whenever an object comes between these two modules the IR-sensor senses less IR-light and changes its output.

*Sorting mechanism*
The sorting mechanism will be done by a servo motor. This motor can be controlled by an Arduino and is connected to a lever. In this way the input can be pushed to the right when it is metal and will be pushed to the left (rejected) when this is not the case.

*Power supply*
A lab bench power supply will be used as power supply for the proof of concept because the focus of the proof of concept will be the correct functioning of the system, and not how the power will be delivered by creating a custom power supply. The bench power supply can deliver up to 30V and up to 6 ampere which is more than enough for the system to function properly.

## Business Plan

Since the project is still in its very early stage of development, only a raw estimate of the costs and profits could be made. This estimation can be done more accurately when the first protype is built as this will give more insight in the cost of certain components and assembly time.

| | Minimum value | Maximum value |
|---|---|---|
| Manufacturing (workforce, materials, raw materials, parts, hardware) | 700 € | 1000 € |

*Table 1: Minimum and maximum costs of producing the machine.*

| | |
|---|---|
| Number of Europe population in 2018 | 746,4 million |
| Cans consumption in Europe in 2018 | 44,68 billion |
| | approx. 60 cans/person/year |

*Table 2: Calculation of approximate can consumption per capita in Europe.*

Considering constant increase of cans consumption, we can assume that in 2022 one person will use 62 cans per year.

| Profit from selling cans | weight | price |
|---|---|---|
| 1 can | 0,015kg | 0,014 € |
| 67 cans | 1kg | 1€ |

*Table 3: Information of profit from selling cans.*

| | |
|---|---|
| Profit from one user | 0,014 € * 62 = 0,868 € |

*Table 4: Calculation of the profit from one user per year.*

| | | |
|---|---|---|
| Number of students | 600 | 0,868 € * 600 = 520,800 € |
| Number of university staff | 45 | 0,868 € * 45 = 39,060 € |
| | | SUM = **559,860 €** |

*Table 5: Calculation of exemplary client's profits (school).*

| | |
|---|---|
| Selling price | 2000 € |
| Return on investment for client | 2000 € / **559,860 €** = 3,572321652 years |

*Table 6: Calculation of the time of return of the investment in the machine.*

It will take around 3-4 years for the client to create the profit from the purchase of the machine.

| Profit of the producers | Maximum profit | Minimum profit |
|---|---|---|
| | 1300 € | 1000 € |

*Table 7: Calculation of the profit of producers.*

Counted basing on the minimum and maximum value of the manufacturing process of the machine.

*Figure 6, cost and profit estimation prototype*

## Conclusion and recommendations

With all the research done, the prototype designed and the proof of concept being build it is possible to answer the main goal How can the environment survive from pollution by recycling aluminum soda cans using the can compactor? To answer this question, it is possible to look at the working of the proof of concept. As it is a machine for public buildings (schools, universities, institutions, etc.) which can compress and store only aluminum cans. The project is intended to save the environment by educating people at an early age to encourage people to throw their waste in the right container to improve recycling percentage.

To improve the concept there can be a couple things changed and improved that were for this project out of scope. There can be looked at the safety of the machine if it is safe for the age of 5 till 80 years. It is also possible to design a machine for more waste streams so everything sort of waste that can be recycled is sorted in the right bin. Otherwise, you will get your waste back if it isn't in the right bin.

## Acknowledgments

We would like to express our appreciations and thanks to Mr. Hay Geraedts the coordinator of Innovation Engineering differentiation at Fontys. We also express our appreciations to Mr. Samsam and Mr. Turko, the supervisors of Fontys and ECAM of the project groups, for their support and guidance to complete this innovation project. We would also convey our gratitude to them for the useful Information they gave about innovation which was beneficial and clear for us. The students gained enough knowledge and information from them to complete their roles.

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3rd International Innovation, Engineering & Entrepreneurship Symposium

ECAM Strasbourg-Europe - January 13th, 2022

# Hazelnut, Almond and Walnut shells as a potential product for construction

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***Keywords—nutshells, concrete, gravel***

## I. INTRODUCTION

Nowadays, everyone is familiar with the concept of sustainability, and it is impossible to imagine society without it. The idea is to think in a future-oriented way, for the well-being of all people. Awareness in this area is constantly increasing, gaining enormous relevance in different areas of the economy, as well as in peoples private life. [1] There are many ways to enforce this and to make a big difference in future. Because of today's knowledge, there is a possibility to ideally use various resources. In the near future this will be implemented, as the demand is overwhelming, and the law will soon encourage it as well. In any case, the intention has to be there to ensure long-term implementation. There are countless types of sustainable alternatives that are already in use today. It even now became a lifestyle, the demand for sustainable products is greater than ever. Not every consumer is aware of how all the existing products are assembled and which factors are important for them to be considered as sustainable. This is the reason why it is important to inform about all the different possibilities which could replace everyday objects as well as food. [2]

"Everyone can identify reasonably quickly where the problems are in his or her environment, what bottlenecks exist, and where the shoe pinches. But one step further is to look for hidden opportunities." [3]

And often people do not even know how valuable some goods are, and how they can be used in a variety of ways. One of these unexpected goods are nutshells. There are lots of different ways to use this material, which is considered as waste. Nutshells haven proven to be a good fossil fuel, which can be used in many ways. Often nutshells are pressed and used for packaging, as they are known to be light and stable. Nutshell blasting has also become an effective substitute for sandblasting. Furthermore, there is a way of using it as a peeling for the skin due to the worthy natural ingredients it possesses. As a consequence of this, they are also often applied in landscaping, for example as fertilizer. [4] Although this project deals with the usefulness of nutshells in the field of construction, the idea is to use nutshells as a component for the manufacturing of concrete. The difficulty of implementation is to be able to use the material the best way possible and provide full warranty like would be the case with the normal concrete.

The idea started with the thought of a company known for working with nuts and wanted to get active in the recycling of their leftover nutshells. Based on various approaches, the decision was made to use nutshells in concrete. And this is exactly the optimal way of taking a product that was thought of as waste and then creating a new product out of it. The main part of the task will be to determine the right use of the nutshells and to adapt it to the legal guidelines to create the best product. [5]

## II. POSSIBLE APPLICATIONS OF NUTSHELLS

Nutshells are a valuable raw material that, as described in the previous chapter, will be an important part of our resource-efficient future. There are efforts to integrate this important resource into the value chain and not only to use it for the incineration. The entire potential of this waste product should be utilised. The following examples show the already successful ideas and uses of different nutshells.

### A. *Paper production from hazelnut shells*

The industry produces an estimated 150,000 t/a of hazelnut shells. Most of them are used locally as solid fuel for the companies. Nowadays, there are more and more manufacturers who want to use their waste products from the main production innovatively.[7]

The EcoPaper project, initiated by the confectionery manufacturer Ferrero, is a very good example for such an innovation. They wanted to create a new packaging option for their products that use the left-over nutshells from the production. The aim is to increase the value of this material, which is currently only intended for combustion. EcoPaper reduces the amount of virgin wood fibre in cardboard production and use fibres from the nutshells instead. The cooperation of Ferrero and PTS (Papiertechnische Stiftung) was very successful. The research results produced by PTS with fine-tuned recipes were promising. The whole project was supported by the European Union, an investment that made this comprehensive and innovative study possible.[6, 7]

Ferrero continued to work with Stora Enso in 2015 to bring the product to the market. There is no further information about the future course of this project, but the results were promising and headed in the right direction.

### B. *Clipboard with Macadamia Nut Shells (From nuts to tables)*

At the University of South Wales, a PHD student did a project in which she pressed the shell waste into chipboard and thus investigated a resource-saving use of these waste products. Besides the benefits of recycling production by-products, this new product has a big advantage over conventional chipboard. They do not draw moisture like the chipboards typically used to. This moisture can result in the release of dangerous substances or even give rise to the risk of mould. It turned out that these boards can be used in wet rooms such as bathrooms or kitchens. Another advantage of such boards is that they are not harmful to humans in contrast to the chipboards currently in use.[8]

### C. *Concrete with nutshells addition*

Concrete is one of the most important building materials worldwide. Due to its excellent properties and high durability, it can be used in a wide range of areas. By adding various additives, it can be adapted to the respective needs. In order to make this non-resource-saving building material more environmentally friendly, attempts have been made to recycle biological waste products from industry. The following possibilities with nutshells have already been investigated in studies and provided basic information for this project.

#### 1) *Concrete Research with Macadamia Nuts*

Already in 1999, this diploma thesis dealt with the possibilities of macadamia nutshells. At the time, as well as today, a large amount of this unused resource was produced. In this work, the possibility of adding concrete from these nutshells was closely examined. However, the result of this research was that it was not recommended for practical use, as durability problems were found during the investigations.[9]

Another study from 2021 investigated the possibility of using macadamia shell concrete for making lightweight and high temperature resistant concrete water storage tanks. It was found that properties that are unwanted in normal concrete can have a positive effect in this setting. The high-water absorption of the shells is used in the poured concrete for further hydration. The lower density of this concrete also means a lower self-weight of for the structures. The porosity of the concrete, which the addition of macadamia shells brings, increases the insulation.[10]

#### 2) *Concrete with ground nutshell ash*

In 2017, the possibility of using groundnut shell ash as an additive for concrete was investigated. In addition to the use of an organic waste product, the consumption of river sand was also reduced by 50% through the addition of quarry dust. Both alternative materials are produced in large quantities in the respective industries and can be used in the concrete industry in a resource-saving way. The tests showed that the use of peanut shell ash and quarry dust improves the strength properties and good results are achieved to use this concrete reasonably. The implementation of such substitutes helps to protect the environment and resources.[11]

#### 3) *Walnut Shell for Partial Replacement of Fine Aggregate in Concrete*

Another project focused on the addition of walnut shells. The replacement of natural fine aggregates with walnut shells was tested. The investigations showed that the amount of walnut shell granulate has a significant influence on the compressive strength and density of the concrete. It was found that 30% of the aggregate at a water/cement ratio of 0.38 can be replaced by walnut shells without affecting the admissible compressive strength of the investigated Portland cement concrete. These promising results show the potential of using walnut shells in the production of environmentally friendly concrete.[12]

## III. NUTSHELL PRODUCTION AND POTENTIAL FOR USE CONCRETE PRODUCTION

In Figure 1 the top nut producing countries are shown. The nut industry produces millions of nuts every year. Nowadays. enormous amounts of shells are discarded without further assessing it possible uses.

● Agran nut ● Brazil nut ● Ground nut ● Hazel nut
● Shea nut ● Walnut ● Cashew ● Pistachio

*Figure 1 Global top nut-producing countries* [13]

In our case, a company based in Spain and the one we aim to assist with this project is Borges Agricultural & Industrial Nuts, S.A. Borges is one of the biggest nut producers in Europe, due to its vertical integration, their main activities are focused in the following sectors: agricultural, industrial and commercial. They pride themselves in producing their nuts, processing and selling them to the mass market.

The next map gives an overview of the presence Borges Agricultural & Industrial Nuts, S. A. has. Pertaining the agricultural sector, their active crops are almonds, walnuts and pistachios – grown in Portugal, Spain and California.


*Figure 2: Borges' presence in the world*

The nuts Borges produces the most are almonds. Almond shells on the other hand, have proved to be a great resource for reinforcement due to their mechanical properties. In the experiment that follows, the aim is to find out whether the shells of almonds and walnuts are good candidates for concrete reinforcement.

Borges is a company whose objective is not only the sale of its products, but they also have a high concern for the environment and that is why they use nutshells as biomass for the walnut and pistachio dryers and dispose of all the waste generated during the agricultural process either as organic amendment in the soil itself or as a by-product for other sectors. As for our work with them, the R&D department was interested in looking for other alternatives to their solutions with this organic waste and as engineering students we have tried to find a viable option with a possible future in the market.

## IV. EXPERIMENTAL CAMPAIGN

*A.* Firstly we had to decide what percentage of gravel we were going to replace with the nutshells provided by Borges. We knew that the compressive strength could decrease significantly if we replaced a high percentage of gravel with the shells, so our final decision was to make 4 different test tubes: first a control specimen for comparison, one with 5% of nutshells, another with 10% and the last one with 20%.

The concrete specimens used are accomplishing with the european concrete norm (Eurocode 2) and are cylindrical with a diameter of 15 cm and a height of 30 cm. The materials used for the manufacture of the concrete are as follows:
-Cement CEM IV/B-Q 32,5 N : fine powder obtained from calcination at 1,450°C of a mixture of limestone, clay and iron ore.
-Sand: 0.0625-2 mm
-Medium Gravel: 8-16 mm
-Gravel: 16-25 mm
-Chopped nutshells 0.0625-2 mm
-Fresh water
The manufacturing process of these specimens is very simple. All the materials are added to a container with a high volumetric capacity and mixed together until a uniform mass is formed. This mass is then introduced into the test mold until it is filled to one third of its capacity. Once it is filled, it is beaten 25 to 30 times with a rod. This process is repeated when it is two-thirds full and completely filled.
The concrete dosification was obtained from a previous study regarding the use of walnut shell in concrete[14]. The final dosification of each specimens is as follows:

| | Cement (Kg) | Sand (Kg) | Small gravel (Kg) | Gravel (Kg) | Water (Kg) | Nutshell (Kg) |
|---|---|---|---|---|---|---|
| No nutshells | 1,62 | 5,57 | 2.79 | 2,36 | 0,91 | 0 |
| 5% of nutshells | 1,62 | 5,57 | 2.79 | 2,24 | 0,91 | 0,12 |
| 10% of nutshells | 1,62 | 5,57 | 2.79 | 2,12 | 0,91 | 0,24 |
| 20% of nutshells | 1,62 | 5,57 | 2.79 | 1,89 | 0,91 | 0,48 |

*B.* The following table shows the results obtained during the compression test:

| | No nutshells | 5% of nutshells | 10% of nutshells | 20% of nutshells |
|---|---|---|---|---|
| Dimension (mm) | 287,7 | 289,8 | 288,7 | 287,5 |
| Weight (kg) | 11,82 | 11,58 | 11,18 | 10,52 |
| Density (kg/m$^3$) | 2325 | 2261 | 2193 | 2070 |
| Load (kN) | 228,31 | 176,56 | 104,14 | 56,352 |
| Strength (MPa) | 12,92 | 9,99 | 5,89 | 3,19 |

As expected, it can be observed that a higher percentage of shell leads to a density diminution and also a significant decrease in its strength and the load it can support. Approximately, for every 5% of nutshells added to the mixture its density decreases by 60-70 kg/m3. Both load and strength decrease in a much more irregular but no less consistent manner. The diminution of the final stress is most noticeable is between the 5% shell and 10% specimens, where both the load it can withstand and its resistance drop by half. The fact that it has a lower load capacity does not mean that it is useless, since, as other studies pinpoint, this concrete can be used for other purposes where a very high resistance is not required and were lightweight and porosity can be seen as interesting properties.

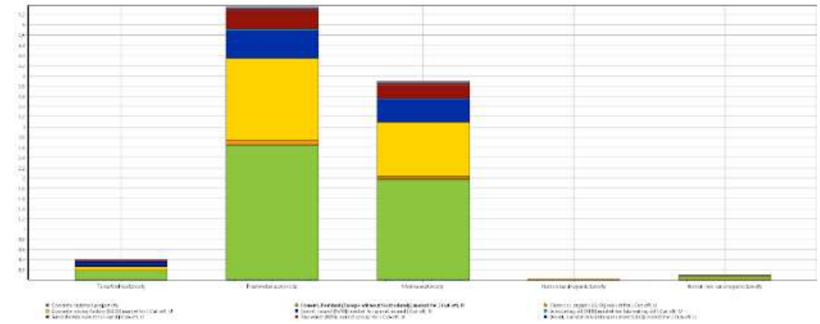
*Image 1: Concrete before and after the strength test*

## V. LIFE CYCLE ASSESSMENT

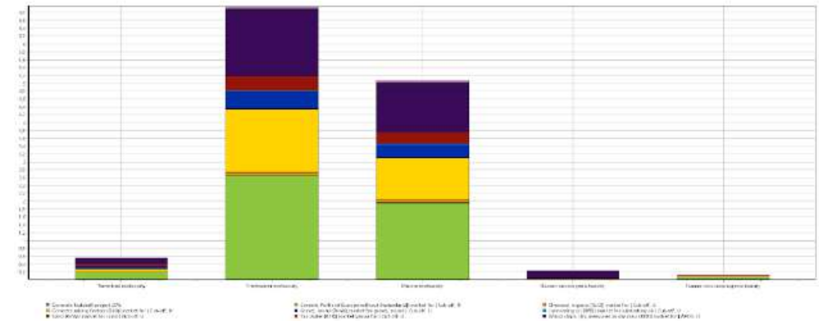
Concrete is one of the most polluting materials in the world and one of the main contributors to global warming . This is due to the fact that practically all construction work is done with this material because of its availability and its low price. It is estimated that every year 4 billion tonnes of this mixture are generated, responsible for approximately 8% of the $CO_2$ emissions that are released into the atmosphere. The construction industry uses 1.6 billion tonnes of cement every year, and for each of these tonnes, one tonne of CO2 is also generated.

Regarding the impact of the gravel, which is the material that we will replace with nutshells, it represents between 70% and 80% of all the raw materials extracted each year (in total all these materials add up to 50,000 tonnes), and due to the extremely high amount of time needed for its formation, it is being consumed much faster than it is generated. In addition, another problem in obtaining this resource is the conditioning required for its use. Most gravel and sand is sourced from rivers, lakes and deltas. The fact that all extraction sites are freshwater is not a coincidence, it is because if it is sourced from saltwater sites, salt washing is required, which is a very polluting process. For the environment, it affects biodiversity, water turbidity, landscape and climate, as well as the CO2 emissions generated by transport. Even knowing all the negative effects of aggregate extraction, there is very little information about it, creating a wide gap between the magnitude of the problem and the general knowledge.

Life cycle analysis is a type of study that calculates the environmental aspects and potential impacts throughout the entire life cycle of a product. Within the 16 points analysed by the impact method we have used, we have chosen the 5 points with the highest impact (measured in Pt, typical of the RecIpe impact method) depending on the amount of nutshells used in each test tube (Terrestrial ecotoxicity, Freshwater ecotoxicity, marine ecotoxicity, Human carcinogenic toxicity, Human non-carcinogenic respectively). Graph 1 and 2 shows the results for the extreme cases: 0 and 20% shell. The cases of 5 and 10% of shell obtain intermediate results. The red colour indicates the contribution to the total impact of gravel and the purple colour indicates the contribution of nutshells.



*Graph 1: 0% nutshell cement impact graph*

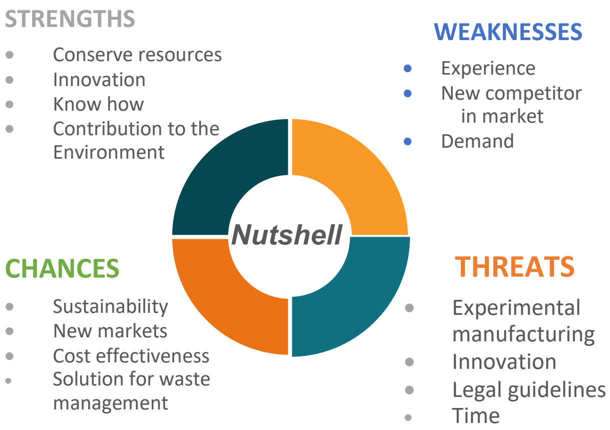


*Graph 2: 20% nutshell cement impact graph*

We can see a considerable increase in the ecopoints (unit that evaluates the different impacts) of all impact indicators. The reduction of impact by using less gravel is negligible compared to the increase generated by the shell. Therefore, environmentally we do not notice an improvement of the product. In the test tubes with intermediate values, the results are in proportion to those shown above.

## VI. Overall Economic Enviroment

The following SWOT analysis analyses the existing market and the environment regarding the use of nutshells. The graph shows the current view of the project.




**Strengths**: Due to the experience of working with nuts over the past years, there is great knowledge about the resource itself. The new way of using leftover nutshells in concrete marks a milestone into construction innovation, while it helps to maintain river ecosystems and not to waste such a precious resource as gravel.

**Weaknesses:** This project opens a new market and thrives on continuous development. It is necessary to prove its reliability in the market and thus generate sufficient demand for it.

**Chances:** Through the reuse of nutshells in this project, this work is seen as a sustainable promoter. As a consequence of recycling, many costs that would otherwise be incurred can be saved. This could be a solution to waste management.

**Threats:** It's a new way of manufacturing and therefore needs to be constantly optimized. This includes figuring out the legal guidelines.

This analysis, the research results and the experiment in the previous section show the various possibilities of this material. It is therefore very important to carry out further research in this area in order to be able to use this material in the construction industry in the future.

## VII. Conclusion

After having carried out the different compression tests, it could be seen that as the amount of nutshells increased, its density decreased, therefore, it becomes a low-density concrete that can be used for the following functions:

- For dividing elements in meeting places where low thermal conductivity is required.
- For levelling floors and slabs where the dead load of the structure needs to be reduced.
- For lightening in roof slabs.
- Prefabricated elements, such as concrete panels.

With regards to the environment, although the impact generated when manufacturing the different concretes is practically the same, looking at it from a more open point of view, we reduce the impact generated on ecosystems, we give a new use to an organic waste product, and we avoid the total depletion of such a precious resource as gravel. Even so, if we want to stick strictly to the emissions and impacts generated, there is hardly any difference between one and the other due to the small amount of shell that is added with the intention of not losing strength.

In conclusion, concrete mixed with nutshells is a viable option for certain functions, but not for heavy loads and although the environmental impact is practically the same as normal concrete, it can be said that we have found another way to recycle this waste.

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