I2E2 Symposium Barcelona

Proceedings of the 4th symposium of the I2E2 Network

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euss School of Engineering

Dear reader,

We are pleased to present the proceedings of the 4th Symposium of the International Innovation Engineering and Entrepreneurship network (I2E2), held on February 3rd, 2023 in Barcelona. The symposium brought together over 100 participants from diverse cultural backgrounds, representing countries such as France, The Netherlands, Germany, Spain, Greece, Italy, and Austria, among others. The event was initiated by Hay Geraedts and has consistently demonstrated its potential to foster the development of innovation engineering competences in a cross-cultural setting.

The projects tackled various challenges facing our society, ranging from the development of drones for natural disaster response to the reduction of single-use plastics. All projects were grounded in solid theoretical bases and had practical applications.

We would like to highlight the two projects that were awarded the prize for the best projects: "Home Automation Solutions for Elderly People," proposing a device to facilitate domestic activities for seniors, and "Embedded 3D-Printed Strain Gauge with Temperature Monitoring for Use in Prosthetics," both demonstrating the social dimension of engineering.

Overall, the involvement of participants and institutions reflected an increase in both the quality and quantity of the projects developed. We hope you enjoy reading these proceedings and are inspired by the innovative ideas and solutions presented at the symposium.

Best regards,

Low-Cost, Lightweight Fixed-Wing Drone Swarm for Efficient Aerial Surveying

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***Abstract*—Drone development has become an industry staple, memorable of its innovation and constant progression. Many vital tasks can be done far more efficiently and with much fewer resources required. Such examples include applications in the agriculture sector, national security and many others. But what would happen when a whole drone swarm gets involved in tackling problems which are known to be solved with traditional aerial vehicles? This paper will focus on finding a suitable solution for open area mapping with the help of drones. With all of this mentioned, the uprising main question is- "What is the best way to develop an autonomous swarm of drones used for large area inspection?"**

Keywords— Drones, swarming, large area inspection, fixed wing, autonomous flying

I. INTRODUCTION

With the current problem of global warming more and more natural disasters happen every year. Tsunamis and forest fires are two disasters directly resulting from global warming. When these disasters occur, rescue teams do all they can to save as many people and as much of the environment as possible. Stopping climate change once and for all would be the best solution for this problem, however this is not a solution that is feasible within the upcoming decade. As of right now, humans should be able to adapt to these situations and try to limit the damage as much as possible.

The use of drones can help to reach certain places that are unreachable by humans during these situations, and they can also be deployed sooner than, for example, helicopters. Multiple drones equipped with cameras that can be deployed at anytime and anywhere can be part of the solution. Within this paper the development of a fixed wing drone able to operate in a swarm will be described. One of the main requirements for this drone is that it should weigh less than 250 grams, having a drone with a weight below 250 grams allows it to be unregistered in the Netherlands. Another important requirement is that the drone should be able to fly autonomously once it has received a mission. Using, using a mission makes it possible to take-off and land the drone anywhere.

These drones can also be used for other purposes that include large area inspections, within agriculture for example. Farmers need to keep an eye on their goods and doing this for large areas can be a time-consuming job. With the use of (multiple) drones, this work can be done quicker and more efficiently. Aiming for affordable drones compared to hovering quadcopters should make this solution also a more accessible solution.

The main research question for this project is "What is the best way to develop an autonomous swarm of drones used for large area inspection?" The development of this drone will take place using the V-model.

This paper will firstly provide background information about drones and swarms, whereafter the approach of the project will also be elaborated on. The design of the drone is the third chapter, both the hard- and software will be explained, this includes the actual 3D model of the drone. The fourth chapter will give an explanation on the test results, and it will verify that the drone meets the requirements. The paper will be concluded with a conclusion, discussion and finally a recommendation.

II. APPROACH AND THEORETICAL BACKGROUND

Background

Defining a swarm

The main objective with the development of this drone is to find the benefits of a swarm of drones, a swarm can be defined in multiple different ways. To understand what a swarm means in the case of drones, the definition of a swarm must be stated first. The definition of the verb 'to swarm' is 'move somewhere in large numbers', which is mostly done by either insects or birds. The use of a swarm has different reasons for drones than it has for birds. The main reason for birds to swarm is to find each other a certain time before settling down for a place to sleep, it is also used to raise awareness of threats. For birds there is no such thing as one single leader of the group, every single bird has its neighbor birds to keep an eye on. If one of these birds decides to make a change in direction, the other birds will follow. However, if there are two birds that want to change direction at the same time, the birds will follow the larger of the group. These are split-second decisions and are very hard to fully understand as humans. There are mathematicians who have made mathematical models to simulate the movement of a flock of birds. These mathematical models are based on switching leaders, not only birds do this, but also with many other species [1].

The main reason for drones to fly in a swarm is to save time and money, also it is beneficial for entertainment purposes. More drones can display a greater image than one single drone, which is why it is also used as a replacement for firework shows. Just using two or more drones is not enough to call it a swarm of drones. Within this project the definition of swarming is stated as ‘two or more drones communicating with each other and with a possible ground station `. Data will be communicated via one drone to the other and the collective data will be displayed on a ground station such as a laptop. When connection with one or more drones is lost, the drones should be able to autonomously find a landing spot and safely bring it down there.

Types of drones

Another vital aspect of the project, if not the most important one, is the actual drone shape and build. Before discussing the specifics, a closer look at all possible drone designs and how they perform will commence. The main drone designs are:

1. Multi-rotor Drones
2. Fixed-wing Drones
3. Single-rotor Drones
4. Fixed-wing Hybrid VTOL

Major research was initiated in an attempt to unveil all challenges each of the drone designs hides. The main issue with all these builds is the fact that they were out of scope regarding the previously set requirements.

If a Multi-rotor Drone was to be chosen, a big portion of the tight budget would have been spent on the main structure and the motors of the drone. This would have been a limitation when it comes to creating a swarm of drones. Not only because each drone would have been far more expensive, but also because the essence of the project demands a high-end flight controller, which would allow for the drones to behave as a swarm. On top of that, a big disadvantage to this specific build is the fact that it will arguably be considerably heavier. This is because there will be a larger number of motors and so a bigger battery will be required. Another thing is that this is a hovering drone, meaning that it can “float” in the air, exerting great amounts of energy [2]. The accumulation of all these facts generates a heavier drone, making it very difficult to fit into the previously stated requirements. To put it short, this type of drone would have been outside of the budget and regulations. Aside from that, it would have been a good option, since it is a stable drone, with good maneuverability.

What the fixed-wing drone design entails is a conventional plane-like shape with one propeller in the back. As with any other thing, there are many variations to a drone design. Here for example, the Fixed-wing drone may be composed of two propellers placed in a strategic place, close to the wings, or a motor in front of the plane. For the project's purpose, the Fixed-wing drone design is a good option. The idea behind the design of mimicking a conventional plane which uses the difference in pressure at the two sides of the wings as a means to stay in the air, allows for a development of a cheap and lightweight alternative for the drone. This is mainly because there will be only one motor per drone. The material which would compose the main structure no longer needs to be high end. This allows for a good budget option. Another big plus is the fact that with fewer motors, more money will be saved. This type of drone design is very forgiving if created properly. Since it mimics conventional airplanes, with decent airfoils and a lightweight main structure, the flying potential is great. At the same time, it is stable and it will waste far less energy since it does not hover, signaling for a need of a far smaller battery. An issue with this drone type is the landing procedure. It is not as easy to solve this issue as with the multi-rotor drones for example. This type of drone requires either a runway or a parachute to land properly or it might crash abruptly and damage itself.

When it comes to the single-rotor drone design, a helicopter-like build appears in mind. This requires a lot of resources in order to execute. This is because a very intricate main structure would be required. The same goes for all other components. They are complex and very difficult to build, so they would have had to be ordered. Another issue with this build is that it would not be too stable. As it would have been a slim and long frame, wind and other weather circumstances would have been a much larger issue. This build is considerably more efficient due to its structure and the fact that it has only one motor, but the landing and take-off sequence would need to be executed perfectly otherwise there would be a risk of both damaging the drone and the operator.

The final design choice which will be reviewed now is the so-called Fixed-wing Hybrid VTOL drone. This is a regular fixed-wing build, with the exception that it can depart directly upwards from the ground on its own as would a quadcopter for example. It would afterward rotate in the air, when the appropriate altitude has been reached, and fly away. This is of course very attractive and futuristic looking, but it comes with far too many challenges. The rotation sequence is complex and, in a sense, unnecessary, when compared to other drone types. Another issue with this design is the fact that it would waste a lot of energy in the departing procedure.

These factors make this drone build too outlandish for this particular application.

Energy efficiency

Now a quick energy efficiency analysis will commence, going over all of the mentioned designs and how energy efficient they are.
The build which wastes the most amount of energy as expected is the VTOL fixed-wing hybrid drone. The take-off is too abrupt and requires a lot of force. It looks very impressive, but the price is a lot of wasted energy.
The next design that is not energy efficient is the multi-rotor. With the drone being larger, respectively- heavier, it requires a lot of additional energy. Another act worth mentioning that the multi-rotor drone does is the hovering mode. What the hovering mode offers is for the drone to stay generally in one place in the air. This requires a lot of energy as the motors need to withstand the drone's weight and keep it stable at the same time. So, this comes at a heavy price always and makes the drone less efficient
The single-rotor drone is relatively lightweight and so does not require a lot of energy to operate, but the most energy-efficient drone has to be the fixed-wing drone. The reason for that is the conventional airplane design and the fact that it could be made from an incredibly lightweight material, such as Styrofoam. In addition to that it is far more aerodynamic than the other drone designs and it has only one direction which it strives towards and that is forward, instead of hovering for example.
More on the energy efficiency of the fixed-wing drone and how a proper air foil can drastically reduce energy consumption, in the upcoming chapters.

The illustration of Figure II.2 hints at the flying properties of almost all of the drone types previously discussed. From that

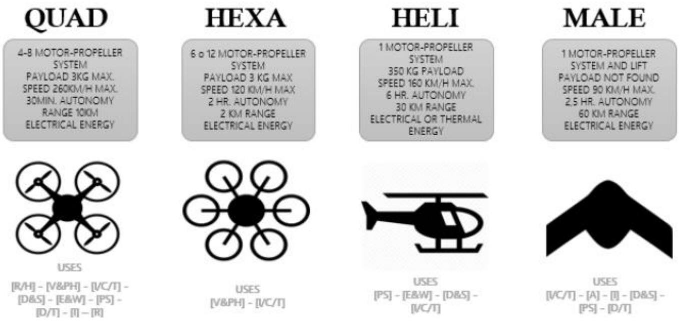

Figure II.2: Drone comparisons [4]

image it is clear that the blended wing design has good range and speed. On top of that it is also relatively lightweight, when compared to the other drones.

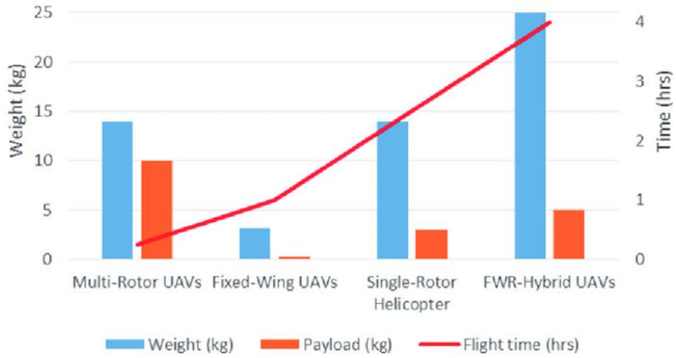

Figure II.1: Weight to Time comparisonFigure II.1 [5]

The conclusion from Figure II.2 and Figure II.1 is that being lightweight promises that the blended wing drone will save a lot of energy and fly for a decent amount of time. Not only that, but since it does not do any excess moves such as explosive take of or hovering, it’s energy will be conserved and used when it needs to propel forward, following the flight plan.

Boundaries

Since the project only has a duration of 6 months and a limited budget, some boundaries must be set. The goal of the project is to build a drone able of flying in a swarm autonomously. The project will be limited to building this drone with an already functioning flight controller. This will be done to save time developing a software that is capable of flying this drone. The design of the drone will be based on an already proven concept, this will be done since there is not enough time to properly design a perfectly working air foil. Research on the air foil will be performed in order to understand the influence of certain parameters, the proven design however saves time. It is desired to build two drones to demonstrate the communication part between the drones. Since this is not possible within the budget, a substitute solution will be made to demonstrate that communication between these drones is possible and GPS coordinates can be received from other drones. Software makes it possible for the ‘following’ drone to read these coordinates of the ‘leader’ drone and to maintain a certain distance to this drone. The aim is to have multiple purposes for the drones, not only the natural disasters should provide the drones with work. Agricultural businesses are one of the many examples that have larger areas (> 5 km^2) that need to be investigated at times.

The drone must comply to certain requirements in order for it to be successful and meet the goal set on beforehand. Some of these requirements are legal requirements and others are desired. The requirements are stated according to the MoSCoW method, the ‘must’ requirements are the most important requirement and thus need to be met. Concepts not meeting this are failed concepts. The following requirements must be met.

- The drone must weigh less than 250 grams.
- Maximum flight height must be 120 meters.
- The drone must possess a GPS module.
- The drone must stay away from restricted areas with the use of the GPS module.
- The drone cannot drop anything.
- The drone must be registered when using a camera.
- The drone must be able to communicate with other drones and the ground station and thus swarm.
- The drone must be able to land by itself.
- The drone must have a flight controller capable of running Ardupilot.
- The ground station must be able to run mission planner and Ardupilot.
- The drone must be able to land itself when connection is lost.
- The drone must be able to start flying autonomously when received a mission and thrown in the air.
- The drone must be environmentally friendly.
- The building costs of one single drone must be below €100.

Other requirements are desired but not necessary for a working prototype. These are requirements regarding the design and filming capabilities of the drone.

Approach

Design choices were made using the Kesselring method, the Kesselring method uses functions the product should need and ranks different concepts to find the concept that meets these functions best. The concepts that are ranked are the different types of drones since specific types of drones are more suited for certain applications. The different types of drones being ranked are; multi-rotor drones, fixed-wing drones, single-rotor drones and fixed-wing hybrid VTOL drones. Some of the functions the drones were ranked on are; speed, flight duration, durability and feasibility. The fixed-wing drone came out on top and is the drone that will be discussed in the next chapters. After the drone has gone through the designing phase, including material choice and air-foil design, a prototype will be built. The main reasons on why the fixed-wing drone is the best drone for larger area inspections are lesser energy consumption, lift generation by the body, flying at higher altitudes and at higher speeds. This allows the drone to complete investigation missions quicker than rotary type drones .

III. DESIGN

Hardware

Formfactor

Four drone formfactors were considered: multi-rotor, single-rotor, fixed-wing and hybrid-VTOL drones. Fixed-wing drones has, as the name say, a rigid wing which creates lift rather than vertical propellors. Fixed-wing drones are like airplanes and multi-rotors are more like helicopters. Unlike multi-rotor drones they don't need large amounts of energy to stay in the air and thus fly more efficiently. Their body is aerodynamically designed which results in stable flight during strong winds . As they can glide through the air, they have a better chance of landing when an engine failure occurs. The biggest advantage of a fixed-wing drone is the flight time. With a single battery a flight time of over an hour is easily achievable. Together with fast cruise speeds, large aeras can be covered by these drones.

However, the fixed wing has its drawbacks. The wings needed to create lift tend to be large thus making it hard to transport. They need airspeed to create lift which means it is not possible to hover and maneuverability is not as good compared to a multirotor. Without the ability of vertical take-off, the drone is harder to launch and land. Lastly, they tend to be more expensive than multirotor drones. With the help of the Kesselring-method different factors were assessed with a score. The drawbacks don't outweigh the benefits of a fixed-wing drone and resulted in the highest score of the Kesselring-method.

The main goal is to get a maximum take-off weight of 250 grams. Most aircrafts use wings to create lift and a fuselage with a long tail to house the components. A blended-wing-body (BWB) design has a body which also creates lift. Conceptually, the main aerodynamic advantage of a BWB design is its lower wetted area to volume ratio and lower interference drag as compared to the conventional aircraft . This will reduce the overall size of the aircraft and increase efficiency. The propellor will be on the rear of the plane increasing the safety of the plane in event of a crash.

Material

The material choice for the airplane is highly dependable on the way the aircraft will be build. Most aircraft are built up of an airframe which is covered with a thin layer of material called a skin. Figure 1 illustrates a conventional type of airframe. The ribs can be produced in different ways like laser cutting a lightweight material or 3D printed. Without the skin, there will be no lift created as there is no closed area. Materials for the skin in aviation are mostly made of alloys or composites. Smaller, radio-controlled, planes often use some kind of thin foil to cover ribs. Downside to this way of building is the number of ribs and cross members needed to form a working airfoil shape, resulting in a heavy overall construction.

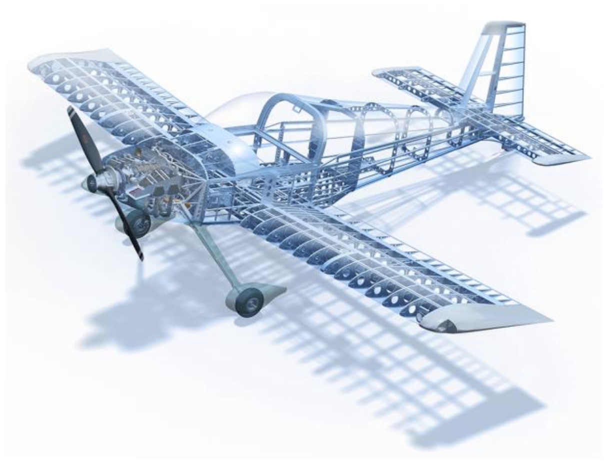

Figure III.1 - Airframe airplane without skin .

Another possibility is to use foam as the material for the aircraft. Foam is lightweight, elastic and durable. It can act as both a structural material and material which creates lift. The surface finish of foam is quite rough but can be covered with a thin layer to smoothen the skin thus reducing skin friction drag. To improve stiffness and impact resistance, the foam can be covered with a composite and resin. This is not a must but a possibility. Using foam will be drastically cheaper than using ribs. A hotwire cutter and templates can be used to create the desired shapes. For this application, foam satisfies the requirements the most. EPS (Expanded Polystyrene) will be used to build the drone. EPS is readily available, cheap, durable and easy to glue. As the wings create most of the lift of the plane, wooden sticks will run laterally through the wings at the center of lift.

Prototype

The 3D model of the fixed-wing drone was based on an already proven concept as mentioned earlier. This proven concept fits inside a 600x310x50 mm bounding box. Being this small is one of its advantages since it can fit inside one's backpack once the wings are detached. Detachable wings are not something currently implemented in the design but is one of the desired features in the future of this product. The fuselage of the drone is hollowed out, this leaves room for the electronics to fit inside. The electronics are stashed inside a 3D printed cage, with an extension to hold to motor in place. All of the 3D printed parts weigh in at only 29 grams. This housing can be seen in FIGFIG, hexagonal cutouts have been made to save material and thus weight.

As per usual in elevon planes, the function of the elevators and ailerons is combined. This type of plane only requires one 'flap' to both roll and pitch. The drone has one elevon on each side of the fuselage. Tailless wings mostly use this setup because there is no extra flap on the tail for roll control. When both elevons are moved in the same direction the drone will increase or decrease altitude. Whereas the elevons move in opposite directions the drone will roll towards one side. The elevons on the plane are controlled via servo's, these servos are connected to the flight controller. The flight controller contains a gyroscope which enables the drone to be auto balancing. The servos are specifically used in recreative type of drones, one of the benefits are that they only weigh 9 grams each.

On the front of the drone there is an optional space for a camera, the prototype does not contain a camera. However, for the final product a camera is necessary. This camera can then also be connected to the flight controller, since this also has an option for first person viewing. The cables can also be redirected to the cage.

To make sure the electronics are fully isolated from rain or other environmental things that can cause damage, a cover was designed to fit over de fuselage and nose of the drone. This cover was made using vacuum forming, a 0.5 mm plastic sheet is placed over a 3D printed mold and a thin shell is formed over this. The full 3D model of the fixed-wing drone can be seen in Figure III.2, an exploded view is showed here.

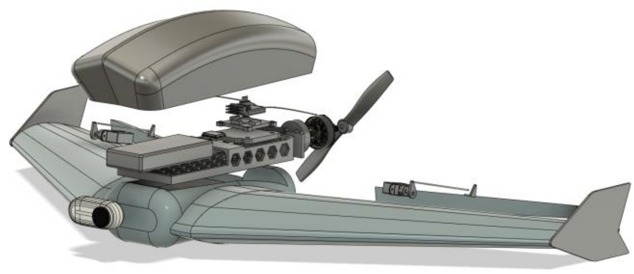

Figure III.2: 3D model of the prototype

Electronics

Motor and propeller

The motor and propeller need to be defined together. A large propeller bonded with a small motor won't be able to spin the propeller and thus generate not enough trust. This applies for a big motor with a small propeller as well. The weight and energy consumption are a good starting point for choosing the combo. As the VELOX V2206 KV1950 motors were available in time, the choice was made to use these.

Generally larger propellers are more efficient than smaller propellers. A propeller pushes air in one direction which results in a force towards the opposite direction. The force generated is equal to the rate of change of momentum of that propwash. Propwash is the accelerated air that is being pushed backwards. The amount of air being pushed back (volume) will produce the force. A large propeller will generate the same thrust as a small propeller but at a lower speed. The small propeller will push the air backwards at a higher speed and thus create more propwash and thus more loss of energy. This is a simplified explanation of why a large propeller is generally is more efficient. More aspects should be considered when actually defining the efficiency of a bladed propeller. The choice was made to go for a 5-inch propeller with a pitch of 4.5. Using the eCalc calculator, a theoretical estimated flight time of around 26.2 minutes is.

Flightcontroller

The flight controller will be the brains for the aircraft and control all the electronics. Because the project does not include programming of the software. This means the flight controller needs to be compatible with the software that is chosen. The flight controller also needs to be compatible with the GPS and the speed controller that will be used. The flight controller that was chosen is the F405-miniTe from Mateksys. The reason this flight controller was chosen is because it is compatible with Ardupilot which will be the software to fly autonomously. This flight controller also has enough ports to connect all the necessary electronics that need to be on the drone. The flight controller has a build in Barometer. The last reason for choosing the F405-miniTE is the relatively cheap price of the controller.

Servo

Because the plane only has one motor there needs to be a way on how to change directions and compensate for the wind. This is done with ailerons as explained in prototype paragraph of the design chapter. To control these ailerons on both sides there will be the use of servo’s that can control these parts. The most important requirement for these servos is the weight because of the weight limit of the drone. Because the foam they need to move around is very light there is a lot of freedom choosing these servos. This led to the choice of the SG90 mini servo that only weights 11 grams.

Battery

The battery of the drone needs to have enough capacity for a long flight time but the bigger the battery the heavier it is. Due to the weight limit of the drone of 250 grams, a lot of consideration went into the battery choice. For the project's purpose, a LiPo cell battery was chosen. It would have 7.4V and 1300mAh. After deep analysis and many comparisons, it was concluded that this specific battery type would be sufficient, not only that, but it would fit perfectly with regards to its weight and capabilities in the scope of the project.

Global Positioning System

For the drone to fly autonomously and to be able to fly in a swarm the drone needs to know its current position. This can be done using GPS (Global Positioning System). For the GPS to work there are three parts. The first part is a ground station, the second part is a satellite, and the final part is a receiver. The satellites send out signals which can be picked up by the receivers. When the receiver picks up the signal of the satellite the receiver can calculate the distance to the satellites. More than 30 satellites are in orbit around the earth and a receiver needs four of them to calculate the position of itself. For the drone to use GPS it needs to be equipped with a receiver. The GPS needs to be compatible with the flight controller that has been chosen. The drone will be equipped with the ATGM336H module.

Speed controller

The speed controller is a piece of electronics that will connect the flight controller to the motor. The speed controller will also connect the flight controller to the battery. This means that it is important that the speed controller is both compatible with the battery and the flight controller. The speed controller works by adjusting the voltage send to the motor and the flight controller tells the speed controller what voltage the motor needs to get.

Electrical schematic

Before the drone can be assembled there needs to be an idee on how to connect all the different components. This can be done with an electrical schematic. In this electrical schematic there will be an overview of what ports of the parts connect to what ports on the flight controller and how the flight controller is connected to the speed controller and the battery.

Swarming and Communication

As stated in the background, a drone swarm is defined as “two or more drones communicating with each other and with a possible ground station”. To be able to fly in patterns or formations and prevent midair collision, the drones must be able to communicate or detect one another. Two methods have been considered. The first being that the drones can detect each other with the help of image sensors. Each drone needs to have a unique marker (e.g., a barcode on products in a supermarket). This way of forming a swarm has the benefit that the drones know each other’s position fairly precise and they do not have to be fitted with a GPS module. The downside is that this requires image processing, a clear line of sight and a small distance between the drones to still detect these markers.

The other way of detecting each other, is by communicating their GPS coordinates. This method requires all drones to have a GPS module. When the primary drone sends its GPS coordinates, the secondary drones can base their position on these coordinates. The position of the secondary drones is based on the latitude and longitude of the primary drone, plus or minus a predefined margin, as shown in Figure III.3: Drone swarm flying north.

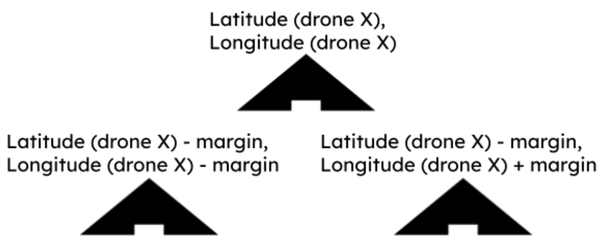

Figure III.3: Drone swarm flying north

The size of the margin depends on the application. If the application requires video footage of an area, the margin depends on the camera used and the altitude. The camera has a certain field of view (FOV) in degrees or radians and the area on the ground that this camera can detect depends on the altitude.

The GPS coordinates from the primary drone are send to the secondary drones with the help of ESP8266 micro controller units (MCU), which contain Wi-Fi modules. The MCU of the primary drone functions as an access point (Server) and creates its own Wi-Fi network. The MCUs of the secondary drones function as stations (Clients) and connect to this Wi-Fi network. When a client sends a HTTP (Hypertext Transfer Protocol) request to the server, the server verifies this request and sends an appropriate response this is graphically displayed in Figure III.4: Communication between MCU's.

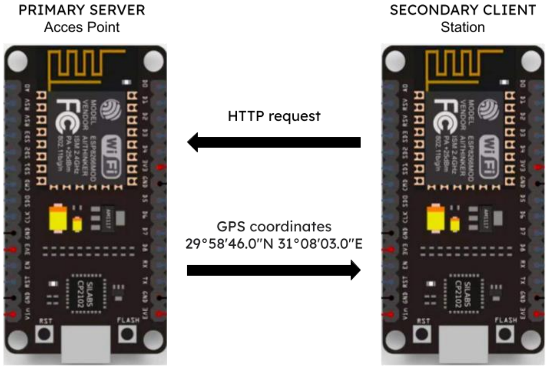

Figure III.4: Communication between MCU's

IV. TEST RESULTS AND VERIFICATION

To make the flight controller ready for autonomous flying it must be flashed using the STM32CubeProgrammer software.

Before connecting al the electrical components, they were tested separately. The drones are meant to be flying autonomous, but to test all its functionalities a remote controller was added to the setup. The servos were tested with the remote controller on their reaction for steering and to auto balance the drone with the input from the gyroscope on the flight controller. The functioning of the motor was tested by pushing the throttle on the remote controller from off to maximal.

The GPS module is not able to find enough satellites to get a fix on its location while inside. This should be a minor problem because the drones are meant for outside applications.

In order to judge whether the drone design is a success, a verification of the requirements should take place. All the most important requirements, the 'must' requirements, must be fulfilled. The drone fulfills most of the requirements, the only ones not fulfilled (yet) are the following;

- The drone must stay away from restricted areas. This requirement has not been fulfilled yet, this is a part that should take place within the mission planner. Since the GPS itself does not know what is restricted, the mission planner should adjust the flight path of the drone.
- The drone must be able to land itself when connection is lost. Currently the following drone will stop working when connection to the leader drone is lost. Software should ensure the following drone to find a safe space to land, instead of just landing wherever connection is lost. The leading drone receives a mission from mission planner, so when this drone loses its connection its due to battery issues. In this case the drone will land wherever it has lost connection without looking for a safe space.

Both requirements can be fulfilled once a proper communication software is written for the drones.

V. CONCLUSION AND DISCUSSION

The main question was; "What is the best way to develop an autonomous swarm of drones used for large area inspection?" The answer to this question consists of a few steps, first of all it is important to fully understand the application the drone will be used for. In this case the drone would be used for large area inspections, fixed-wing drones are the most suited for this application since they are the most efficient with respect to flight distance and speed. With a constant speed the fixed-wing drone can fly up to 30 minutes with the current setup. This is with an average speed of about 50 km/h, this would lead to a 25 km flight distance. Other drone types are more suited for tasks where hovering is important and where the drone needs to be agile. For large area inspections neither one of these functions is important.

When the decision for the type of drone is made, the requirements and specifications for the drone should be setup. Different propellors and motors lead to different results after all. The drone should also be able to fly on its own and within a swarm, which is why the decision for the correct flight controller and software should be considered carefully as well. Ardupilot comes with a Mission Planner which makes it possible to give directions to the leader drone which communicates with the following drone. The flight controller should thus be compatible with Ardupilot, eliminating a part of the flight controllers. Once the hardware and electronics of the leader drone have finished, the calibration for the drone takes place in Ardupilot. The communication of the drone is the next step in developing this autonomous drone, which is done with MCU's containing Wi-Fi modules. Each drone contains one of these MCU's after which GPS coordinates can be send to one another.

As for the recommendations, a few things can be handled differently in the future of this project. First of all, the budget is on the lower side, with double the money able to spend spare parts could have been order on beforehand. This prevents any time-loss and if nothing bad happens, a second drone can also be built quicker. For a second prototype one of the things that could be added is a way of landing instead of slowly flying the drone to the ground. Some type of parachute would be a great solution, preventing the drone to fall to the ground without people noticing. Also a camera should be implemented, possible with video stitching software available on the ground station. As of right now this was not possible within the time window and the available knowledge, hence the reason why this was out of our scope. An integrated cover for the cage would be the next step for complete isolation of the electronics within the fuselage. When more drone prototypes are developed, the actual software behind the swarming can also be made. Proving that the concept given in the communication chapter works the way it should.

REFERENCES

[1] E. Cristiani, M. Menci, M. Papi and L. Brafman, "An all-leader agent-based model for turning and flocking birds," p. 3, 27 Augustus 2021.

[2] P. Partners, "Different types of drones," Position Partners, [Online]. Available: https://www.positionpartners.com.au/position-partners/survey-drones/. [Accessed 20 01 2023].

[3] A. Drone, "Drone types: Multi-rotor vs Fixed Wing vs Single Rotor vs Hybrid Vtol," Vertech Group Sites, [Online]. Available: https://www.auav.com.au/articles/drone-types/#3. [Accessed 21 01 2023].

[4] S. Farmers, "Applications of Unmanned Aerial Vehicle (UAV) in Agriculture - Scientific Figure on ResearchGate," ResearchGate, [Online]. Available: https://www.researchgate.net/figure/UAV-weight-and-payload-vs-flight-time_fig3_337948739/actions#reference. [Accessed 20 01 2023].

[5] T. Elijah, R. S. Jamisola Jr., Z. Tjiparuro and M. Namoshe, "A review on control and maneuvering of cooperative fixed-wing drones," 3 November 2020. [Online]. Available: https://link.springer.com/article/10.1007/s40435-020-00710-2. [Accessed January 2023].

[6] M. Murison, "Fixed-Wing vs Multirotor: Which Drone Should You Choose for Aerial Surveying?," DJI enterprise, 14 October 2020. [Online]. Available: https://enterprise-insights.dji.com/blog/fixed-wing-vs-multirotor-drone-surveying. [Accessed 16 January 2023].

[7] N. e. a. Qin, "“Aerodynamic considerations of blended wing body aircraft,” Progress in Aerospace Sciences," *Elsevier*, pp. 321-343, 40(6) 2004.

[8] VansAircraft, Artist, *Airframe airplane without skin.* [Art]. 2015.

[9] L. Brassaw, "Ailerons – What are They, and How do They Work?," Thrust Flight, 15 August 2022. [Online]. Available: https://www.thrustflight.com/ailerons/. [Accessed January 2023].

[10] L. Niles, *Why larger propellers are generally more efficient than smaller propellers,* 2021.

[11] M. Müller, "motorcalc," Soltuion for All Markus Müller, 17 Juni 2022. [Online]. Available: https://www.ecalc.ch/motorcalc.php. [Accessed 25 Januari 2023].

[12] “trakkitgps,” 8 January 2023. [Online]. Available: https://trakkitgps.com/how-gps-works/.

[13] Army-technologies, "SmartPlanes," Army-technologies, [Online]. Available: https://www.army-technology.com/contractors/surveillance/smartplanes-army/pressreleases/drones-energy-efficiency/. [Accessed 20 01 2023].

[14] C. Rozas, "Developing Solution for Drone Manufacturing - Scientific Figure on ResearchGate," ResearchGate, [Online]. Available: https://www.researchgate.net/figure/Drone-comparison-analysis-using-a-simple-benchmarking-approach-Parameters-quantity-of_fig1_326749255/actions#reference. [Accessed 20 01 2023].

Technical Paper:
3D Recycled Material Innovation

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Abstract

3D printing has an undeniable importance to the industry market, as it represents one of the most significant variables in the industry equation.

3D printing however produces a significant amount of waste in a form of support regardless of the used material. Therefore, a project has been assigned to fourth-year students of Fontys university and EUSS by the name of recycling 3D printed objects. The answer aims to highlight how innovation can utilize this 3D waste and create a scalable product from the solution. The paper concludes that while a plastic pallet created out of the waste is entirely possible and can be easily scaled up to commercial levels, the current hold wooden pallets have over the industry is a great obstacle. A great effort of lobbying and introducing distribution centers for the plastic pallets to ease in transport cost would allow them to overtake the wooden counterpart and have a good return on investment.

Keywords— (Innovation, 3D Printing, Recycling, Euro Pallets)

I.Introduction

Plastic waste has been a long-standing issue on the world in more ways than one, impacting economies of developing countries, introducing myriads of health issues in poorer communities with no access to proper waste disposal and damaging the environment and our oceans in multiple ways [1]. This paper aims to investigate how a subsection of the wasted plastic, 3D printed plastic material, can be recycled, and reused in useful ways to prevent harming health and the environment. Innovation has played an integral part in the international response against the plastic pollution epidemic, from companies building decentralized reusable packaging cleaning infrastructure around the world [2] to aide in the efforts, till companies such as RecyclePoints [3] introducing plastic collection pick-ups that use a reward incentive system to redeem food, household equipment and cash. These innovations have inspired the team to come up with multiple solutions of which the eco-pallet was chosen.

The paper initially investigates a 3D printed material used in Fontys, a mixture of Polypropylene (PP) and glass fibers. The paper will focus on the technological innovations in the recycling field as well as discuss how some of the innovation design methodologies and methods apply to this topic, methods such as brainstorming, environment or context association and the TRIZ method. As this project is a collaboration between Fontys students and EUSS students, the paper will also touch on intercultural connections and the experiences shared when the teams visited one another to challenges faced in international collaboration environments. Finally, the implementation of the conclusion and solution will be discussed in an intrapreneurial scope.

II.Paper Background

With the environmental state of the world in steady decline, the need for innovative engineering practices is on the rise. To prepare engineering students for the challenging world of Innovation Fontys School of Engineering allows the pursuit of a specialization course in the 4th year by the name of Innovation Engineering. This Specialization combines the skills and knowledge gained from the Engineering Curriculum offered by the school and combines it with the business aspects of designing products or services. This allows students that complete the specialization to be even more well-rounded engineers that have even more options to choose from post-graduation.

Also offered within the Innovation Engineering course, are many projects that focus on designing in a sustainable, safe, and market friendly manner and this assigned project is no different. The project that this paper is focused on was instated by a professor at the EUSS Technical University. Moreover, a student team from EUSS was also tasked to work on the project together with a group of students from Fontys School of Engineering in Eindhoven. During the Innovation Engineering specialization, a course was given by the name of Product Innovation during which it was taught how to write a research paper according to IEEE standards. In spirit of this course, this paper is written according to those standards as well.

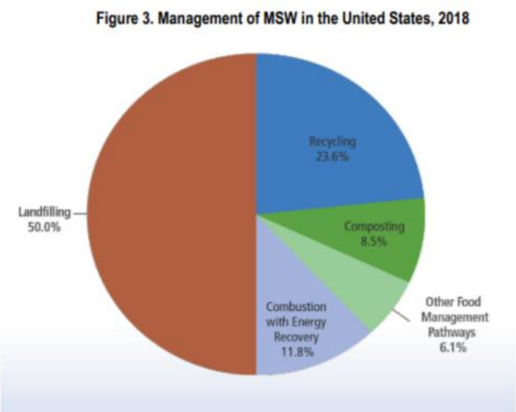
What is innovative about the 3D Recycling Material Project is mentioned in the name, it focusses on producing a product from the recycled material from 3D printed objects. As stated, prior, this material is a mixture of Polypropylene and is a very popular choice of printing material in the 3D printing industry [7]. Hence, through research it can be concluded that should a product be created, the material used to produce such a product will be in large supply.

III.Innovation Basics in Plastic Recycling

Innovative principles are key in combating the plastic epidemic to achieve long term sustainability, good population health and the reduction of waste harming the environment. However before tackling this problem, we must establish a baseline to understand the problem in more detail and convince the populace of why it should be solved or mitigated.

Waste in Numbers

Today, we produce over 400 million tons of plastic waste every year [4]. A worrying section of that waste is attributed to manufacturing process where 3D printing is commonly used. This plastic comes in the form of supporting material, failed part prints or dysfunctional parts. PP plastic accounts for around 20% of the total waste, 50% of the total plastic waste in the US alone was landfilled instead of being recycled or reused.



What effects does this waste have on us

There is lots of increasing evidence on the effects everyday exposure of plastic chemicals and material has on our health. There has been links established between health issues, these links are evident in all age groups [6]. Some of these include:

-Reproductive health issues

-Brain health issues

-Different types of cancers

The microplastics responsible for these problems have been found in over 80% of humans tested in a study at the Vrije Universiteit Amsterdam in the Netherlands. These discoveries are extremely alarming as the impact on humans will be for generations to come.

Environment Impact

The harm of PP plastic comes mainly in the manufacturing process, it's a large contributor to greenhouse gases during production as it relies on petroleum and natural gas to create [9]. This is expected to contribute over 1.3 billion tons of carbon dioxide to the environment in the next thirty years if the industry is not heavily regulated or changed. The plastic products end up in the oceans, contaminating marine life, killing turtles and other aquatic creatures that mistake it for food, causing them to starve and suffocate to death [9]. As mentioned previously, this plastic can also cause reproductive issues, especially in smaller animals where it has been found heavily in their body and diet, animals such as birds or rodents.

All these previously listed problems fulfill the basic needs for innovation in this field. The international community, people, planet, and animals who suffer massively from these effects are aware of the risks and recognize the need for a solution. These innovations can involve the creations of new technologies such as devices to make the recycling process profitable and easy to new policies to limit plastic waste and emissions during the manufacturing process and social policies to educate the population about the importance of this issue. These needs are the source of opportunities for innovation. These issues allow us to determine what the customer needs and helps us focus on that objective.

Finding solutions for these problems is also ethically sound as reducing plastic waste helps keep people healthy and reduces the impact to the economy and thus livelihood of the global population. While there may be some initial profit losses, the long term effects of such innovations can be determinantal.

All these decisions and factors contribute to the final innovative ideas the team came up with. The main problems are identified, the advantages of solving them are also identified thus providing the basis and importance of these innovations. The following sections discuss the research done by the team and the proposed solutions.

IV.Intercultural Connections

When it comes to recycling 3D printed plastic, intercultural connections come into play. Different cultures may have different attitudes towards recycling and environmental sustainability, and this can affect how 3D prints recycling are viewed and used. For example, in some cultures, recycling is seen as a civic duty and is heavily promoted and incentivized. In other cultures, recycling may be less of a priority and may not be as well-established. As 3D printing technology becomes more widely available and accessible, it's important for people from different cultures to understand and learn from one another about best practices for recycling 3D printed plastic and promoting sustainability.

Global perceptions on recycling

In the United States, recycling 3D printed plastic is still a relatively new concept. However, some cities and states are beginning to implement programs to recycle 3D printed plastic waste. For example, the city of Austin, Texas has a program called "Re3D" that collects and recycles 3D printed plastic waste from businesses and individuals. According to the program's website, the goal is to "keep plastic out of landfills and waterways, reduce the need for new plastic production, and create a closed loop for plastic waste."

In Europe, there are various initiatives to promote recycling of 3D printed plastic waste. For example, Repair3D [11], a project that "Aims at the development of innovative reclamation and repurposing routes for end-of-life plastic and carbon fiber reinforced polymer (CFRP) components. This will be achieved by employing advanced nanotechnology solutions, Additive Manufacturing (AM) and recycled resources, for the production of high added value 3D printed products with advanced functionalities."

Project development Challenges

Some of these challenges were apparent during the development of the project, both teams had to fly out to meet each other and spend some time working in each other's countries and universities. The Fontys team initially flew out to Barcelona and a workday was scheduled with the Spanish students. There were a few challenges and cultural clashes where both teams had to adjust, some of these included:

1-Time Management

There were constant time conflicts due to the busy lives of the EUSS team, as many had classes late into the afternoon, accompanied with nighttime jobs. Therefor meetings had to be arranged around late night or early mornings during breaks, this proved challenging for both student groups as it was out of the norm for how they usually worked. However, in retrospective, these circumstances forced both students to adjust and accommodate in order to work together effectively, this proved successful as meetings went on.

2-Language Barriers

There were language challenges which contributed to difficulty in working together. Some students were unable to communicate fluently, this was however remedied with a constant effort by both sides in translating to the nonnative English speakers on both teams. This was another obstacle that the team overcame by understanding the cultural differences and working through them. Another important factor is the restrictions in collaboration between the different shareholders regarding innovative solutions. The result of the collaboration weighed differently on each team. This forced a balance between equal effort and reward between the teams. The Fontys team had more at stake and thus needed to provide more effort and work towards the solution.

All of these factors are important considerations to take into account with innovation in the final result of this project, especially during an important phase in the educations and work of both teams. They play an important part in any decision taken regarding an innovation or idea. The solution can be the main focus of that decision, however the challenge of taking account every shareholder involved, the cultural values of the involved parties and the fulfillment of the basic needs cannot be undermined. We must consider certain aspects of responsible innovation, however we must not rely entirely on concrete guidelines for our solutions, instead we must focus on adapting the solution to the target market and its cultural aspects.

V.Innovation Development Within Your Capabilities

In today's fast-paced business world, innovation has become a critical component of success. Companies must constantly evolve and improve their products, processes, and services in order to remain competitive and meet the market's ever-changing demands. This includes the production of recyclable plastic pallets via a molding process. In this chapter, we will discuss the project's capability for innovation and its impact on the manufacturing industry.

Process Innovation:

The invention of the molding process used to make plastic pallets was a significant breakthrough. The process was created to be highly efficient, reducing manufacturing time and costs while maintaining high output quality. The use of recycled 3D printed waste as the primary raw material is also a unique and innovative approach that distinguishes this project from others.

Product Innovation: The plastic pallets produced by the molding process are an innovative product in and of themselves. The pallets have a distinct advantage over traditional wooden pallets due to the use of recycled 3D printed waste as the primary raw material. Plastic pallets are lightweight, durable, and resistant to harsh environmental conditions, making them ideal for use in a variety of industries.

Model Innovation in Business:

The business model for manufacturing plastic pallets is also novel. Molding allows for large-scale production while lowering costs and increasing efficiency. The use of recycled 3D printed waste as the primary raw material reduces the costs associated with raw material sourcing. Furthermore, the low cost of the plastic pallets compared to traditional wooden pallets makes them an attractive option for many businesses, increasing the potential market for this product.

To summarize, the project's innovation development has a significant potential to impact the manufacturing industry. The use of recycled 3D printed waste, the efficient molding process, and the innovative business model all contribute to the project's success and value to the industry.

VI.Interdisciplinary Connections and Patents

Interdisciplinary Connections:

The production of recycled plastic pallets from 3D printed waste is a multidisciplinary project involving materials science, engineering, and sustainability. The intersection of these fields offers a once-in-a-lifetime opportunity to address multiple challenges in the manufacturing industry and the environment.

The materials science component of the project is concerned with the selection of polypropylene as a recycling material, as well as its processing into high-quality plastic pallets. The use of polypropylene, a thermoplastic polymer, enables the recycling of 3D- printed waste into pallets with the required physical properties and quality.

The engineering component of the project is concerned with the design and construction of the molding process as well as the equipment used. The engineering challenge is to create a process that can produce high-quality plastic pallets that meet safety standards, last longer than wooden pallets, and are economically feasible to produce.

The project's sustainability aspect addresses the environmental impact of the manufacturing process and the use of plastic pallets. The project aims to reduce waste generated during 3D printing and provide a solution to reduce the use of unsustainable wooden pallets.

Patents:

It is critical to protect the project's intellectual property, which can be accomplished by obtaining patents. Patents protect the distinguishing characteristics and processes used in the manufacture of recycled plastic pallets, ensuring that no one else can produce and sell similar products without permission.

To see if similar products or processes have been patented, conduct a patent search. If not, a patent application should be filed to protect the project's intellectual property. A detailed description of the process and the unique features of the plastic pallets, as well as any drawings or diagrams that help to explain the invention, should be included in the patent application.

Finally, the interdisciplinary connections and patent protection are critical components of the project's success and longevity. This project can have a positive impact on the manufacturing industry and the environment by combining the fields of materials science, engineering, and sustainability, as well as protecting intellectual property through patent protection.

VII.Intrapreneurial Thinking and Attitude

Entrepreneurial Thinking is to be defined as a combination of thinking ways and styles. Hopeful thinking, melioristic thinking, holistic thinking, action-oriented and team-oriented, emancipatory thinking, social and ethical thinking, heuristic and dialectical thinking and utopian thinking are all a significant part of Entrepreneurial Thinking definition. And most importantly, ET is about connective problem-solving, meaning solving a problem without creating another one.

According to the guest lecturer, an entrepreneurial attitude revolves primarily around working creatively toward the end goal while investing blood, sweat, and tears in it. However, clear communication combined with critical and realistic thinking is also required to see opportunities on the sustainable innovation horizon.

When taking Intrapreneurial thinking and attitude into consideration the team's end goal for the recycling pp material project is to be able to enter the EPAL market system during the startup phase, if possible. However, because the EPAL system is currently limited to wooden pallets, the team hopes to create an entirely new EPAL market during the scale-up phase that is only limited to recyclable plastic pallets made from recyclable plastic waste.

Producing recycled plastic pallets from 3D printed waste necessitates a mindset that combines creativity, innovation, and a dedication to sustainability. Converting 3D printed waste into high-quality plastic pallets necessitates the use of cutting-edge technology as well as a thorough understanding of the manufacturing process.

This project's success is dependent on intrapreneurial thinking. It entails thinking outside the box, developing new and innovative ideas, and taking calculated risks to bring those ideas to life. This way of thinking is essential for the development and execution of successful projects, particularly in the manufacturing industry.

An entrepreneurial mindset is also required for the project's success. This requires a growth mindset, an unwavering determination to succeed, and the ability to adapt to changing circumstances. The production of recycled plastic pallets is a non-traditional process that necessitates the ability to adapt and evolve in response to new challenges.

It is critical to cultivate a culture that values and rewards intrapreneurial thinking and entrepreneurial attitudes in order to ensure the success of this project. This can be accomplished by fostering an environment that fosters creativity, innovation, and an openness to new ideas. This can be accomplished through programs such as training, mentorship, and recognition and reward systems.

Furthermore, it is critical to assemble a team of individuals who are committed to using their skills and expertise to make a positive impact on the environment and who have a strong entrepreneurial spirit. A team dedicated to these values is more likely to overcome the challenges that arise during the production process and bring this project to fruition.

Finally, intrapreneurial thinking and entrepreneurial attitudes are critical to the project's success in producing recycled plastic pallets from 3D-printed waste. Building a team of individuals who embody these qualities and cultivating a culture that values them are critical to the success of this project.

VIII.Conclusion

The question of How innovation can utilize this 3D waste and create a scalable product from the solution has been addressed throughout the report. The conclusion is that the use of recycled plastic pallets provides a sustainable and cost-effective solution that can benefit both the manufacturing industry and the environment. The project has demonstrated the feasibility of the solution and the potential for further innovation, development, and growth. The team should continue to consider the interdisciplinary connections, have a proactive and innovative mindset, and explore opportunities for further development within their capabilities.

Finally, the project investigated various aspects of manufacturing recycled plastic pallets from 3D printed waste. According to the findings of the market research, the startup phase analysis, and the solution of using a mold to produce the pallets, this project is feasible and has significant potential. The use of the EPAL system, as well as comparisons with traditional wooden pallets, have demonstrated the viability and benefits of using recycled plastic pallets even further.

Furthermore, the chapter on Interdisciplinary Connections and Patents emphasizes the importance of considering other ndustries and the possibility of patenting the solution. The chapter on Intrapreneurial Thinking and Attitude emphasizes the importance of a proactive and innovative mindset within the team to ensure the project's success. The Innovation Development Within Capabilities chapter explores the opportunities for further development and growth of the solution.

IX.Acknowledgments

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Section IX.01 REFERENCES

[1] Plastic Pollution , Plastic Pollution (unep.org)

[2] Again decentralized reusable cleaning infrastrucute, Contribution: Building decentralised reusable packaging cleaning infrastructure✪ (weforum.org)

[3] RecyclePoints RecyclePoints Limited: Providing Innovative Technology Based Post Consumer Waste Recovery Systems✪ - UpLink - Contribution(weforum.org)

[4] Plastic waste in numbers, Visual Feature | Beat Plastic Pollution (unep.org)

[5] Plastics: Material specific data, Plastics: Material-Specific Data | US EPA

[6] Health effects, Plastics & Human Health | No Plastic Waste | The Minderoo Foundation

[7] Polypropylene as a Proper Printing Material, Polypropylene

[8] Heather A. Leslie, Martin J.M. van Velzen, Sicco H. Brandsma, A. Dick Vethaak, Juan J. Garcia-Vallejo, Marja H. Lamoree, Discovery and quantification of

plastic particle pollution in human blood, Environment International, Volume 163, 2022, 107199 ISSN 0160-4120, https://doi.org/10.1016/j.envint.2022.107199.

[9] PP effects on environment, Is Polypropylene Bad for the Environment? (ourendangeredworld.com)

[10] Re3D, X re:3D HOME | re:3D | Life-Sized Affordable 3D Printing (re3d.org)

[11] Repaird3D, Repair3D – RECYCLING AND REPURPOSING OF PLASTIC WASTE FOR ADVANCED 3D PRINTING APPLICATIONS

Almond shells as a base for an alternative to wooden boards

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***Abstract*—This document is an exposition of the experimental process to make and analyze the impact of an almond shells composite.**

I. Introduction

After a long internet search and brainstorming, it came to us that it could be a good idea to make furniture out of almond shells, because they have some mechanical properties that can be useful.

The main idea is to be able to make wooden boards from almond shells and glue without chemicals and in a natural way. These boards will be used to make tables, cabinets or shelves.

In case we do not get a good adhesion of the shells and therefore poor mechanical properties, we think that a good idea would be to use these same boards as insulation material for constructions, as in that case we do not require mechanical properties.

II. Almond shells processing

One of the first steps to be able to create our new conglomerate material is to grind the almond shells. In this way we will be able to compact our material in a suitable way.

In order to grind them we have to take into account that it is a very hard material that could damage some of our tools. Finally, we decided to use a food grinder to carry out the process. The specifications of own food processor are the following (Thermomix):

Motor Power = 500 W

Speed = 10-10000 rpm

The result obtained can be seen in the following image:

Image: Crushed almond shells

As can be seen in the image above, the material obtained has a sandy aspect with very different grain sizes. This was obtained by crushing the shells for 45 seconds. In spite of having a much smaller size, the material does not seem to present an adequate moldability and compressibility for our objective, since the larger pieces do not allow a great moldability.

In order to carry out our objective, we need to be able to classify our shredded material, this is due to the fact that, as we have already said, the large pieces do not allow us to generate a conglomerate.

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In order to carry out our objective, we need to be able to classify our shredded material, this is due to the fact that, as we have already said, the large pieces do not allow us to generate a conglomerate.

In addition to sieve the material, we need to have a filter that allows us to classify the different grains obtained. In our case we have used the following device:

Image: Interchangeable sieve

This is a sieve with four different filters. With them we can classify our material in five different sizes. In our case, the filters have the following sizes:

0,5 mm

1 mm

2 mm

3 mm

With these different sizes we can make samples with different characteristics and thus obtain the optimized version of the sample within the sieve.

III. Mold design

In our case we have a compression testing machine, this exerts compression with a 20mm piston. Our intention with this is to machine a compression mold, our 20mm piston will exert pressure on a mold with an inlet of more than 20mm to facilitate its entry.

The female mold we have designed for our case is as follows:

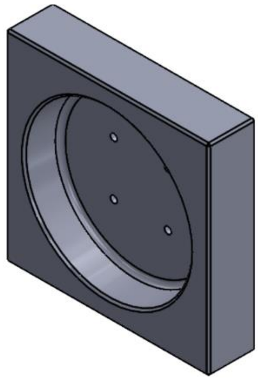
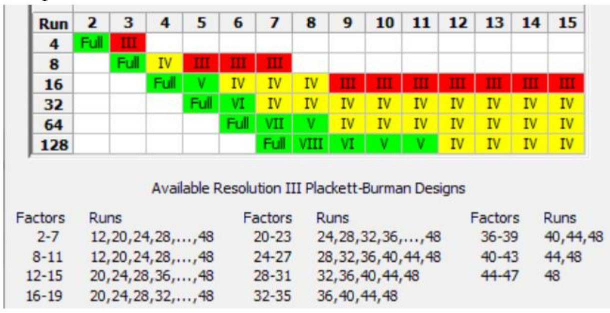


Image: 3D model of the mold

As can be seen in the image, the mold has a slight inclination on the walls to be able to compress our material more easily. In addition, we have also decided to incorporate 4 relief holes, this way it will be much easier to extract the samples from our device.

IV. Testing

We have decided to do a DOE (Design Of Experiments). A DOE is a statistical method to know which variables affect the most to a desired characteristic of a sample.
We think it is necessary to do a DOE because as we want to propose an alternative to the use of almond shells as a fuel, we want this alternative to be the most efficient as possible. Because later on we will do a LCA, so the less resources we need to do our alternative the better will be to compare in the LCA.
So the main goal of doing a DOE is to get the least amount of resources possible to get the higher mechanical properties with minor resources.
In this DOE we will make samples taking into account two different variables: the size of the almond grains and the amount of white glue.
In this case, we would only carried out 4 tests due to lack of time and lack of resources.
We think that is a low value but valid. According to Minitab simples chart.



Run	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

Image: Minitab samples chart

Unfortunately, due to the lack of time and materials we are not able to do the tests, therefore the DOE is not possible to be done.
As said before we designed a mold to compress the mixture of almond shells and glue. This mold couldn't be done at

time to do all the samples. Even so we have been able to compress the material and make some conclusions.

We wanted to know the consistency of the samples just by pressing them. That's why the first tests we did for the manufacturing of the samples was without using white glue. All samples were made by pressing with a force between 130kN and 185 kN.
The best results were obtained in the samples where the smallest grain size (smaller than 0.5mm) was used. These samples also looked compact and hard and did not break when removed from the mold.

Image: Smallest grain size sample

V. Lifecycle Assessment

The goal of our study is to make an LCA on the process of making furniture out of almond shells. The results will be used to compare the process of burning almond shells for energy and the process of making furniture from it. The test will consist of a piece of board from the composite made with shells to test its properties.

The functional unit is 1 kg of almond shells. This unit will be used in the end to compare the burning process to the board making process. With that it will be possible to decide which of the two options is better for the environment.

Due to limited information, it does not include the harvesting and drying of the almond shells. It is also assumed that all of the buildings and machines used in the burning process are already existing so the production of them is not taken into account. Also it neglects the use phase of the almond shell board but the waste treatment is included. During the process of grinding and pressing, all the energy inputs of the machines used in the tests and the emission will be taken into account. So it will be possible to collect all the energy consumption of the process. So the study will also include the energy consumption in both cases.

In the process of burning the almond shells the system also starts with the dried almond shells. The pellet making and the burning process will be incorporated. It also includes the energy that is used to produce the pellets, the emissions of the burning process and the waste treatment of the ashes. In the end it is possible to get the amount of energy produced during the burning process.

In the process of making a solid board from almond shells we start with 1 kg of raw, dried almond shells obtained from BORGES AGRICULTURAL & INDUSTRIAL NUTS, S.A.. The shells are then grinded with a food processor. So we calculated an electricity input of 6,67 Wh per kg. After the grinding process almond shell powder is obtained, which is then separated into different grain sizes. Because we weren't able to quantify the different grain sizes we calculated without the sieving process.

The test mould fits a volume of 2,8 x 10-5 m3 . The density of the almond powder is around 550 kg/m3. THis results in 0,016 kg of almond shell powder per sample.

After that the powder is put into the metal mould. To compress it is used a hydraulic press which produces power usage of 0,3664 Wh/kg. The pressing delivers the test board piece in a round shape with a diameter of 120 mm.

After the life cycle the board goes to a landfill to decompose.

The burning process starts with pellet making. Here we use about 1 kg of almond shells to produce 1 kg of pellets. We calculated energy use of about 0,3664 Wh and produced 0,116 kg of CO2. After that the pellets are burned it leaves a residue of 1.1% of ashes so around 0,011 kg of ashes. Furthermore you get 0,438 mg of carbon monoxide (calculated knowing that 1kg of pellets equals 0,0015 m3 and 1 m3 produces 285 mg of CO) [1, 2] and 0,477 mg of NO2.

In the case of study it is assumed that the transport from the Almond producer to our factory and the transport from the producer to the burning site is equal so we can neglect it in the study comparison.

[3]

The results obtained from simapro are the following ones:

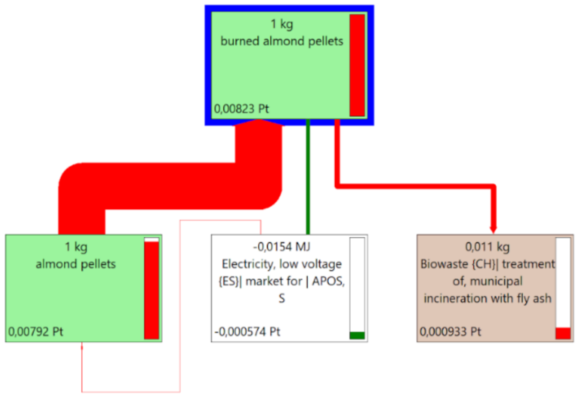


Image: Flow chart of the process of burning pellets

The graph shows that getting the almond pellets is the second worst process of all. This is because the waste of energy and de chemical components that it has generate this amount of general damage to the environment. The principal question is why burning the pellet is almost generating the same amount of points as manufacturing the pellets. The answer to this is that the chemical components of the pellets, what they do is to decrease the amount of CO, CO2 and NOx more than 20 times in comparison to burning common wood. So that is why burning pellets is not generating a big amount of impact.

The problem comes if the almond shell is burned without this treatment, because the impact could be 20 times worse than the impact that we are getting with the pellets.

In the other way the data obtained from the conglomerate is the following one:

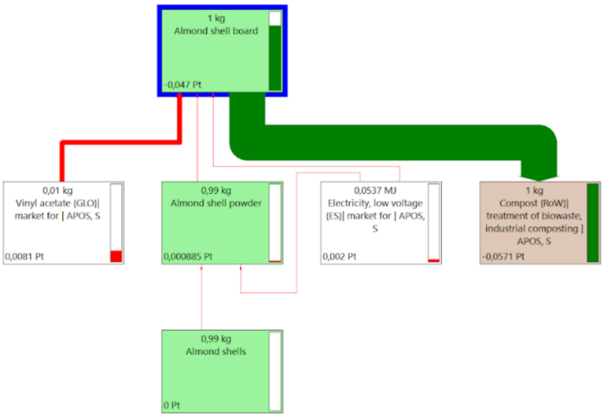


Image: Flow chart of the process of creating conglomerate

As we can see the data obtained from simapro shows that the worst component of the chart is the Vinyl acetate (white glue) used to generate the composite. But the impact that it has is minimal because the amount that we use is low, and also it is a product that in contact with the water only generates alcohol.

The electricity used to crush the almond shells is also giving some impact, but the general result of the process is negative, so instead of contaminating we are generating a positive process for the environment, with -0,0571 points in the end.

VI. Conclusions

Creating a conglomerate of crushed almond shell for the manufacture of environmentally friendly furniture is an excellent alternative to creating pellets for burning almond shell. This is due to several important reasons.

Firstly, sustainability is a key factor to consider. Using crushed almond shell for the manufacture of furniture is a more sustainable way to utilize this waste, instead of burning it and releasing carbon dioxide into the environment. In addition, recycling this waste reduces the amount of waste produced, which contributes to a lower carbon footprint.

In addition, furniture made with crushed almond shell conglomerate is very durable and resistant, making it ideal for use indoors and outdoors. This means that furniture made with this material will have a longer lifespan, contributing to a lower environmental impact compared to furniture made with less durable materials.

Crushed almond shell conglomerate is also an excellent thermal and acoustic insulation, making it ideal for use in furniture and construction structures. This means that furniture made with this material can help reduce energy consumption in the home by keeping heat in during the winter and keeping cool in the summer.

Finally, but not least, crushed almond shell conglomerate is a very versatile material and can be used for the manufacture of a wide variety of furniture, from tables and chairs to shelves and cabinets. This means that furniture made with this material can adapt to a variety of styles and needs, making it ideal for any home.

In conclusion, creating a conglomerate of crushed almond shell for the manufacture of environmentally friendly furniture is an excellent alternative to creating pellets for burning almond shell due to its sustainability, durability, thermal and acoustic insulation, and versatility. It is a way to utilize waste and turn it into something useful and long-lasting, reducing carbon footprint and contributing to a cleaner environment.

VII. Bibliography

[1]https://www.econologia.net/Pellet-almacenamiento-volumen-necesaria-Silos/

[2]https://www.ocu.org/vivienda-y-energia/energia-renovable/noticias/emisiones-estufas-pellets

[3]https://www.sciencedirect.com/science/article/pii/S0378382005000494?via%3Dihub

Artificial Muscle Prosthetic

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Abstract

Artificial muscle technology has the potential to revolutionize the medical field by providing new and innovative solutions for prosthetics, robotics, and other assistive devices. One promising area of research is the use of magnetic fields to create movement in artificial muscles. This approach utilizes the interaction between ferrite and coil to generate controlled contractions, mimicking the behavior of natural muscles. How to implement the capabilities of magnetism in a prosthesis? The project will involve a collaboration between Fontys and Icam - Strasbourg-Europe Campus students and will consist of a series of steps to achieve the final goal. The answer will be presented by outlining the steps and research conducted during the project.

Keywords—Prothesis, Artificial muscle, Innovation, Magnetic

I. Context

It is an international university project involving 4 universities: Icam - Strasbourg-Europe Campus, Fontys University of Applied Sciences, Università degli Studi di Ferrara and EUSS Catalunya . The objective is to have students from different parts of Europe work together in the same team to carry out a research project. The global project consists in the realization of a robotic prosthesis. For this purpose, the students have been divided into 4 groups, each of which has been assigned a part of the research topic. For our part, we are responsible for thinking about the motorization of the prosthesis. We must assemble the technical means to create the movement of the prosthesis based on the information signal transmitted by the device created by the BCI (Brain Computer Interface) team. Following several meetings, brainstorming and exchanges, we have currently chosen 1 research track that we have called "stair solution". These two solutions use the magnetic field as a source of movement. To find out more about these potential solutions, we have formed a research group composed of 4 students with the aim of providing as much information as possible that could be useful. This potential solution is in line with the initial objectives which are to create an innovative artificial movement. Our project team consists of 8 members, each with their own specialties, including a project manager:

- KERKHOFS Tijn, (Mechanical student Engineer)
- BAIJENS Maud, (Mechatronical student Engineer)
- SOERIA Emerick, (Mechanical and Electronic student Engineer)
- GIJSEL van Mike, (Mechanical student Engineer)
- KUIJTEN Gijs, Manager (Mechanical student Engineer)
- KATCHOULI Mohamed, (Industrial Organization and Management student Engineer)
- KRAKER de Lisanne, (Electrical student Engineer)
- SHUBIN Maksim (Mechatronical Engineer)

II. INTRODUCTION

Artificial muscles, also known as prosthetic limbs, represent a significant area of innovation in the field of medical technology. These devices aim to mimic the function and movement of natural muscles, allowing individuals with limb loss or paralysis to regain mobility and independence. One of the most promising areas of research in this field is the use of magnetic fields to control the movement of artificial muscles. This technology offers several advantages over traditional methods, including increased precision and reliability. This innovative technology has the potential to revolutionize the field of medical innovation, offering new hope to individuals living with limb loss or paralysis.

In this paper we will outline our innovation by taking stock of the problem area, summarizing the research carried out within the project, detailing the design phases, and finally explaining our Proof of Concept.

III. PROBLEM AREA

The field of prosthetics is rapidly evolving as technology advances, allowing for more natural movement and function for amputee patients. Research and innovation in this area are crucial to help these individuals regain their motor skills and improve their quality of life.

A. *Classic prothesis*

A classic prosthesis is a type of artificial limb that is designed to replace a missing limb or body part. These prostheses can be divided into two main categories: body-powered and electric-powered.

Advantages of classic prostheses include:

- They are relatively inexpensive
- They are low maintenance
- They are durable
- They are relatively lightweight
- They provide a high degree of control over the prosthetic limb

Inconveniences of classic prostheses include:

- They can be heavy, bulky and have limited range of motion
- They often provide limited feedback to the user
- They can be uncomfortable to wear for long periods of time
- They may not look as natural as more advanced prostheses
- They can be fatiguing for the user to operate for long periods of time.

Overall, classic prostheses have been used for many years and have been improved over time, but they are not as advanced as new types of prostheses such as myoelectric prostheses which are powered by electrical signals from the residual muscle and can provide more natural movement.

B. *The artificial muscle*

Artificial muscle refers to technology that mimics the function of biological muscle. It can be made from various materials, such as shape memory alloys, electroactive polymers, and smart fibers. Artificial muscle can be used in a variety of applications, including robotics, prosthetics, and biomedical devices. It offers advantages such as high strength-to-weight ratio and the ability to change shape. However, current artificial muscle technology is still limited in its performance and durability compared to natural muscle. Research and development in this field is ongoing to improve its capabilities and potential uses.

C. *Main goal*

The main goal of artificial muscle technology is to improve the performance and functionality of prostheses, specifically by eliminating the inconveniences and limitations of traditional, classic prostheses. Artificial muscle can provide a high strength-to-weight ratio and the ability to change shape, which can help to make prostheses more lightweight, flexible, and natural-moving. Additionally, artificial muscle can be designed to mimic the properties of biological muscle, such as the ability to contract and relax, which can enhance the control and feedback provided to the user.

The use of artificial muscle in prostheses can greatly improve the range of motion, strength, and endurance of the prosthetic limb, allowing for more natural movement and greater independence for the user. Furthermore, it can also reduce the weight and bulkiness of traditional prostheses, making them more comfortable to wear for longer periods of time.

1) *Geometry requirement*

The project has was been focused on the biceps muscle. Indeed, in the complexity of the human body, the biceps remain a simple muscle to study in many fields. Thus, the geometric requirements will simply be based on the average dimensions of a biceps muscle in an average sized man.

- length of 180 mm in extension
- length of 176 mm in contraction

2) *Performance requirement*

As with the geometry requirement, the performance requirement is based on that of a human bicep. Our solution needs to be able to lift a 10-kilos load during a classic curl exercise.

3) *Safety requirement*

In Europe, implantable medical devices are regulated by the European Medicines and the European Union. These regulations ensure that implantable medical devices are effective for the use for which they are intended before they can be marketed. Like the FDA, the EMA and the EU impose safety requirements on implantable medical devices that use electricity. All medical devices must be compliant with the European Medical Devices Directive and Active Implantable Medical Devices Directive. This includes meeting basic requirements such as biocompatibility, electrical safety, and performance.

IV. Research

A. Biology

Muscles are body tissues that can contract and relax for movement and force production like Fig. 1. There are three types of muscles in the body skeletal muscle, smooth muscle and muscle.

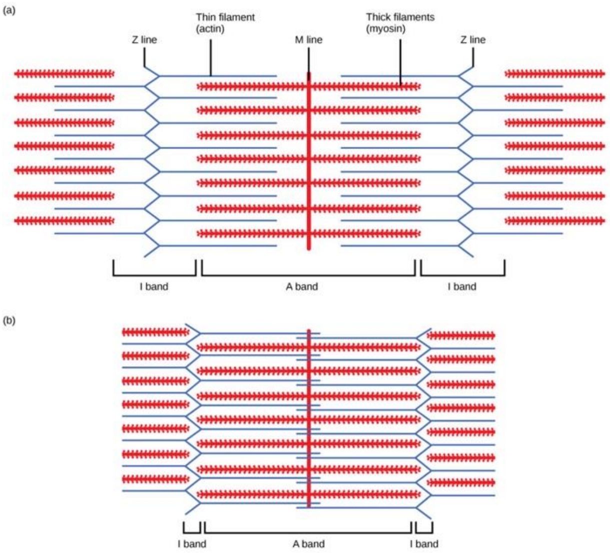


Fig. 1 - Sliding filament model of contraction

The biceps muscle is a skeletal muscle located in the upper part of the arm that plays a key role in the movement of the elbow joint, see Fig. 2. The muscle is made up of two separate heads, the short and the long head, which originate at different points on the scapula and converge to a common point on the radius of the forearm. The biceps muscle is responsible for the flexion of the arm which is the movement that brings the hand closer to the shoulder. It also plays a role in supination which is the movement that turns the palm upwards.

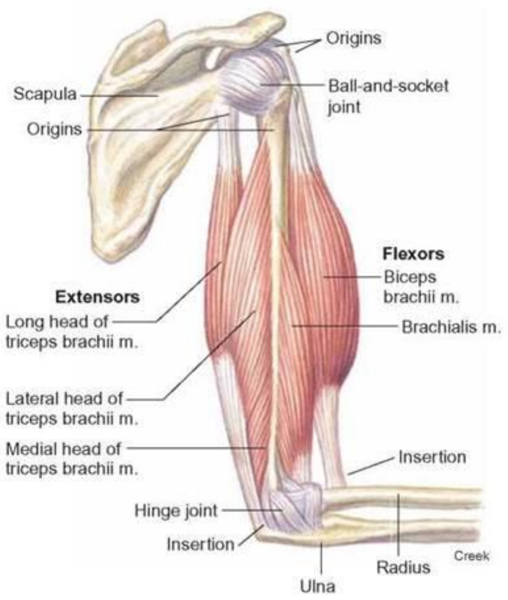


Fig. 2 - Antagonistic Muscles

B. Biomechanics

Based on the average size of a man's body see Fig. 3, it takes a force of 933.4 N to lift 10 kilos. The force that a muscle can exert varies from 80 to 100 N per square centimeter of surface area. Therefore, it would take a cross-section of about 10 square centimeters to produce a force of 933.4 N. This corresponds to a muscle of about 3.5 centimeters in diameter.

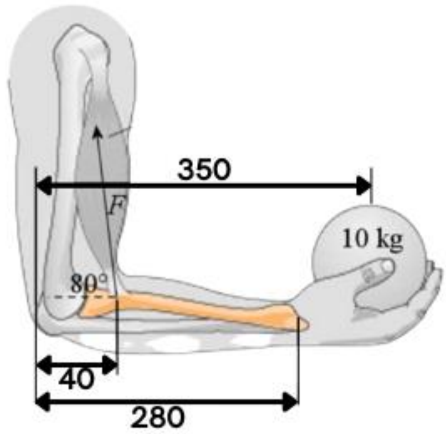


Fig. 3 - Arm dimension

C. Classic prothesis

1) Cosmetic prothesis

Cosmetic arm prostheses are designed to look as much like a real human arm as possible, using materials such as silicone and resin to create a more natural appearance. These prostheses can be used to improve the physical appearance and confidence of people who have had an arm amputated.

2) Mechanical arm prosthesis

Mechanical arm prostheses are designed to replace the basic functions of an arm, such as gripping and mobility, using lever and pulley mechanisms. These prostheses can be used to perform everyday tasks such as grasping and holding objects.

3) Myoelectric arm prosthesis

Myoelectric arm prostheses use sensors to detect electrical muscle signals, allowing for greater precision and more natural control of movement. Myoelectric prostheses can be used to perform more complex tasks such as handling tools and writing. These prostheses are more expensive than mechanical prostheses but offer higher levels of control.

Myoelectric prostheses have several advantages over body-powered devices, such as reduced harnessing, increased strength and grip options, more natural hand movements, and improved control through TMR surgery. Additionally, they have an aesthetically pleasing "robotic look" when not covered by a cosmetic glove. A common limitation of myoelectric is their lack of waterproofing, but recent technological advancements have addressed this issue for some models.

4) *Bone attached prothesis*

Osseointegration is a technique for attaching artificial limbs directly to the body, rather than using the traditional stump and socket method. This method involves inserting a titanium bolt into the bone at the end of the stump, allowing the bone to fuse with the bolt over time. An abutment is then attached to the bolt and the removable artificial limb is connected to the abutment.

The benefits of this method include improved muscle control, the ability to wear the prosthetic for longer periods of time, and the ability for transfemoral amputees to drive a car. However, the main disadvantage of osseointegration is that it does not allow for high-impact activities such as jogging, as it could cause the bone to break.

D. *Patent about artificial muscle*

There are many patents filed for the different types of artificial muscles. Patents can cover the materials used to make the artificial muscles, the designs of the muscles, the methods of manufacture and the specific applications for which they are used.

There are patents for artificial muscles that use electroactive polymers, shape memory alloys, pneumatic actuators, and hydraulic actuators. There are also patents for specific applications, such as artificial muscles for prosthetics, robots, and vehicles. It is important to note that intellectual property and patents may vary from country to country. It would therefore be important to check the intellectual property laws and regulations in force in the country where you wish to exploit these patents.

E. *Electro-magnet with plunger hub*

A common use of electromagnets is the "plunger core", see Fig. 4. It is made of a ferromagnetic material, such as iron, nickel, or chromium oxide, which is sensitive to magnetic fields. When an electric current is applied to the coil of an electromagnet, a magnetic field is created around the coil. This magnetic field then interacts with the plunger, causing a mechanical force that can be used to move an object or to vary the resistance of an artificial muscle.

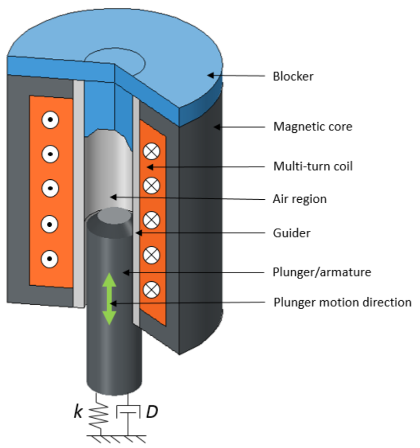


Fig. 4 - Linear electromagnetic plunger with a blocker

There are two types of plungers, fixed and moving. The fixed plunger is fixed in the electromagnet coil and can only be moved by the force created by the magnetic field. The movable plunger, on the other hand, can be moved manually or automatically to change the orientation of the magnet.

V. DESIGN PHASE

A. *Function block diagram*

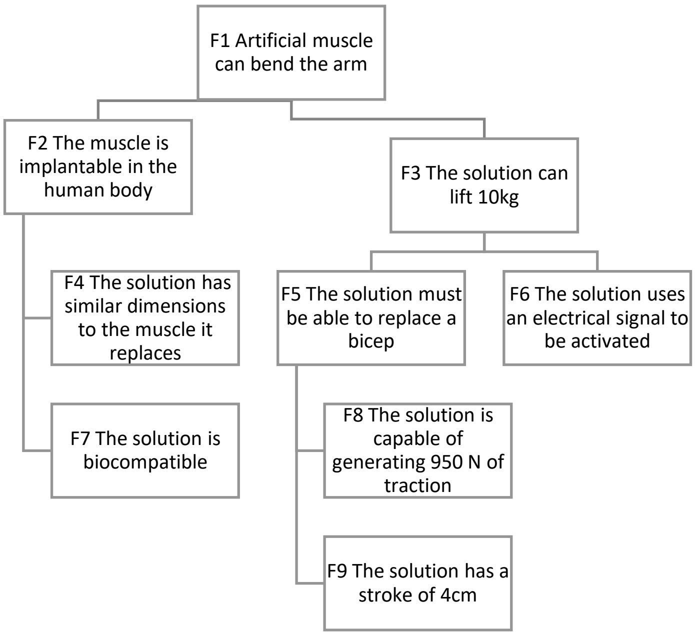


Fig. 5 - Function Block Diagram

B. *Concept creation*

1) *Book solution*

When viewed from the side, the principle appears as follows: on the Fig. 6, there is no current flowing through the wires (indicated by the red crosses) and they are stationary. On the Fig. 7, a current is flowing through the wires, creating a magnetic field that attracts the adjacent plate, causing the wires to align with each other.

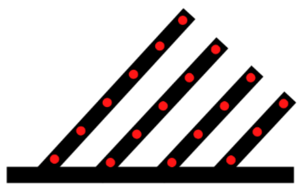


Fig. 6 - Book solution – No current applied

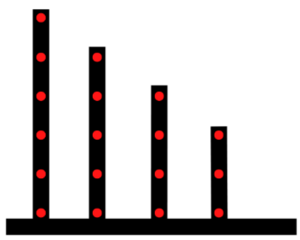


Fig. 7 - Book solution - Current applied

2) Champagn glass solution

On the Fig. 8, some champagne glass shaped objects are presented. The first object on the left is connected to a fixed point, in between the champagne glasses, a ferrite is attached to a champagne glass shape. The red and green indicators are the coils. While at rest when no current is running through the coils, the ferrite isn't attracted by the coil and the total is stretched out at its maximum value. Whereas when we run a current over the coils, see Fig. 9, magnetic forces will make sure that the positive field attracts the ferrite, indicated as red attracting the grey part. In that way the total will contract and make the movement of the muscle.

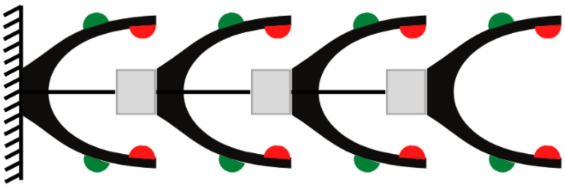


Fig. 8 - Champaign glass solution - No current applied

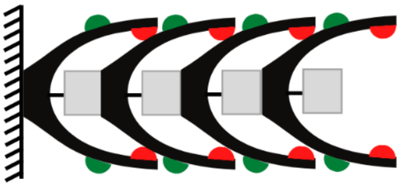


Fig. 9 - Champaign glass solution - Current applied

3) Stair solution

This solution is described in detail in the Final concept section.

C. Concept selection

The "book solution" concept was initially proposed as a way to achieve a specific goal, but upon further examination, it was determined that the level of complexity required to implement it would make it unfeasible. Combining innovative materials, magnetism, and mechanics would have required a significant amount of resources and expertise, making it a challenging and costly endeavor.

Considering this, the decision was made to explore alternative solutions. One option was the "champaign glass solution," which had its own unique set of benefits and drawbacks. However, the team ultimately decided to pursue the "stair solution" as it offered a more viable solution.

The "stair solution" utilizes an architecture in which the components are arranged in parallel, which allows for a greater pulling force. This makes it more efficient and effective in achieving the desired outcome. Additionally, the "stair solution" is less complex and less resource-intensive than the "book solution," making it a more practical and cost-effective choice. Overall, it was determined that the "stair solution" was the best option for addressing the problem at hand.

D. Final concept

The "Stair Solution" is a novel approach to motorizing robotic prostheses using an artificial muscle system. The key components of this system are ferrites and coils used to create magnetic fields that can be used to control the contraction and relaxation of artificial muscles.

1) Final concept sketch

The final concept can be described in two phases. The first when there is no current applied Fig. 10 and the second when a current is applied Fig. 11.

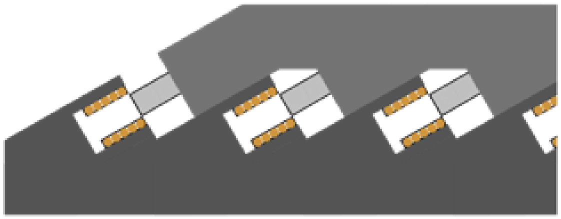


Fig. 10 – Stair solution - Current applied

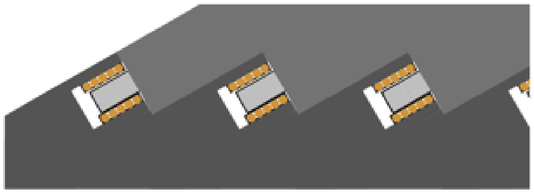


Fig. 11 – Stair solution - No current applied

2) Final concept explanation

When no current is running through the coils, the artificial muscle is under tension and stretched out to its maximum value. When a current is applied to the coils, the magnetic field attracts the ferrite, causing the muscle to contract. This movement can be used to drive the movement of the prosthesis.

3) Main principles

Electromagnetic force is the interaction between electric charges and magnetic fields. It can be used to create movement, such as in the case of an electro-magnet. To amplify this force, the solution proposed arranges the coils, which are responsible for generating the magnetic field, in parallel. This way, the force generated by each coil adds up, resulting in a stronger overall force.

The special architecture employed by this solution also plays a crucial role in amplifying the electromagnetic force. By optimizing the space in which the coils are arranged, the solution can generate a larger traction force. This can be achieved by using a more efficient coil design, or by arranging the coils in a specific pattern that maximizes the strength of the magnetic field.

4) Advantages

One advantage of this approach is that the artificial muscle can be precisely controlled by adjusting the current running through the coils. This allows for finetuned control of the prosthesis, which is essential for tasks that require delicate movement.

Another advantage is that the artificial muscle system is lightweight and compact, which can be beneficial for prostheses that need to be worn for long periods of time. Overall, the stair solution appears to be a promising approach for motorizing a robotic prosthesis and can be further developed with experimental testing and optimization of the system. It is important to validate the efficiency and reliability of the system through testing and evaluate the power consumption and durability of the ferrite and coil.

VI. PROOF OF CONCEPT

A. *Mathematical proof*

To determine the formula governing the system, you will need to focus on a specific subset of the overall system, Fig. 12. This will likely involve breaking down the system into smaller, more manageable components and analyzing each one individually.

One approach to determining the formula governing the system could be to start by analyzing the behavior of the ferrite and coil when a current is applied. This may involve measuring the strength of the magnetic field created by the coil, and how it changes as the current is varied.

Next, the ferrite responds to the magnetic field generated by the coil will be analyzed. You need to measure the displacement of the ferrite in response to a change in the magnetic field, and how that displacement changes with a change in current.

After a clear understanding of the behavior of the ferrite and coil, this information to develop a mathematical model of the system could be used. This may involve writing a set of equations that describe the behavior of the system and solving these equations to predict how the system will behave under different conditions.

It's also important to verify the results of the mathematical model with experimental testing, to validate the accuracy of the formulas and adjust them if necessary. Once the formula governing the system is determined, it can be used to optimize the system, control the movement of the prosthesis, and predict its behavior.

1) *Subset sketch*

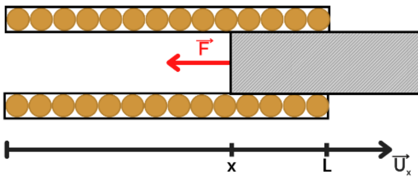


Fig. 12 - Subset sketch

2) *Basis Formula*

$$\vec{F} = \frac{1}{2}\frac{dL(x)}{dx} i^2.\overrightarrow{U_x}$$

$$\vec{F} = \frac{1}{2}\frac{d}{dx}\left(\frac{N^2\mu_0 A}{x}\right) i^2.\overrightarrow{U_x} \quad (1)$$

3) *Data*

N: Numbers of winding

D: Diameter of the plunger

i: Current

L: Length of the coil

μ_0 : Vacuum permittivity, $4\pi.10^{-7}$

4) *Case study*

To determine the subset formula, there are three cases to consider:

- x is equal to 0
- x between 0 and L
- x is equal to L

Case (1) $0 < x < L$

$$\vec{F} = \frac{1}{2}\frac{dL(x)}{dx} i^2.\overrightarrow{U_x}$$

$$\vec{F} = \frac{1}{2}\frac{d}{dx}\left(\frac{N^2\mu_0 A}{x}\right) i^2.\overrightarrow{U_x}$$

$$\vec{F} = -\frac{1}{2}\frac{N^2\mu_0 A}{x^2} i^2.\overrightarrow{U_x}$$

$$\vec{F} = -\frac{\pi N^2\mu_0 D^2}{8x^2} i^2.\overrightarrow{U_x} \quad (2)$$

Case (2) x = 0

$$\vec{F} = -\frac{\pi N^2\mu_0 D^2}{8x^2} i^2.\overrightarrow{U_x}$$

For the Case (2) where x is equal to 0, there is a mathematical error present due to the neglect of leaks. To model this in a more accurate way, a small positive value ε can be add to x when x is equal to 0. This can be represented as x = x + ε for x = 0. This change would account for any leaks that may be present and provide a more realistic representation of the situation in real life.

$$\vec{F} = -\frac{\pi N^2\mu_0 D^2}{8(x+\varepsilon)^2} i^2.\overrightarrow{U_x} \quad (3)$$

Case (3) x = L

$$\vec{F} = -\frac{\pi N^2\mu_0 D^2}{8L^2} i^2.\overrightarrow{U_x} \quad (4)$$

This value (X) corresponds to the boundary between the inside of the coil and the outside; however, this case is not likely to occur in practice.

Equations (4) and (3) are not relevant in practice as they correspond to scenarios that are unlikely to occur.

5) *Data influence*

Based on the formula we demonstrated earlier, the influence of each data on the system can be plotted. Fig. 13 shows the variation of the electromagnetic force on the plunger as a function of the position x of the plunger with all other data fixed. It can be seen that the force is maximal when the value of x approaches 0, so when the plunger is fully retracted.

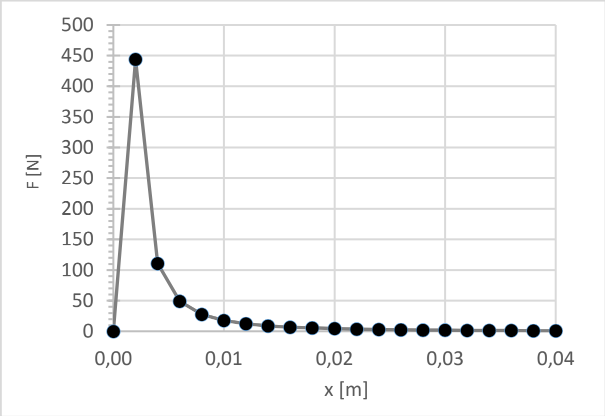


Fig. 13 - Force as function of x

Fig. 14 shows the variation of the electromagnetic force on the plunger as a function of the number of windings N, with all other data fixed. It can be seen that the force and number of windings are linked by a square law. That is also the case for the link between the force and the current and the force and the plunger's diameter, see Fig. 15 and Fig. 16.

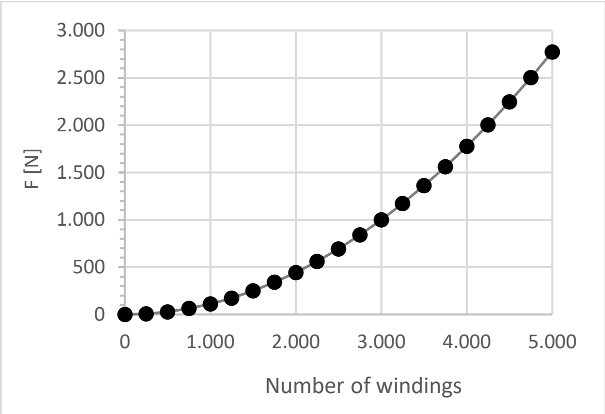


Fig. 14 - Force as function of the number of windings

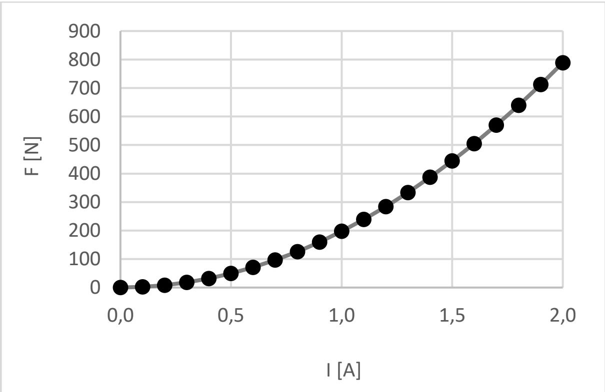


Fig. 15 - Force as function of the current

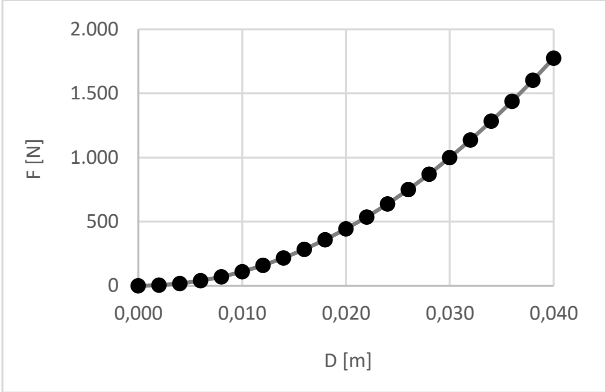


Fig. 16 - Force as function of the plunger's diameter

Fig. 17 shows the evolution of the plunger's position as a function of the time for an input current I when 10 N charge is applied. We used data present on the TABLE I to fill the formula.

TABLE I. Data

Number of windings N	Plunger's diameter D [mm]	Current max Imax [A]	Plunger's length L [mm]	Resistive Force F_r [N]
2000	20	2,3	40	10

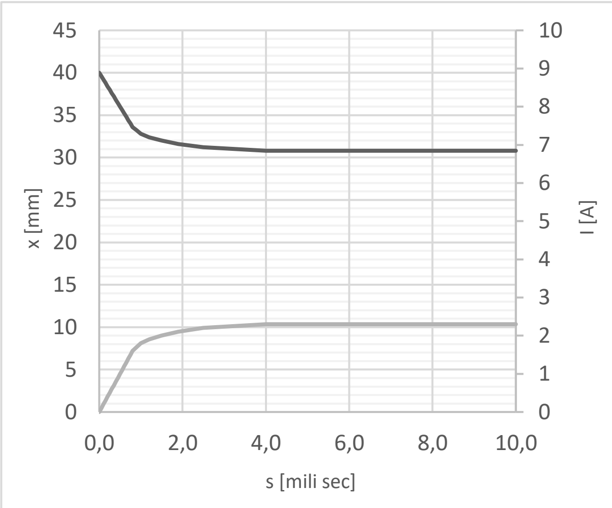


Fig. 17 - Response of the subset to a current input I and a charge of 10N

B. Coils dimension

It is necessary for our system that we size each coil so that each electromagnet provides the necessary electromagnetic force for our solution to work.

As it's mentioned before, an average man needs to provide a force of 933.4N at the biceps to lift a 10kg load. For sizing purposes, a value of 950N will be assumed:

Thus, we have:

$$\overrightarrow{F_{tot}} = 950N.\vec{x}$$

The architecture of our system allows us to say that the total force will be distributed equally on each electromagnet, see equation (5) and Fig. 18. If we consider that our system is composed of n electromagnets, then we have:

$$\overrightarrow{F_{sub}} = \frac{F_{tot}}{n}.\vec{x} \quad (5)$$

This force obtained by equation (5) corresponds to the force that the electromagnet should generate along the x axis. Thus, it is necessary to project this force onto the translational axis of the plunger, to determine the real force that the electromagnet must generate, see equation (6). The angle between the x-axis and this axis will be represented by θ:

$$\overrightarrow{F_{sub}} = \frac{F_{tot}}{ncos(\theta)}.\overrightarrow{x_{sub}} \quad (6)$$

If we apply formula (6) to our hypothesis with an angle of 30° and a total of 4 subsets, we obtain:

$$\overrightarrow{F_{sub}} = 205{,}7\,N.\overrightarrow{x_{sub}}$$

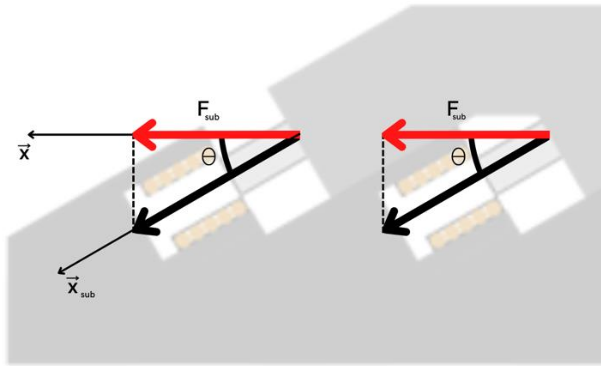


Fig. 18 - Pattern of forces

Now that we have determined the electromagnetic force to be generated by a subset, we must determine the diameter of the plunger and the number of turns of the coil. To do this, the torque values which the electromagnet provide a force of 210 N must be determined. There is a range of choice between 200 and 250 N. TABLE II shows in green the couple for which the value of the electromagnetic force falls within the above range.

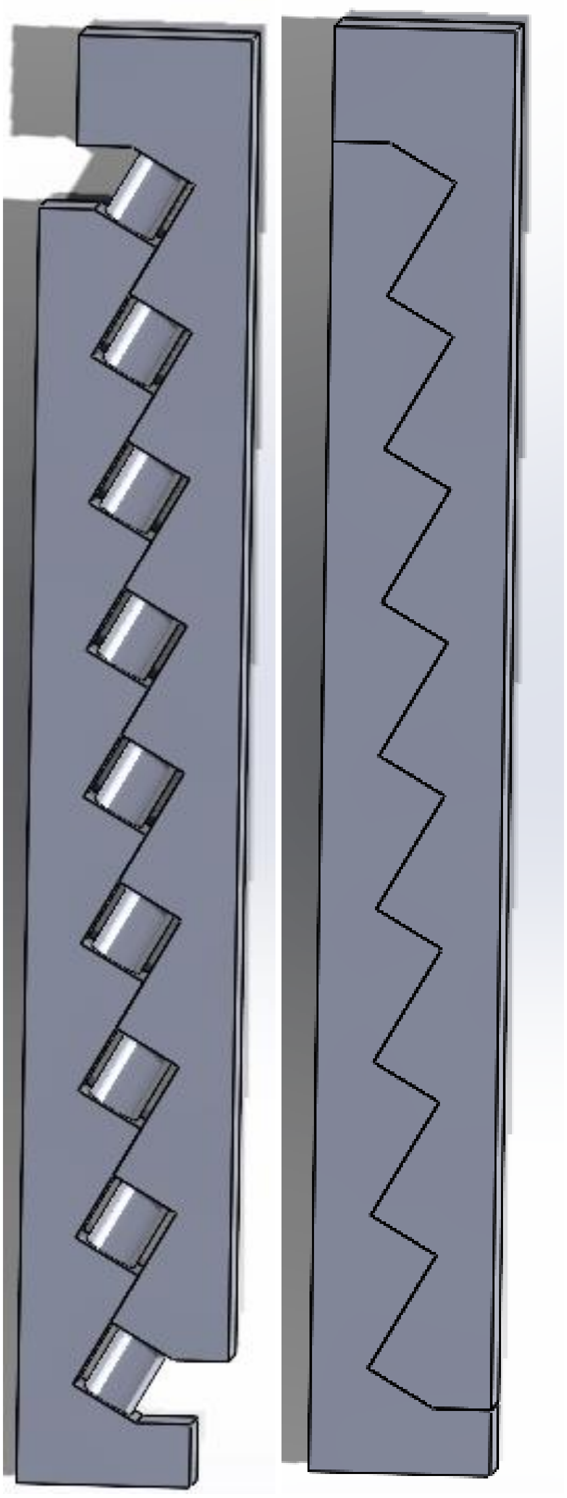
Several pairs allow to achieve the attraction. However, the space factor must also be considered, so it is necessary to remove the extremes, and make choice between:

- Plunger's diameter: 18mm, number of windings: 1000
- Plunger's diameter: 24mm, number of windings: 750
- Plunger's diameter: 26mm, number of windings: 750

TABLE II. Electromagnetic force as a function of the number of turns and the plunger size for a current of 2.3A

Plunger's diameter D [mm]	**Number of windings, N**				
	500	***750***	***1000***	***1250***	***1500***
10	16,31	36,69	65,23	101,92	146,77
12	23,48	52,84	93,93	146,77	211,34
14	31,96	71,92	127,85	199,77	287,66
16	41,75	93,93	166,99	260,92	375,72
18	52,84	118,88	211,34	330,23	475,52
20	65,23	146,77	260,92	407,69	587,07
22	78,93	177,59	315,71	493,30	710,35
24	93,93	211,34	375,72	587,07	845,38
26	110,24	248,04	440,95	688,99	992,14
28	127,85	287,66	511,40	799,06	1150,65
30	146,77	330,23	587,07	917,29	1320,90
32	166,99	375,72	667,95	1043,67	1502,89
34	188,51	424,16	754,06	1178,21	1696,62
36	211,34	475,52	845,38	1320,90	1902,10
38	235,48	529,83	941,92	1471,74	2119,31
40	260,92	587,07	1043,67	1630,74	2348,27

C. Modelisation



D. Materials

When considering materials to use in the human body, it's important to consider factors such as biocompatibility, durability, and safety. Some commonly used materials in medical applications include:

1) Stainless steel

Stainless steel is a type of metal that contains a minimum of 10.5% chromium, which gives it its corrosion-resistant properties. It is also a biocompatible material, meaning it does not cause an adverse reaction when in contact with living tissue. These properties make it a popular choice for surgical instruments and implants such as orthopedic screws and plates, as well as dental implants. Stainless steel is also easy to sterilize, which is important for preventing infection in medical devices.

2) Titanium

Titanium is a lightweight, strong, and biocompatible metal that is resistant to corrosion. It is commonly used in orthopedic and dental implants, as well as in cardiovascular stents. The corrosion resistance of titanium makes it a good choice for implants that will be in contact with bodily fluids. It also has good mechanical properties and can be shaped into a variety of forms, which makes it an ideal material for implants.

3) Polyethylene

Polyethylene is a type of plastic that is used in many medical devices such as artificial joints, heart valves, and catheters. It is biocompatible, flexible, and able to withstand high loads. It is a popular choice for artificial joints because it is wear-resistant and has low friction properties, which helps to reduce the wear on the joint

4) Ceramics

Ceramics such as alumina and zirconia are biocompatible, durable and have high wear resistance, making them suitable for joint replacements and dental applications. These ceramics have a high strength-to-weight ratio, which means they can withstand high loads while being relatively lightweight. They are also resistant to corrosion, which makes them well-suited for use in joints and dental implants. Alumina and zirconia ceramics are also biocompatible, meaning they do not cause an adverse reaction when in contact with living tissue.

5) Biocompatible polymers

Biocompatible polymers are a newer class of materials that are being developed for medical applications. They mimic the properties of human tissue and can be used in artificial organs, tissue engineering and drug delivery. These polymers are biocompatible, meaning they do not cause an adverse reaction when in contact with living tissue. They can also be designed to have specific properties such as biodegradability, which makes them suitable for temporary medical devices such as sutures, wound dressings, and controlled drug release systems.

6) Carbon fibers:

Carbon fibers are lightweight and strong and are used in combination with other materials to create prosthetic limbs, spinal implants, and other medical devices. Carbon fibers have high strength-to-weight ratio, which makes them ideal for use in prosthetic limbs. They are also biocompatible, which means they do not cause an adverse reaction when in contact with living tissue. Carbon fibers are also often used to reinforce other materials such as polymers, which improves the mechanical properties of the device.

It is important to keep in mind that even though a material is biocompatible, it can still cause an allergic reaction or other adverse effects. Additionally, it is important to conduct thorough testing and clinical trials before bringing any medical device to the market.

Based on the information provided, it may be recommended to use High-Density Polyethylene (HDPE) as the initial material for the robotic prosthesis because of its ease of production and ability to be tested. HDPE has been successfully used as a prosthetic foot (external) but failed in some cases as an implant material due to limited mechanical properties. HDPE still is the most used polymer in prosthetic limbs. Furthermore, it is a hard, opaque material that can withstand high temperatures and is 100% recyclable, meaning it can be used again to make things such as limber, fencing, and plastic crates.

After the concept is proven, it may be recommended to repeat the process with metals such as titanium, which is a lightweight, strong, and biocompatible metal that is resistant to corrosion. This may be a suitable option for long-term use as it has good mechanical properties and can be shaped into a variety of forms, which makes it an ideal material for implants.

It might also be useful to explore the use of hybrid composites, which are a combination of different materials, in the human body. This is because not much is known about the effects of these materials on the human body, and it may be a way to improve the properties of the prosthesis. For example, by combining HDPE with carbon fibers, the strength of the prosthesis could be improved without increasing its weight.

VII. Conclusion and recommendations

We have now reached a crucial stage in the development of our project where we will move on to simulation and prototyping in order to validate the results of our research and design. This step is essential to fine-tune our solution and ensure that it is both effective and cost-efficient.

However, we recognize that there are still areas for improvement that need to be explored. For example, we will continue to investigate the most efficient angles for sub-assemblies, as well as developing formulas to determine the optimal number of sub-assemblies. Additionally, we will be researching new and innovative materials that can help us reduce the weight and costs of our solution.

We are confident that through these efforts, we will be able to further improve our project and make it even more effective and cost-efficient. We believe that this approach will help us achieve our goal of creating a solution that is both practical and cost-effective.

VIII. Acknowledgments

We would like to express our gratitude to all the individuals who contributed to the realization of this university project. First of all, we would like to thank our supervisor Mr. Turko for his valuable advice, support and guidance throughout this project. We would also like to thank all the members of the working group for their dedication, commitment, and effective collaboration. Their help and expertise were fundamental to the success of this project. Finally, I would like to thank the organizers of this project who made this exchange and collaboration between students from around the world possible.

Bibliography

[1] LUMEN, Sliding Filament Model of Contraction, *https://courses.lumenlearning.com/wm-biology2/chapter/sliding-filament-model-of-contraction/*

[2] La Biomécanique, Luc Tremblay Collège Mérici, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwi-yOLRt9b8AhU0VqQEHauGBfUQFnoECBAQAQ&url=https%3A%2F%2Fphysique.merici.ca%2Fautres%2Fbiomec.pdf&usg=AOvVaw0HJVaUhBSXyEhXbZkWm20_

[3] COMSOL, Model a Linear Electromagnetic Plunger with a Blocker, *https://www.comsol.fr/blogs/part-2-model-a-linear-electromagnetic-plunger-with-a-blocker/*

Brain-Computer Interface

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Abstract— Brain-computer interfaces (BCIs) acquire brain signals, analyze them, and translate them into commands relayed to output devices carrying out desired actions. The main goal of the BCI is to replace or restore useful functions to people who are disabled by neuromuscular disorders. From initial demonstrations of neurological device control, researchers have gone on to read brain signals for increasingly complex control of robotic arms, prostheses, wheelchairs, and other devices. Brain-computer interfaces may also prove helpful for rehabilitation after a patient has had a stroke or further required recovery.

Recent technological advances have profoundly impacted the field of neurological health care, including the development of Brain-Computer Interfaces. This paper presents a research study on using BCIs in medical settings, focusing on exploring innovative ways that technology is being used to improve the diagnosis and treatment of neurological conditions. The main research question for this study is: "In what innovative way can the living quality, in a non-intrusive way, be improved for patients with brain conditions?"

The study involved a review of existing literature on the use and design of BCIs. The study's findings indicate that BCIs are being used in various innovative ways, including for the diagnosis and monitoring of neurological conditions, as well as for the rehabilitation and treatment of these conditions.

Overall, this research suggests that technology plays an increasingly important role in the brain and that BCIs are particularly promising for future research and development. However, further studies are needed to understand the potential of these technologies fully and to identify additional ways that they can be used to improve the lives of patients with neurological conditions.

Keywords— Technical Imagery, Brain Computer Interface, Medical, Health Care

I. Introduction

"Take up one idea. Make that one idea your life - think of it, dream of it, and live on it. Then, let the brain, muscles, nerves, and every part of your body, be full of that idea and leave every other idea alone. This is the way to success."- Swami Vivekananda.

Neurologist Jonathan Coutinho, clinical technologist Wouter Potters and professor of radiology Henk Marquering of Amsterdam U.M.C. are the inventors of the bright swimming cap, which can be used to make an E.E.G. (brain video) in people with a stroke in the ambulance. This brain video shows a cerebral infarction (a specific type of stroke) and whether the closed brain blood vessel is large or small.

Recent research done by the U.M.C. Amsterdam is about an intelligent swimming cap, supposed to read the brain signals of a patient in the ambulance to get an early diagnosis of whether the patient is suffering from a stroke. In the case of a stroke, the diagnosis must be made earlier; this way, the patient can be helped as soon as possible. This will reduce the adverse effects.

One of the recent research developments is creating a BCI for paralyzed people, helping them communicate through technology. This research by U.M.C. Utrecht is still going, and people with A.L.S. will be able to communicate when the investigation is verified and implemented into health care.

Brain-Computer Interfaces (BCI) enable communication lines for users between the brain and body parts or objects and allow people to use their brains for things they usually could not. The possibilities for developments in this technology go from being able to control an artificial limb to control devices such as a computer with their brain.

There is also much research going into BCI being able to help patients with physical disorders; the function of the BCI would be for the people to support their mobility. Currently, the most significant interest in the development of the BCI comes from the hope that this technology could be a way for people who suffer from disorders like A.L.S. to live as unlimited as possible. Something to keep in mind is that more physically apparent disorders, such as neuromuscular disorders, are also mental disorders that, in the future, can hopefully be helped with a Brain-Computer Interface.

II. Project Definition

The goal of this project is to come up with an innovative way to implement the topic BCI. But, of course, for a product to be an innovation, much research will have to be done on what is already there on the market. And find an exciting topic to adapt or think of competitive innovation.

A. Current-State-Of-Art

In recent years, several companies have been working on brain-computer interfaces to use signals emitted by the brain to control machines or devices. Initially developed for the personal assistance of disabled people, brain-computer interfaces are now opening up to a broader public and healthy people for entertainment in particular. These different BCI systems use different types of brain signals, such as electroencephalography (E.E.G.), but also electrocorticography (ECoG) or magnetoencephalography (M.E.G.).

The various companies involved in BCI systems are mainly Emotiv, Neurosky or O.C.Z., which have developed commercial products based on E.E.G. for consumer entertainment applications; for example, Emotiv has developed a headset that allows emotions (data) to be transformed into waves of sound via the E.E.G. headset; they have also developed virtual reality driving and control of a car, according to the driver's will, who can change the road or other things, depending on his mood. In addition, Neurosky has developed sleep tracking to improve sleep, as well as wearable devices in everyday life, which can be analyzed afterwards, and to make improvement programs, for example, for a sports routine.

Regarding the development of M.C.I.s for assisting people with disabilities or limb loss, Stanford University is developing an interface that will allow the user to write words by thinking about how they would have written them in handwriting. For the use of an MCI-assisted prosthesis, most companies working on the subject prefer the use of E.M.G. (electromyography) rather than E.E.G., as the brain's functioning is still too complex to understand and guide a prosthesis such as an arm.

B. Justification for the project

One of the reasons for this project is that the BCI is starting to impact the technological aspect of our society significantly. The BCI technology makes communication from the brain to, probably shortly, any device. It is important to keep researching the BCI because researchers will only partially understand the working of our brains. However, when doing this research on the BCI, we can learn to understand better how the brain works and what we can do with those results. Another reason is that the BCI is also starting to have a massive effect on health care. The BCI is beginning to be used to support or take over parts of health care which professionals still need to do now—for instance, reading the brain cells to get an early diagnosis of a stroke or even psychoses. With the capability to get these early diagnoses, people get help sooner, and any future adverse effects can be prevented. In the medical branch, the BCI is also used to replace the function of a limb; this is called a prosthesis. People with a prosthesis can now rely entirely on an artificial limb replacement.

C. Main research question

1) Main question

• In what innovative way can the living quality, in a non-intrusive way, be improved for patients with brain conditions?

2) Sub-questions

• What housing, connection options and materials used for this project are IP67 waterproof, anti-allergic and dust resistant?
• When connected, what connector options ensure they won't interfere with the measurement results due to too much movement of the device?
• How can be made sure that the connector and housing cannot cause signal loss or noise for the most accurate E.E.G. signal due to a bad connection or unstable connection?
• How can the BCI be placed all the time correctly?
• Is a BCI the best option for the target audience to wear?
• Where is the optimal position on the head to put the BCI?
• How can the BCI housing be made so it won't be intrusive to the wearer?
• What connector options are easy for caregivers but can't be removed easily by the wearer?

D. Project Boundaries

This project aims to create a non-invasive way to implement a brain-computer interface for the project. Stakeholders for this product could be people with limb loss, by accident or born with it. Other possible stakeholders could be people who can no longer send the brain signals for specific muscle movements due to a brain or spinal injury. However, for this project, the focus will only be on people with amputees.

E. Conditions

III. Function tree and system requirements

A. Function Tree

Appendix A

B. Patch requirements

When designing a brain-computer interface (BCI) system that uses electroencephalography (E.E.G.) to control a prosthetic device, several necessary conditions must be considered for the E.E.G. electrodes, or "patches." These requirements can include factors such as the number and placement of electrodes, the type of electrodes used, and the methods for attaching the electrodes to the scalp.
Here are the requirements that need to be considered when looking at the patch placement:

The number of electrodes: The number of electrodes used in the BCI system will depend on the system's specific application and goals. A more significant number of electrodes can provide more detailed information about brain activity but may also be more cumbersome to use and require more complex signal processing.

Placement of electrodes: The placement of electrodes on the scalp is essential in designing a BCI system. Electrodes should be placed over the brain areas related to the specific task or movement being controlled by the prosthetic device. For example, electrodes would typically be placed over the scalp's primary motor cortex (M1) area to hold a prosthetic arm, overlying the hand representation of the brain.

Type of electrodes: Different E.E.G. electrodes can be used, including silver/silver chloride, gold, tin, and carbon. The choice of electrode type can depend on factors such as cost, signal quality, and ease of use. Also, it is essential to choose electrodes that can give a reliable signal and are comfortable for the user.

Methods for attaching electrodes: Attaching the electrodes to the scalp can also affect the performance of the BCI system. Some systems use "dry electrodes," which are directly connected to the skin, while others use gel-based electrodes that require a conductive gel to be applied to the skin. The choice of method will depend on factors such as comfort, signal quality, and ease of use.

Electrode impedance: The impedance of the electrodes should be as low as possible to minimize the noise and distortion of the E.E.G. signals. It's essential to check the impedance of the electrodes before the recording, and if it's higher than the limit, clean the electrodes and change them.

Signal Quality: The patch should be able to record a high-quality signal. This includes low noise levels, minimal artefacts, and a stable impedance during the recording session.

Comfort: The patch must be comfortable for the user, as high-quality signals can only be recorded if the user is relaxed and comfortable.

C. Headband requirements

Here are some specific requirements that need to be considered for the headband in a BCI system:

Electrode placement: The headband should be designed to hold the electrodes in the correct position and orientation on the scalp. This will ensure that the E.E.G. signals are correctly recorded, and the feature extraction and classification algorithms will be more accurate.

Adjustability: The headband should comfortably fit various head sizes and shapes. Additionally, it should be able to adjust the placement of the electrodes over time if the headband is used by multiple users or over time as the users' head changes.

Durability: The headband should be durable and withstand frequent use and handling. It should be able to withstand the pressure of being adjusted, being put on and off and being in contact with the hair, skin and any cleaning products that might be used.

Comfort: The headband should be for the user to wear for long periods; it should distribute the pressure evenly over the head and not cause discomfort.

Ease of use: The headband should be easy to put on and take off and should not require special tools or training.

Electrode connection: The headband should provide a secure and stable relationship between the electrodes and the amplifier to prevent noise, artefacts, and signal loss.

Cleaning and sterilization: The headband should be designed to be easily cleaned and sterilized, especially if it is to be used by multiple users.

Compatibility: The headband should be compatible with the electrodes, amplifiers and other equipment used in the BCI system and provide stable and secure connections between these components.

D. Electrical connection requirements

Signal quality: The electrical connections should provide a stable, low-noise, high-quality E.E.G. signal. The references should minimize noise and artefacts, such as electromagnetic interference, and maintain a sound signal throughout the recording session.

Stability: The electrical connections should provide a stable and reliable connection between the electrodes, the headband or cap, and the amplifier. This ensures that the signals are correctly recorded, and the feature extraction and classification algorithms will be more accurate.

Durability: The electrical connections should be designed to withstand frequent use and handling. They should be able to withstand the pressure of being adjusted and should not break or wear out quickly.

Ease of use: The electrical connections should be easy to use and should not require special tools or training to connect or disconnect the electrodes, the headband or cap, and the amplifier.

Electrode impedance: The electrical connections should be designed to minimize the electrode-skin impedance to improve signal quality and reduce noise.

Compatibility: The electrical connections should be compatible with the electrodes, amplifiers, and other equipment used in the BCI system and provide stable and secure connections between these components.

Cleaning and sterilization: The electrical connections should be designed to be easily cleaned and sterilized, especially if it is to be used by multiple users.

Size and weight: Depending on the specific use case, the connectors, cables, and other hardware should be compact and lightweight so as not to add any unnecessary bulk or weight for the user.

IV. Working with the BCI

A. Working of the brain and EEG

A brain-computer interface (BCI) for prosthetics is a system that allows a person to control a prosthetic device using their brain activity. This can be achieved by measuring brain signals. The measuring is done by electroencephalography (E.E.G.) and then using algorithms to decode these signals into commands for the prosthetic device. The BCI based on E.E.G. involves measuring the brain's electrical activity using electrodes placed on the scalp.

One common way to control a prosthetic device with a BCI is through using a "control signal" generated by the user intentionally or by the device by analyzing the brain activity. This control signal is then used to move the prosthetic device, for example, a robotic arm or leg. The user can learn to control the prosthetic device by associating certain thoughts or mental tasks with specific movements of the device.

A typical BCI prosthetics systems have several main components:
• Sensors: These are used to measure brain activity and include E.E.G. electrodes.
• Signal processing: This step involves cleaning and analyzing the raw brain signals to extract useful information. This can include removing noise, detecting specific features of the brain activity, and transforming the signals into a format that can be used to control the prosthetic device.
• Feature extraction: This step involves extracting features indicative of the users' intention or command to control the device.
• Classification: This step involves using machine learning algorithms to map the extracted features to specific commands.
• Actuation: This step involves using the classified command to move the prosthetic device.

B. Location of E.E.G. patches

Electrodes are used to measure brain activity. These are tiny metal plates connected by a wire to an amplifier. Either loosely or in a bathing cap, the electrodes adhere to the head with paste or glue. Electrodes are attached to the ears, eyes, chest, arms, and legs to measure eye and limb movements. A computer processes and stores the signals. During the E.E.G., a video recording is frequently also made. Also monitored is the heart rate. [9]

The location of E.E.G. electrodes or "patches" on the scalp is an essential aspect of designing a BCI for prosthetics. This is because the specific area of the electrodes can affect the quality of the E.E.G. signals and the ability to decode brain activity accurately.

The most common location of E.E.G. electrodes used in BCI research for prosthetics is the motor cortex, which is the area of the brain that controls movement. The motor cortex is located in the frontal lobe, just behind the forehead. Therefore, electrodes are typically placed over the areas of the motor cortex that control specific body parts, such as the arm or leg.

For example, to control a prosthetic arm, electrodes are typically placed over the scalp's primary motor cortex (M1) area overlying the hand representation of the brain; see Figure 1 for the precise location. This is because the M1 is responsible for the control of voluntary movements of the hand, fingers, and arm. [10] It is also common to use additional electrodes to capture E.E.G. activity from other parts of the brain, depending on the specific goals of the BCI system and the study. For example, different electrodes can be placed over the premotor cortex, posterior parietal cortex, or even over other brain regions related to cognitive processing like attention, memory and more.

In addition, it is common to use a reference electrode placed somewhere other than the scalp to serve as a reference point for the E.E.G. measurements. The most common reference electrode is located on the earlobe or forehead and is used to cancel out any interference unrelated to brain activity, such as electromagnetic noise.

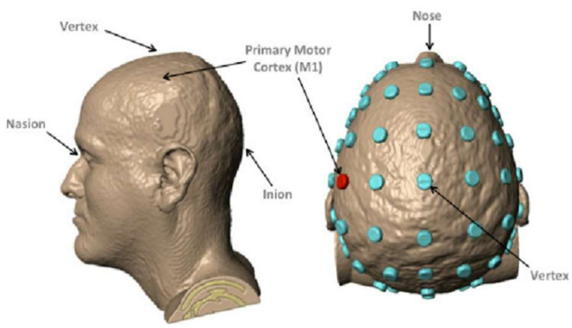


Figure 1 Depiction of the brain Motor Cortex [10]

V. System design

A. User acceptance and usability

To ensure the innovation has a purpose, it has been considered and tested for user acceptance and usability. The goal is for a non-invasive design, so at the stages of designing, it must be made sure that the invention's comfort and look are acceptable. Prototyping helps test it physically and adjust on parts that cannot be foreseen, as well as give the client an idea of the direction.
With usability in mind, the design must make sense while using it. For example, while adjusting for electrode placement of the BCI unit, the user does not accidentally turn it off or misalign the other electrodes.

B. Patch design

After some consideration and further research, the conclusion was made to use a pre-made patch design. This way, the project could focus on the headpiece and placement of the patches and ensure the quality of the measurements would still be good. The team discussed with Amsterdam U.M.C. the most appropriate E.E.G. patches for this project. There are three different options the project could conclude are viable options for the BCI.

1) Dry Electrodes

Wet electrodes frequently have the problems mentioned above. Hence dry electrodes (See Figure 2) are suggested as an alternative for stable long-term E.E.G. recordings.

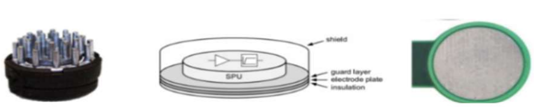


Figure 2 An example of a contact, insulating and non-contact dry electrode [13]

The fact that dry electrodes require less time and effort to prepare the scalp than wet electrodes makes this one of their key advantages. Dry electrodes fall into three categories: insulating, contact, and noncontact. The electrode surface,

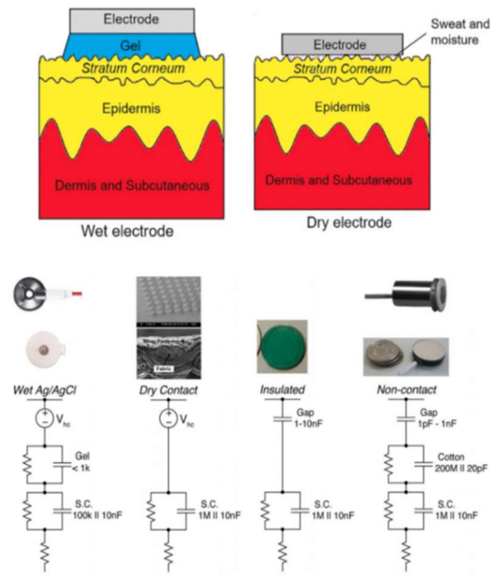


Figure 3 Detailed view of difference in electrodes [13]

made up of a metallic array of spikes in a dry contact electrode, is in direct touch with the scalp. In some circumstances, the electrode can even be punctured through the stratum corneum (S.C.) to produce more excellent mechanical and electrical properties. The bottom plate of a noncontact dry electrode is constructed of metal capacitively connected via an insulator, such as clothing or hair. As the name implies, an insulated electrode uses capacitive coupling to function, and its bottom plate is made of an insulation substance. Dry contact electrodes are more frequently utilized in E.E.G. applications than the other two varieties because of their slightly lower impedance.
[13]
Dry electrodes only come with their share of issues. First, there is a large amount of noise and interference in the E.E.G. Movement artefacts are more common due to the lack of a conductive layer and the resulting increased impedance (as high as a few M at 50/60 Hz). Dry electrodes must be insulated. As a result, it reduces interference-related noise. Poor signal quality will result from employing dry electrodes connected to an E.E.G. amplifier by non-shielded wires (passive electrodes). Instead, active electrodes are required, which intensify the E.E.G. at the scalp and lessen the impact of background noise. Additionally, insulated cables are less frequently needed to maintain signal quality, a benefit for small wearable technology. Furthermore, wearing the spikey electrodes for extended periods is not recommended due to their discomfort. [13]

2) *Wet/gel electrodes*

The electrical characteristics of the electrode-skin Interface are significantly influenced by electrode-skin impedance. Therefore, the quality of the E.E.G. signals will improve when the electrode-skin impedance decreases. Low electrode-skin impedance can also lessen power line interference and increase the resistance of E.E.G. signals to movement artefacts, such as cable motion. The silver/silver chloride (Ag/AgCl) electrode is currently the most widely used electrode. With Ag/AgCl electrodes, commonly known as wet electrodes, the electrode-skin impedance is decreased by creating a conductive route between the skin and electrode using an electrolyte gel. Although wet electrodes are currently the gold standard in clinical practice, they have several drawbacks [13]:

- The impedance may take a long time to be reduced to a reasonable level (5–20 K). [13]
- The gel may dry out in a few hours after an adequate impedance is established, which would increase the impedance once more. For instance, it was shown that 5 hours after applying the gel, the impedance of wet electrodes decreased from 5 to 15 K. Wet electrodes are therefore inappropriate for long-term E.E.G. [13]
- Because the distance between electrodes gets smaller as the number of electrodes increases, using a dense array of electrodes (i.e., E.E.G.) might be troublesome. Due to this, a conductive bridge between two electrodes may emerge between the electrolyte gels. [13]
- It takes time and expertise to set up the E.E.G. using wet electrodes (skin preparation, waiting for impedance to reach appropriate value, etc.). [13]
- Finally, the patient may find it uncomfortable to use the electrolyte gel and abrasive paste (both used to prepare the scalp). [13]

3) *Sponge Electrodes*

Sponge electrodes are a revolutionary form of the electrode that, like dry electrodes, take very little time to prepare and don't need conductive gel. Another name for these electrodes is "semi-dry electrodes." Using sponges or an electrolyte liquid is the essential characteristic of sponge electrodes. Some sponge electrodes improve the conductivity between the skin surface and the electrode by using water sponges filled with tap water or saline solution. Other sponge electrodes drip a modest amount of electrolyte liquid to the scalp over a sustained period. These techniques take less time to prepare and clean up than gel electrodes because they don't need to apply or abrade the skin. [14]

Sponge electrodes have multiple advantages and more incredible setup speed compared to gel electrodes as they are cleaned more quickly than gel electrodes, they are suitable for testing at home, possibly in some circumstances without a qualified technician to use, and water helps dry electrodes overcome issues with high impedance and signal instability. [14]

However, there are also some disadvantages of these electrodes; compared to gel electrodes, they dry out more quickly, necessitating more frequent rewetting.
They are more prone to mains interference and movement artefacts than gel electrodes.
The skin-electrode contact quality can only be improved through several actions. [14]

All three of these electrodes need comprehensive research and testing for the final decision to be made for the BCI. [14]

4) *Active and passive electrodes*

There is one word that you will undoubtedly come across when setting up your E.E.G. measurement: impedance. A substance's electrical impedance, measured in Ohms, is the ease with which charged particles, or current, can pass through it. Every electrode has a gold or Ag/AgCl coating on its head to make this as simple as possible on the electrode side. [15]

However, reducing the impedance that separates the electrode head from the scalp, thereby facilitating the flow of current, is a significant component of setting up an E.E.G. measurement. The E.E.G. data will be more likely to reflect electrical signals from brain activity beneath the scalp if the electrode impedance is lower. It will also be less likely to be dominated by other electrical signals that aren't important (like line noise, for example). As a result, better data quality is ensured by a higher "signal-to-noise ratio" and a lower electrode impedance. [15]

Active and passive electrodes are essentially the same thing. The most crucial difference is that the E.E.G. is amplified at the scalp with active electrodes. In contrast, it is amplified in the (pre)amplifier at the end of the electrode wire with passive electrodes, as seen in Figure 4. The electrode and the wire to which it is generally attached function as antennas. It records the electric activity as part of the E.E.G. signal by picking up electric activity from computer monitors and other electrical and electromagnetic sources. [16]

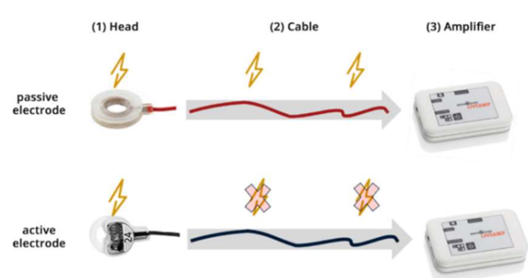


Figure 1 Active and passive electrodes

5) *Ground electrode*

An electric potential difference is what makes up an E.E.G. signal. To measure a "difference," we need at least two electrodes. In principle, any pair of electrodes can record a potential difference: You compare the electric potential registered by one electrode to another electrode when measuring the electric potential. Nevertheless, not all differences are equally fascinating. [16]

Imagine recording the potential difference between two electrodes placed on the scalp near one another. The majority of brain activity that reaches the electrodes will be picked up by both electrodes roughly equally; As a result, there won't be much of a potential difference between the electrodes. [16]

Adding a separate ground electrode can reduce noise in the E.E.G. Two electrodes and a voltage amplifier are required to transmit an E.E.G. signal from a person's head to a data acquisition system (D.A.Q.). The amplifier's primary function is to strengthen the weak scalp recorded E.E.G. signal so that the D.A.Q. can read it. [16]

Single-ended amplifier A single-ended amplifier only has one input, the active E.E.G. electrode, and it refers to its standard potential—or, more succinctly, the expected return path of the internal circuitry that enables current to flow—from this input. The common is frequently connected to the earth (the "ground connection"), which has an arbitrary potential of zero for non-biological applications. A reference to the o ground for an E.E.G. electrode is theoretically possible. [16]

However, this is unacceptable for several reasons, including the patient's or test subject's safety. As a result, E.E.G. amplifiers have what is known as a "floating ground," a common signal ground separate from the actual earth ground. Through the reference electrode, it derives its potential value from the average potential of the test subject's body. As a result, the signal ground and the reference electrode are identical in a single-ended amplifier circuit. [16]

A single-ended circuit's susceptibility to noise, primarily from capacitive coupling, is the main issue. The subject's body and signal wire noise are fed into the amplifier and amplified with the signal. The signal may become extremely noisy to the point of being unusable if the amplifier-induced noise is added.[16]

6) Final choices of electrodes

Only four electrodes reach a small form factor and a comfortable, simple structure. One electrode is located at the front cortex, and one on each side, behind the ear. The final electrode is considered a reference, connected to the ear lobe in a clipper style. The formation of the electrodes makes it so that the controlling electrode is the one on the forehead, where the frontal cortex is. With an area for signal amplification and processing being part of the design, the BCI unit would be manageable with different connecting interfaces. In addition, AI-powered computers are getting smaller and more powerful, so processing can be done while wearing them, and the data can be transmitted wirelessly over to a computer, app, etc.

Individual electrode electrical connections are better than others based on the material that they are made of. This is because of the different electrical conductivity some materials have. Appendix D is a table that showcases different materials and their advantages and disadvantages. With this information, the materials are looked into based on their electrical conductivity, the slowest degrading over time and if it's affordable.

For this project, the most suitable materials are silver (Ag) and Gold (Au). These materials have the highest electrical conductivity together with copper. Unfortunately, copper reacts to water relatively quickly, and the material's conductivity gets less and less rapidly over time.
The three types of electrodes (dry, wet and sponge) must be tested extensively under the right circumstances to make a final decision for the BCI. This is why there has yet to be a final decision on this.

C. Headband design

Following the requirements, the headband system design can be considered minimalistic compared to other methods. Only four electrodes reach a small form factor and a comfortable, simple structure. One electrode is located at the front cortex, and one on each side, behind the ear. The final electrode is considered a reference, connected to the ear lobe in a clipper style. The formation of the electrodes makes it so that the controlling electrode is the one on the forehead, where the frontal cortex is. With an area for signal amplification and processing being part of the design, the BCI unit would be manageable with different connecting interfaces. AI-powered computers are getting smaller and more powerful, so the processing can be done while wearing it, and the data can be transmitted wirelessly over to a computer, app, etc.

D. Electrical Connection

The electrical connections to the electrodes and the processing units would be either small and thin wires or flat wires. This way, the wires do not add much weight and make the design simple and less intrusive. However, the disadvantage is that thin wires are more prone to wear, damage, and signal interference. Therefore, the circuit of the processing unit would have filters countering interference issues.

E. Conclusion system designs

The product's design is heavily impacted by user acceptance and usability aspects. Therefore, iterations of the designs are unavoidable so that the plan will be adjustable. With the research done on the headbands and the patches, a morphological map was created to see the different iterations/options the BCI could look like. See Appendix C for the various iterations chosen to test/work out. The Kesselring method has been used for the reasons why these four have been selected. See Appendix C.1 and C.2 for this.

VI. Module Design

A. Headband design

1) First Design

The first concept will have the following parts integrated into it: gold electrodes connected with flexible wires and will consist of 8 channels. This concept will have 2 Velcro pieces on top; this way, it can be worn with any cloth that the customer wants and will avoid any slip of the hat or cap that will be worn above. The number of channels in any design is represented by the number of electrodes used in the concept. Because we are talking about the brain-computer Interface, there is no need for more electrodes than 8. The total number of electrodes will be 8 + 1 electrode for grounding. For any design, double grounding should be avoided; if dual grounding occurs, the customer wearing the product will be harmed. Electrodes will be placed at the end of every "spike" of the headband in the middle, and grounding will be placed behind one ear. Gold Electrodes are the best candidates for the fabrication of M.E.A.s due to their high electrical conductivity, biocompatibility and good chemical stability. In this way, the team will ensure the reading of the signal without any outside influences from environmental frequencies. One advantage of this concept is that The unique shape of these Gold Cup Electrodes allows easy placement of the electrodes on the scalp (E.E.G.) or the patient's face (E.O.G.). They also provide a constant and reliable signal during E.E.G., P.S.G., E.M.G., E.C.G., E.O.G. and Video-EEG-Long-Term-Monitoring (LTM). This electrode will not be uncomfortable for the patient to wear for an extended period (more than 6 hours) because of the mounts. They also are applied fast on a person's head (gel is not needed for this situation) and can also be used in an ambulance by doctors because of the electrodes that can be applied and removed fast by not being required to clean the gel from person hair or

2) Second Design

The second concept will consist of the following parts: spiked dry electrodes with flexible wires and eight channels. This concept is inspired by the Amsterdam U.M.C., a clinic doing neurology study. After the meeting with the hospital, this design was better understood, how it will be used and where. Using this design, ambulances usually focus on speed to apply the cap on a patient. This can be improved by using spikes of dry electrodes; in this way, doctors are not required to apply any gel on the electrodes to attaché them to a person's head. This design also consists of 8 electrodes and one grounding electrode placed behind the ear. The electrodes will be placed in each whole present on top of the cap, four on each side. The disadvantage of this type of concept comes from electrodes because of the spiked dry electrode type. After wearing the hat for 3-4 hours, electrodes will become uncomfortable for the person wearing them. Also, an extra filter in the system will be required because of direct contact with the skin. There will be an influence on signal reading because external frequencies will occur in the task.

3) Third design

The third concept would be a 4-channel design that is easily mounted to the head in the style of headphones. It consists of 4 gold electrodes and a reference electrode. Two electrodes would be located in the frontal cortex area, the other two behind the ear. The final reference electrode is attached to the earlobe. A common problem in the brain interface is reading the signals through hair. Finding a solution to that problem is what inspired this third design concept. And indeed, the first advantage of the design can be considered the position of electrodes on areas with bare skin. The plan would have features like latching onto the head through bendable vital points. That way, the design could be attached tightly to any authority, which can help improve the quality of the signals read. In the back, an area for battery and amplification circuitry so that the device can be potentially made wireless or at least have a minimum set of wires.

The disadvantage of this kind of design is the need for more sensors. The user case of this kind of design is limited to more entertainment and simple controlling rather than medical. The method can also be complicated to make comfortable, as there are many variables when introducing bendable points. That also means many failure points in an everyday use scenario.

4) Fourth Design

The fourth and final design was considered as a concept of adding the electrodes to an everyday wearable, in this case, a sports cap hat. In between the layers of the cap material, flexible wires would be spaced out around the top of the head, following the 8-channel electrode positioning. Again, the idea of the concept is to make it as non-intrusive as possible and make it invisible for outside users to see that it is a brain interface signal reading tool. Another advantage is also that more sensors can be added to the design.

One significant disadvantage is that the sensors must be on top of the hair, making the signal reading difficult. Also, the inside wires might be invisible, but wires would still have to come out of the hat. Someway making an inconspicuous design would not make work anyways. Caps are also prone to move and bend, so the wear and tear would be faster. Overall, to make the design more cohesive, more innovation and solutions are needed to get to the skin level of the head.

B. Patch Design

For patch design focus of the team was to place the patches for the Brain signal to be read without any interference. The number of patches was decided to be eight plus one patches that will be used as ground. Each design will have a different patch to complete the headband's function.

Patches will be bought from a company that produces them. In this way, the project's focus will be the understanding of electrodes and the design of the headband to be as unique as possible.
In this project, patches will avoid interference from the outside frequencies to prevent disturbing the signal read from the brain. These patches/electrodes will be tested further to see which one will be preferable with the desired headpiece.

C. Final Design

The final design chosen for the project is design 3/C, this option was selected because of its advantage with electrodes placed in areas where there is no hair or less hair, and it can be identified easily. A morphological map and the Kesselring method were used to acquire this information. (See Appendix C and D.1/D.2 for more details). As was mentioned before, one of the problems with reading brain signals is hair; placing electrodes on top of the head will be a problem with electrodes because it will take more time to put the need to use a gel to ensure the stability of the electrodes. However, the main problem is not that the electrodes will fall off; before that happens, the signals read by electrodes will be wrong, and the signal will not be usable. See Figure 5 for the final design.

Figure 2 Final Design

The gel will help to protect electrodes from reading the wrong signal, but one of the objectives of this project is to place electrodes fast and remove them quickly off the patient's head. Therefore, the gel will require some extra time to be identified, will have to be replaced after 4-5 hours and will have to be cleaned after usage.
The advantage of this product is that for Brain-Computer Interface, there is no need to read signals from the upper part of the head, and it can easily avoid areas where hair is.

Eight channels that are implemented in the final design also have the function of correcting each other. If one electrode reads a value that is not expected, the other two electrodes next to them will fix it. The correction will be done by approximating the electrode's worth using the neighbours, in this case, the electrodes next to it.

VII. Test results

A. Connection and patch test plan

To make improvements in the domain of BCI and to make the proof of concept for our project, a brainstorming was made to find a solution that would be:

- Realizable, considering the time and way are limited, and the team is not professional in the domain.
- Original, innovative, and can be deepened during and after the project.

Also, it was essential to find a solution to simulate the connection between the electrodes and a total prosthesis (because no prosthetics are available for the team's project). For this, it was decided that L.E.D.s would be used to simulate different movements from the prosthesis connected to the BCI (for example, an L.E.D. will light on for a specific signal because the user wants to move with his prosthesis).

After the brainstorming, the project-oriented itself to a simulation that considers brainwaves that come from the part of the brain that reacts when people hear music; as our brain didn't respond in the same way depending on what we hear, it is an exciting point to do research around the subject and to make tests. Also, using fewer electrodes than classic BCI is another way to attach the study around only this part of the brain and to be sure not to detect brainwaves that don't come from the auditory cortex (the part of the brain that reacts when we hear something).

So, at this point, the proof of concept that will be made will be:
The connection of 4 to 8 electrodes to detect the brainwaves when we hear different kinds of music, which could be recovered by an oscilloscope, to see the other way it goes, the separate changeset, and connect to different L.E.D.s, to simulate the action of the prosthesis, depending on the signal, and so the brain activity of people.

1) Test results for electrical connection

To make the simulation, it is mandatory to have a code that will be useful to make the L.E.D.s light on and off when needed and to display the brainwave signal that will be returned by the electrodes connected to the brain of people. For this, one way to do, and the one chooses, is to use a

code with Python3; also, it is required to use a Raspberry Pi4 with a breadboard and some wire.
Considering that E.E.G. electrodes are not easy to get, the team also anticipated and decided to create a program that would simulate brainwaves in case the E.E.G. never arrived or was not used for any reason. So, using Python3, the first step was to make a menu that asks to enter the frequencies and the amplitudes that could be obtained from E.E.G. using an oscilloscope. Then, depending on the entry, the program will make waves and return in which state the user is (e.g., excited, calm.).
Going back to the simulation/proof of concept, the experimentation is going to use 5 L.E.D.s, connected with a proper resistor and at the Raspberry Pi4, as shown on the scheme below in Figure 6:

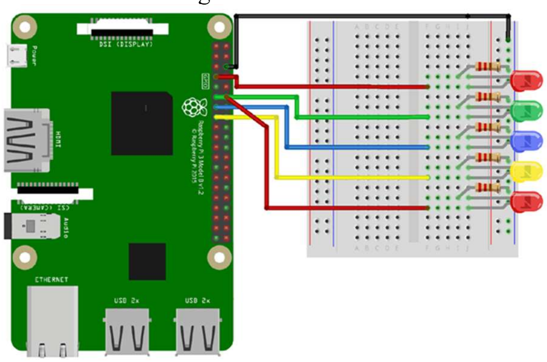


Figure 6 RaspberryPi3 with L.E.D. wiring

Returning to the menu, the menu is composed of two entries: frequency and amplitude. The « simulate » button will launch the brainwave's plot with the amplitude in the function of the time, then detect the type of brainwave. Additionally, a servomotor was connected to the circuit to have something else in output, making another prosthesis simulation.
Finally, the brainwave detected that goes in the output depending on the frequency can be displayed by the program made with Python3 in Figure 7:

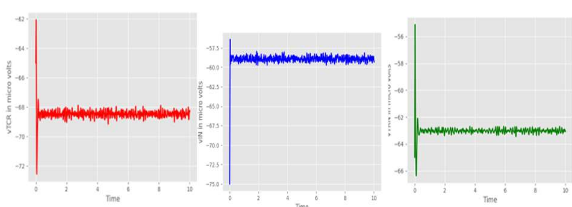


Figure 7 Brainwaves simulated (with three electrodes)

Also, it is important to know that all humans display five "brain waves" across the cortex; the most important are listed below:

- Gamma γ between 30Hz and 100Hz (hypervigilance)
- Beta β between 13Hz and 30Hz (active)
- Alpha α between 7Hz and 13Hz (calm)
- Theta θ between 4Hz and 7 Hz (light sleep)
- Delta δ between 0.5Hz and 4Hz (deep sleep)

So, as seen in the simulation, with a frequency of 12 Hz, the program returns a « calm » brainwave detected.

2) Test results for patch connection

As previously demonstrated, the patch connection must be positioned precisely to capture the patient's brainwaves. Figure 8 is an illustration of an optimal approach to obtaining results from a strong patch connection:

Additionally, the team decided to test a different method of working with patch connections for the BCI to obtain a signal from fewer E.E.G. electrodes first. Second, the

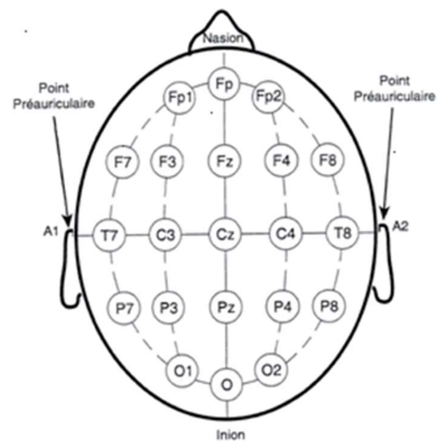


Figure 8 Strong patch connection visualization

strategy was to get a further call when the patient heard music by placing the electrodes close to the auditory cortex. Finally, the team also wanted to make various L.E.D.s blink with this signal, depending on this frequency (and thus what the patients will hear or the kind of music they will listen to), simulating various arm prosthesis movements. Sadly, this strategy was never fully implemented because the ordered E.E.G. patches were never delivered.

VIII. Conclusion and Recommendations

A. Conclusion

The report presents research into the brain-computer Interface. The following analysis is stated: In what innovative way can the living quality, in a non-intrusive way, be improved for patients with brain conditions? To answer this question, firstly, an analysis of people's needs and much research about existing BCI and how to deal with it was made. The project was then cut into three significant parts, each as important as the others: the first part of defining the project, state of the art, the system requirements, and everything mandatory to know before going further in a project like this, to be the most efficient possible. Then, a new design for BCI was developed to help people that have recourse to BCI to live. And finally, an experimental part to test the unique way we want to operate everything we learn to develop and improve our proof of concept for the project.

Though the entire project cannot be concluded yet for the phase the project has gone through, a conclusion can be drawn. This project aimed to design a BCI to help people in need. Up to this point in the project, the design phase has been completed, and concepts have been made. Unfortunately, for the experiment and test part, the project couldn't go to his conclusion due to some incident in the command and the fact that the commanded electrodes never arrived.

To go further with this project, the focus will be on making a prototype (See Figure 5 "final design" for the prototype) and the proof of concept the team will begin to create. Then, with different and additional tests, the final image can be validated, and the project can be completed.

B. Conclusion on research questions

What housing, connection options and materials used for this project are IP67 waterproof, anti-allergic and dust resistant?

The best options for the housing and connections are the sponge electrodes or the golden electrodes. This is due because of the conductivity of the gold and its durability. The sponge electrodes add another layer to the conductivity, are more comfortable than the dry electrodes, and require less work than the wet/gel electrodes. However, the design needs to be tested for waterproofness as there has yet to be a final product.

How can the connector and housing be ensured not to cause signal loss or noise for the most accurate E.E.G. signal due to a wrong or unstable connection?

The design of the headpiece is made so that the wearer can constantly adjust to the size of their head. This ensures that the wearer is always a good fit for their headpiece. Furthermore, the excellent fit ensures minimal noise or signal loss from the E.E.G. electrodes.

How can the BCI be placed all the time correctly?

The headpiece's design is made so that the wearer can only wear it in one particular way. The wearer can adjust the headpiece once they have put it on their head to become more comfortable and read the signals correctly.

Where is the optimal position on the head to put the BCI?

The most optimal position to find a good E.E.G. signal must be tested. This is because the E.E.G. signal has only been tested using a computer E.E.G. signal, not a 'real' brain signal. According to the U.M.C. hospital in Amsterdam, the most optimal positions for the electrodes are two on the front of the head, two at the back of the head, and one electrode on the side of the head/on the earlobe for the reference or ground point of the signals.

How can the BCI housing be made so it won't be intrusive to the wearer?

Using the sponge electrodes as the brain signal wave detector makes the BCI more comfortable for 8 hours daily. The sponges are always wet and will dry out slowly thane wet/gel electrodes. When eventually dried out, the wet/gel electrodes are very uncomfortable to wear as they become dry spiked electrodes. This will not be a pleasant experience for the wearer as there are spiked digging into the skin.

The sponges won't have this effect. In addition, and as an added benefit, the gold from the electrode and the wetness of the sponge provides more conductivity than the wet/gel sponges.

The design of the headpiece is made to resemble a pair of headphones. They look nice and thin in the front, so the wearer barely notices the device itself.

In conclusion, the main goal of the project was achieved in the final prototype by implementing eight channels (8 electrodes) and placing them in areas that are easy to be applied, with no need for the gel to be placed on the patient's head and time to remove them will be minimal.

The headband has a unique design which will use a similar method as headphones to change the dimension of the headband for every person's head to fit perfectly. See Appendix F for a more detailed drawing. With this method, any stress will be minimal on the headband (which will be made of flexible plastic) and will ensure a longer lifetime of the product by avoiding constant pressure, which in the final, will result in the product breaking over time.

C. Recommendation

The proposed recommendation is that when the three different E.E.G. patches arrive, they need to be tested and validated with the electrical connections and headband that have been designed. In addition, the patches need to be tested in comparison with another BCI device while walking/running for an extended period to ensure a signal is produced without noise or motion loss.

The comfortability must also be tested for an extended period (8 hours daily) for all three E.E.G. electrodes, as this couldn't be tested during this project.

These tests also need to include the headpiece design, as they can look at the adjustability of the electrodes working appropriately.

IX. ACKNOWLEDGEMENT

The authors of this research would like to thank Mr Timothé Turko and F.M. van Kats for their guidance during this project. They have been the tutor for the project groups and have provided insights, advice and knowledge regarding the project structure and the idea for the project. Also, thanks to H.G.M. Geraerdts and Mr Leandro Di Domenico, that have helped us with the organization of the journey to Barcelona and with the presentation of the project at the Symposium. Finally, the group would like to mention Mr Mathias Reheisser for his advice and professionalism.

X. BIBLIOGRAPHY

[1] U. o. Calgary. [Online]. Available: https://cumming.ucalgary.ca/research/pediatric-bci/bci-program/what-bci#:~:text=A%20brain%20computer%20interface%20(BCI,device%20using%20only%20your%20mind..

[2] Dictionary, 2022. [Online]. Available: https://www.dictionary.com/browse/atria.

[3] "Pubmed," [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4001219/#:~:text=Introduction,is%20a%20non%2Dinvasive%20test..

[4] "BrainyQuotes," [Online]. Available: https://www.brainyquote.com/quotes/swami_vivekananda_213397?src=t_brain.

[5] "I.X.A.," October 2022. [Online]. Available: https://www.ixa.nl/news/thanks-to-the-smart-swimming-cap-people-with-a-stroke-are-immediately-taken-to-the-right-hospital/.

[6] "Emotiv," [Online]. Available: https://www.emotiv.com/.

[7] Neurosky. [Online]. Available: https://neurosky.com/.

[8] “Tweakers,” [Online]. Available: https://tweakers.net/nieuws/52219/ocz-start-massaproductie-muis-met-neurointerface.html.

[9] Hersensticking. [Online]. Available: https://www.hersenstichting.nl/behandelingen-van-hersenaandoeningen/eeg/.

[10] Researchgate. [Online]. Available: https://www.researchgate.net/figure/Anatomical-landmarks-left-and-primary-motor-cortex-M1-localization-based-on-the_fig3_253335335.

[11] University, "Limb Loss Statistics," [Online]. Available: https://u.osu.edu/wheelbarrows/upper-limb-injury-statistics/#:~:text=60%25%20of%20arm%20amputations%20are,under%2021%20years%20of%20age .

[12] D. M., "Inspiring Stories," [Online]. Available: https://xcgif.org/story_MaryDague.html.

[13] E. Methods, "Sapien Labs," [Online]. Available: https://sapienlabs.org/lab-talk/wet-and-dry-electrodes-for-eeg/#:~:text=Dry%20electrodes%20can%20be%20broadly,a%20metallic%20array%20of%20spikes..

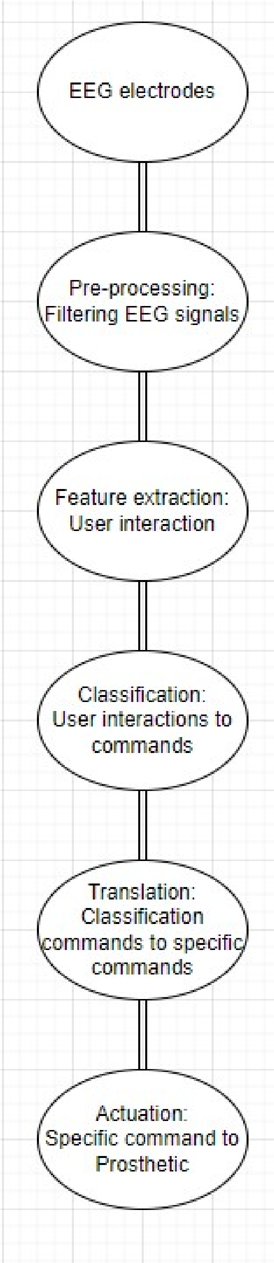
[14] “T.M.S.I.,” [Online]. Available: https://info.tmsi.com/blog/types-of-eeg-electrodes.

[15] B. products. [Online]. Available: https://pressrelease.brainproducts.com/choosing-your-electrode-technology/.

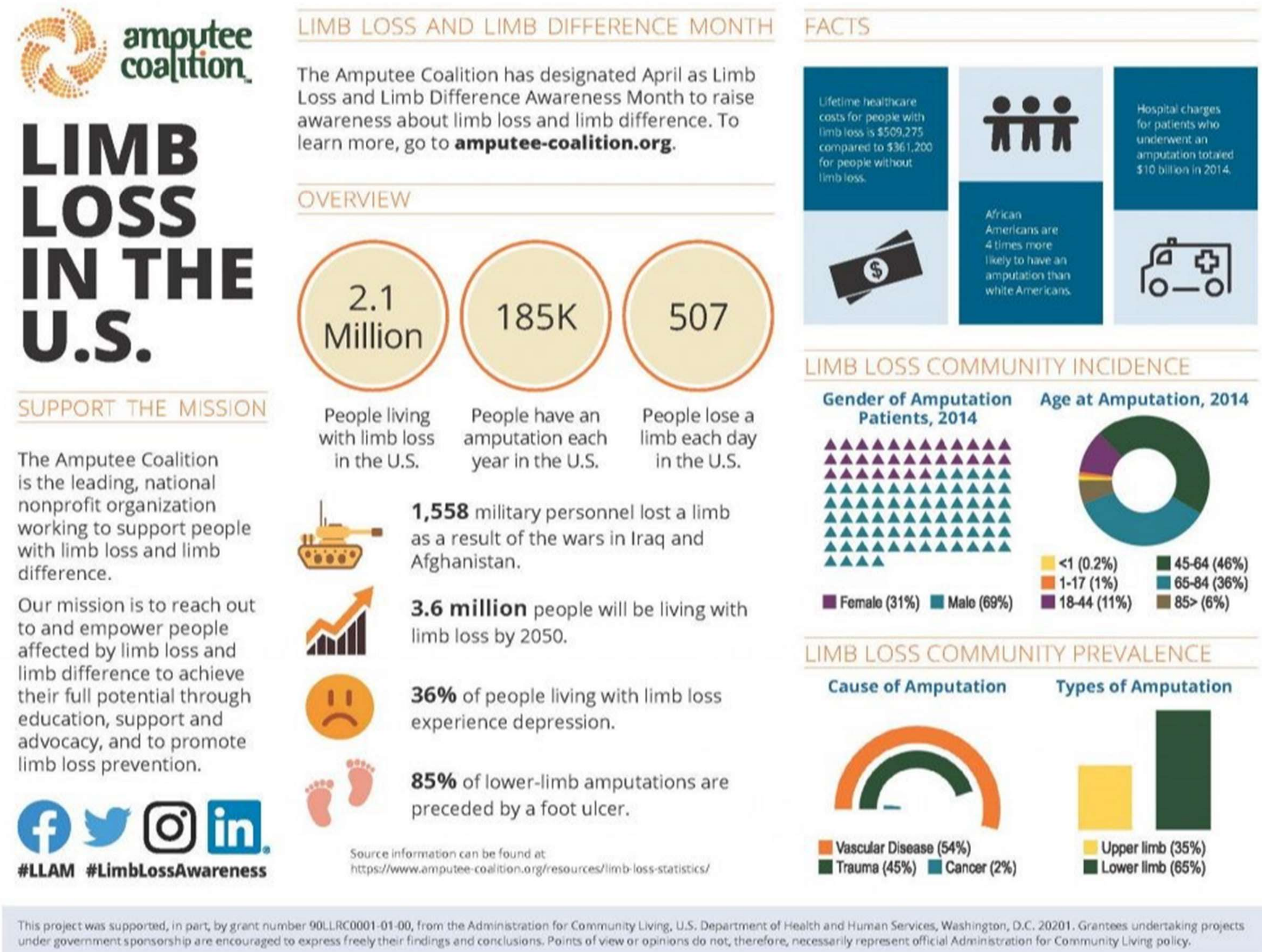
[16] “E.E.G. get it,” [Online]. Available: http://eegget-it.nl/eeg_electrodes.html#:~:text=There%20are%20basically%20two%20types,end%20of%20the%20electrode%20wire..

[17] H. Critchley, 2022. [Online]. Available: https://link.springer.com/referenceworkentry/10.1007/978-1-4419-1005-9_13.

Appendix A


EEG electrodes
Pre-processing:
Filtering EEG signals
Feature extraction:
User interaction
Classification:
User interactions to
commands
Translation:
Classification
commands to specific
commands
Actuation:
Specific command to
Prosthetic

Appendix B


amputee coalition
LIMB LOSS IN THE U.S.
SUPPORT THE MISSION
The Amputee Coalition is the leading, national nonprofit organization working to support people with limb loss and limb difference.
Our mission is to reach out to and empower people affected by limb loss and limb difference to achieve their full potential through education, support and advocacy, and to promote limb loss prevention.
#LLAM #LimbLossAwareness
LIMB LOSS AND LIMB DIFFERENCE MONTH
The Amputee Coalition has designated April as Limb Loss and Limb Difference Awareness Month to raise awareness about limb loss and limb difference. To learn more, go to amputee-coalition.org.
OVERVIEW
2.1 Million
People living with limb loss in the U.S.
185K
People have an amputation each year in the U.S.
507
People lose a limb each day in the U.S.
1,558 military personnel lost a limb as a result of the wars in Iraq and Afghanistan.
3.6 million people will be living with limb loss by 2050.
36% of people living with limb loss experience depression.
85% of lower-limb amputations are preceded by a foot ulcer.
Source information can be found at https://www.amputee-coalition.org/resources/limb-loss-statistics/
FACTS
Lifetime healthcare costs for people with limb loss is $509,275 compared to $361,200 for people without limb loss.
African Americans are 4 times more likely to have an amputation than white Americans.
Hospital charges for patients who underwent an amputation totaled $10 billion in 2014.
LIMB LOSS COMMUNITY INCIDENCE
Gender of Amputation Patients, 2014
Female (31%) Male (69%)
Age at Amputation, 2014
<1 (0.2%)
1-17 (1%)
18-44 (11%)
45-64 (46%)
65-84 (36%)
85> (6%)
LIMB LOSS COMMUNITY PREVALENCE
Cause of Amputation
Vascular Disease (54%)
Trauma (45%) Cancer (2%)
Types of Amputation
Upper limb (35%)
Lower limb (65%)
This project was supported, in part, by grant number 90LLRC0001-01-00, from the Administration for Community Living, U.S. Department of Health and Human Services, Washington, D.C. 20201. Grantees undertaking projects under government sponsorship are encouraged to express freely their findings and conclusions. Points of view or opinions do not, therefore, necessarily represent official Administration for Community Living policy.

Appendix C.1

Functional requirements	Scale Factor (1-3)	Dry electrode	Gel/wet electrode	Gold electrode	Sponge electrode	Monopode	Maximum Reachable total
Safe to use	3	9	9	7	9	8	12
Easy to use	2	8	5	6	5	8	8
Conductivity	2	2	3	3	3	2	4
Comfortable	2	8	6	8	8	4	8
Weight	1	2	3	2	2	1	4
Size	1	2	2	2	1	1	4
Total score		31	28	28	28	24	40
Percentage		77,5%	70%	70%	70%	60%	100%

Fabricating requirements	Scale factor (1-3)	Dry electrode	Gel/wet electrode	Gold electrode	Sponge electrode	Monopode	Maximum Reachable total
Cheap	2	6	8	6	7	6	8
Doable	3	9	9	6	7	6	12
Cleaning	3	12	7	12	7	7	12
Material	2	6	6	7	7	5	8
Total score		33	30	31	28	24	40
Percentage		82,5%	75%	77,5%	70%	60%	100%

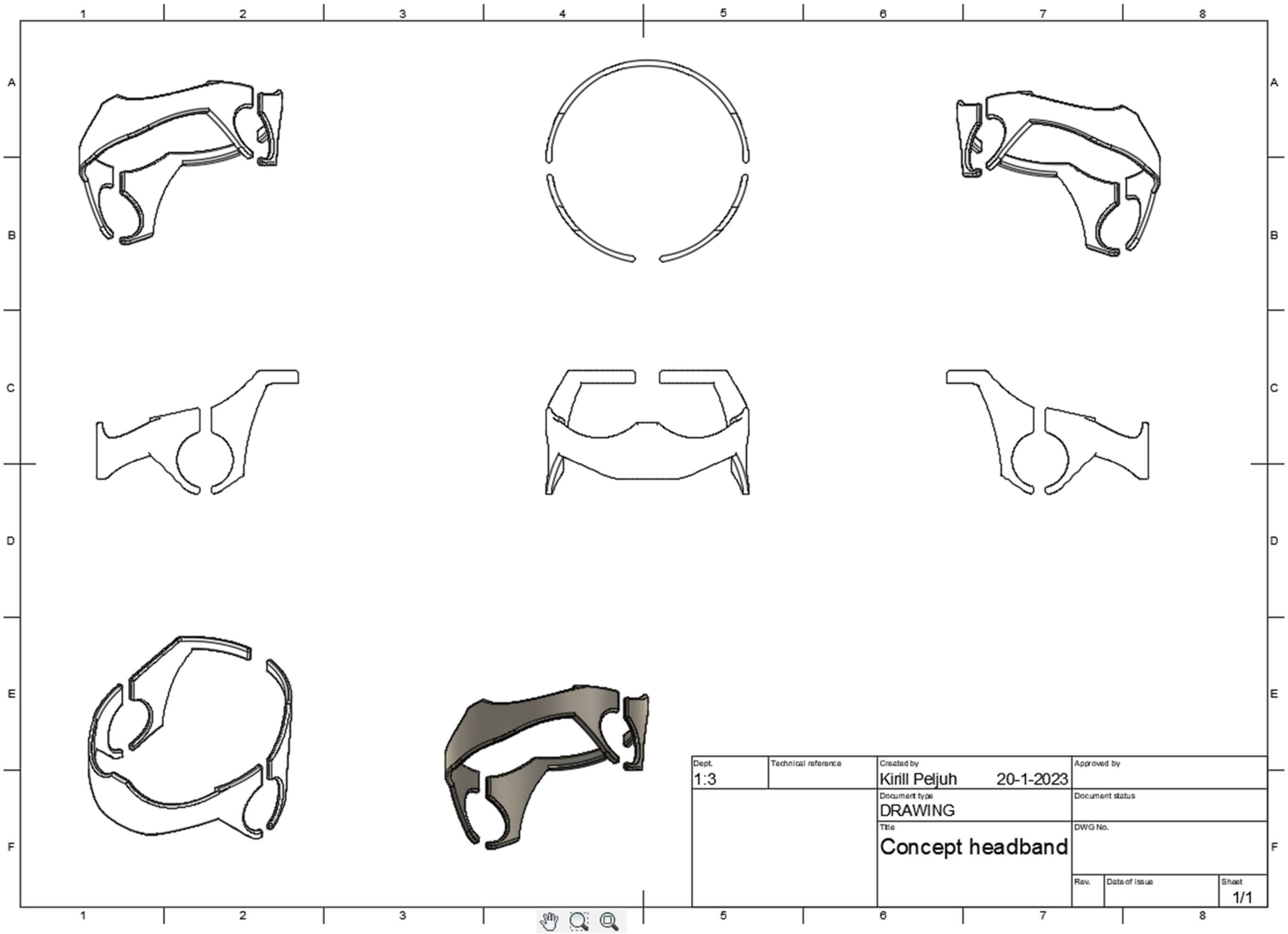
Appendix C.2

Functional requirements	Scale Factor (1-3)	Headcap	Cap hat	Velcro headpiece	Strap	Headphone	Maximum Reachable total
Safe to use	3	9	9	7	9	9	12
Easy to use	2	8	5	6	5	8	8
Conductivity	2	2	3	3	2	3	4
Comfortable	2	8	8	7	5	7	8
Weight	1	2	3	1	1	1	4
Size	1	2	2	2	1	1	4
Total score		31	30	26	23	29	40
Percentage		77,5%	75%	65%	57,5%	72,5%	100%
Fabricating requirements	**Scale factor (1-3)**	**Headcap**	**Cap hat**	**Velcro headpiece**	**Strap**	**Headphone**	**Maximum Reachable total**
Cheap	2	6	8	6	7	6	8
Doable	3	9	9	6	6	6	12
Cleaning	3	10	7	8	7	10	12
Material	2	6	6	7	5	5	8
Total score		31	30	27	25	27	40
Percentage		77,5%	75%	67,5%	62,5%	67,5%	100%

Appendix D

Materials	Advantages	Disadvantages	Electrical conductivity σ(Siemens/m at 20°C)
Silver (Ag)	+High electrical conductivity even when tarnished +Most materials can be silver-plated	-High rate of degradation -More expensive to produce -Reacts to water and oxygen and degrades over time into semiconductors, becoming much less efficient in moving electricity.	$6.30x10^7$
Copper	+ Soft, Ductile and Malleable +Recyclable +Anti-bacterial	-Reacts to water and oxygen and degrades over time into semiconductors, becoming much less efficient in moving electricity.	$5.98x10^7$
Gold (Au)	+Does not react to water and oxygen +Low rate of degradation	-Expensive	$4.52x10^7$
Aluminium	+Light weight	-Reacts to water and oxygen and degrades over time into semiconductors, becoming much less efficient in moving electricity.	$3.5x10^7$
Nickel (Ni, electrolytic)	+Cheap	-Reacts to water and oxygen and degrades over time into semiconductors, becoming much less efficient in moving electricity. It-Not allergy-friendly	$1.46x10^7$
Iron (Fe)	+Cheap	-Reacts to water and oxygen and degrades over time into semiconductors, becoming much less efficient in moving electricity.	$1.04x10^7$

Appendix E


Dept.
1:3
Technical reference
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Kirill Peljuh
20-1-2023
Approved by
Document type
DRAWING
Document status
Title
Concept headband
DWG No.
Rev.
Date of issue
Sheet
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Sky of Safety

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Abstract— *Flying drones in a swarm is an idea that targets a niche market typically in the military, the entertainment industry for lightshows or in geographical mapping for surveying landscape. Drones have recently experienced a surge in the economy and shows no sign of slowing down. This paper is written to show how flying drones in swarms can be used in a different scenario such as in a case of emergency especially in hard-to-reach areas. The objective of the paper is to demonstrate the design, construction, and assembly of the drone as well as the development and installation of the software that will ultimately enable each drone to do its designated task.*

Keywords— *drones, swarm, flight controller, battery*

I. Introduction

When drone swarms are looked up on the internet, the first results found are linked to military use which is a controversial area. However, this has not stopped the growth of drones in the economy, with the Worldwide Commercial Drone Market Size expected to hit around USD 47.38 Billion by 2030 [1]. Drones are being implemented into different industries such as agriculture, wildlife preservation, transport, and delivery etc. With this sporadic growth, it became apparent that there is still much to be developed and understood from drones due to its evolving technology.

As said earlier when researching drone swarms, mainly information pertaining to military use and lightshows is what is found and any additional knowledge that is outside that context is limited. With drones being a rapid technological advancement and proving to be a lucrative business it has become a hot topic. This paper aims to present an innovation of drone swarms for a target audience that has special requirements which focus on how user friendly the interface is, affordability, randomized starting locations and the weight of the overall drone which should be less than or equal to 250g.

This entire project is an assignment for the fourth-year students in Fontys University of Applied Sciences that are specialising in Innovation Engineering. It is a team of engineering students from different disciplines as well as applied mathematics, business, and external assistance from a computer engineering student from Hellenic Mediterranean University.

II. Use Case

Accidents on the road happen merely daily, some of more fatal nature as others. However, in every case a human life or even several human lives are endangered. The aim of this project is to improve this situation using small and lightweight drones. It is imagined that the drones get placed throughout a city or defined area covering every place to be reached in minutes or even seconds. When an incident happens at a random place the authorities/emergency services are notified and are instantly able to convey the location of the accident to a software system connected to the drones. The software chooses which drones get sent-off based on certain criteria such as the distance to the incident, the type of incident and the number of drones needed. Each type of incident can have different pre-settings concerning how the swarm will operate. Types of incidents, scale of the incidents, distance to the incident could be criteria to base the swarm intelligence on.

The drone's added value is offering timely information to the emergency services. This information can result in a proper response. Knowing the accident type, the number of people/vehicles involved, images or video of the surrounding area will be the first aspects emergency services can consider. The emergency services could then respond and act to the best possible scenario which will result in improved aid, reduced response time, and less fatal casualties.

III. Hardware

The first step in the definition of the hardware components was the clarification of the user requirements, as shown in Table 1. From here, the requirements were translated into system requirements, which can be found in the report (see table 2). The analysis for the best design was split into a mechanical and an electrical section. On one hand the mechanical subgroup was responsible for the selection of the following hardware components:

- Frame
- Material
- Motor

On the other hand, the electrical subgroup had to pick the following components:

- Battery
- Flight controller
- Led

It should be noted that throughout the research for the components, calculations were employed if needed. For example, to understand the requirements for the specification of the battery. The choice was based on the requirement that the drone must be able to stay in the air for thirty minutes. The formulas used in that subchapter were reported below in

$$time = capacity * discharge/ADD$$

$$ADD = AUW * I$$

Figure 1: Battery Calculation

Here, “discharge” represents the battery discharge that is allowed during the flight. LiPo batteries can be damaged if fully discharged. Hence, it is common practice never to discharge them by more than 80%. “ADD” stand for average ampere draw from the drone’s motors. “AUW” stand for all up weight of the drone. Finally, “I” represents the current required to lift one Kg in the air.

Table 1: User requirements

Reference	Name	Description	MoSCoW rating	Categories
#U001	Drone is light	Drone weighs less than 250g	Must	Mechanical Design
#U002	Drone is cheap	Drone costs less than 40 euros in components	Must	Mechanical Design
#U003	Drone can fly in swarms	Drones communicate with each other to fly together and generate shapes in the sky	Must	Software Design
#U004	Start from different locations	The drones must start from different locations	Must	Software Design
#U005	Return to home feature	After the task is done the drones need to return to their original locations	Must	Software Design
#U006	Drone can fly outdoors	Drone is able to adjust to wind changes and fly without disruption outside	Must	Electrical Design
#U007	Drone can fly for 30 mins	Drone can start, perform its task, and return home within a period of time of 30 min	Should	Electrical Design
#U008	Drone features a light source	Drone features a light bright enough to be visible from a distance	Must	Electrical Design
#U009	Drone is autonomous	Drone is piloted by a program and no external input is required while running the task	Must	Software Design
#U010	5 proof of concepts are required	5 proof of concepts that work together need to be built.	Should	Mechanical Design
#U011	Safe to be used	The drone needs to land in a safe manner (without harm to people) in unexpected situations.	Must	Mechanical Design
#U012	Sustainable design	Drone is designed with the environment in mind, taking care of material choices, waste, energy use and other factors affecting the impact of the product on earth.	could	Mechanical Design
#U013	Drone light visible from the ground	Each drone can be represented as a pixel. They should be able to be seen from a distance	Must	Electrical Design
#U014	Write a user manual	User manual should be done so that the end users can understand how the system and overall product works	Could	Software Design
#U015	Drone is self-balancing	The drone should be able to stay in a stationary position	Must	Software Design
#U016	Geographical Location for the drone navigation	The hardware should have a GPS chip to be able to know its position in space.	Should	Software Design
#U017	Data communication drone to drone	There is no central computer required to provide the commands to the drones. Communication is done between them using sensors.	Should	Software Design

This research culminated with the definition of the Morphological chart (see Figure 3). The chart sums up the option taken into consideration during the research for the components. The selected hardware solution for each category were highlighted in green and indicate the singular parts of the final design.

As it can be seen from the said figure, the choice used for the battery were a specific kind of batteries: lithium-polymer (LiPO). This is the most used type of battery for drone purposed with optimal weight to capacity ratio. For the frame to be employed, many different versions were looked at, but the final decision was the most utilized and classical approach: a quadcopter design.

About the material, an analysis through the software Granta Edupack was conducted. The following options were taken into consideration:

- Polyamide 12 (PA12/Nylon)
- Polyethylene terephthalate glycol (PETG)
- Polylactic acid (PLA)
- Acrylonitrile butadiene styrene (ABS)
- Polycarbonates (PC)

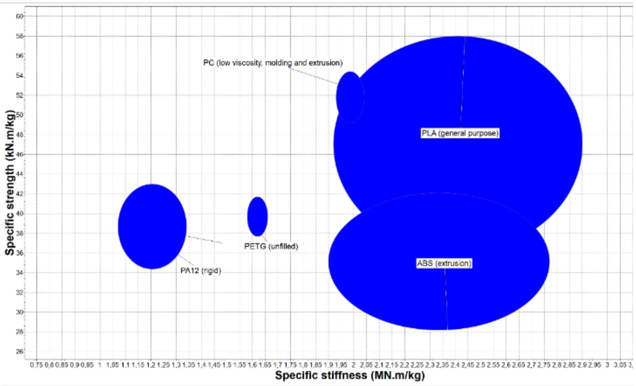

Figure 2: Specific strength - specific stiffness ratio thermoplastics

In this case, the three most important (mechanical) properties were: low density, high strength, and high stiffness.

Since there are no initial values, finding the best ratio between these three properties is the ideal route to determine the optimal material. Therefore, the chart will consist of two properties: specific strength and specific stiffness as shown in Figure 2:

The kind of motor was selected to be brushless, over linear, accordingly to most of the drones on the market. For the flight controller and ESC choice, the flight controller for sport flying along with the Speedybee BLHeli32 45A 4 in 1 ESC (V22) were selected for the reasons that were explained in the following section: Software.

The led choice was conducted mainly through the parameters or luminosity, weight, and cost. A ring set of led by the weight of 3.3g was chosen for this component.

MORPHOLOGICAL CHART					
	option 1	option 2	option 3	option 4	option 5
BATTERY	lithium-polymer battery (LiPo)	lithium iron phosphate battery (LiFePo4)	Lithium Ion (Li-Ion)		
FRAME	Tricopter	Quadcopter	Hexacopter	Octocopter	
MATERIAL	NYLON	PETG	PLA	ABS	PC
MOTOR	brushless motor	linear motor			
FLIGHT CONTROLER	Flight controller For Sport Flying - SpeedyBee	Flight controller For Autonomous flying - F405 FC	Flight controller For Cinema Flying - The DJI NAZA-M V2	Mateksys F405TE	
ESC	Speedybee BLHeli32 45A 4 in 1 ESC (V22)				
LED	3.3 gr 37 mm	- gr 112 mm	1.5 gr 23 mm	24,21 gr 71,17mm	- gr 1000 mm

Figure 3: Morphological chart

The most feasible and efficient options (in green) were chosen to create a concept that would satisfy the user and system requirements. This approach was taken instead of creating and analysing three different concepts because of the many limitations that the components gave to one another. These requirements made it impractical to create other combinations of components that could compete with the chosen one.

IV. Software

Swarming drones present a significant technical challenge due to the inherent complexity of coordinating the movements of multiple autonomous systems. To achieve effective swarming behavior, it is necessary to develop algorithms that can handle the communication and decision-making requirements of many drones operating in close proximity. This requires the integration of multiple technologies, including real-time communication systems, sensor networks, and advanced control algorithms. Additionally, the dynamic nature of swarming scenarios introduces the need for robustness and adaptability in the underlying control systems. Overall, the development of swarming drone systems requires a high level of expertise in a range of technical fields and presents a significant engineering challenge.

A. Autonomous navigation and pathfinding techniques

In terms of autonomous navigation, the team used the Python programming language and several libraries. Some of them are the pandas [2] library for data analysis, matplotlib [3] for visualization, and geopy for calculating geographical distances. The team has developed code that generates target coordinates for the drones to form different shapes in the air.

B. Pathfinding Algorithms and Reinforcement learning

To determine the optimal path for each drone to reach its assigned target coordinates. The method is to implement a pathfinding algorithm. This algorithm calculates a predetermined path based on the starting coordinates of every drone and its assigned target coordinates. The paths generated by the algorithm should ensure that the drones reach their target coordinates without colliding with each other whilst being the shortest path possible for maximizing efficiency. A possible algorithm to use is the A* pathfinding algorithm. It's well-known and widely used to solve a variety of problems. It is a type of best-first search algorithm, it is also optimal and complete, meaning that it will find the shortest path between two points in each environment if one exists. A* is efficient as it uses a heuristic function to guide the search toward the goal, which reduces the number of nodes that need to be evaluated [4].

C. Software of displaying a message

For drones to display a message they need to work together. Firstly, it is important to know where the figure will be displayed and with how many drones this will be done. To solve this a meeting location will be made. On this location drones will meet and wait for each other for a set time, this time is given by the user. During this period the drones will line-up in a long waiting line for other drones to join.

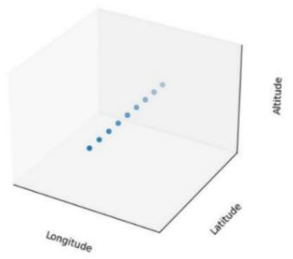

Figure 5: Waiting in line

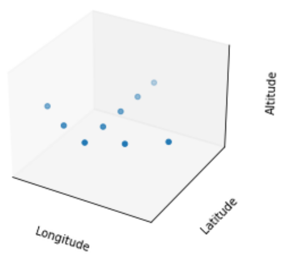

Figure 4: Arrow display

A new coming drone will get a unique ID number and coordinates to be placed in the waiting-line. When the set time has been passed no new drones can join the swarm to display a figure. The drones that were in time are each given a new coordination to display the figure. There are 3 figures: a circle, an arrow and a cross. Each figure will increase in size when the number of drones is higher than the minimum number, which is 5.

V. Final Design Concept

With the outcome of the choice in mechanical components and electrical components, a drone frame was designed. All the research regarding dimensions of each component was conducted from the relevant datasheets.

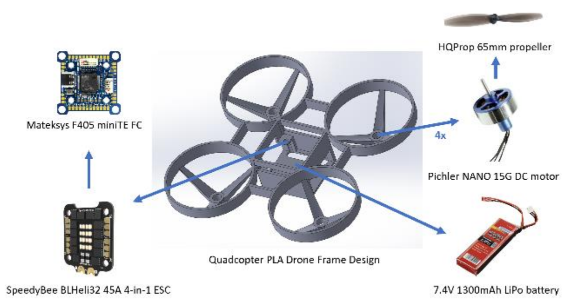

Figure 6: Exploded view final drone design

For the design of the frame as seen in Figure 6 a quadcopter concept was chosen, and the four motors are placed as an "X" on the frame. To maintain the balance of the drone, it was decided to place the battery pack, the motor controllers, and the flight controller in the middle of the frame.

Following the "Sky of Safety" use case, safety is a big aspect of the project. It is therefore very important that the drone is safe for society. Since the drone frame contains four rotating propellers, it was decided to protect it with a surrounding cylinder that limits damage to both the drone and the colliding object in the event of a collision.

VI. CONCLUSION

The goal of this project was to design a drone that is lightweight, affordable, safe to use and starts flying from random locations. For the mechanical aspect, all components were able to fit in the desired position on the frame. After weighing the frame together with all components, it came to be 246g fulfilling the lightweight requirement. The frame design took safety into account by shielding the propellors.

A software has been made that makes it possible for the drones to display 3 figures, these are: an arrow, circle, and a cross. Every drone is given new coordinates for their position to display emergency information. The software provides a data frame with coordinates for displaying the figures for each drone, this could be done in any location. The location and the distance between the drones can be pointed out by the user themself.

VII. REFERENCES

[1] STRATEGIC MARKET RESEARCH , "Commercial Drone Market – Report on $47.38 Billion Industry Opportunity, Increasing Usage of Small Drones in Commercial Applications & Remote Sensing Technologies to propel the industry growth.," 30 December 2022. [Online]. Available: https://www.globenewswire.com/news-release/2022/12/30/2581124/0/en/Commercial-Drone-Market-Report-on-47-38-Billion-Industry-Opportunity-Increasing-Usage-of-Small-Drones-in-Commercial-Applications-Remote-Sensing-Technologies-to-propel-the-industry-.html.

[2] W. McKinney, "Data Structures for Statistical Computing in Python," in *Proceedings of the 9th Python in Science Conference*, 2010.

[3] J. D. Hunter, "A 2D graphics environment," in *Computing in Science & Engineering, 9(3)*, 2007.

[4] S. Russel and P. Norvig, Artificial Intelligence A Modern Approach, New Jersey: Pearson, 2010.

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Fully renewable energy system for a household

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I. Introduction

Global warming is a major problem facing all of humanity. And the crisis is getting worse, global greenhouse gas emissions are rising and 2016 was the hottest year on record. The Earth is warming, the ice caps are melting, climate disasters are becoming more frequent and more intense. There is no doubt that our planet is changing, and scientists agree that humans are responsible.

The environment must be protected quickly by acting now on our electricity consumption, because 40% of the world's CO2 emissions are due to electricity production. The use of renewable energies is a way of reducing greenhouse gas emissions and dangerous radioactive waste, and their resources would be infinite thanks to the wind, water, the heat of the earth and the sun.

Thus, our project of autonomous house is part of a current dynamic by providing an answer to a real need that is expressed. We can therefore ask ourselves if a house that is fully autonomous in renewable energy is a sustainable way of life for both the environment and for human needs?

II. PROBLEM ANALYSIS

A. *Problem and objectives of the project*

To address today's climate change concerns, energy producers must be environmentally friendly, while energy consumers should be thrifty. To fill this gap, producers and consumers should merge into prosumers to tackle environmental, economic, and social sustainability.

The project consists of three steps. Firstly, a theoretical study of the overall energy demand of a household, like heat, electricity, cooling energy, per year. Then they will study the different quantities of energy produced by the different renewable energy systems.

Therefore, in a second step it will be necessary to correctly size a household using a fully renewable energy system, by coupling the different equipment together in order to optimise the energy production/consumption ratio. For example, a photovoltaic panel with a solar thermal collector, to supply electricity to a geothermal heat pump or absorption chiller.

Thus, to finalize the project, the students will have to design a proof of concept, which means a house with pre-defined dimensions at the start, which has the renewable energy system dimensioned in the second stage. In order to reduce the cost of the prototype, it will have to be realized with a 3D CAD software.

III. TECHNICAL SOLUTIONS

A. *Energy demand*

It is important to note that these energy needs depend on many parameters, such as the size of the house, the number of inhabitants, local weather conditions, the desired temperature in the house, the hours of use of the house, the electronic devices used in the house.

This is why our team decided to work on a concrete case, which allowed us to focus on a specific situation, to take into account the real constraints, and to validate the feasibility and efficiency of an energy solution before its extension.

A.1. Thermal Energy demand

First of all, it was necessary to determine the amount of heat needed to heat the water in the sanitary facilities. That is, the water in the shower and the water in the taps used for washing up. With the flow rate of an economical shower head of Qv = 6 L/min = 0.0001 m³/s, [1] an ideal shower duration of 7min for one person, we obtain a consumption of 210 L/day for a household of 5 persons. Knowing that it takes 1.162 Wh to heat 1L of water by one degree, and knowing the temperature of running water per month, we can determine the amount of heat Q needed to raise the water temperature to 35°C for a shower.

$Q = V \times Cv \times \Delta T$

Q: Quantity of heat in [kWh]

V: Volume processed in [L]

Cv=1,162: Heat density of water in [Wh / L.K]

ΔT: Temperature difference in [K]

Months	January	February	March	April	May	June	July	August	Septembe	October	November	December	Total :
E (kWh)	225,3	217,7	202,6	187,5	106,8	91,7	69	76,6	106,8	202,2	210,2	225,3	1921,7

Figure 1:Thermal energy demand per month to heat water

The second step was to determine the quantity of heat needed to heat the living rooms. For this purpose, a heat loss study was carried out in order to find out how many degrees a room in the house loses during the day when nobody is at home and the heating is switched off. Of course, it depends on many parameters such as the outside temperature, the insulation of the walls, ceiling and floor.

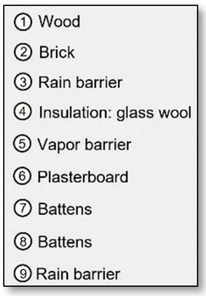
Heat flow through the wall:

$$\phi = \frac{\Delta T}{R}$$

ϕ: heat flow(W)

ΔT: Temperature difference(K)

R: Thermal resistance(K/W)



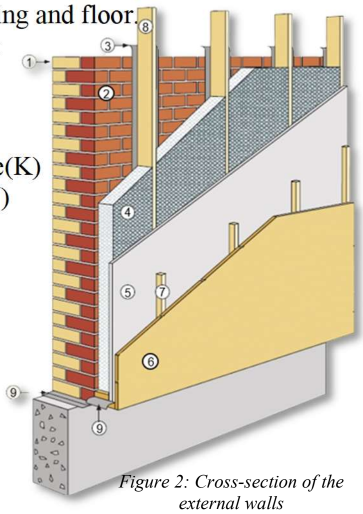
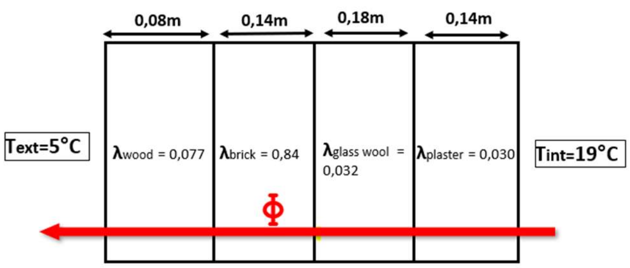
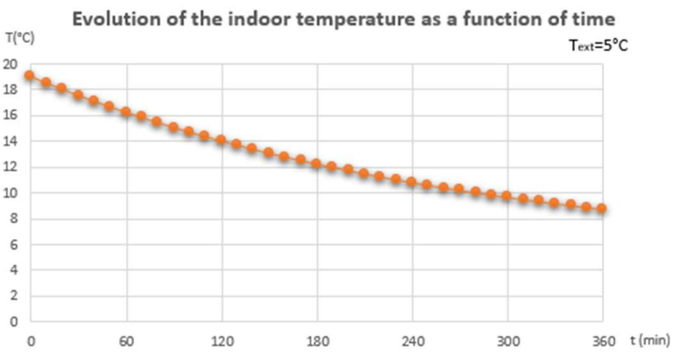


Figure 2: Cross-section of the external walls



After calculating the thermal resistance of the room, R_{room}= 0.148 K/W, and then its heat flow, we obtain the quantity of heat lost by the room, and therefore the number of degrees lost per hour.



Based on the average outdoor temperatures between 9am and 5pm in Strasbourg in 2021[2], we can determine the number of degrees lost in the room compared to T_{inside} between 9am and 5pm for each month. Then we find the quantity of heat needed to heat the room to 19°C from 17h.

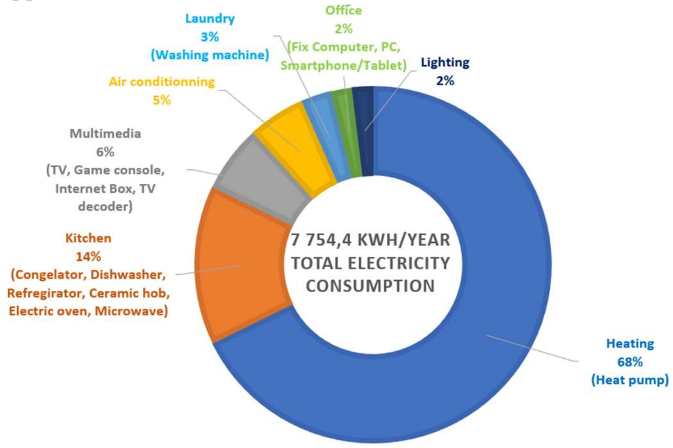
By adding up the quantity of heat needed to heat the sanitary water and that necessary to heat the living rooms, we obtain the thermal energy demand of the house, it takes 2450 kWh of thermal energy per year to meet the demand for a family of 5 living in 150m².

A.2. Electrical Energy demand

To facilitate the search for these data and to obtain results that are as close to reality as possible, it was useful to use data from the ADEME website [3].

Most of the household appliances have been chosen with the best ecological class, class A, in order to reduce consumption as much as possible. In addition, our calculation assumptions were based on four 40°C washing machine cycles for normal laundry and one 60°C cycle for boiling laundry per week.

For heating, the selected geothermal heat pump can heat an area of 150 m². This device is used in heating mode in winter and in cooling mode in summer. It is therefore a reversible system. Most of the electricity consumption is due to the geothermal heat pump system, which represents 68% of the total consumption. But compared to a standard 150m² house, which would consume about 23 000 kWh of electricity per year. Our energy efficient house with energy saving appliances would save more than 66%



B. Electrical Storage

The best storage method is the Lithium-Ion battery as it is the method that is best suited for a stand-alone house. Firstly, because it has a suitable size, secondly because it has the best capacity and storage time, and in addition because of its safety and reliability.

It exists a last electrochemical method to storage electricity, the battery Ion – Lithium. This method is the most popular for houses autonomous in energy to connect this battery with solar panels. On the market xStorage Building Compact by Eaton can storage 150 kWh for a consumption of 21.2 kWh per day, so this battery can storage one week (7 days) of electricity. [4]

In addition, a 2m² photovoltaic panel produces 400 kWh per year, so with a 207 m² south-facing roof covered with 78 photovoltaic panels, this produces 31 200 kWh per year. So with a production of 85 kWh/day, and a consumption of 20kWh, the battery can store 65kWh per day.

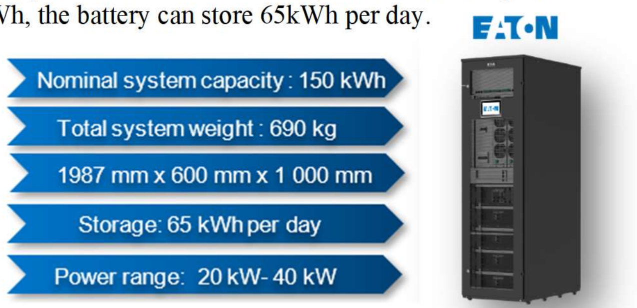


Figure 3: Example of a battery: xStorage Buildings

C. Thermal Storage

Thermodynamic hot water tanks are often considered the most suitable for self-contained houses. They allow thermal energy produced by renewable sources to be stored and redistributed for heating and domestic hot water production.

Most of the household appliances have been chosen with the best ecological class, class A, in order to reduce consumption as much as possible. In addition, our calculation assumptions were based on four 40°C washing machine cycles for normal laundry and one 60°C cycle for boiling laundry per week.

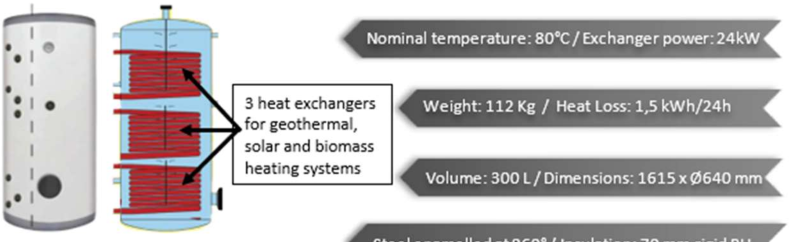


Figure 4: Hot water storage tank

D. Coupling of different energy devices

Firstly, the coupling of different renewable energy sources allows for more reliable, optimized and flexible energy production. Renewable energy sources are not always available continuously, for example, solar energy is only produced during the day and wind energy depends on weather conditions. By coupling different renewable energy sources, it is possible to have more reliable and constant energy production. Some renewable energy sources are more suitable for certain seasons, for instance, solar panels are more efficient in summer while wind turbines are more efficient in winter. Thus, thanks to coupling it is possible to optimize energy production according to actual needs.
In addition, it is possible to adapt energy production to real needs and to compensate for periods when there is not enough energy produced by renewable sources. For example, combining solar thermal panels with a biomass burning stove to heat water for sanitary facilities.

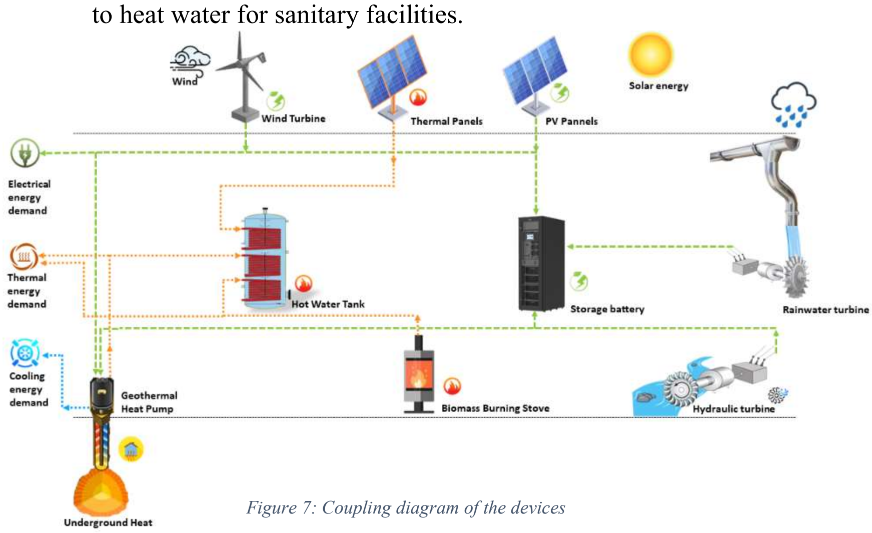


Figure 7: Coupling diagram of the devices

E. Proof of concept : 3D model

This is the last step of the project, creating a house with the calculation assumptions already defined before, with the fully renewable energy system selected above. The 3D model was designed with the building design software, Revit.

Location is important for an energy autonomous house because it can affect the efficiency of renewable energy generation systems, such as solar panels and wind turbines. For this reason, a south-facing location was chosen to maximize sunlight reception. Choose a location that is high up or away from obstacles such as buildings to optimize wind exposure, and also check for the presence of a waterway for the installation of the Hydroelectric micro-turbine.

Figure 26: Location of the selected parcel *Figure 25: House orientation*

The 3D design was made following the previous assumptions, with the same insulating materials in the walls. It has a very large roof of about 200m² with a 30° south-facing slope to allow the installation of numerous solar panels. The construction of a glazed greenhouse glued to the house reduces heat loss in winter, as it acts as an additional insulator with the inside air warmer than the outside. In the summer it will be covered to keep the house cool and provide a barrier against the heat. A wind turbine has even been placed on top of the house to take advantage of the best wind flows.

Figure 5:Exterior view South

Figure 6: Exterior view North West

Figure 8: Inside view greenhouse

Figure 9: Solar access study

The purpose of the solar access study is to measure the amount of sunlight received by a given building or site over a given period of time. It can be used to determine the viability of a solar energy installation on a given site, and can maximise the use of daylight in a building, which can reduce lighting costs and improve energy efficiency. In addition, it can help plan landscaping to maximise the use of solar energy and minimise shading. According to the software's solar study, a 30° inclination of south, southwest, and southeast facing panels provides the best energy efficiency.

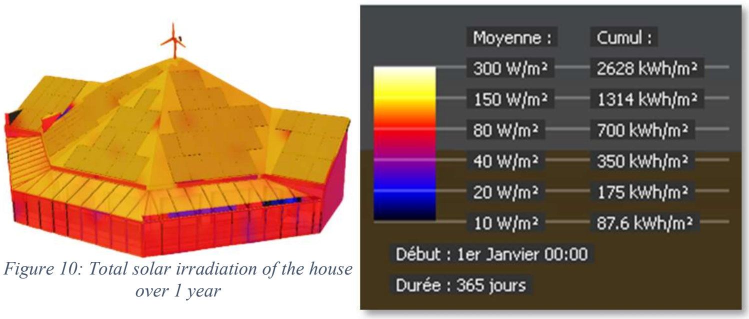
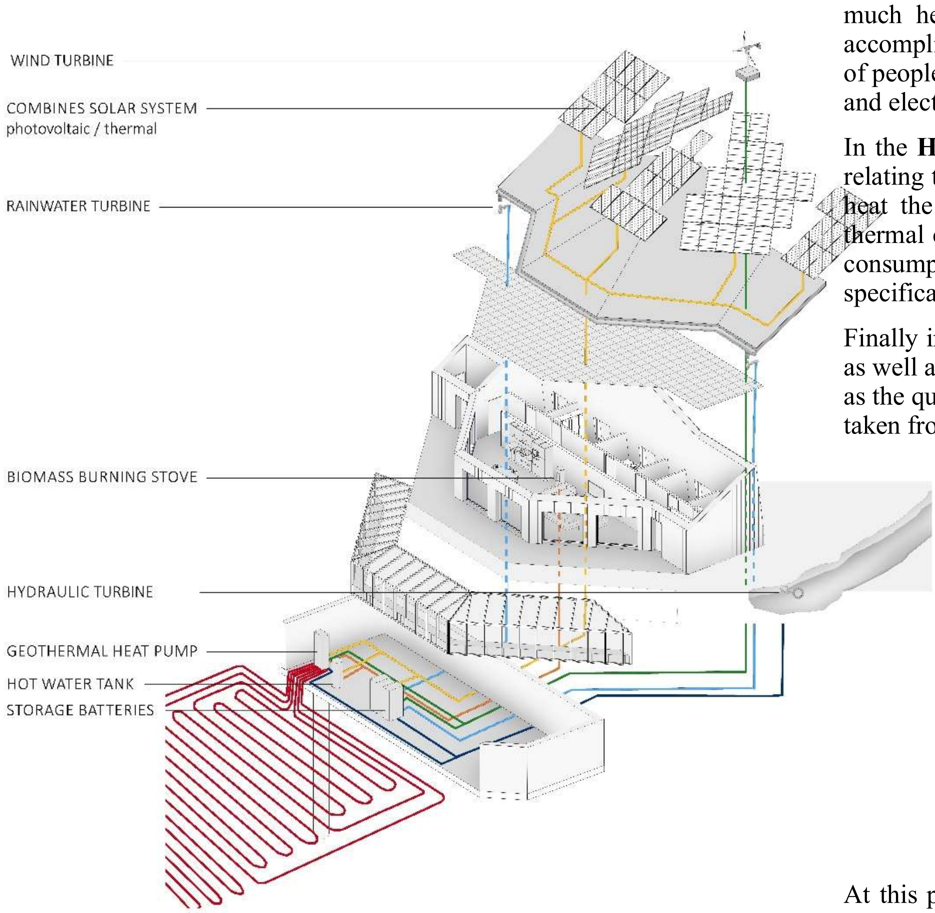


Figure 10: Total solar irradiation of the house over 1 year

F. Implementation of the fully renewable energy system



G. Creation of a photovoltaic system sizing application

The use of energy monitoring and control systems is increasingly used to manage energy production and storage systems. Therefore, the aim was to develop an application to size a household's photovoltaic system, with the aim of reducing the need for energy from the grid to be more sustainable and environmentally friendly.

G.1.1 Functioning of the application

The application is structured in several folders; we proceed to describe in the various sub-chapters how each of the folders work analysing every input and output.

G.1.2 Input folder

It is necessary to enter the data on the building under study, size, presence of windows, area of the house, in order to obtain the necessary information in order to calculate the heat exchange within the rooms.

In the **transmission** section, general values for the transmission coefficients of windows, floors and walls are pre-filled, however, if the user wishes, it is possible to modify those values.

In the **ventilation** section, a target ventilation rate per hour per person can be provided with heat recovery through a mechanical ventilation system (pressure drop and heat recovery efficiency are referred to this).

In the **internal heat gains** section, the aim is to estimate how much heat is produced inside the house and in order to accomplish this, the following inputs are needed: the number of people generally present in the house, the number of lights and electronic appliances per square metre.

In the **Hot Water section** section, there are the parameters relating to the calculation of the electrical energy required to heat the water contained in an electric boiler using solar thermal collector; it is therefore necessary to enter the water consumption amount per person and some technical specifications of the panels.

Finally in **economy**, the system component price are shown, as well as some parameters that are then used for sizing, such as the quantity of energy produced per PV, the rate of energy taken from the grid.

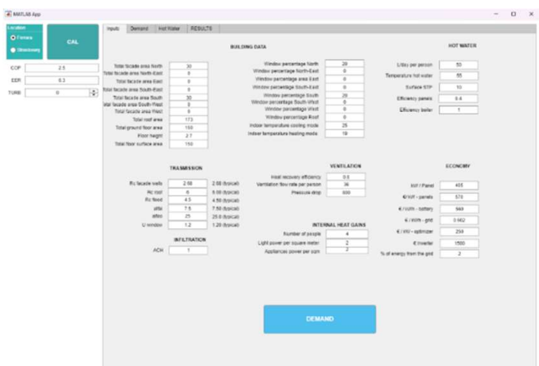


Figure 11: Input folder

At this point, the location (Ferrara or Strasbourg) has to be selected so that the irradiance parameters referring to the location taken from database [5].

H. Results

We have designed an algorithm considering different criteria in order to size the battery by knowing the PV panel capacity.

At this point the trend of the battery charge analysis and of the economic side for each hour of the year is calculated, based on 25 years (lifetime duration of the system).

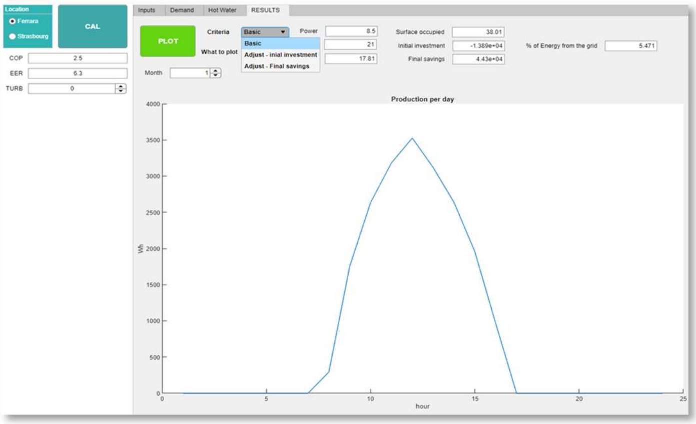


Figure 12: Energy production in kWh from solar panels per hour

I. *Achievement of objectives*

The objective of building a proof of concept with a fully renewable energy system has been achieved. As for possible improvements, a simulation of the heat flow in a 3D model could have been done to have a better view of the insulation, but also a central automatic system to manage all the energy flows by the user living in the house.

The aim of this application was to size a household's photovoltaic system, and it has been achieved. A future upgrade could be the introduction of multiple sources of energy production, for example the wind turbine or the geothermal energy. Another improvement could be the possibility to select multiple positions all around the world, using the irradiation and temperature data from each location. Artificial intelligence and the current application make it possible to create a first estimate of the sizing of the energetical devices, however, for more precision, it is necessary to take into account the characteristics specific to each area. For example, topography, surrounding buildings and trees can create important solar masks, which cannot be anticipated by the application as long as it only considers the solar irradiation of a city.

IV. CONCLUSION & FUTUR DEVELOPMENTS

To conclude, firstly, the theoretical study on the energy demand of a household has been carried out only on the thermal and electrical part. It would be important in the future to also look at the cooling demand. In addition, it would have been interesting to study the electricity consumption of appliances hour by hour in order to obtain the most realistic data possible.
In a second step, for the dimensioning of the fully renewable energy system, an optimal coupling of all renewable energy technologies was carried out with concrete solutions. For example, the use of a micro-hydro turbine, which is not yet widely used. To improve our coupling, the study of an automatic central system to manage all energy flows by the user or by an AI could have been done.

To finish this project, the design of a 3D model with the coupling of the different devices was carried out. As for future improvements, an economic assessment can be made to optimise the cost of the house and thus determine the payback period.

REFERENCES

[1] https://www.ecohabitation.com/guides/1018/la-pomme-de-douche-a-faible-debit-linvestissement-le-plus-rentable/

[2] https://www.infoclimat.fr/climatologie/annee/2021/strasbourg-entzheim/valeurs/07190.html

[3] https://bilans-thermiques.fr/energetique-batiments/isolation-thermique/conductivite-thermique-materiaux

[4] https://www.eaton.com/content/dam/eaton/products/energy-storage/xstorage-buildings/fr-fr/eaton-xStorage-Buildings-Compact-fr.pdf

[5] https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

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Eliminating single-use Packaging

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Abstract
This paper answers the main question: “How to eliminate single-use packaging in Dutch supermarkets and the Spanish municipal markets?”.

After completing the project, it can be said that by using the new reusable sustainable packaging design, the usage of single-use containers can be completely eliminated. In order to do this, the group followed the conceptual, design, and business phases, during which a final implementation plan was created. To stop using single-use packaging, an implementation strategy must be followed. You can find it in chapter VIII. This document provides more explanations of the group's process for arriving at the answers and outcomes.

Keywords - Reusable, Sustainable, Plastics, Single-use packages, Supermarkets, Food Industry

I. INTRODUCTION

In this world full of plastics and semi-plastics, the earth pollution is getting bigger and bigger every hour and every minute. Most of these plastics are non-recyclable or non-biodegradable which leads to huge junkyards everywhere on the planet. Furthermore, the more plastics are being produced, the more emissions of CO2 are released in the atmosphere. Not only the production, but the processing of the plastic waste has a harmful effect on the only planet people can live. All this pollution is then leading to consequences suffered by all the living creatures. In the recent years, the sustainability has become a largely discussed topic, especially in Europe [1]. There are numerous official documents that were signed for reducing the carbon emissions and plans how to move to a more sustainable world. Perhaps, this requires not only agreements to be made, but companied, industries and people to change their mindsets towards a green future.

In the Netherlands, nearly forty percent of the plastic waste is generated by the food industry [2]. This huge plastic waste can be seen in every household on this planet which makes this problem not only Dutch, but Global. Thus, it requires quick actions to be made in the direction of lowering the amount and in the end eliminating all the single-use packages. The innovation and the creative technological thinking in mind should be used to fulfil the end result.

This is the reason why as part of the sustainable society, Fontys University of Applied Sciences is gathering students from different streams to form teams in order to solve some of the sustainability issues of our world, especially the extensive use of single-use packages. These group of students should collaborate with each other and gather their knowledge and through the engineering find solutions for these problems.

II. BACKGROUND OF THE PROJECT

Every person has ever been in the supermarket, and he/she has seen how many fresh products are in plastic packages that are thrown in the garbage right after they were used. Plastic single-use containers are being used because they preserve the quality of the food, are light-weight and it’s easy and cheap to be manufactured and sold. Food industries find this solution the cheapest and easiest without considering the life cycle of these containers. Moreover, most of these plastics are not reusable and the consumer is forced to get rid of them as soon as possible. They are either thrown in the garbage or somewhere in the nature. This problem not only occurs in the food industries, but in others as well stimulating the so-called “throw-away” culture. Most of these plastic packages tend to contaminate the food with micro-plastics which can lead to health problems and serious stomach diseases [3]. However, lowering the amount and gradually getting rid of these single-use food packages is of high necessity. An innovative, reliable, eco-friendly and corporate solution is needed together with interdisciplinary work to accomplish the final goal.

At the moment in The Netherlands most of the people tend to go to the big supermarkets, rather than open markets, to buy fresh groceries. They find it convenient to choose one store and buy all the food they need. Walking through the supermarket, the customer can notice how many fresh vegetables, meat, fish and pre-cooked meals are wrapped in single-use plastics. There are no showcases from where the customers can pick whatever they want and place the products in a personal, reusable container. Therefore, the packaging system should be changed so that it fits the current way of selling fresh food.

III. CONCEPTUAL PHASE

Methods

The two methods that are most used for choosing the concept are the Kroonenberg method [4] and Design for eXcellence. The Kroonenberg method is a way to decide which concept is the best, a tool in this method is the Kesselring method. In the Kesselring method you put the aspects that are important, if you have 5 concepts, you give the best concept in this aspect a score of 5 and the worst a 1. You also use a factor for which aspects are important, so if you think the design is important you will do the scores form the design times 3. At the end every concept gets a total score and the concept with the highest score, is the best concept. Next to the Kroonenberg method the Design for eXcellence is used, this almost the same as the Kesselring method but the factor does not get used. Also, in the DFX method there can only be a curtain aspect because with the DFX method a web can be made, in the web you can see immediately which aspects are the strongest.

Table 1 Design for eXcellence method

Aspect	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Functionality	5	7	8	9	6
Costs	9	6	7	2	1
Recyclability	8	6	6	3	1
Reusability	1	8	9	6	2
Food safety	3	6	9	7	10
Appearance	2	6	6	5	3
Total	28	39	45	32	23

Concepts

At the start of the concept there were five concepts. The concepts are explained shortly. The first one was using bee wax paper to wrap around the meat or fish. The second one was an already existing box, a Tupperware. The third one is to make a box with an air-tight film on top of the box. The fourth concept is a reusable box with solar panels and an integrated cooling system. The last concept was that the meat or fish is sealed in vacuum bags. To choose the right concept the Kroonenberg method and the Design for eXcellence method is used. In both methods the concepts are rated on some aspects that are important for the project. In both methods concept 3 got the best score, concept 3 is to make a box with an air-tight film on top of the box, this box is made of reusable plastic so only the film can’t be used again. In this way it is easy to implement in the current market and the same machines can be used to put the film on the boxes. That it's easy to implement is an important aspect for the project.

IV. SYSTEM EXPLANATION

Because the current system, where the linear ‘take-make-dispose’ model is still in place for the largest part of the packaging system. A new future proof system, which is sustainable, must be implemented. To accomplish this four optimizing systems can be used, which are the systems of reduce, reuse, remake and recycle. The group wants to accomplish this, for food packaging of meat and fish products, by focusing on reusing in the following way:

First a cycle for the Dutch market is designed. in this new system the packaging is reused many times over. Which means no waste is created. When the packaging is used too many times, when it starts to show signs of wear, the packaging gets recycled into new packaging. In this system material used for the packaging is seen as an asset, which is important for a sustainable system. The different choices in the whole process are chosen because of requirements that have been made for this project.

The food is put in the box and packaged with a film. This part is crucial because it covers multiple requirements. A film is chosen because of the following reasons. Because of the film it can be seen if the package has been opened or not. Because of the film, the packaging is for single use. This is also for the contamination after the packaging.

The product information is put on the film. In this step the following requirements are covered. The requirement ‘adjustable price and information per cycle’ is covered because the box will be used for multiple products with different prizes. By putting the information on the film, the information won’t be permanent, because the film will be thrown away after every use.

The film of the box will be seen through and the packaging will be the same size as the current packaging. In this way the product inside will be seen by the customer. When the customer chooses their food, a goal is to make the experience as easy as possible. The new system is more attractive to the customer.

Customer brings the box back to the supermarket. The design of the box is made in such a way, that the boxes can be stacked when they are empty. This will make the experience even easier for the customer, because there is not a lot of space needed to return the boxes to the supermarket.

Customer delivers box at supermarket and retrieves the deposit money. The two requirements that are implemented in this step are ‘Encouragement to bring back the product’ and ‘reusable’. Because the customer paid some deposit money to bring the box home, it will encourage them to bring the box back. The box can only be reused if the customer brings the box back. If there is no deposit money implemented in the system, the customer will throw the box away, or keep it at home if possible.

The box gets transported to the factory. Because of the requirement ‘limited sizes’, the logistic will be easier. There only will be a few sizes of boxes, so the transportations will be easier.

The box gets checked for wear and quality. This step is crucial because here there will be checked if the box is good enough to use for another cycle. A few requirements will be covered in this step. The requirement ‘food safe material’ will be implemented when making the box. This step is needed to make sure no hazardous materials can get into the food. Also, the requirement ‘May not absorb substances’ is implemented, to make sure no bacteria can grow in the material. The design will be hygienic design (no sharp edges and holes), to make sure no bacteria can

figure 1 Sub cycle of packaging

grow in between edges and no particles can stay there. The design should also be fool proof (no breakable parts), to make sure less packaging needs to be replaced. When the box gets rejected, it will be demolished to make a new product.

The box gets cleaned at the factory. The requirement ‘the design is dishwasher safe’ is added because the box will also be cleaned in the factory. This will happen in high temperatures, so the material that will be chosen for the box should handle these temperatures, and not deform or change shape. The requirement ‘open design for access to clean’ is also covered because the cleaning must be done by machine so it´s easier to have access.

Box gets demolished, and material is being reused for new boxes. The material should be recyclable to make sure that the impact on the environment is as low as possible. When the box shows signs of wear, the box will be demolished, and the material will be used again to make new boxes. When the box gets checked for wear and quality, and the box shows the signs of wear of damage, it gets rejected. After rejection the box gets demolished, so the material can be reused easily. From the raw material, the boxes will be made again to enter the cycle where the food is being packaged and used.

For customers who decide to use the meat or fish inside the packaging for multiple dishes on different days. It is possible to buy an additional lid. With this lid it is possible to close the packaging again after use, this makes it possible to save part of the portion in the fridge for another time.

In the Spanish market, the food gets packaged in the open markets, so the system will be slightly different. Instead of the boxes that will be used for the packaging in the factory, the Spanish markets could also implement a system with buying the boxes in the market instead of paying a deposit and returning it.

V. DESIGN CHOICES

Health safety restrictions

The "Nederlandse Warenwet" [5] contains a list of the specifications for materials that come in contact with food. The "Nederlandse Warenwet" is expanded to include European legislation. For material used with provisions, there are two basic constraints listed in the Verordening (EG) nr.1935/2004 [6].

- Material that is hazardous to human health is not allowed to migrate to the provision in adequate quantities.
- It is prohibited for the material to degrade in flavour or health, or to make unacceptable changes to the way it is provided.

An explanation of plastics used with provisions is given specifically in Verordening (EU) nr. 10/2011 [7]. Additionally, it is stated how many elements can be added to the provision before it becomes harmful. The Panel on Food Contact Materials, Enzymes, and Processing Aids must certify a material before it can be used as a food contact material (FCM) (CEP). A panel working for the European Food Safety Authority is represented here (EFSA). [8]

Cleaning

The boxes should be cleaned after the customer empties them and returns them. This will be accomplished by returning the boxes to the factory, where they will be cleaned and sent back out to be refilled with a new product. [9] Using steam is one method of cleaning the boxes. For instance, butchers use steam to clean their cutting boards and other supplies. The department that sells fresh goods also uses this method of cleaning. To clean with steam, water must be heated to temperatures between 100 and 150 degrees Celsius. Following are a few benefits of steam cleaning:

- Effectiveness: The cleaning process is quick and thorough. The surface of the product is cleaned and disinfected by steam cleaning. There is no need for chemicals for disinfection.
- Sustainable because it requires less to no cleaning agents and uses less water than washing the boxes with water.

Selecting a material

Edupack can be used to select a material. There are many requirements that the material must meet. This is divided into four categories, mechanical properties, thermal properties, durability properties, and remaining properties. The reference standards that are used are derived from a material analysis of all materials used for similar purposes, such as Tupperware or lunch boxes. It is possible to get a picture of what kind of material characteristics the substance should have by looking at what materials are used to make these products. Next, it can be determined which of these characteristics are the most crucial for this product's application using these characteristics. Following the research, a margin may be drawn to allow for the addition of more materials. Because consideration can be given to this when designing the packaging, for example, by considering the product's shape.

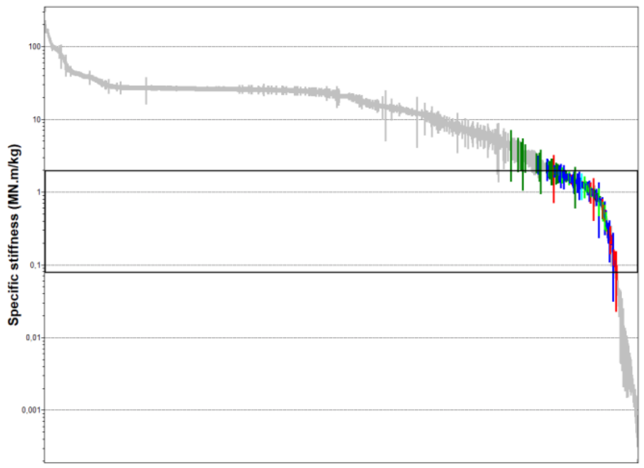


figure 2 selecting Specific Stiffness (CES edu pack)

Final selection

The following step is to make an appropriate selection from these materials. The best material suitable for the packaging must now be identified from the overused materials. By observing what has typically occurred when using these materials, this can be accomplished. Another important consideration is whether the material is food-safe; this is especially important for any material that meets food intended for individual consumption. Next, materials that can be built to create a package for the right occasion can be chosen from the materials that were previously mentioned. These are the materials that are provided in this article once more. The truly appropriate materials have been chosen from this list of excessively blended materials. With the chosen materials. with the selection of the 4 materials that can be found in the appendix, FEM calculations have been made with the design of the packaging. This to make a final selection to get the best material. This led to the conclusion that **PC+PBT (general purpose)** is most suitable for the application that is in mind.

Packaging design

The design of the new packaging is crucial in bringing new sustainable packaging to the stores. To make it simpler to adopt the entire system of new sustainable packaging, this design must work with the existing workflow. A list of prerequisites must be created to achieve this. To achieve this, the first step is to examine the existing single-use packaging.

The new packaging must be able to be used in the current system, which is an important need. This means that the new packaging will need to roughly match the dimensions of the existing single-use packaging. Some criteria for the new design were aided by the single-use packaging that is currently in use. There will be a list of every requirement before a new design can be made.

These requirements have been taken into consideration as the three different designs were developed. When designing the new concepts, the material must be taken into consideration. The material influences the way of manufacturing and designing. In the previous paragraph a material was chosen for the new design of the boxes. The material chosen is PC+PBT and is an excellent choice for injection molding according to the material properties. Most meat will grow bacteria faster when the meat is laying in moisture, therefore there are ribbons in the design of the current packaging. These ribbons are also implemented into some of the concepts of the new packaging. The ribbons in the boxes are the primary difference between these three variations. The liquid is able to rest between these ribbons, the meat is placed on top of a piece of paper on the ribbons. This will ensure that the meat within the package will not lay in its own moisture.

The first design is based on the current steak packaging. In these kinds of packaging no ribbons are used. After this design the ribbons are introduced in the second design. These ribbons will prevent the meat from laying in its own liquid which can cause bacteria to grow. In most currently used single-use packaging there is a grid pattern of ribbons. This is not used in the new packaging because a grid formation will have more corners and edges which are harder to clean. This is also the reason for the third design to not have the outside ribbons. A major downside to not having the outside ribbons is that the box is no longer stackable when empty. The first and second design have an inclination of 6 degrees which makes them stackable.

To choose the best concept out of the three concepts the method of the Kesselring diagram is used. This method is done with six of the most important requirements for the final concept. Which are: easy to clean, easy to manufacture, prevent meat from laying in moisture, hygienic design, stackable, amount of material necessary. These requirements are split in realizing and functioning requirements and are graded individually.

The Kesselring diagram leads to the conclusion that concept 2 is the concept that is closest to the ideal line. The best of both worlds may be found in concepts that are close to this line, which aided in choosing the ultimate concept to employ moving forward. Concept 2 has been picked as the concept to continue with. The validity of this concept will be discussed in later paragraphs, and if necessary, minor design changes will be made to make this reusable container more durable to withstand all tests. An illustration of concept 2 can be seen in figure 1

Figure 1: Illustration of concept 2.

Calculations

Calculations must be performed to verify if the container is robust enough to withstand specific forces in order to ensure that the concept is resilient enough to tolerate repeated usage. Calculations on this container are also necessary to optimize the container's material thickness. A large number of containers must be created before the containers are used in supermarkets. The quantity of material required may be significantly decreased by making the containers as thin as possible while yet allowing for reuse after being subjected to specific stresses.

To test the durability of the container different kinds of tests are performed. At first there is a drop test performed to validate if the container will survive an accidental drop. The container is dropped from two meters in the test with a weight inside the container of 500 grams. The container itself weights 128 grams. This makes the total weight of the container 628 grams. In this drop test the container falls on the corner with a speed of 6,26 m/s, this speed is calculated for a height of two meters. By using this simulation, it is possible to find multiple results of the forces on the container during different times of the drop. The simulation will also show the speed of the drop, the displacement, and the stresses. For this test the container is dropped on a concrete floor. Results of the impact force can be seen in figure 2.

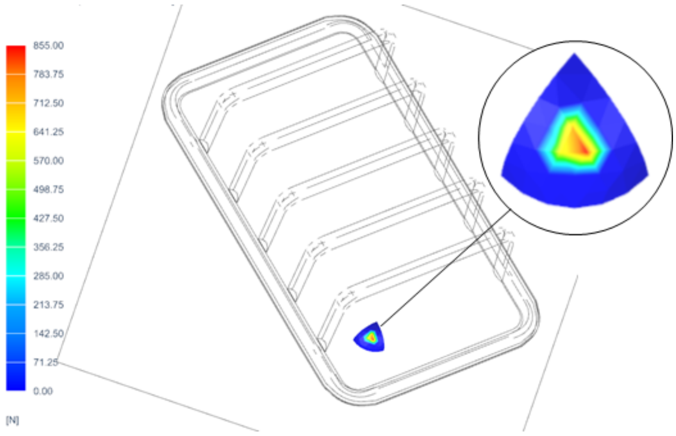


Figure 2: Impact force on corner. Max: 855 N

The average stress of the corner the container is dropped on is 51,29 MPa. Earlier in the “Material research” paragraph, a table with the material properties of PC+PBT was given. In these material properties the tensile strength and yield strength can be found which are important to compare with the results of the simulation.

This is not an exact number because this depends on the composition of the material and the circumstances of the material. For this comparison the average of both strengths is taken to come with a conclusion if the container can withstand the drop or not. As earlier found in the simulation results the stress on the containers corner is 51,29 MPa. When compared to the material properties of PC+PBT this is under the limit of the yield strength and the tensile strength. This means that the container will survive the fall and only deform elastically. The stress of 51,29 MPa is barely under the yield strength and tensile strength limit. This indicates that the wall thickness of the container is set up properly for a two-meter drop. If the stress result is substantially lower than the yield strength, the material's wall thickness is likely too thick, which will result in more plastic being used for each container. Costs and plastic consumption would rise as a result.

FEM simulations must always be validated with manual calculations. it assumes a situation in which the container is dropped from a height of two meters. the container will hit an infinitely hard surface exactly at one of the corners. it is also assumed that the container contains an object of 500 grams. upon contact with the ground, an x speed has already built up. the container will deflect at the corner. it is assumed that the deflection that the container has is equal to the amplitude of the natural frequency of the container. when the container hits the ground, it will move a certain distance through with a certain energy. the energy can be determined by looking at the potential energy of the container just before hitting the ground. The results of the FEM and the hand calculation are compared, and the difference is 0,92 % which is within the generally acceptable limit of 5% there for it can be assumed that the FEM simulations are valid.

VI. BARCODE AND TRACKING SYSTEM

Apart from the design of the box and all the benefits that it will have for the sustainability and the environment, a barcode system should be implemented so that the supermarkets can sell their products. Next to that, the sustainable package should be tracked to be able to know how many cycles it had. These two aspects are thoroughly reviewed to find the best scanning method suited for the packaging.

Speaking of the barcode that every product has, it should be applied on the packaging as well. For this reason, some concepts are investigated to find the best one that fits the packaging. The first one is an NFC chip placed in the package itself that contains all the information of the product and the package. The idea sounds modern and technological, but it’s not sustainable enough when the product will be recycled together with the NFC. Furthermore, there is a risk of failures in long term, and it is not suitable for industrial wash processes. The package should not contain any non-recyclable or other types of materials such as metal, copper, wood etc. [10]

The second option that might be applicable in the project is placing a NFC sticker (as in the clothes and book stores) but then this sticker might be ripped off by everyone and all the information regarding the package will be lost. Furthermore, the NFC implementation requires extra equipment and software to read and write data on the chip which adds extra investments into the general concept. This NFC idea adds the technological value to the packaging but makes the design and concept complicated and costly which might not be appealing to the food industries and the supermarkets. The other option that might be applicable to track the usage cycles is a normal QR code or a barcode sticker placed at the bottom or on the side of the package. In this case again the downside of this solution is that this sticker can be lost easily by ripping it off or compromising it by scratches or while washing.

The solution that will really fit within this packaging system consists of two types of barcodes. The first part is the barcode that has the information regarding the product that is inside a certain box. This will remain unchanged, as it is nowadays. In this case, the supermarket/food industry has the freedom to place their unique barcodes on top of the plastic lid. In addition, leaving the current barcode stickers, the supermarkets will not be forced to pay extra for devices and software that read and write on the NFC chip. This scenario is easily implementable and does not require extra investments, by just placing the barcode stickers and the product information on the already existing plastic lid. Regarding the tracking of the usability of the package itself, it was decided that after the box has been made, a laser or similar machine will engrave a long barcode at the bottom of the container, containing the serial number of the box. In this case the package can be tracked how many cycles of usage it has and can be applied in the software systems of the food industries. The reason why the barcode should be long, is the fact that possible scratches or unwanted small damages can be made to the barcode, compromising the information. Making it long enough, the chance of scanning the package even with scratches increase.

VII. BUSINESS ABILITY

A business plan should be created before entering the market. For this the challenges and opportunities where researched. Numerous steps were followed to make sure the business can be successful financially.

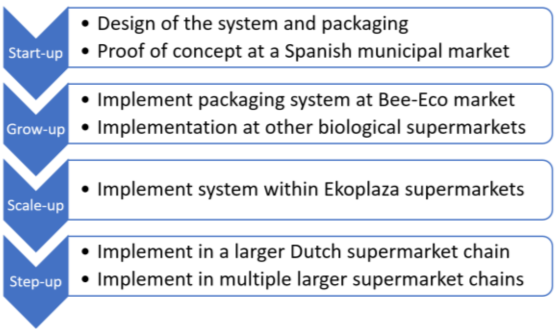
As a first step the target group was analyzed to see if people are willing to pay extra for sustainable packaging. As the world, especially Europe, is moving towards sustainability, the need for sustainable packages is rising [11]. Nowadays, in some of the Dutch markets, they found a way to remove the single-use bags for vegetables and snacks by replacing them with a cloth type of bag which is washable and reusable [12]. This means that these supermarkets are already moving toward the plastic-free market and there is a potential for this project. But if small and big supermarket chains are willing to use the new sustainable packaging, then there should be a way to make people pay for it. The project group has decided to look into the "Attitude of European citizens towards the environment" report for truthful survey performed by the European commission for all the European members. In this report there are mentioned two main aspects of the Europeans' attitude: 85% of people believe they can play a role in protecting the environment and three-quarters of Europeans are willing to pay a little bit more for environmentally friendly products. These two main conclusions that were made are indicating that people in Europe are willing to invest in the new sustainable packaging idea if they find it sustainable for the environment [13].

The group used the DESTEP analysis to find the current trends in the market and determined for every trend what the influence will be on the demand/supply market. This analysis is a useful tool to do market and business research. The project group also performed a basic Strategic/Marketing model called the SWOT analysis. This technique helped the group to find their strengths, weaknesses, opportunities and threats. According to these analysis, there are more opportunities available for the project and even though that there is a lack of some competences, the project's idea is entrepreneurial. There is room for a future business integration and good prospective.

VIII. IMPLEMENTATION PLAN

To be able to implement the new sustainable packaging the group needed an implementation plan which is in line with their strategy. The end goal of the group is for their company to eventually have the largest market share in sustainable food packaging for at least fish and meat products in the Dutch supermarkets. This means their sustainable packaging will be the new standard packaging in the future (for at least fish and meat products). The group wants to accomplish this by following the start-up, grow-up and scale-up phases that can be seen below.

Table 2 Implementation plan



At first, during the start-up phase, it's important to see if the reusable packaging works in a municipal market. Here it's easiest to get it implemented for a ''proof of concept''.

To be able to implement this in a municipal market there needs to be an extra stand where the packaging can be returned and cleaned. The customers at the market pay a small deposit for the reusable packaging, if the customer brings back the reusable packaging to the "packaging stand" they receive their deposit back and the deposit can be used in the rest of the market. When the concept is proven to work the next phase can start.

For the grow-up phase, Bee-Eco is used as an example, a local biological supermarket in the Netherlands. Because this is a local supermarket and not a chain of supermarkets it's easier to pitch the idea and to convince the management team/owner to get the packaging implemented.

To be able to convince Bee-Eco it's important that the concept is proven to work at the municipal market and that the results can be shown in this pitch. With the product, the reusable packaging, there is no plastic waste anymore and it's expected that Bee-Eco and it's customers are willing to pay for that. Also here, a deposit system will be used. It needs to be like the deposit system used for bottles, which is already in place in the supermarkets. If everything works in this stadium and the customer(s), the supermarket, is satisfied the next phase can start.

For the scale-up phase a small chain of supermarkets would be ideal, Ekoplaza is used here as an example. The Ekoplaza is used because it's a biological supermarket and as mentioned customers that buy their food in a biological supermarket, tend to pay a little extra to be better for the world. Ekoplaza has 85 stores in the Netherlands and Belgium combined and has 35 pickup points in the Netherlands.

For Ekoplaza the same deposit system is going to be implemented as used in the local supermarket in the earlier stadia. Because Ekoplaza has more stores there needs to be a different and more efficient way of cleaning the reusable packaging, a cleaning company can be used for this or a machine that cleans the packaging can be implemented in the food production line(s). This will make the system more complicated because there are more stores, and the food is packaged at food producers (factories). After the package is used, the customer brings it back, a cleaning company cleans it or it gets cleaned in the food production line of the food producer by a machine, the food is placed in and then it goes back to the supermarkets. If this system works here and there are no boundaries the step to the next stadium can be made.

For the step-up phase a big chain of supermarkets, the Albert Heijn is used as an example. To convince the Albert Heijn the results from the previous phases need to be presented, also because the Albert Heijn has a lot more stores, they need a lot more reusable packaging. Because they need a lot more packaging, it can be mass produced, which will make the reusable packaging itself cheaper. Of course, at first it is still going to be more expensive to use as the current packaging, but not in the long run. This is because the reusable packaging can last many cycles and after that the material can be recycled into new packaging, which will make it cheaper in the long run. The same deposit system as in previous phases must be used here as well, maybe in this case the Albert Heijn needs to start their own cleaning company to make the system cheaper or implement the cleaning step in the food production lines itself to reduce transportation steps. These ideas can only be used for the larger supermarket chains like Albert Heijn, because they can afford it. Together with Albert Heijn it must be discussed what is the best and most efficient way for them to implement it within their supply chain.

Using the phases mentioned above, the group made a strategy roadmap in which these phases are mapped out in a multi-year plan. This is of course not predictable, but it can be a guide for them when going through the different stages in practice. While this happens, the steps and goals can still change depending on the future developments.

IX. LIFE CYCLE ASSESSMENT

A life cycle assessment (LCA) is a method that can be used to determine the environmental impact of a product. This is an ideal method to determine if the new reusable sustainable packaging is really better for the environment than the current single-use packaging. Because in the end that's the reason to start using sustainable packaging.

The collaboration with students from the EUSS School of Engineering in Barcelona, made it possible to perform the LCA´s. These LCA´s are used to compare the current impact on the environment with the expected impact after implementing the sustainable packaging. This was done for the ''start-up'' phase, which will be done as a proof of concept at the Spanish municipal market. The current packaging used was compared with the new reusable packaging.

What can be concluded from these LCA's is that the reusable packaging starts with a higher impact than the single use one, because the production of it has a higher impact on the environment. But after a couple uses in between 5 to 10, the reusable one already has a lower impact on the environment.

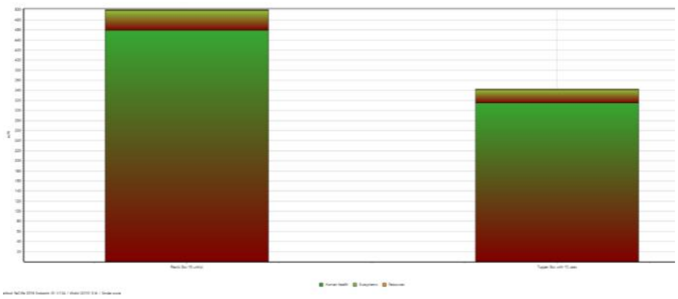


Figure 3 Environmental impact of 10 single use packages (left) vs using reusable package for 10 times (right)

The results show the impact of using 10 single-use packages (left) and shows the impact of using 10 times one reusable package (right). This shows that the impact on the environment of the reusable package after 10 uses is already about 30 percent less compared with using 10 single use packages. After more than 10 uses the percentage amount in impact on the environment becomes even higher. This means the total impact on the environment will be lower the more cycles it's used.

X. CONCLUSION

After working on this project for several months there is an answer given to the research question, which was: "How to eliminate single-use packaging in Dutch supermarkets and the Spanish municipal markets?"

The concept phase of the project was the first and included several concepts. The best concept is selected using the Morphological Chart, Kroonenberg approach, and Design for eXcellence method. Concept 3, a reusable box with a film on top, was chosen, in part because it is the most straightforward to implement in the existing market and the film can be applied to the box using the same machines. It was more crucial to come up with a simple notion than a revolutionary, high-tech solution that would be too difficult to implement in the market at the time.

It was important to run simulations to evaluate if the design is sturdy enough to validate the packaging's construction and establish whether it is suitable for use in the real world. A FEM simulation was used to validate the design. Then, the FEM simulations were validated using manual calculations. These hand calculations are accurate and are within a 0,92 percent tolerance of the results of the FEM simulation. The drop test results show that the container can withstand drops of two meters. Since the maximum stresses on the container's corner are below the yield strength of PC+PBT, it can only bend elastically. The container's wall thickness has been efficiently optimized, and it can sustain drops of two meters because the peak stress from the drop is just a little bit below the yield strength. The endurance of this container's design has also been confirmed by other tests done on it. It is therefore determined that the packaging may be utilized in the real world, where the product must be quite robust to life through sufficient life cycles, by employing realistic tests that occur in the real world.

The group used the DESTEP and SWOT analysis to get better understanding of the current market conditions. It became clear that the current market is waiting for solutions for the single-use packaging problem. There has never been a better time to introduce new ecological packaging. The group created a business strategy with several execution phases to accomplish this. They used start-up, grow-up and scale-up phases with suitable markets in every phase. Starting from a small municipal market and growing to a larger supermarket chain by following the different implementation phases. For every phase an expected business canvas was made, and a strategy roadmap was delivered as a guide when everything gets implemented in the real world.

The fact that more and more individuals are prepared to pay a little bit more for sustainability is another positive effect. In addition, people dislike changes, which is another reason why the idea which is a sustainable solution without significant changes works so well. The only modification is that you now must return your box for a small payment.

XI. ACKNOWLEDGEMENT

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XII. REFERENCES

[1] S. M. a. J. D. Mulder, “Strategic Environmental Assessment and Sustainability in Europe,” *Strategic Environmental Assessment and Sustainability in Europe,* 2005.

[2] H. v. Nederland, „Wij gebruiken 26 miljard plastic voedselverpakkingen per jaar en het wordt alleen maar meer,” *Hart van Nederland,* 2019.

[3] A. V. B. R. Luís Gabriel Antão Barboza, „Marine microplastic debris: An emerging issue for food security, food safety and human health,” 2018.

[4] H. Geraedts, „week 2 Kroonenberg Method Haay Geraedts,” [Online]. Available: https://canvas.fontys.nl/courses/12185/pages/week-2-literature?module_item_id=266698.

[5] Staten-genertaal, „Warenwet,” 17 11 2018. [Online]. Available: https://wetten.overheid.nl/BWBR0001969/2018-11-1718. [Geopend 14 11 2022].

[6] Eur-lex, „Document 32004r1935,” 14 5 2017. [Online]. Available: https://eur-lex.europa.eu/legal-content/NL/ALL/?uri=CELEX:32004R193518. [Geopend 5 11 2022].

[7] EUR-lex, „Document 32011r0010,” 15 5 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/NL/TXT/PDF/?uri=CELEX:32011R0010&from=nl18. [Geopend 6 11 2022].

[8] C.Panel, „Panel on food contact materials, enzymes and processing aids,” 17 3 2018. [Online]. Available: https://www.efsa.europa.eu/en/panels/18. [Geopend 6 11 2022].

[9] Nilfiks, „waarom reinigen met stoom de beste oplossing is wanneer hygiëneessentieel is,” 20 5 2018. [Online]. Available: https://new.nilfisk.com/nl-nl/article/steam-solution-when-hygiene-is-critical/18,20. [Geopend 8 11 2022].

[10] C. F. E. Kosuke Ishii, „Design for product retirement and material life-cycle,” 1994.

[11] E. Commission, „Single-use Plastics,” 2021. [Online]. Available: https://environment.ec.europa.eu/topics/plastics/single-use-plastics_en.

[12] DutchNews.nl, „AH and Aldi to stop using plastic bags for fruit and vegetables,” April 2021. [Online]. Available: https://www.dutchnews.nl/news/2021/04/ah-and-aldi-to-stop-using-plastic-bags-for-fruit-and-vegetables/.

[13] D.-G. f. E. Directorate-General for Communication (European Commission), „Attitudes of European citizens towards the environment,” European Commission, 2017.

[14] U. Nations, „Paris agreenment,” *Paris agreenment,* 2016.

The Infinity Light

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Abstract

As part of the Innovation Engineering specialization, the participation in the I2E2 project was an opportunity to work on a hands-on a international collaboration project. For this group, the project was completely centred around the safety of joggers. Within this subject, the choice of innovation was entirely open for interpretation. The chosen innovation for this project was to create a sustainable form of lighting for joggers. After thorough patent, design and target group research, the choice for an innovation fell on a wearable lighting accessory with a circular coil. With the use of a moving magnet inside this coil, electricity would be generated and be used for powering a LED. The movement of the magnet will be caused by the movement of the runners arm during running. A long testing phase, with different magnets and coils, resulted in a working proof-of-concept with a burning LED light.

Keywords

Innovation, Energy Generation, Jogging, Sustainability, Safety

I. Introduction

As part of the Innovation Engineering specialization, the participation in the I2E2 project was an opportunity to work on a hands-on a international collaboration project. For this group, the project was completely centred around the safety of joggers. Within this subject, the choice of innovation was entirely open for interpretation. The chosen innovation for this project was to create a sustainable form of lighting for joggers. After thorough patent, design and target group research, the choice for an innovation fell on a wearable lighting accessory with a circular coil. With the use of a moving magnet inside this coil, electricity would be generated and be used for powering a LED. The movement of the magnet will be caused by the movement of the runners arm during running.

II. Project Definition

Jogging is a hobby beloved by millions around the world. Be it casual or professional, jogging is a healthy activity that allows a person to build up their cardiovascular strength. However, this activity comes with its fair share of problems, and this project aims to address and assists in one of the main problems.

Those who can't jog in the daytime due to a variety of reasons, tend to find times later in the day or very early in the morning to try and fit this sport into their schedule. Often, times like these are lacking in natural light, thus needing the jogger to find some way to illuminate their path or themselves to prevent running into obstacles or others running into them. This is where running lights come in.

However, the biggest issue with running lights is the generation of power. Batteries are the main source of energy for said lights, and battery disposal can be quite harmful for the environment as chemical leakage can contaminate soil and underground water.

In order to oppose this, this project tackles the creation process of a wearable accessory that generates power through movement and converts that power into a form of light. Possible waste and harm towards the environment are removed by doing this, and the duration of light is only limited by the jogger's own movement and energy.

III. Project Management

The project management has been done using the agile work principles. The goal of this way of planning is to be more flexible and make it easier and better to react to changes. This is done by creating a detailed plan for a shorter timeframe to decrease the effect of later emerging requirements. With this method the project has been split into 4 phases: Requirement phase, concept phase, detailing phase and realisation/testing phase. At the beginning of each phase a sprint meeting is held. During this meeting the objectives of the phase are listed and all the tasks are divided. During the phase itself weekly scrums take place to talk about the progress and the problems that occur while working on the different tasks.

IV. Requirements

One of the most important parts of starting and ending a project is paying attention to the requirements of the project. Requirements are quite important at the start of a project to find the scope and needs of all the stakeholders within the project. At the end of a project the requirements are very important to decide whether or not the end product meets all the criteria. For this project the requirements are divided into five different categories: End user, Geometrical, Reliability, Functional and Electrical requirements. The requirements are described following the SMART-principal.

A. End user requirements

In order to determine the end user requirements a form has been send out to as many people as possible to get an insight in what the consumer expects from a running light. The end user requirements will be listed from the results obtained by the answers from the people who do go running in the dark, since this is the most important target group. For most questions the results are almost the same between the two groups except for the maximum weight and size the light can be.

The following end user requirements were provided from the most common answers in the form:

- The light must be visible from a minimum of 90 meters.
- The device must emit white light, but could also emit red light.
- The device must be rain water proof.
- The device must run on a renewable energy source.
- The maximum weight of the device is 100 grams.
- The device must last at least 3 years.
- The maximum size of the device must be the same as a credit card holder.
- The maximum price of the device must be between 30 euros.

B. Geometrical requirements

The geometrical requirements described the goals or demands for the characteristics of the total product: size, mass and resistance to wear/water. The product has to be smaller than 80x80 millimetres and lighter than 100 grams.

C. Reliability requirements

The reliability requirements have a lot to do with the geometrical requirements, because these requirements define the reliability that the costumer can expect from the product. The product should be proven to have a water/dust resistance level of IP65 [1]. The lifespan of the product needs to last at least for 10 million fluctuations, with one fluctuation occurring at one step, it needs to last 10 million steps. Additionally, the product should withstand a fall from 5 meters. As a whole, the product needs to suffice with the RoHS health guidelines and EU Ecolabel sustainability guidelines [2] [3].

D. Functional requirements

On the more mechanical side, the product also has functional requirements. This category of requirements describes the needs and demands for using the product. The first and most important functional requirement of this project is that the mechanism must be guided by the movement of running and must use this energy to generate electric energy. Generating this energy by move the human body means that it should be comfortable to wear and thus be made of comfortable materials. This goes hand in hand with the requirements of the size and weight, which should also make it comfortable to wear. Furthermore the product should be easy to use, which makes is easy to be put on and taken off fairly quickly. Of course the product should also be save to wear, so there should be no possibility for any electric shock or other ways that the user can get hurt.

E. Electrical requirements

The last category of requirements contains the electric characteristics the product should/must possess. Of course the product must have a source of lighting and an energy generation that runs. Besides that, the light should have a low energy consumption to improve the light-up time. The light must be visible from a minimum of 90 meters and must burn constantly during activity.

V. Research phase

In this project, research plays a very large role in innovating to a working proof-of-concept. The research into patents, designs, solutions and components gave the project group the best insight on the options for a good concept.

A. Patent research

In order to find out what (self-sufficient) running lights are already existing, a thorough patent research was carried out. This patent research was split into two separate parts: a mechanical patent research and an electrical patent research. The research on mechanical patents was focussed on different ways to use light-emitting accessories for running. As a result of this research, six different mechanical patents were found on the patant database called espacenet.com:

- Directional free-hand wrist illumination device: This lighting device is composed of a wristband equipped with plurality of forward-facing LED [4].
- LED self-reeling luminous bracelet: A LED strip is arranged fully through the band and emits light all the way around the bracelet. The on/off switch is triggered by shaking or moving the bracalet in a fast manner. [5]
- LED light-emitting wrist strap: The utility model is composed of a LED-light, housing and a wrist strap. By pushing the button, the light will turn on and the area surrounding the bracelet will be illuminated. The two sides of the bottom end of the mounting plate are connected with an RFID chip and a microprocessor in an embedded mode correspondingly. An operation button is arranged in the middle section of the upper end of the mounting plate. [6]
- Chest light for sport uses: The product is compiled from 2 straps around the user's shoulders and a light emitting 'box' on the belly of the user. This apparatus uses energy given by a battery to emit the needed amount of light to be visible in the dark and other natural circumstances. [7]
- Clip type light: This device is attachable to a cap visor to ensure the vision field of the user. It also makes the user visible for oncoming traffic when running or doing other activities in the dark. The LEDs can be powered via a cable but there is also a way to power them via solar cell. The clip light can easily be attached or detached without damaging the visor [8].
- Multi-functional lamp: This multi-functional lamp includes a carrier module, a rotating

element, a light emitting module, a compressing mechanism and an elastic clamp mechanism. It can be used for a numerous amount of thins [9].

Besides a research into the mechanical patents, there is also research conducted into the electrical part of a running light. More specifically, the electrical patent research was focussed on self-sufficient energy system for running. In the case of this project, it means that the energy is generated by the movement of the human body during sports activities. In this research three patents on self-sufficient energy systems were found:

- Wearable power generation device for collecting user exercise through movement: The energy that is needed to power up the device comes from a moving magnet inside a coil. When the magnet moves at a certain speed inside the coil it generates a magnetic field. In the patent visible that a device is strapped around the ankle [10].
- Improved energy storage system using capacitors: The utility model does not have an energy source. It needs to generate its own energy. This energy needs to be temporarily stored and outputted to the LED to provide light. A capacitor can be used for different purposes. A few example of the purposes are: energy storage, energy release and filtering [11].
- Planetary geared motor and dynamo: The model is using a circular coil with a magnet in the middle. The magnet moves in the middle around the coil to generate a magnetic field which then creates a voltage. The generated voltage then is used to power up the component inside the model (like a dynamo) [12].

All of the nine found patents give a great insight on both the existing mechanical as electrical designs/products that have been patented before. The results from this research gives therefore a better idea on which techniques, designs and products are not available to use as an innovation in this project.

VI. DESIGN PHASE

For the design of the Infinity Light two morphological charts have been made. One morphological chart is for the functionalities of the light. The functional morphological chart has been split into different subjects to find out how the device needs to function and what the device needs the be made of. Some of the subjects are: the position of the light, material and the attachment to the user. Positioning of the lights is important because visibility is a key factor of safety.

The material subject is mainly for the durability and sustainability of the product. The attachment to the user focuses on the way the light will be attached to the use.
The other morphological chart is made for the electrical components used in the concept, such as energy transportation and the light source. The parts are also very important for the end product, because these components decide whether the runners motion is able to generate enough energy to power the light.

A. *Functional components*

The functional morphological chart has been split into different subjects to find out how the device needs to function and what the device needs the be made of. Positioning of the lights is important because visibility is a key factor of safety. The runner needs to be always visible when running, so by attaching the light onto a specific location of the runners body, it is more visible to the surrounding. The best options are the ankle and wrist, because movement is the largest at these places when running.

In order to generate energy by movement it needs to be in a position where movement is optimal, therefore the decision of ankle and wrist. When jogging or running, these are the limbs that move the most. The device needs to be attached to the body since when the runner is running it causes shocks and if the device is not attached properly it can fall off or even be damaged, the options were, a magnet closure since this is already used on the watch, same goes for the clasp. These options will result in secure closure of the device when attached. By choosing the right material the runner can be more comfortable while wearing the device, so by choosing aluminium the device can be lightweight. It is important to make sure that the device is waterproof, this is due to the fact that when the runner is running in the rain, it is especially important to be visible by making the device with stainless steel material it is resistant to rust. When the device is not waterproof and the rain seeps in the device it can cause malfunction, by using a gasket the gaps are sealed.

B. *Electrical components*

The electrical components have been split in two different subjects which provide the inside device. The energy that is generated needs to be transported/delivered to the designated components to provide them with energy so that the device can fully operate. options for this are a PCB and wire. A PCB has traces on the board itself so that electricity can be transported. With a wire it can go through the wire to provide electricity. The light is an important part of the project, therefore choosing the right light is crucial to make the runner more visible. Options for this are a LED or a lamp. LED is more efficient and can provide lots of illuminations, depending on what kind of LED is chosen. The lamp is a basic light source, but it can take up a lot of energy. The energy needs to be generated. This can be done is various ways so in the morphological chart, options were presented to make sure that energy is generated in the most efficient way. By using movement, you can generate energy with a coil. By using a piezo element, pressure can be converted to energy.

C. *Different concepts*

The earlier described morphological charts led to four different concepts. All the concepts have one part in common, Generating electricity by movement while running. The concepts will be explained below.

- Concept 1: Circular coil bracelet

The circular coil concept will consist of a magnetic sphere in a coil. This coil will be circular and thus the magnet can move freely inside the coil without being stopped. When a magnet is moving through a coil it will generate electricity. So when the magnet is moving constantly it will provide a constant flow of electricity. The coil will be as big as a watch and will be placed on the wrist. The wrist is chosen to be the best place because there is the most movement while jogging, resulting in the magnet moving more than placed in a different spot.

- Concept 2: Dynamo

The dynamo concept will consist of two parts. A moving part, this could be the arms or the legs, and a part which doesn't move as much, This could be the body or the chest. An idea would be to use a rope attached to a moving part which will turn the dynamo on a part which doesn't move as much. This way movement can be converted to electrical energy.

- Concept 3: Dual magnet coil

This concept used the same principle of generating electricity as the circular coil. A magnetic sphere moves through a coil and thus generates electrical energy. In this concept 2 coils on different places on the body will be used so the chance of one of the two magnets moving through a coil is bigger than using only one coil. This results in the light lighting up more times.

- Concept 4: Knee light

The Knee light concept consist of a dynamo in the knee cavity. The dynamo will be attached to the backside of the thigh and to the calves. With every step the user makes, the dynamo moves and generates electrical energy. This is an interesting concept but is could potentially be dangerous due to the machine restricting movement in the leg.

D. *Definitive concept*

A definitive concept is chosen by ranking the four concept on how good they fulfil the requirements set up earlier. By using this ranking system concept 1, the circular coil, is the most the most promising concept.

VII. Design phase

In the first tests the principle of generating electricity by moving a magnet trough a coil was tested by using a straight tube. Per test there was gradually put on more windings around the tube to test how much voltage it would get to and to get a feeling for it. The voltage given by the product will be given in sparks because the magnet passes through the coil with a high velocity and then comes to a stop. These tests were done with a copper wire thickness of 0,5 mm. The spherical magnet has a diameter of 6 mm. The diameter of the inside of the tube is 7 mm so the magnet has some space to move around.

The first test has the least amount of windings tested. It generates a peak to peak voltage of 700mV. This is not enough to power the led used in this project. But it gives a promising perspective for the next test using more windings of copper wire.

For the second test there was used more copper wire than in the first test. The outcome of this test was significantly better than the one used in test one. This test generated a peak-to-peak-voltage of 1,76V. Since the last test gave a good output, it is time to use the same principle but in a circular form. Doing this will emulate the potential end-product output. Because of the coil being in a circle the output of voltage is more even throughout the motion instead of the sparks seen with the straight tube testing. The circular tube in which the magnet is moving is 3D printed in the 3D print lab facility at Fontys University. The outcome of this test is very promising, it has a quite constant peak-to-peak output of 2,42V. This is nearly enough to power the LED.

A. *Final testing*

With these test results that are nearly enough the logical point to improve on is the copper wire thickness. In the test above a copper wire thickness of 0,5mm is used. For the next test a thickness of 0,15 mm is used. There is chosen for this number because it has to be strong enough not to snap or break, but also thin enough that there can be many windings in a small space and thus generate more electricity. For this test 100 meter of copper wire is used to wind around the tube. The outcome of this test gave a peak voltage of around 4,1V and a average voltage of around 2,5V. A circuitboard is made to see if the coil is able to power the LED light. When atttachng the circuitboard to the coil the and shaking the infinity light up and down the light lights up and provides quite a bright source of light. The light dims out softly over time and is thus very constant in its illumination.

B. *Prototype*

The prototype consists of the circular coil tested last. A casing is designed to keep the device safe from wheater conditions such as rain and mud. Also a strap is designed to make sure the infinity light stays attached to the wrist as long as the user wants it to be. All together this makes it the first prototype of the infinity light.

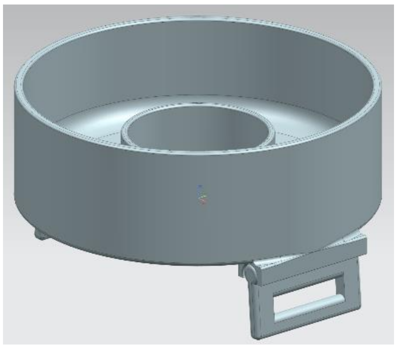

Figure 1 CAD design of the complete casing of the product

Figure 2 Prototype of the end product

VIII. Discussion

The project itself, the communication and end result came out better than anticipated at the first couple of weeks. However, besides being satisfied with the end product, there is enough room for improvement. With the subject 'Safety for joggers' being as vague as it was in combination with the international collaboration starting after a month, the project group started with the so-called running blade project. When the collaboration started, the choice was made to innovate into the lighting for joggers. Unfortunately, at this time about half of the given project time had passed. A clear project subject and communication with the collaborating students could make a large difference in preventing this lost time.

The designing and concepting phase of the project went quite according to plan. The elaboration on the goal, the components and the requirements was made quite smoothly. However, when building and assembling the proof-of-concept some problems came to light. After doing numerous tests, the conclusion was drawn that a coil should be made with a lot more windings and thinner wire. Unfortunately, the 100 meters of 0.15 mm thickness copper wire, cost about 20 hours of winding by hand. When manufacturing this product, this is something that should be taken into account. It is quite hard to industrialize this winding due to the circular coil.

In addition to the large amount of hours of winding, did the coil become very large in size. The coil became 7.5 cm in diameter (which is within the requirements) and quite heavy, it is too large to wear around a wrist during running. A conclusion from the testing phase was that the large amount of findings was more important than the thickness of the wire. This means that an even thinner wire could be more suitable, since the size and weight would be smaller with the same amount of windings.

However, as was witnessed during the end of the testing phase, the used wire was already very thin and broke off quite easily. This happened multiple times at the end of the wire when the product was shaken during testing. This problem will be even larger when an even thinner wire will be chosen. Despite that, when the electronic components are hidden safely in the case, there will be a lot less tension on the wires and the chance that the wire snaps will be a lot smaller.

IX. Conclusion

In conclusion, the project truly kicked off once the scope of the specifications and the requirements were clearly defined by the stakeholders, both internal and external. The goal of the project was to ultimately create product-driven business that is backed by innovative research to help solve a solution, whilst still being environmentally friendly. The final prototype did just that. With the use of a kinetic generator to throw away the need for a battery, the infinity light generates a bright light for the jogger to wear while running. In contrast to the competition in the same field, instead of a temporary blinking light that turns on every couple of seconds, the infinity light will stay on continuously for as long as the runner is running.

To elaborate further, the main requirements involved the prototype's geometrical shape, reliability, functionalities, and electrical components. There were also end-user requirements such as the ones stated in Table 2. The prototype consisted of electrical components that were soldered onto a 2 by 2-centimeter prototype board. The board was then surrounded and connected to the circularly winded coil and encased in a 3D printed casing with a laser cut plexiglass covering.

The coil was able to generate over 3V of electricity once rigorously shaken with the magnetic ball inside it to emulate running. This was more than enough to power the LED to a certain brightness to meet the initial set requirement.

Throughout the process, the business side of the project also needed to be developed. By following a business case that was made at the start, and edited during the project, multiple business canvases were made to explain the stage the business is in. As the business only realistically lasted for 6 months, the other business canvases were made with possible value predictions in a best-case scenario situation.

With both the engineering and business aspects of the project working in tandem, the project has successfully ended with a symposium in both Barcelona and Eindhoven, where the prototype had to be presented to curious listeners and engineering enthusiasts. The future of the project lies in whether the initial team would like to continue developing the business after the given timeframe.

X. Recommandation

For this project there are a lot of possible options left to improve the current device. The device that is created now has the fundamentals. An recommendation is to further improve the device could be to think about a new way to generate energy instead of a magnet and coil. There are many different ways to generate energy, so by using different ways to generate energy or even combining them it is possible to make the device more efficient. By placing the device on another body part it can be more challenging to generate the sufficient energy. This could pose as an interesting project challenge. Another recommendation is to re-design the casing or to make it with different materials. This aspect can always be improved suiting the way how energy is generated and to make it more comfortable regarding the user input. For future project regarding the infinity light it is possible to improve and innovate on.

In the beginning of the project, there was a brainstorming session about the subject "Safety for joggers". In conclusion to this brainstorming, there was another project subject created: The Running blade". Since safety is also important for people with an amputee, an option is to improve and innovate on the running blades to make sure that people with an amputee can run safely on uneven terrain and other obstacles. There are many ways to improve a running blade and to make sure that it is sustainable. This project is highly recommendable for a future project.

ACKNOWLEDGMENT

This paper contains a compact elaboration of all the work done by the project group containing both students from Ulm and Eindhoven. The paper itself has been written by the students from Eindhoven but will contain information provided by the students from Ulm. First of all, we would like to thank the Technische Hochschule of Ulm for their collaboration in this project. With this, special thanks to Robert Watty, the coordinator from Ulm and the students, Steffen, Fabio, Semih, Markus, Victoria and Umut for their pleasant collaboration. Secondly, we want to thank Kennedy Aduda, who has started the project with us as our tutor, and Hay Geraedts, who took over from Kennedy in the last month. They both helped us work together and guided us to a better final result.

This project has been a lot of fun for us as students because it let us implement everything we learned in our first three years into one last project. This includes all the technical skills from both mechanical and electrical engineering but also all the soft skills we learned in the first three years. On top of this, being able to do this with an international group and presenting and finalizing the project phase at a symposium in Barcelona made it even more interesting.

REFERENCES

[1] Ledsgogreener, "IP65, Ip66 en IP68? Waterdicht of stofdicht?," Ledsgogreener, [Online]. Available: https://www.ledsgogreener.nl/ip65-ip68-waterdicht-of-stofdicht. [Accessed 19 January 2023].

[2] European Commission, "Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS)," European Commission, 15 November 2017. [Online]. Available: https://environment.ec.europa.eu/topics/waste-and-recycling/rohs-directive_en. [Accessed 19 January 2023].

[3] SMK, "Over EU Ecolabel," SMK, [Online]. Available: https://www.europeesecolabel.nl/over-het-keurmerk/. [Accessed 19 January 2023].

[4] K. Smith, „Directional Hands-Free Wrist Illumination Device". United States Patent 0310592, 22 December 2011.

[5] B. Liu, „LED (Light Emitting Diode) self-reeling luminous bracelet". China Patent CN203828214U, 17 September 2014.

[6] L. J. Congming Pi, „LED light-emitting wrist strap". China 2 September 2019.

[7] K. o. systems, „Chest light for sport uses such as Nordic walking jogging or langlauf has lamp and belt fitting around the chest and preferably a shoulder strap". Germany Patent DE202005000110U1, 5 January 2005.

[8] S. Dae, „CLIP TYPE LIGHT DETACHABLY COUPLED WITH CAP". South-Korea Patent US2007109768A1, 17 May 2007.

[9] W. Ho-sheng, „Multi-functional lamp". Taiwan Patent US2011141751A1, 16 Juni 2011.

[10] S. MINGLEI, L. MIAO, C. XIAOQI, F. ZHENYU, Y. CHENG, H. QINGBANG en C. BINGYAN, „Wearable power generation device for collecting user exercise energy". CN Patent CN110336486A, 15 10 2019.

[11] P. I. LAZAREV, I. S. KELLY-MORGAN en M. R. ROBINSON, „IMPROVED ENERGY STORAGE SYSTEM USING CAPACITORS". US Patent WO2017139682A1, 17 8 2017.

[12] Y. MIZUSHIMA, „PLANETARY GEARED MOTOR AND DYNAMO". Japan Patent CA2642249A1, 16 8 2007.

Embedded 3D-printed strain gauge with temperature monitoring for use in prosthetics

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***Abstract*— This paper outlines the development of two proof-of-concepts 3D printed strain gauges embedded in 3D printed materials for use in prosthetic applications. The strain gauges were developed with the intention of reducing the price of prostheses and making them more accessible to those in need of a cheap and fast to produce prosthetic. One strain gauge consists of a conductive PLA filament with two outer layers of flexible TPU with an added thermocouple to measure temperature. The other proof of concept consists of just a printed strain gauge from conductive PLA without the flexible TPU encasing. The two proof-of-concepts, developed by Fontys University and ICAM, were tested for maximum angle bend, repeatability, and resistance measurements. The results showed that the 3D-printed strain gauges were feasible for use in prostheses, providing a cost-effective and customizable solution for measuring strain and temperature.**

Keywords—prosthetics, 3D-printing, Strain Gauge, temperature

I. Introduction

The World Health Organization estimates that 30 million people need prosthetic devices. Yet as low as 1 in 10 people have access to assistive products such as prostheses. Mainly because of their high cost. Without access to prostheses, people who need them are often excluded, isolated and locked into poverty. [1]

This is why it is paramount to make prostheses as affordable, durable and effective as possible. They give a person who needs it the ability to fully take part in society and perform day to day tasks.

Strain gauges can be implemented in prostheses for different purposes such as user movement feedback and pressure sensing. Giving the user more feedback provides the user with a better connection to his/her prosthesis.

The team developed two proof of concepts demonstrating the feasibility of 3D printed strain gauges embedded in 3D printed materials. The 3D-printing of the strain gauge reduces the cost of the part and allows for variability of dimensions. This allows the strain gauge to be implemented in different prostheses and other applications. Adding the ability to measure the temperature makes it possible to make compensations according to the temperature.

II. Concept

A. Measuring strain

K. Elgeneidy et al [2]. demonstrated that it could be feasible to measure strain with a 3D-printed strain gauge for use in a different field, while not taking the temperature into account. The strain gauge consists of three layers, with the middle layer being a conductive PLA filament. The two outer layers are non-conductive flexible TPU. The flexible TPU makes it easier to bend and pull the Strain Gauge. It also gives the possibility of adding more and larger non-conductive layers for different purposes, while still retaining flexibility.

B. Measuring temperature

A thermocouple consists of two wires of different materials. Depending on the temperature at the connection point, the voltage between the two wires will change. There are various different types of thermocouples with different properties.
The thermocouple will be embedded in the strain gauge, so the temperature can be measured more effectively.

A difference in temperature results in a difference in resistance value. As there is a current flowing through the strain gauge, the temperature will rise. This, and the potential differences in ambient temperature need to be accounted for to keep measurements reliable.

Research and development co-funded by Fontys University and ICAM

III. Implementation

A. *Two proof of concepts*

Both the Fontys and ICAM teams realised a proof of concept with different properties, to better showcase the potential of the concept. The main difference is the non-conductive part: The ICAM team embedded the strain gauge in a 3D printed flexible part [Figure 1]. The Fontys team attached the strain gauge to a piece of acrylic, which was then embedded in a 3D printed hand [Figure 2].

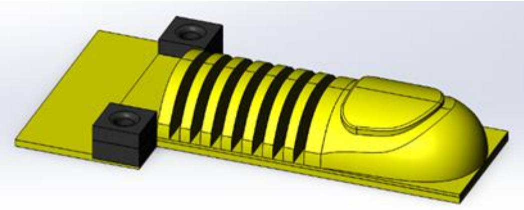


Figure 1 ICAM proof of concept

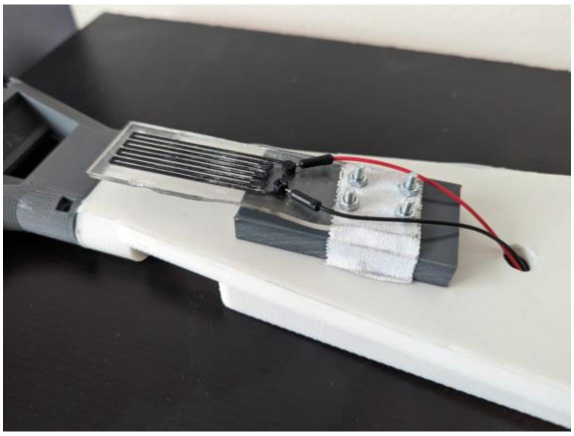


Figure 2 3D-printed strain gauge

B. *3D-printing*

3D-printing a flexible strain gauge requires a conductive filament and a flexible non-conductive filament. For the conductive filament, the Proto-Pasta Conductive PLA was used by both teams. For the non-conductive filament, the ICAM team used NinjaFlex 3D-Print Filament 85A. This filament is very flexible, making it possible to easily bend the strain gauge without too much effort.

C. *Architecture*

The architecture diagram for both proof of concepts can be seen in Figure 3.

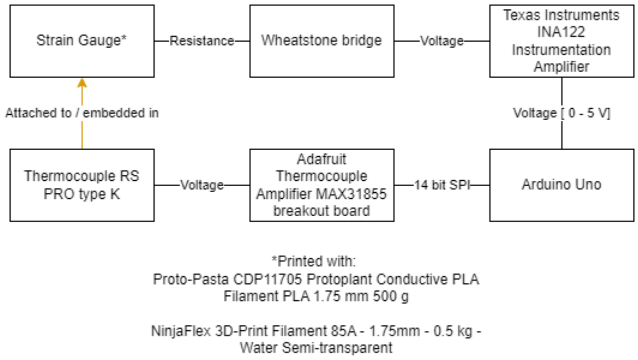


Figure 3 Architecture diagram

IV. Results

A. *Test method*

Both the Fontys and ICAM team conducted tests on their respective proof of concepts. The tests consist of four parts:

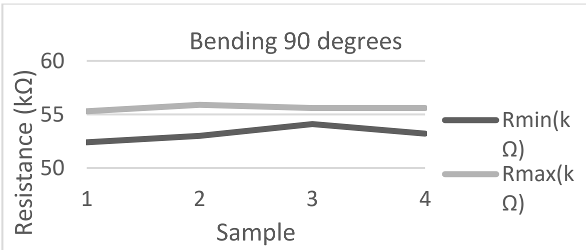
1. Maximum angle bend test
2. Half of maximum angle bend test
3. Repeatability of maximum angle bend test
4. Repeatability over time

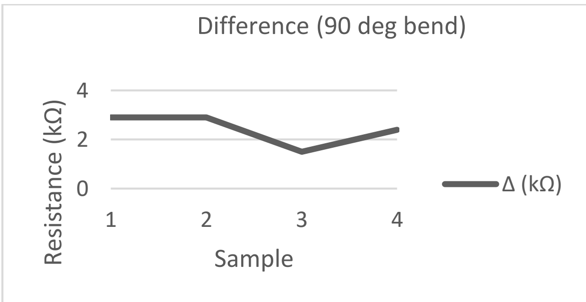
B. *Resistance measurements ICAM Proof of Concept*

The results of the four parts of the test can be seen in the figures below.

Test 1: Maximum angle bend test

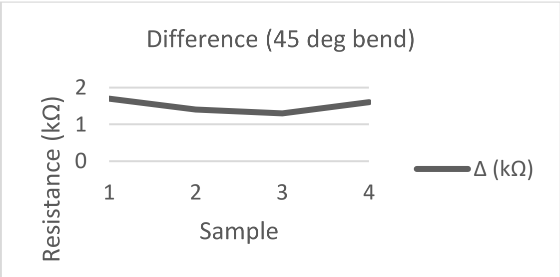
	Rmin(kΩ)	Angle	Rmax(kΩ)	Δ (kΩ)
1	52,4	90°	55,3	2,9
2	53	90°	55,9	2,9
3	54,1	90°	55,6	1,5
4	53,2	90°	55,6	2,4
			Average:	**2,425**

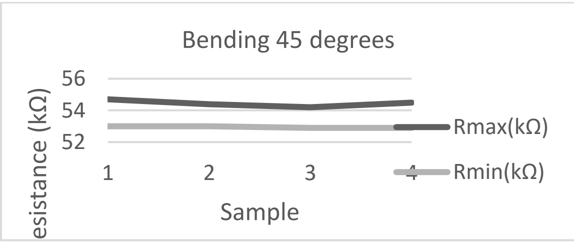




Test 2: Half of maximum angle bend test

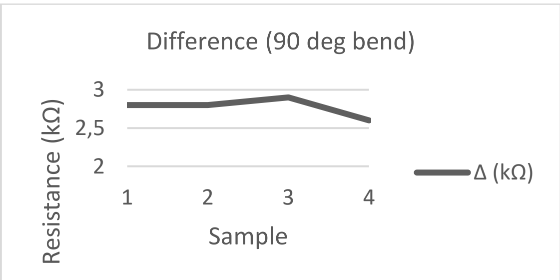
n	Rmin(kΩ)	Angle	Rmax(kΩ)	Δ (kΩ)
1	53	45°	54,7	1,7
2	53	45°	54,4	1,4
3	52,9	45°	54,2	1,3
4	52,9	45°	54,5	1,6
			Average:	**1,5**





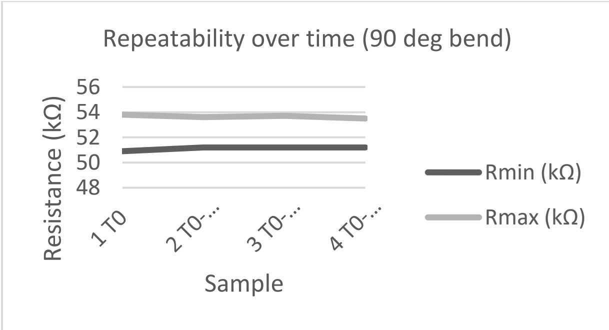
Test 3: Repeatability of maximum angle bend test

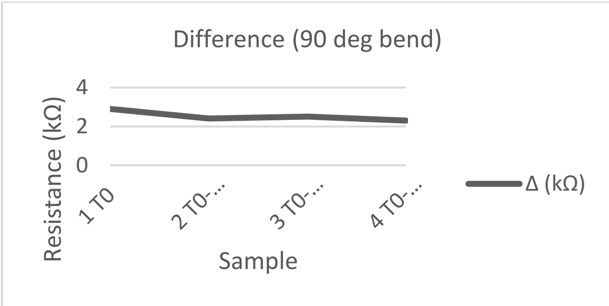
n	Rmin(kΩ)	Angle(°)	Rmax(kΩ)	Δ (kΩ)
1	52,5	90°	55,3	2,8
2	52,8	90°	55,6	2,8
3	53	90°	55,9	2,9
4	53	90°	55,6	2,6
			Average:	**2,775**



Test 4: Repeatability over time

n	Rmin (kΩ)	Angle	Rmax (kΩ)	Δ (kΩ)
1 T0	50,9	90°	53,8	2,9
2 T0+ 5min	51,2	90°	53,6	2,4
3 T0+ 10min	51,2	90°	53,7	2,5
4 T0+ 15min	51,2	90°	53,5	2,3
			Average:	**2,525**





C. Temperature measurements ICAM Proof of Concept

Unfortunately, temperature measurements did not give the expected results. The team hoped that the temperature of the strain gauge would cause a measurable increase of temperature during use. It was not possible to measure this change, as it was probably too small for the sensor.

However, the team did succeed in measuring the ambient temperature accurately. But, as this was not the intended goal of the temperature sensor, has not been recorded in detail. The possibility for the ambient temperature measurements is valuable to consider for future applications.

D. Resistance measurements Fontys Proof of Concept

3 Tests were conducted: 100% load/change, 50% load/change and repeatability. The 3D printed load cell is glued to pieces of acrylic.

1st Strength tests pushing sensor 10mm downwards 1<min interval

Sample	Start(KΩ)	End resistance (KΩ)	Delta (KΩ)	R per mm
1	171,79	177,1	5,31	0,531
2	172,08	178	5,92	0,592
3	173,1	179,8	6,7	0,67
4	173,79	180,1	6,31	0,631

The 2nd test is a 5mm test. which is 50% of the bending range.

Strength tests pushing sensor 5mm downwards 1<min interval.

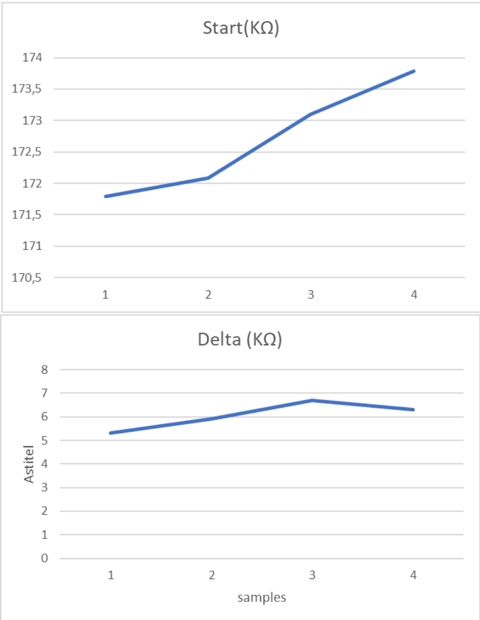


Figure 4 First tests Fontys group

In this test, the load cell is clamped to a table and pressed down on the edge of the table for about 10mm. What you can clearly see is that the starting resistance is varying. It does not return to the previous starting resistance. However, the difference in starting resistance to pressed down resistance does not vary that much. The change in resistance can clearly be measured.

Sample	Start(KΩ)	End resistance (KΩ)	Delta(KΩ)	R per mm
1	182,9	185,1	2,2	0,44
2	183	185,3	2,3	0,46
3	183,3	186,3	3	0,6
4	183,5	186,5	3	0,6

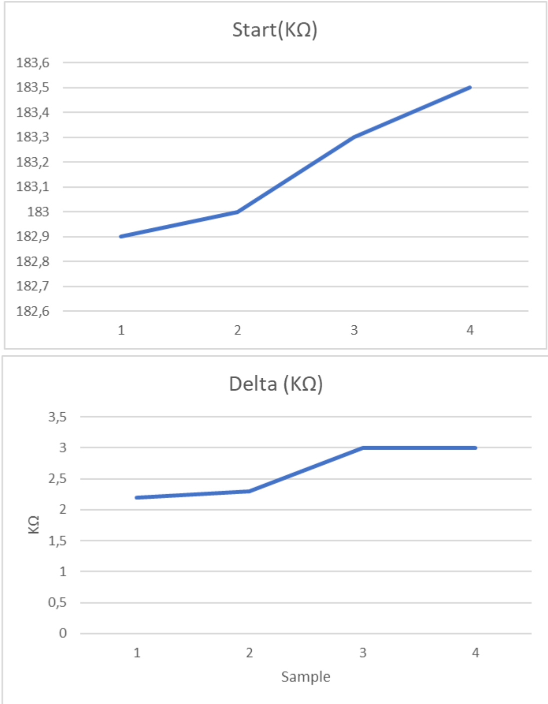


Figure 5 Second tests Fontys group

The same behaviour is found with this test but less. There is less force applied to the sensor, so it returns to its starting position more easily.

3rd test Repeatability over time

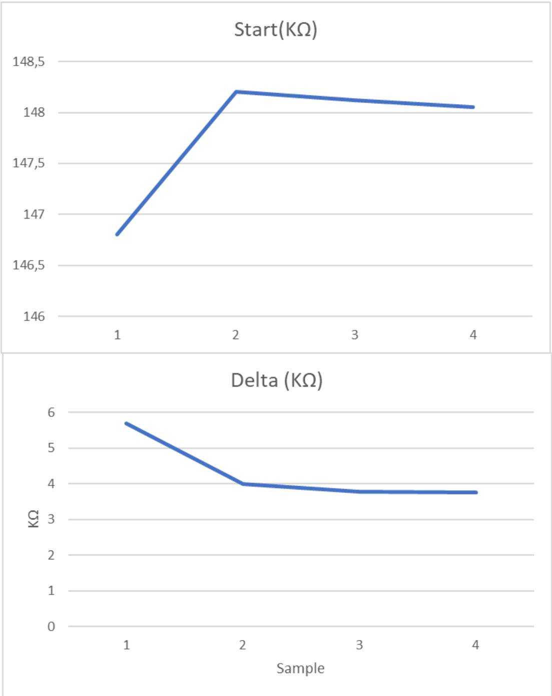


Figure 6 Third test Fontys group

Sample	Start(KΩ)	End resistance (KΩ)	Delta(KΩ)
1 T0	146,8	152,5	5,7
2 T0+5min	148,2	152,2	4
3 T0+10min	148,12	151,9	3,78
4 T0+15min	148,05	151,8	3,75

It is clear that if there are 5min intervals between each test, the repeatability is much better

V. Discussion

Both tests show that it is possible to see a strain gauge is being bent, by looking at the resistance value and measured ADC values. There were some deviations in the resistance differences.

The deviations can be explained by the following:

1. It takes time for the resistance to return to the base value. This means a test can start with a higher R_{min} than the previous test, which impacts the resistance difference. This was evident in sample 3 of test 1. For future research, this should be accounted for by leaving more time between tests.
2. The method of manually bending the strain gauge to a certain angle makes it difficult to guarantee the same angle was reached. For future research, a device should be made that always bends the strain gauge in the same way.

VI. Conclusion

In conclusion, the concept of a printed strain gauge as a sensor in prosthetics shows great potential as a cost-effective solution. By using printing technology to create the sensor, the cost of production can be significantly reduced, making it more accessible to a wider range of amputees.

Additionally, the small size and flexibility of the sensor allows for easy integration into prosthetic limbs, providing a more natural and comfortable experience for the user. The printed strain gauge is a promising technology that could revolutionize the field of prosthetics by making it more affordable and accessible for all.

Unfortunately, the temperature sensor could not be used as intended. It was, however, possible to read the ambient temperature with the sensor. Further research has to be done for this application.

VII. Recommendations

One solution to the high cost of prosthetic sensors is to improve the technology itself. For example, by testing new and more advanced support materials, the elasticity and ability of the prosthetic to return to its default position can be improved. This can increase the performance and durability of the prosthetic, making it more cost-effective in the long run. Also, it is worthwhile to further develop the proof of concept into a full prototype.

VIII. References

[1] World Health Organization, "WHO standards for prosthetics and orthotics," 1 February 2017. [Online]. Available: https://www.who.int/publications/i/item/9789241512480.

[2] K. Elgeneidy , G. Neumann, M. Jackson and N. Lohse, "Directly Printable Flexible Strain Sensors for Bending and Contact Feedback of Soft Actuators," *Frontiers in Robotics and AI*, vol. 5, no. 2296-9144, 2018.

Home automation solutions for elderly people

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***Abstract*—Increasing ageing population leads to a fundamental expanding lack of elderly caretakers in the future. SenDom Solutions is partially solving this problem with the Duvair; an inflatable A-shape tube that replaces a duvet cover with minimal effort. With comprehensive market research, the product has the potential to relieve muscle strains among elders and caretakers.**

Keywords—Elderly, Domotics, Bedding, Innovation, Duvet

I. Introduction

The need for aid in the work around the house is enormous in a society where the ageing population is growing immensely. The population of elderly people aged 80 years or older is expected to triple between 2020 and 2050 and reach 426 million [1]. On the other hand, the workforce in healthcare is shrinking. There is a need for products that can help the elderly and caretakers ease household chores and improve quality of life. For instance, elderly have a hard job making the bed because it requires quite a lot of power to wave the bedsheet and put the bed cover around the edges of the bed.

The Elderly can have an injury more quickly if they fall to the ground. And when they are on the floor, they have difficulty getting back up. With smart home automation, solutions for these problems can be made. With smart devices to aid them with difficult chores elderly can be independent again and work will be lessened for caretakers. And if there were to be a device that could help the elderly when needed, they would feel more self sucre allowing them to do more by themselves.

As part of a bachelor's in engineering at Fontys Eindhoven, a group of students, driven to innovate, chose a project to create home automation for the elderly generation. This group of students decided to create a company called SenDom Solutions, a company that is willing to make the lives better for elderly and help them be more independent. To improve the quality of life Sendom Solutions wants to create home automation products that automate tasks for both elderly and caretakers. One of these products is the Duvair. The Duvair is a product that can make the duvet without having to lift and shake the duvet cover. This will make the lives easier for elderly and caretakers, automating the strenuous part of this task.

II. Problem analysis

A. Problem Research

The Hartford, a book about starting businesses, says: ‘Market research provides critical information about your market and your business landscape. It can tell you how your company is perceived by the target customers and clients you want to reach. It can help you understand how to connect with them, show how you stack up against the competition, and inform how you plan your next steps.’ [1] In other words, doing good market research can determine whether your company succeeds or fails. For this reason, SenDom solutions started its product design with market research. This chapter will look at how this market research was done, what was researched and why and what its results were, finally conclusions will be drawn on which the product will be designed.

For the initial market research, the research question was: what is/are the biggest problem(s) that the elderly face in their home? Interviews and surveys answered this question with elderly and caretakers, the most likely users of SenDoms future product. The second part was doing literary research surrounding problems elderly people have in their homes that lead to a loss of independence or are a big inconvenience. Every relevant problem mentioned in literary research, surveys or interviews has been grouped and compiled into one table. The number of independent times the problem was mentioned was tallied. Each individual tally was divided by total number of sources to get a percentage of sources that acknowledge the problem. All problems with a mention less than 35% are deemed irrelevant and will not be looked at further.

General problem	Subcategory	Specific problem	Number of times mentioned	Percentage mentioned	Substantial problem or not
lifting	Objects	Heavy	3	23	Not Relevant
		High up	2	15	Not Relevant
		Low/bending	3	23	Not Relevant
		Opening door	1	8	Not Relevant
		Bedding	4	31	Not Relevant
	Themselves	Out of bed	5	38	Relevant
		Chair	2	15	Not Relevant
		From the ground	2	15	Not Relevant
Orientation	Seeing	In the dark	1	8	Not Relevant
		Blindness	1	8	Not Relevant
		Balance	1	8	Not Relevant
Forgetting	Planning	Appointments	5	38	Relevant
		Tasks	4	31	Not Relevant
		Medicin	4	31	Not Relevant
	Objects	Loosing them	1	8	Not Relevant
Balance	Falling	Stairs	5	38	Relevant
		Ledges	4	31	Not Relevant
		Shower	7	54	Relevant
		Bath	6	46	Relevant
		Getting up	3	23	Not Relevant
		Walking	6	46	Relevant
Cooking	Safety	Burning	1	8	Not Relevant
		Sharp knifes	1	8	Not Relevant
		Multitasking	1	8	Not Relevant
	Tiring	Standing	2	15	Not Relevant
		Time-consuming	7	54	Relevant
		Physical Activity	5	38	Relevant
Cleaning		Floor	3	23	Not Relevant
		Bedding	6	46	Relevant
		Stairs	2	15	Not Relevant
		Patients	2	15	Not Relevant
		Dishes	4	31	Not Relevant

Fig. 1. Table of research results about what is the main problem for elderly in their homes. [2]

Through the research table, the design team chose five possible problems to look into.

- Loosing balance after waking up
- Remembering appointments
- Time consuming aspect of cooking
- Making the bed
- Falling

B. *Problem statement*

Now the team has a number of possible problems that could be solved through smart home automation that are all considered problems by the target audience. The design has to chose one problem, this chose is done based on market growth potential. A large factor in that is competitors. The problem with the best market growth potential will be chosen.

Loosing balance after waking up, is partially being dealt with by installing handrails, using smart lighting to light up paths and using walking aids. [3] Though no perfect solutions exists, there are products available to improve the problem. Remembering appointments, the app developer mango display says: 'Life can be extremely hard for people with early stages of dementia, Alzheimer's or age based memory loss. It can also be really tough for those who care for them.' [4] Their app offers a solution to this problem. Among with most big tech companies also offering various calendars and reminders. In other words this is a very competitive market.

Falling was definitely the biggest problem found during the problem research. However falling occurs in many different locations, some also outside the house. This makes the problem very broad and not directly aligned with SenDoms core value of home automation. Based on the market potential for each potential product based on a problem the bedmaking problem seems to have the highest potential. For this reason the problem: 'making the bed' will be the problem which will be solved by SenDom solutions through smart home Automation.

Time consuming aspect of cooking is a problem not only found with elderly people. This is not an overlooked problem and a plethora of tools exist to aid with cooking [5] And there is always the option of readymade meals. So there are a lot of products already on the market to tackle (parts of) this problem. Making the bed is a time consuming and strenuous task that is often left to caretakers because the elderly cannot lift the blankets anymore. Some patents exist surrounding this problem [6], most often more catered to hospital care and bedridden patients. No relevant Dutch patents were found which means there is little known competition for this problem.

Falling was definitely the biggest problem found during the problem research. However falling occurs in many different locations, some also outside the house. This makes the problem very broad and not directly aligned with SenDoms core value of home automation. Based on the market potential for each potential product based on a problem the bedmaking problem seems to have the highest potential. For this reason the problem: 'making the bed' will be the problem which will be solved by SenDom solutions through smart home Automation.

C. *Problem aspect*

The problem 'making the bed' was pointed out as a problem by both elderly and caretakers. To ensure SenDom solutions focusses on the most problematic aspect of bedmaking, the physical or mental aspects that cause the problem need to be researched. To this purpose a short literary study will be done, the results of which can be found in the next part of the paper.

Rodney S. Barret a masters in science did a paper on the measurement and assessment of lumbar stress during bedmaking. He draws the conclusion that in situations were a person needs to make many beds, like caretaking, bedmaking is a major factor contributing toward the causation of musculoskeletal injury, particularly to the low-back region. [7] The paper 'Heavy lifting at work and risk of genital prolapse and herniated lumbar disc in assistant nurses' by S. Jørgensen, H. O. Hei and F. Gyntelberg found in their research: 'This study confirmed the suggestion of previous epidemiological studies that herniated lumbar disc is associated with heavy lifting at work.' [8]. Due to the size of a blanket it requires overhead lifting to change the blanket sheet, this is most likely the cause of these health problems. This is also a big problem for elderly people. An article of the elder gym an institution in senior fitness says: 'Lifting your arm overhead requires a lot of strength and coordination from your arms, shoulder and back. The overhead press is probably the most demanding exercise an older adult can do with their arms.' [9] Based on this literature a two conclusions can be drawn. The first conclusion is changing the duvet cover is the hardest aspect of bedmaking. The second conclusion is the weigh of the blanket is the main reason changing the duvet cover is hard and can cause health complications. SenDom Solutions should thus focus on creating a product that takes over the lifting part of the duvet cover replacement.

III. SOLUTION

With the exact problem determined to be solved, the design team went to work to develop potential concepts to solve this problem. During the research, the Kesselring analysis method was the best suitable technique.

A. V-Shape concept

With the use of two linear actuators or similar technology in a V-shape, The duvet can be easily lifted into place. The connection piece is connected to the end of the duvet. Both arms are placed in the opening of the duvet cover and extended to the maximum length. The attachment is released with the duvet now in place inside the duvet cover. The arms are retracted to their original position and removed from the centre of the duvet cover, thus leaving the duvet inside.

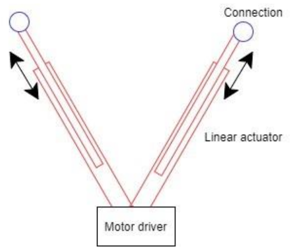

Fig. 2. V-shape linear actuator concept for duvet replacement purposes. [2]

This device can be sold to elderly care homes and hospitals, allowing the minimal use of muscle power to replace the duvet cover.

B. Trolly concept

The second concept to replace the duvet cover is the rolling trolly. A tall, movable cart, somewhat like a clothing rack on wheels, will be highly adjustable with attachment spots for the blanket at a top hanging bar. First, the user will lower the top bar to the height of the bed and attach the veil to the bar. Next, the trolley will lift the attached blanket. Finally, the force of gravity, and some minor adjustments from the user, will let the duvet cover fall to the ground, thus taking the blanket out of the blanket sheet. Four cords are also attached to the top bar, being able to be wheeled in by a small motor. The cords are clipped to the new blanket sheet on both sides of the blanket. Being wheeled in and thus covering the blanket. Finally, the trolley is rolled over the bed and simultaneously on the two sides of the bed with the bar in the middle; the blanket cover and blanket are, thus, put needly on the bed. The device will be too bulky for an individual user to be bought. Thus, Care homes and hospitals are the potential customers of this product.

C. Final concept components

After potential concepts were generated, The decision was made to continue research for the V-shape extendable arms concept due to the increasing smart home appliances market [10], Kesselring analysis and feasibility study. However, the design was significantly adjusted due to cost-saving purposes. The improved concept implements the same principle of the V-shape linear actuators. However, instead of using motors to push the duvet into the corners, inflatable A shape tubes will act as the actuators. It can be inflated and deflated to get the duvet into place inside of the cover.

Each component in the concept has been selected using the Kesselring method and morphological chart design. In addition, the following parts have been highlighted:

- The material choice for the inflatable tube is essential because of the harmful characteristics some fabrics can have while using the product. Another factor to consider is flexibility, how easy it is to work with the material. The factors considered while choosing the material are producibility, costs, durability, feeling in blanket, allergy sensitivity and flexibility. PVC is the preferred material for the Duvair with the best possible characteristics while considering the factors. This fabric is highly durable, easy to work with and does not result in any health violations such as Latex allergy [11] during use. Another benefit of PVC is the cost price. All these features allow for the best possible product for the customer.
- The tubes' shape plays a vital role due to the force the tube has to displace within the duvet cover. The critical factors to consider are producibility, volume, top corners, bottom corners, side verticals, stiffness and absence of horizontal. The inflatable tubes' final shape is a medium sized volume. It has strong rigidity in the direction of the top corners but is weaker in the bottom corners. It does not have the top horizontal tube, which improves sleeping comfort.
- A detachment connection piece is placed between the blanket and the end of the inflatable tube. To choose the right connection piece, producibility, costs, durability, feel in the blanket and strength of the connection. For the blanket attachment, the best suitable option was the snap button. This easy-to-use, cost-effective mechanism holds a tight connection and is minimally noticed within the blanket. Another benefit is the availability of the snap button.
- In between the air pump and the inflatable piece is a detachment mechanism which allows the air to escape once the duvet is in place within the cover. Different designs were realised during the design phase. The factors taken into account were producibility, costs, durability, airtightness and strength of the connection. The final choice for the connection part is the twist and lock mechanism. This neat connection piece is durable, wholly airtight and highly cost-effective due to the possibility of producing in-house with a 3D printer.
- When choosing the right air pump for an air mattress or similar inflatable product, there are several factors to consider: Flow rate, Power source, Noise level, size, weight, durability, ease of use compatibility and costs. The final exact type of pump was selected during the test phase due to the varying factors.

D. Final Design

With the individual components determined, the test phase optimised the proof of concept. In addition, interviews with potential customers and seniors gave insight into confident design choices such as material use. Any further small design iterations were optimised with the feedback from the end user at this stage. Chapter IV feasibility discusses the exact design iterations, including the business aspect considerations.

Fig. 3. An initial prototype of the Duvair, this prototype is a proof of concept and does not directly reflect the eventual product. [2]

IV. Feasability

Now with a sensible design based on customer base research, a feasibility study is needed to follow this design. There are two aspects to this feasibility study, the technical and the business. In the technical aspect, it is researched whether the chosen materials, shapes and constructions will have the desired effect and adhere to all the previously setup user requirements. This is also checked with the users themselves. The business aspects research the market feasibility. With questions like can the product be sold at a profit, is the market that was initially found (still) there. It also considers the type of business the company will want to do. These questions were considered throughout the development process, however, only now in the paper will they be discussed.

A. Technical aspect

To proof the Duvair will work research has been done. This research is done on the internet and has been found on multiple sources. The material of the Duvair is PVC. The same material is used for air mattresses. Air mattresses have proven to be a product made from a strong and flexible material. This flexibility is used in the Duvair by pumping air into the pipes so the Duvair will spread itself into the bedsheet. Another characteristic of the material is softness. With the reduced strength of skin from seniors, possible cuts are more likely, thus increasing the importance of a softer material, such as PVC. Air pressure can be build up and the Duvair doesn’t have a particular way to place in the bedsheet.

To make the pipes of the Duvair, PVC glue will be used. PVC glue is a chemical solvent that melts the surface of the PVC pipe. The two pieces bond together in a process called cold welding. This creates a single piece that can't be separated unless cut [12]. With this process the pipes of the Duvair will be sealed tight and no air will be lost during the inflating process. It will be hard to shear hence it is two PVC sheets becoming one whole. During the appliance and removal of the Duvair after the duvet is placed within the cover, the PVC has to be rigid to ensure a high quality product. The shape of the Duvair is designed to be comfortable if the product is in your bedsheet while sleeping, and it will spread completely into the bedsheet. This shape is chosen out of multiple options by using the Kesselring method and a morphological chart, the Duvair has chosen the A-shape.

B. Business aspect

Sendom Solutions have a business plan to keep the company running and to let the company grow. The business plan is made to look forward to the goals Sendom Solutions strives to achieve. Business model canvasses for different phases are made to set the goals for Sendom Solutions. Business model canvasses were made for these phases: start-up, grow-up, scale-up and step-up [2, 12]. With research on which components give the best performance for the best price, the key partners are chosen. These partners will play a big part in the business strategy of Sendom Solutions. To keep trying to grow, Sendom Solutions will need resources.

The key resources are everything Sendom Solutions needs to achieve its goals to be successful per the company's phase. Making products is something that Sendom Solutions will do as a start-up, but this activity will change per phase. The Key activities are the most critical activities that must be done to maintain the company's quality per phase. Sendom Solutions also have values they can give per phase to provide meaning to the customer. To connect with customers, Sendom Solutions will use channels to reach them. For instance, by mail or with a good website. Sendom Solutions wants to create a company that can be successful but could also give a personal feeling to the customer. With customer relationships, goals are set that Sendom Solutions will maintain for the business with its customers. The customer segments will lead Sendom Solutions in deciding where and how the company can reach their customers. With a cost structure and revenue streams, balance sheets are made to set goals so Sendom Solutions can build up to expectations to keep the company running financially. In the cost structure, a plan is made about the costs that Sendom Solutions will have to deal with. In the revenue streams are the incomes of Sendom Solutions stated.

Using a customer journey map, the way of approaching to customers is made. This will give a clear map so Sendom Solutions can track where they are and where they want to be when dealing with customers[2, 13]. Sendom Solutions have a supply chain that is clear about how the journey of the Duvair will be. From customer order until customer delivery. This supply chain will change a little per phase, but in extensive outlines, Sendom Solutions will keep its strategy forever [2, 14].

V. Conclusions

With the project nearly ending, Sendom solutions, including seven engineering students and two business students, has laid the foundation for a successful company in the future. Since the project's beginning, the mission has been to improve the life and independency of elders. With the first launched product, the Duvair promises a duvet replacement assistant, allowing elders and caretakers to change the cover with minimal effort, discarding the intense muscle task it takes now. The groundworks for the launched product is well-researched, ensuring a customer base for the automatic bed sheet replacement market. The design follows the V-model method guaranteeing thorough technical considerations, resulting in the best product that Sendom Solutions offers. In addition to the technical aspects, the team has published a business plan highlighting the current and future steps the firm will take, Consolidating a positive future for the company.

VI. Recommendations

With the project only lasting for one semester, Sendom Solutions is happy with the achievements. However, there is always room for improvement. In the following chapter, certain refinements will be discussed. During the research phase, most of the interviews were high-quality and personal. However, this led to a low quantitative amount of dialogues. Although the high quality of the interviews supplied new insights for the research, a quantitative high number of interviewees would have improved the customer market foundation for the Duvair. Another improvement Sendom Solutions has encountered is during the proof of concept design. PVC glue has shown a weak bond when pressure increases, resulting in an underperforming product. This issue can be solved by melting the PVC together, which is the air mattress market standard method. However, within the Fontys University environment, this method can not be applied nor tested. Another technical consideration for the Duvair 2.0, is the refinement of the connection between the duvet and the bed. A common problem with the Duvair is the lack of extending horizontally every single time. With an additional link in the middle, this problem can be solved.

Within the team, with seven engineering students, the shortage of experience from business perspectives lead to a decrease of performance on the business case. However, the two business students helped tremendously with supporting and guiding the engineering students during the reporting process. In future iterations of the Duvair, the features should be expanded, including replacing the fitted sheet and improving ease of use. The final Duvair variant should do the whole process of making the bed automatically.

VII. References

[1] The Hartford, „Why Do Market Research?," The Hartford, 23 01 2023. [Online]. Available: https://www.thehartford.com/business-insurance/strategy/market-research/business-market-research#:~:text=It%20can%20help%20you%20decide,well%20as%20effective%20marketing%20messages.. [Geopend 23 01 2023].

[2] SenDom Solutions, „Duvair final report," Eindhoven, 2023.

[3] United Zion Retirement Community, „Tips for Avoiding Nighttime Falls," United Zion Retirement Community, 24 09 2020. [Online]. Available: https://www.uzrc.org/blog/health-wellness/tips-for-avoiding-nighttime-falls/#:~:text=Position%20of%20Bed%3A%20If%20an,one%20side%20instead%20of%20two.. [Geopend 23 01 2023].

[4] Mango Display, „Mango Display App is a perfect digital clock and calendar for the elderly," Mango Display, [Online]. Available: https://mangodisplay.com/digital-calendar-clock-for-elderly/. [Geopend 23 01 2023].

[5] Laura, „15 Must-Have Time Saving Kitchen Tools," A food lover's kitchen, 24 06 2020. [Online]. Available: https://afoodloverskitchen.com/tools-that-save-time-in-the-kitchen/. [Geopend 23 01 2023].

[6] X.-Z. Cheng, „Hospital bed capable of changing bed sheet without moving the patient". US Patent US7191479B1, 20 03 2007.

[7] R. S. Barrett, „The measurement and assessment of lumbar stress during bedmaking," University of Wollongong, 1992.

[8] H. O. H. F. G. S. Jørgensen, „Heavy lifting at work and risk of genital prolapse and herniated lumbar disc in assistant nurses," Occupasional medicine, 1994.

[9] Elder gym, „SHOULDER REHAB EXERCISES FOR SENIORS AND THE ELDERLY," Elder gym, [Online]. Available: https://eldergym.com/shoulder-rehab-exercises/. [Geopend 25 01 2023].

[10] Z. M. research, „Zion Market Reseach," 01 01 2021. [Online]. Available: https://www.zionmarketresearch.com/report/smart-home-market. [Geopend 29 01 2023].

[11] C. A. Parisi, „Update on latex allergy: New insights into an old problem," World Allergy Organization Journal, World, 2021.

[12] tigerfishtools, „tigerfishtools," 2023. [Online]. Available: https://www.tigerfishtools.com/news/pvc-glue/#:~:text=PVC%20glue%20is%20a%20chemical,this%20Red%20Hot%20deal%20below.

[13] E. E. Stīpniece, Business plan pt.1.docx, Eindhoven, 2023.

[14] E. E. Stīpniece, Business plan pt.2.docx, Eindhoven, 2023.

[15] E. E. Stīpniece, Business plan pt.3.docx, Eindhoven, 2023.

The Spice Dispenser: The company and invention

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***Abstract*—"In which way will the innovation "The Spice Dispenser" reduce the most amount of plastic food packaging waste of spices and herbs in grocery stores?". The Spice Dispenser will reduce the amount of food packaging and food waste when a profitable company is launched to develop the device and its after-care. The stores should receive large packaging to refill the spices and herbs in the machine. Therefore, all single-use plastic packaging used for individual packaging is avoided and the containers from "The Spice Dispenser" are cleanable and reusable, therefore sustainable. A proof of concept was made, and tests are prescribed, but not yet verified.**

Innovation, Food packaging, Single-use, Spices, Engineering, Dispenser, Sustainability

INTRODUCTION

"The Spice Dispenser" is a project that designed an innovation and created a conceptual company around this product. The company has not yet launched but a business plan has already been performed for the near future. "The Spice Dispenser" is a sustainable solution designed to address the significant amount of single-use plastic food packaging waste in grocery store chains, particularly in the spice and herb aisle.

By using sustainable and reusable containers instead of individual single-use plastic and glass packaging, the waste reduction will be maximal in this area. Another feature is the possibility to change the requested amount of (mixed) spices and herbs, so that food waste will also be reduced because a customer no longer must buy the predetermined amount set by the manufacturer.

Soon grocery store chains must reduce their plastic waste by law [1], therefore this will be our market. First, the product and service will be launched in The Netherlands and later on, this can be expanded to multiple countries. Another possibility for growth is expanding to dispensing other products, such as nuts, rice, grains, etc. Another possibility can also be expanded to other customers, for example, fast food chains and restaurants.

Another problem is the unfairness in the market where farmers get paid too little share for their product [2], using a food passport visible to the users of the machine, they can inspect the origin of the products they are buying. Due to the transparency of the origin of the spices and herbs and the working circumstances they are harvested and processed, the Customer can make a more informed choice and improve the situation. The situation would improve if fewer customers or ideally nobody would buy the products from unfair markets.

BACKGROUND OF THE PROJECT

"The Spice Dispenser" is a result of the International Innovation Engineering and Entrepreneurship Network projects, also known and further referred to as I2E2 Projects. The I2E2 projects are part of semester seven at the differentiation Innovation Engineering from the engineering bachelor from Fontys Eindhoven. The I2E2 projects are an international collaboration between multiple universities in Europe and are meant to give students the opportunity to prepare themselves to enter the engineering market. Within the I2E2 Projects 'The Spice

Dispenser' was invented and executed by group five. The topic for this group was free, meaning they could choose their direction. The problem area is defined as *'It is always difficult and risky for a person to start-up his/her own company. Especially when this start-up is aiming for an innovation that will have a market impact and profitably grow. The challenge lies in finding the innovative idea/concept that would be the center of operations in the idealized company' [3]. The assignment is defined as 'Students need to identify and develop an innovative concept in form of technological devices and/or systems that can fill an existing gap in the market. This should be accompanied by analyses to support the commencement of a start-up company based on the concept'* [3].

The group working on this project from Fontys Engineering Eindhoven is a total of six fourth-year bachelor students, of which three are mechanical engineers, two are mechatronics engineers, and one electrical engineer. For the building of the company, the team had assistance and advice from two second-year students from the PROUD program from Fontys Eindhoven, consisting of one Communication student and one International Business Administration student. For the mechanical design, another team is situated in Ulm, Germany. The five students from the Ulm University of Applied Sciences are all part of the fourth year of Mechanical engineering.

The Fontys Engineering students gain information and knowledge from the courses Business Innovation, WABI, and Product Innovation, WAPI, to use for the project. Information and workshops regarding patents and (creative) innovation methods are learned, such as TRIZ. Also, information obtained previously in their bachelor's is used to work on the project. The invention of a Spice Dispenser was made for in-home by project member J. Solagnier, this was part of an EXPO project at Fontys from two years ago. Research from this project has also been used in this new project 'The Spice Dispenser'.

The project will be delivered by a presentation and presence in Barcelona in the setting of a symposium on the third of February 2023. A presentation, paper (this document), final report consisting of design documents and business report, and a demonstration by a proof of concept are all part of the deliverables for the project.

The time available for the Fontys Engineering students is from September 2022 till the 3rd of February 2023, for each student 10 ECTS worth, one ECTS short for European Credit Transfer and Accumulation System is worth 28 hours. The Fontys PROUD students each gain 2 ECTS from the project and the students from Ulm each gain 4 ECTS for the project. The total amount of hours for the project is therefore 2352 hours, or approximately 1,5 Full Time Equivalent (FTE).

APPROACH AND THEORETICAL BACKGROUNDS

The verification of the project has been done according to the V-model. The V-model is a linear software development method developed by Paul E. Rook [4]. This is a method where on one side verification and the other side development are described in multiple phases. Each phase has a product or certain milestone that must be reached to be successful and proceed to the next phase. The product or milestone from a previous phase is the basis or input for the next phase.

Another method used is Design Thinking, which was used at the start of the project to get to innovation. Design Thinking consists of five phases, empathize, define, ideate, prototype, and test. In the first phase of the project, multiple fields and ideas were discussed, this was followed by defining a couple of problems in the fields. In the ideation phase, possible solutions were searched for by using TRIZ, this will be discussed later on. For each idea pros and cons were discussed and finally tested according to multiple factors by a score table filled anonymously.

In the previous paragraph, the TRIZ method is mentioned. TRIZ is the Theory of Inventive Problem Solving, also known as TIPS. TRIZ is invented by Genrich Altshuller beginning in 1946. The theory starts by searching for contradictions in an innovation, followed by looking into a similar problem in a different field and searching for an existing solution. After this knowledge is obtained the original contradiction may be solved (partly) by the input of the solution from the other field. This is meant to create the best possible solution. To do the research in a different field or even the same field patent research is used for input.

The main question to be answered is the following: "In which way will the innovation "The Spice Dispenser" reduce the most amount of plastic food packaging waste of spices and herbs in grocery stores?". To create a sustainable solution, it is necessary to build a healthy company around the innovation, or sell the idea to a company, however, due to the assignment given it is chosen to prepare all the documents to start up a company. Next, there is looked into how spices are sold nowadays, and how reducing plastic waste is possible without changing most of the current supply chain network. When this is defined it is possible to set requirements and define a proof of concept. Finally, this defined proof of concept will be built. The proof of concept and presentation is the end point of this project. A possible follow-up can take recommendations from the proof of concept to design a prototype and launch the company.

For defining the company, multiple principles have been utilized. The marketing mix, also known as the four P's, defines, price, product, promotion, and location. Also, a SWOT-analysis is made to create a clear overview for the start up. A SWOT analysis defines the strengths, weaknesses, opportunities and threats for a company or product. Finally, all this information was used to fill a Business Model Canvas, short for BMC.

sub questions:

- How to start up a sustainable company around the innovation "The Spice Dispenser"?

- How are spices kept and sold currently and how is the supply chain structured and how is it possible to reduce the plastic waste with the use of "The Spice Dispenser" without massive changes to the current supply chain network?

- How should "The Spice Dispenser" be designed?

- In what way can the design be improved, using the input from the created proof of concept?

DESIGN AND RESEARCH MAIN RESULTS

How to start up a sustainable company around the innovation "The Spice Dispenser"?

First of all, the definition of a sustainable company: '*Sustainability in business refers to a company's strategy and actions to eliminate the adverse environmental and social impacts caused by business operations.*' [5]. The innovation "The Spice Dispenser" must be developed in a sustainable way, with minimal waste of material and resources. To accomplish this goal, documentation must be done online in shared folders, so that multiple people can work together on the same document(s). Also, time management is very important, because there is a maximum number of hours available for the project. Time management in the project will be done by following the provided GHANT Chart. This way, it is easy to monitor when, why and who is going off the set course.

A healthy company consists of a clear vision and mission statement. This has been defined as the following: "*Our **vision** for the future is a fully cradle-to-cradle food packaging. Our **mission** is to cut out single use plastic waste in the herb and spices supply chain within grocery stores. Our **goal** is to cut out plastic waste on the spices and herbs aisle for a grocery store chain such as Jumbo or Albert Heijn. Our **objective** is to make a proof of concept for the machine before the 3rd of February 2023. The **strategy** to achieve this is a Focus strategy, this involves targeting a specific market niche or segment. Finally, our **tactics** is the development of the business (strategy) and the R&D needed to prove the concept*." [6] .

Before entering the market, market research must be done, and a marketing strategy should be defined. The market research results in a clear finding, the innovative product is not yet on the market, however, the same concept of using a dispensing mechanism for spices has entered the market as a pilot from Albert Heijn [7]. What can be learned from this pilot is that the request and problem exist, but to gain a fair share of the market the product must have a unique selling point. The existing product is fully mechanical and hard to dose and takes up lots of space. So, "The Spice Dispenser" should have a solution to at preferably all these issues.

To finish the research a SWOT Analysis is done. The strength of "The Spice Dispenser" is the sustainable character. The opportunity is the possible diversification of the product because the product is still in development phase. Our weakness is the slower pace of the solution compared to competitors as described before. The biggest threat is that the competitors are further in marketing and communication and companies are preferably not willing to invest in the same problem twice.

Next the marketing mix is defined: the **product** is "The Spice Dispenser", the concept or product is a machine which dispenses spices, herbs or even mixes of multiple spices into sustainable and reusable containers in an automated system with a fun user experience. This user experience will be enriched by fun facts, for example the origin of the product. Additionally, the consumer will have the option to choose the amount they wish to purchase, rather than the traditional system where you must buy the prescribed amount given in the containers. Additionally, an after-care service will be provided. The **price** cannot yet be established, because only a proof of concept is designed and not yet the final design or prototype. The **promotion** will be done by one-on-one contact and conferences. The **place** will be the spices and herbs isle from a grocery store chain, for example Jumbo, Albert Heijn, Plus or Nettorama in the Netherlands.

How are spices kept and sold currently, how is the supply chain structured and how is it possible to reduce plastic waste with the use of "The spice Dispenser" without massive changes to the current supply chain network?

The current supply chain is structured as followed: farming -> transport -> spice factory -> transport -> distribution center ->

grocery store. The containers for "The Spice Dispenser" should be filled with spices and herbs instead of the small single use containers which factories produce currently. Ideally the factories which will fill "The Spice Dispensers" containers and put these on transport to the grocery store's distribution center, will continue in the same way they are operating at the moment. Therefore, the supply chain does not have to change if the factory agrees to fill the containers. This way, the infrastructure of the current system can be used for the new sustainable containers.

The sustainable containers should either be cleaned by the spice factory, or the Spice Dispenser company should invent another way to clean the containers so that they can be reused. Another option is making the containers recyclable, so that they can be used for something else, but are still sustainable. There has not yet been made a choice and contacts to realize this part of the concept.

How should "The Spice Dispenser" be designed?

To prove the concept, other requirements for the design are necessary than the actual device. This paper will go further into the requirements for the proof of concept. For the proof of concept, only a one-axis movement mechanism is required to show that the dispensing mechanism is operable with one hand. The actual prototype can use multi-axis movement mechanism to improve volumetric efficiency of the machine. For the proof of concept, two rows of spices must be made to show that multiple spices can be dispensed without cross-contamination.

The frame of the proof of concept can be made from multiple kinds of materials, the choice has been made for an aluminum extrusion profile system, because this is stiff and can easily be adjusted, also it is easily accessible. The next choice that had to be considered is the fixation of the container. The container will use a dovetail style mechanism that allows container to slide in from the side, this way the container can be slid into the machine. This is easily understandable and technical knowledge is not mandatory for store staff for its operation. This also provides an easier way to clean compared to the other options, therefore it is scalable to the prototype.

The device must be refillable, this can be done in two ways: number 1 lets the spice factories fill the machine's reusable container, however from a technical and zero waste perspective it is more desirable to go with the second option because option 1 requires the machines reusable containers to be shipped back to the spice manufacturer. Option 2 lets the spices be supplied in large quantities where the store's staff refills machines' containers, this is the preferred choice because this way no containers must be send back to the factory and cleaned by the factory, but this can be done in the store itself saving traveling time.

To make a clear vision of the proof of concept it is chosen to make the internals of the proof of concept completely visible, so that all the movement can be analyzed and where needed improved. Even though this can look unappealing, for a proof of concept it is more desirable to show 'how' the dispenser works, rather than focusing on form and looks of the machine.

For the proof of concept four different types of prescribed Mason jars must work with machine, later on with extra technology this might be expanded to a principle where customers can bring their own desired jars to be filled by the machine. Another point to consider when speeding up the system is the stability of the jars, to ensure jars do not fall over, several sizes of holes are made in the bedding where the different sizes are supported.

Finally, the proof of concept will be made by wired connections. Wireless connection is unnecessary in this case, because there is only a small amount of wires and they also have only short distances. Connections between the different modules can be made by spring loaded pin connectors in the future. As with no technical background these can be easily connected, however for the proof of concept where only members with a technical background are working on, simple pin connectors can be used. The proof of concept will look like figure 2.

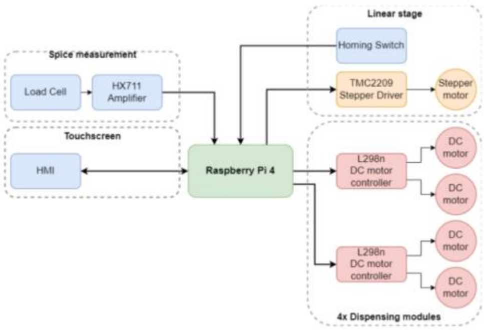

Figure 1 - Electrical System Overview

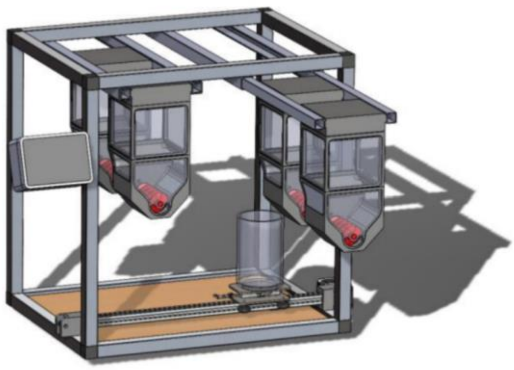

Figure 2 - Complete system rendering

To integrate the entire mechanical system and automate the machine, it must be programmed to be operational. In figure 1 the electrical system overview can be obtained. A stepper motor and a DC motor are used in the automated spice dispenser to regulate the carriage's movement and the dispensing of the spices. The Raspberry Pi is the main computer that controls the entire system. The Raspberry Pi controls the DC motors in the dispensing modules to start and stop dispensing of the appropriate spice. The loadcell will measure the dispensed amount and signals the raspberry pi to stop dispensing when the desired spice amount is reached. This makes for a precise and accurate spice dispensing solution.

In what way can the design be improved, using the input from the created proof of concept?

Tests should be performed to check what must be improved and what is recommended to improve. It is not yet possible to determine what should be improved due to the lack of test results.

VERIFICATION RESULTS

Six total tests were scheduled for the validation of the system requirements. Unfortunately, due to having experienced a delay in the delivery of measuring equipment, only four out of the six were performed within the specified timeframe.

The first “DWH test” performed was deemed non-valid, given the W dimension exceeding the designated limit by a total of 50mm. However, due to the later logistics adjustments, in which the proof of concept would not require to be shipped for the presentation, no negative results were expected from this outcome. For future applications and logistic requirements, it would still be advised to perform the dimension adjustment for the system.

The second test; “Overall system weight” yielded a positive outcome due to being vastly below the designated threshold. This was expected due to the materials employed in the prototyping cycle, yet the large gap from the designated threshold provides a positive insight for the final product regarding future expansion capabilities, as well as offering a wider selection range for the Bill Of Materials. Alternatively, said weight may be maintained minimum, for future shipping logistics. The following two tests; "Peak load testing" as well as "granular delivery & accuracy" are the single tests that could not be performed due to lacking measuring equipment. Therefore, no analysis has been performed yet on these two elements.

The final test, "Operation time" was deemed successful, due to the operation being performed under the designated time. Nevertheless, the delivery observed was deemed improvable; by increasing the operation speeds through the optimization of the code timings.

CONCLUSION

It is clear that the world is waiting for a solution for plastic pollution. The first steps have been made for a profitable and sustainable solution in the food industry with the introduction of "The Spice Dispenser". The proof of concept is not yet finished due to the lack of (valid) test results. Unfortunately, the time to finish the project was limited due to the end of the semester as a set deadline.

This does not mean that the project has failed because an innovative product was (partly) developed and a potential business was created around this product. Also, the students have gained more experience in working in multidisciplinary teams working on a long-term project, which is the goal of I2E2, preparing students for the innovative world. With the conference and symposium that have been attended in combination with all the research and most of the development done the project is still marked as a success. Also, the product has potential, and it is recommended to create a follow-up project.

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REFERENCES

[1] E. Comission, Commission takes action to reduce waste from single-use plastics., EC Presscorner, September 2022.

[2] C. M. o. f. affairs, Which trends offer opportunities or pose threats on the European spices and herbs market?, www.cbi.eu, December 2021.

[3] H. Geraedts, "I2E2 Project discription," Eindhoven, 2022.

[4] M. Seçkin Durmuş, İ. Üstoğlu, R. Yu. Tsarev and J. Börcsök , "Enhanced V-Model," Sadenco, Yildiz Technical University, Kassel University, Siberian Federal University, Antalya, Turkey; Istanbul, Turkey; Krasnoyarsk, Russia; Kassel, Germany, 2017.

[5] IBM, "What is sustainability in business?," 2022. [Online]. Available: https://www.ibm.com/topics/business-sustainability.

[6] The Spice Dispenser, "Final report," Fontys Univeristy of Applied Sciences, Eindhoven, 2022.

[7] Albert Heijn, "Albert Heijn introduceert verpakkingsvrij boodschappen doen," 05 April 2022. [Online]. Available: https://nieuws.ah.nl/albert-heijn-introduceert-verpakkingsvrij-boodschappen-doen/. [Accessed 12 Januari 2023].