Proceedings of the 5th Symposium on

International Innovation, Engineering & Entrepreneurship

1 February – 2 February, 2024, Heraklion, Crete, Greece.

Editors:

Konstantinos Karampidis, HMU

Giorgos Papadourakis, HMU

Leandro Di Domenico, ICAM

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INTERNATIONAL INNOVATION, ENGINEERING & ENTREPRENEURSHIP

Proceedings of the 5th Symposium

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Foreword I

This volume contains the Proceedings of the 5th edition of the International Innovation Engineering Entrepreneurship (I2E2) Network. The I2E2 Network is an association of Higher Education institutions aiming to promote innovation projects to students in a multicultural context. Engineering students from eight different Institutions conducted 11 projects from October 2023 to January 2024 and their results were presented in a Blended Intensive Program (BIP) entitled "International Innovation Engineering Entrepreneurship" organized by the Department of Electrical and Computer Engineering of the Hellenic Mediterranean University in Heraklion, Crete, Greece, January 29, 2024 – February 2, 2024 and are documented in this volume Proceedings.

The key objective of the "International Innovation Engineering Entrepreneurship" BIP was to bring together engineering students from 5 different Institutions and teachers from 6 European Institutions for a weeklong physical mobility. Teachers provided lectures on specialized subjects of Engineering while the students presented their innovation projects which are contained in the Proceedings.

We would like to thank the Chairman of I2E2 Network Leonardo Di Domenico, ICAM – Strasbourg, France, and Hay Geraedts, Fontys University of Applied Sciences, Eindhoven – The Netherlands, for coordinating and evaluating the presentations of the students as well as all the professors and students that participated in the event.

We would like to thank Stavros Grymanis a Hellenic Mediterranean University student assistant, for helping with the formatting of the papers and the preparation of this publication.

Konstantinos Karampidis
Giorgos Papadourakis
HMU Organizers

Foreword II

Welcome to the proceedings of the 5th edition of the International Innovation Engineering Entrepreneurship Network. It is with great pleasure and anticipation that we present this compilation of insights, research findings, and collaborative endeavors resulting from this innovative initiative.

With participation from eight international universities and engineering schools, this edition marks a significant milestone in fostering cross-cultural exchange and interdisciplinary cooperation under a Blended Intensive Program (BIP). Financed by the ERASMUS program, a BIP serves as an opportunity for students and educators alike, surpassing geographical boundaries to cultivate an environment of learning and discovery. Through a blend of intensive coursework, hands-on projects, and experiential learning, participants have had the unique opportunity to engage with diverse perspectives, harness their creativity, and hone their entrepreneurial expertise.

On behalf of the I2E2 network, we extend our deepest gratitude to all those who have contributed to the success of this program and mainly the Hellenic Mediterranean University for warmly hosting this event. May these proceedings serve as a testament to our shared commitment to excellence and our unwavering belief in the transformative power of education and innovation.

Leandro Di Domenico
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Assistive technology and universal design

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***Abstract*— This paper answers the main question: "How to help people with disease or disability using assistive technology?"**
During this semester, there has been to reduce the Tremors of the Parkinson's disease using assistive technology ?".
After completing the project, a real scale model has been printed in order to simulate Parkinson's tremors and detect them with an electronical setup. With that affordable technology, researchers will gain more time during their development of solutions for people with Parkinson's symptoms.

I. INTRODUCTION

Patients suffering from Parkinson's disease not only face difficulties in their daily lives, but can also be severely affected. This is the case of Isabelle, who suffers from this syndrome, and confides in an interview.

“"Isabelle is 48 years old when she wakes up every morning feeling very tired. Her doctor referred her to a neurologist, who diagnosed her with Parkinson's disease. [...] It was a huge shock, a real tsunami. I thought it was a disorder of old age. [...]
I can't drive long distances any more, and airport queues are starting to get hard to bear. [...] You have to learn to live with it, or rather learn to live differently. Like brushing my teeth or making an omelette. Both of these activities require a back-and-forth gesture that I can no longer perform." [1]

Discovered by James Parkinson in 1817, an English surgeon who diagnosed six individuals with symptoms of shaking. He then described those behaviors in his book called An Essay on the Shaking Palsy, the first book written about the disease which bears his name. Parkinson's disease is the second most common neurodegenerative disease in the world. The most common symptoms of Parkinson's disease are tremors, involuntary movements and imbalance.

On the picture below, it can clearly be observed that one part of the brain is responsible of the Parkinson's disease, that is why it is called neurodegenerative.

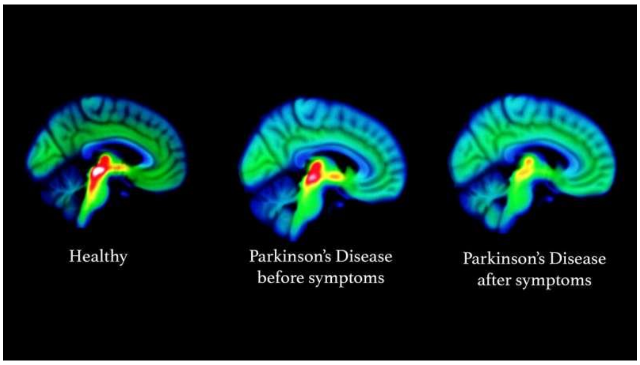


Figure 1 IRM of a brain during Parkinson's symptoms

According to the website of the French Brain Institute (ICM):

"Parkinson's disease combines a parkinsonian syndrome with at least 2 of 4 other criteria:

- *Improvement of parkinsonian syndrome disorders with dopaminergic treatment.*
- *The appearance of abnormal involuntary movements under dopamine treatment.*
- *A unilateral or asymmetric resting tremor.*
- *A decrease (hyposmia) or even complete disappearance (anosmia) of the sense of smell.*

Patients may also present so-called "non-motor" symptoms, such as intestinal disturbances, apathy and REM sleep disorders." [2]

II. Project Definition

The goal of this project is to bring innovative solutions for research about the Parkinson's disease ..

A. Current-State-Of-Art

Many company already developed orthesis for people with Parkinson's disease:

- **CalaTrio:** n electrical device is placed on the surface of the skin to stimulate the sensory nerves. These nerves have various functions, including controlling limb position. This solution is still highly experimental, but there is already a prototype with this mechanism in the form of the "Cala Trio".

- **Gyroglove:** In this mechanical device, tremors are detected and countered by an active force, as in the case of gyroscope stabilization, used to counteract tremors. It greatly reduces tremors, but its cost is very high : $5,899.00.

- **Tremelo:** A mechanical device to mechanically absorb the tremor using springs, a magnetic system, or an elastic glove.

Universities also develops innovative orthosis like the Politecnico di Milano laboratory with the Zmorph, an exosqueletton concept for the human hand.

B. Justification for the project

According to WHO estimates, there has been 8.5 million Parkinson's sufferers in 2019 [3], including 1.2 million in Europe, according to the NGO Parkinson's Europe [4].

The patient will be able to benefit from an assistive orthesis in his daily life, enabling him to live better with his disease. It will also be an opportunity to support researchers in their thesis work and bring about new discoveries. If the technology is a success, more advanced technologies could even be commercialized, contributing to the economic growth of the partner countries.

C. Main research question

1) Main question

• "How assistive technology can help a patient with Parkinson's disease ?

D. Project boundaries

The initial goal was to innovate a new orthesis, but the testing of this orthesis would have been quite difficult. Indeed, meeting people with Parkinson's disease and asking them to test those solutions isn't realistic. It could also have been considered rude or unethical.

Instead another solution has been found to allow maximum experimentation without having to involve patients, the simulation of Parkinson's disease. This simulation can be carried out by computer or with the help of a physical model.

The solution adopted by the project group will be to use a physical model, as this will free us from the constraints of programming.. These tremors will be used to mechanically simulate Parkinson's disease. The tremors will be detectected and measured with an accelerometer.

III. Specifications

Patients with Parkinson's have hand tremor in flexion and extension as their main symptom, however, existing treatments and devices do not provide the necessary comfort for daily use.
So, taking this approach into account, the patient needs the device to be designed to cushion hand tremors in flexion and extension while maintaining the comfort of the device, whether in weight, size or material, in addition, it must be easy to use due to because it will be used by elderly people who may not know much about technology and who seek autonomy in their daily tasks.

a) Main function
The main function of the device will be to dampen hand tremors in flexion and extension. Likewise, in order to present a product capable of competing with current devices, the design must be able to reduce tremors by at least 70%,

b) Geometry
The tremor suppression system will be a non-invasive device for the patient, in that sense, it is proposed that the device be attached to the hand externally.
The cushioning device, which is attached to the hand, should not have any component that exceeds 2 centimeters above the skin. In this way, any discomfort on the hand will be avoided, also allowing the patient to quickly get used to using the device.
the average measurement of an adult person according to the NASA-STD-3000 standard will be taken as a basis.
The anthropometric characteristics to be taken into account will be based on the ISO 8559:1989 Standard "Garment construction and anthropometric surveys", which provides appropriate suggestions regarding the parts of the body that should be measured when you

want to design a garment or, in this case, case, a device that will be attached to the patient's body

c) Ergonomics
The device to be designed must allow the patient to carry out their tasks at home and at work normally. fit the hand, can be used in a comfortable working posture and will not cause harmful contact pressure.

d) Materials
All materials that will be in contact with the patient's skin, or that will be exposed to the environment, must not represent a danger to the user. The main considerations will be that the material is not toxic via oral, skin or inhalation. contributing to ergonomics with respect to the heat to which the user is subjected, all materials in contact must maintain the skin temperature at its usual value23 (33°C), in order not to generate sweating in the patient.
e) Kinematics
Wrist movements: supination-pronation, flexion-extension and abduction-adduction will be allowed at all times, whether the device is activated or deactivated.

Furthermore, as long as the device is not activated, the resistance exerted by the mechanism will be practically zero, which is why the use of complex components will be avoided in order to avoid any obstruction.

g) Energy
The energy supplied to the system must be portable and rechargeable because the patient must have complete freedom to use the orthosis anywhere, without the need to be connected directly to some fixed electrical energy source. In addition, it must have sufficient capacity to operate continuously for 4 hours, considering constant tremor detection. Finally, the recharging method will be using a single-phase 220VAC – 60Hz charger, because it is the most common power outlet around the world present in homes.

h) Control
The system will be able to differentiate an everyday movement from a tremor in the hand. For this, frequencies in the range of 4 - 10 Hz will be taken into account, which are characteristic of the tremors produced by the Parkinson's
Then, having detected the occurrence of the tremor, the system will be activated with the aim of damping it and will be deactivated when the tremor is no longer present in the patient's hand.

j) Signs
The device will require an activation signal, which will be provided by the patient in order to select whether the device will be active or inactive. battery level signal, which will indicate that the battery level is low to charge it timely; and tremor detection signal, which will be activated when the device detects tremor in the patient's hand.

k) Security
because the proposed system is an orthosis, and since the device does not replace a function or part of the human body, but rather helps it, the provisions of ISO/TC 168 “Prosthetics and Prosthetics” will be used as a safety reference.
The design of the components will not have components with sharp or pointed edges that could hurt the patient when carrying out their activities.

l) Manufacturing
Because the system to be designed is subject to future improvements, the construction will be based mainly on rapid prototyping machines and processes such as 3D printing, silicone molding and material sewing.

m) Assembly
Mounting the device to the person should be quite easy, allowing the patient to put on the orthosis on their own without any difficulty. For this reason, the Poka-Yoke24 method will be applied, which establishes a series of recommendations to minimize errors when performing a coupling task, in the design of the orthosis assembly elements

n) Operation
The manipulation and operation of the orthosis must be simple enough so that it can be used by older adults. Then, it will be enough for the person to put on the orthosis and turn it on so that the entire system can work automatically. Later, when the person wishes not to use the orthosis, they will only perform the actions in reverse to achieve their goal.

o) Maintenance
The elements used in the construction of the device will be possible to find in the local market. In this way, the costs regarding repair or replacement of any component will be minimal. o) Maintenance
The elements used in the construction of the device will be possible to find in the local market. In this way, the costs regarding repair or replacement of any component will be minimal.

p) Cost
Because the device should be accessible to all users, a maximum cost of 1,500 soles is proposed. According to what is stated in the state of the art, this value is lower compared to well-performing orthoses on the current market, presenting an economical and, at the same time, effective proposal.

IV. The Parkinson’s tremors model

It is known that when an opposite signal are summed together and without delay, the obtained signal become null. It is a phenomenon called destructive interference.

An already existing technology using this phenomenon is called the noise-cancelling headphone. The exterior sound is recorded with a microphone and at the same time the signal of this sound is reversed. Once those two signals summed, a destructive interferences happens and gives to the user the ability to hear his music without the exterior sounds.

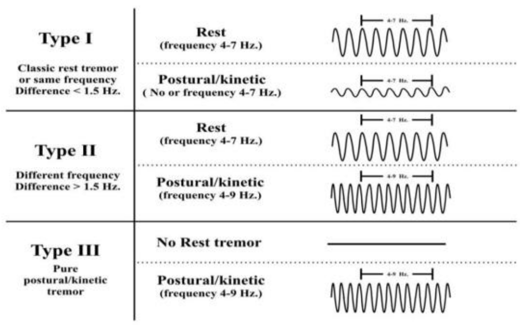


Figure 2 Table of the three types of tremor in Parkinson's disease based on the criteria of the International Parkinson and Movement Disorder Society®.

Applying the same methodology of destructive interference but this time on a mechanical orthesis, it would eliminate the tremors of Parkinson disease. The tremors are now well known in scientific community

First the movements of the hand must be measured, then, a mechanic orthesis will produce an opposite movement to the hand's movements.

In order to counteract all those hand's movements, a good knowledge of the structure bone's hand is needed to determine the kinematic movement of a human hand.

Each assembly of bones is equivalent of a kinematic link, most of them are ball joints. The assembly of Ulna and radius bones is equivalent to the rotation of the wrist. The group of 7 bones just over withcomplex structure, they are equivalent to the two other rotations of the wrist. Between metacarpals andphalanges. And finally the asembly of phalanges corresponds to ball joints

Figure 3 Bone structure of the hand

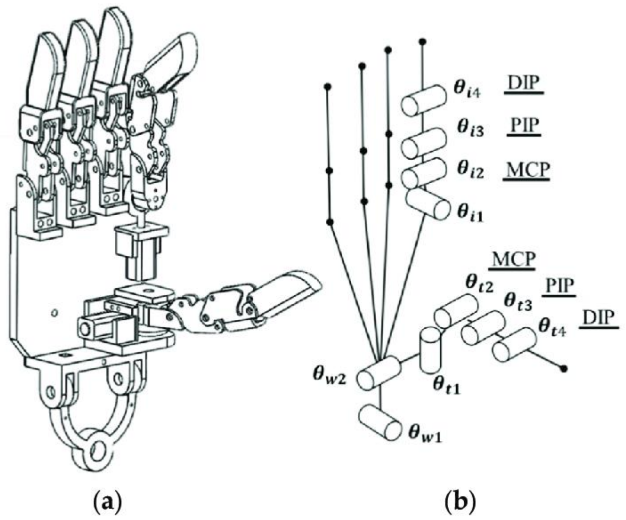


Figure 4 Kinematic diagram of a hand

It is also necessary to know the degrees of freedom of the hand in order to be able to build one experimentally. There are many articulated hand projects available on the Internet where you can visualize their kinematic diagrams, including this one above:

The mechatronic system will be powered by a motor, so it is necessary to choose a motor according to its size, torque and speed.

First of all, the type of current circulating in the motor, the desired result being a rotation speed allowing oscillation at a frequency of 4Hz for the articulated hand. It is not necessary to vary the motor speed, as is the case with other projects such as a remote-controlled car.

Among DC motors, the first thing to consider is whether to prioritize speed or torque. By default, DC motors are faster with lower torque, while stepper motors have the advantage of torque but much lower speed.

The mass of the articulated hand is estimated at 300g, which is low enough to use a simple DC motor. However, if the motor's torque is insufficient, the maximum rotation speed will be reduced, and the result obtained will not be the one we're looking for. If the torque is too low, the motor may jam and break.

This problem can be summed up by the mechanical power formula:

$$P = \tau\omega$$

- P: motor power in Watts.
- τ : motor torque.
- ω : motor rotation speed.

It is also possible to add a gear train to a motor in order to directly modify the motor's torque or speed. The transmission ratio k can be calculated as follows:

$$k = \frac{N_{2/0}}{N_{1/0}} = \frac{\omega_{2/0}}{\omega_{1/0}} = (-1)^n \frac{Z_1}{Z_2}$$

- N2/0: rotation frequency of 2 in relation to 0 in rpm.
- N1/0: rotation frequency of 1 in relation to 0 in rpm.
- ω2/0: rotation speed of 2 in relation to 0 in rad/s.
- ω1/0: rotation speed of 1 in relation to 0 in rad/s.
- n: number of external contacts (the negative sign of the quotient indicates an opposite direction of rotation between the two wheels)
- Z2: number of teeth on gear 2.
- Z1: number of teeth on gear 1.

However, PLA-printed gears need to be treated to remove 3D printing surpluses. These surpluses are harder to remove if the parts are small. Designing gear combinations requires a lot of trial and error. To save time, it's best to put this idea aside for future improvements.

A stepper motor is an inexpensive solution for testing the assembly. The hand's oscillation speed will be low, so we won't be able to achieve the hoped-for 4Hz result, but the model will be functional for the first orthotic tests.

Once the model has been built, the next step will be to design a prosthesis adapted for Parkinson's disease.

The model has several electronic components: microcontroller, sensors, motors …

V. Project development

A. User acceptance and usability

The innovation will help researchers simulate quickly the tremors and test directly an orthesis on the model. It is a significant gain of time, a low cost solution and user friendly.

B. Model design

The orthosis is tested on the model. Placing the orthosis at wrist level to slow the amplitude of oscillation of the articulated hand.

Several methods of vibration attenuation have been proposed:

1. Place an oscillating robot arm opposite the hand vibration (in phase opposition).

2. Place a robot arm stretching the hand perpendicular to the direction of vibration.

3. Place a pneumatic balloon around the wrist, which inflates when the wrist vibration reaches 4 Hz (like a car airbag). Once the balloon is inflated, the vibration will be attenuated by the force exerted by the balloon on the wrist, without blocking movement.

To detect tremors, touch sensors, buttons or vibration sensors like those found in smartphones, seismic devices or potentiometers can be used.

Vibration sensors would have been more suitable, but the less expensive ones simply have an LED that lights up when a vibration is detected. As for the more expensive ones, they are often too bulky and expensive.

The accelerometer is therefore better suited to detecting angle rotation.

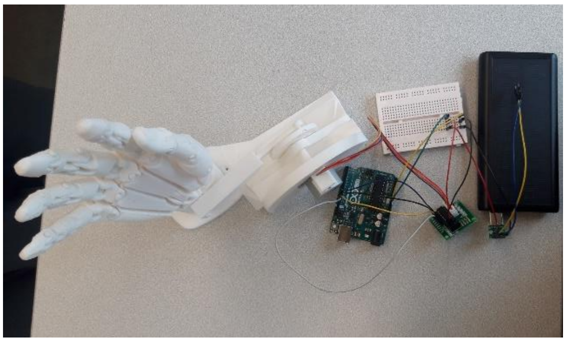
C. 3D printing of the model

The model simulating Parkinson's tremors was designed using blender software. The methodology of the design of the model is as follow:

1. Creation of the parts on FreeCAD with all functional surfaces

2. Adjustment the other surfaces on blender if necessary and assembly of the sub-parts

3. Models are then put into the cura software, a compiler to convert the blender code into a Gcode for printing



The design didn't work right the first time, and it took several trials before the final design was achieved. Difficult-to-predict clearances between parts repeatedly posed problems for the desired kinematic result. To correct these gaps, we had to modify the lengths, thicknesses or diameters of certain parts.

The first printed articulated hand was too large, and had to be reduced to a more realistic scale. Once reprinted, the hand had a more realistic volume, similar to the hands of the project members.

The motor-driven wheel for the connecting rod was modified several times. The first version was not suitable for hand oscillation, as the connecting rod was too short and the hand oscillated more to one side than the other. A second experimental version was therefore designed with several holes to see which hole worked best for good oscillation.

The final versions were then adapted to suit the length of the connecting rod. The male slide used as a connecting rod and attached to the wheel was too short in the first version, there was also a cutting force and not enough clearance. The air and hole length had to be modified twice.

The wrist axle, which enables the hand to oscillate and is connected to the other end of the male slide, was modified three times. In the first version, the hole in the wrist pin was circular, but this had the undesirable effect of creating play between the male slide and the wrist pin. This parasitic play prevented rotation of the articulated hand.

In the next version, the hole was modified to a rectangular shape, so that the male slide would drive the wrist axle like a key in an engine bore.

In order to amplify the oscillation speed, a geared motor consisting of two gears can also be placed between the stepper motor and the crank-rod.

C. Electrical Connection

Most electrical circuits have been wired on a microcontroller called “Arduino”. Connection’s nodes of the microcontroller are called pins, the cable are directly connected on them.

Sometimes welding is necessary to avoid disconnections, below it can be observed an example of cable connection between the microcontroller and the step motor.

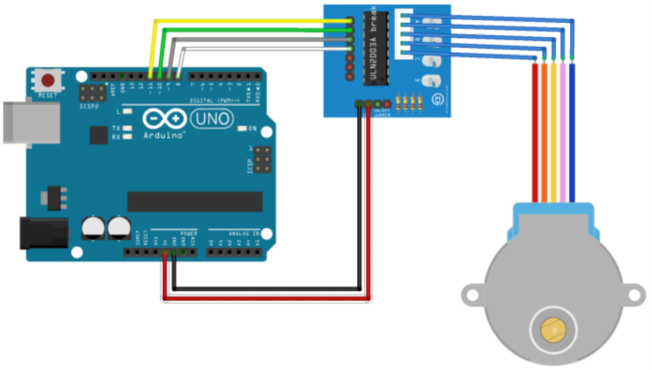


Figure 5 Circuit diagram of a 28byj-48 motor controlled by a microcontroller (Arduino)

VIII. CONCLUSION AND RECOMMENDATION

A. Conclusion

During this research, a physical model with the scale of a real hand has been developed. Any researchers can print it and use it to test their orthesis solutions on it. It is not expensive and needs only simple electronic components. The model could even be used to other project outside of applications of Parkinson’s disease research.

B. Recommendation

In the future, the project can be improved with a more powerful motor in order to come to the Parkinson’s frequencies’ tremors. Another could be using a more sophisticated moto reductor. And finally adding reactive captors to the model so the orthesis could adapt faster to those tremors.

ACKNOWLEDGMENT

We would like to thank Mr. Reheisser, for his advice as a supervisor of the Strasbourg’s team of the project. We would like to thank Mr Turko for the prototype counselling. Also we thank Mr. Di Domenico, that has helped us for the organization of the journey to Heraklion.

REFERENCES

[1] https://www.psychologies.com/Bien-etre/Sante/Maladies/Articles-et-Dossiers/Temoignage-J-ai-ete-diagnostiquee-Parkinson-a-48-ans

[2] https://institutducerveau-icm.org/fr/parkinson/quel-est-le-diagnostic-de-la-maladie-de-parkinson/

[3] https://www.who.int/fr/news-room/fact-sheets/detail/parkinson-disease

[4] https://www.parkinsoneurope.org/get-involved/donate/

GreenPy - An Energy-Efficient Code Analysis Tool

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Abstract— In the dynamic landscape of technology, the intersection of innovation and sustainability is a critical focus for addressing environmental concerns. This article delves into the GreenPy project, a six-month endeavor at ICAM Strasbourg, which not only aimed to develop a functional and user-friendly Python application but also sought to foster a mindset integrating environmental consciousness into software development. This article explores the objectives, methodologies, challenges, and outcomes of the project, showcasing the commitment to align technological advancements with environmental stewardship.

Keywords— Green IT, Sustainability, Software Development, Carbon Footprint, GPU Optimization

I. Introduction

In the rapidly evolving realm of software development, the surge in computational demand has ushered in a pivotal juncture marked by increased energy consumption. This paradigm shift requires a fundamental reassessment of programming practices, with a pronounced emphasis on energy-conscious methodologies. As the software industry grapples with the tangible environmental repercussions of escalating energy use during code execution, a critical need emerges for innovative tools that not only diagnose inefficiencies but actively contribute to the pursuit of energy efficiency.

This article delves into the theoretical framework that contextualizes the contemporary challenges in software development, characterized by an unprecedented demand for computational resources. The surge in energy consumption during code execution raises palpable concerns within the software development community, prompting a nuanced examination of the need to balance innovation and robust software development with a conscious effort to reduce energy consumption and its associated carbon footprint.

II. Problem Statement

The project addresses the environmental impact of software applications, particularly focusing on energy-intensive GPU operations, inefficient algorithmic choices, and the lack of Green IT practices in software development. By tackling these challenges head-on, GreenPy aims to set an example for a more sustainable approach to software development, fostering awareness and implementation of sustainable software engineering practices within the academic community.

III. SPECIFICATIONS:

GreenPy's objective is to create an editor for Python programs that calculates the CO2 equivalent consumed by the code it generates. The application provides an alternative, more energy-efficient code to the user, highlighting the environmental gain achieved by making the suggested code changes. The project utilizes Blackbox.ai to optimize the code and calculates the CO2 equivalent based on the user's country and processor specifications.

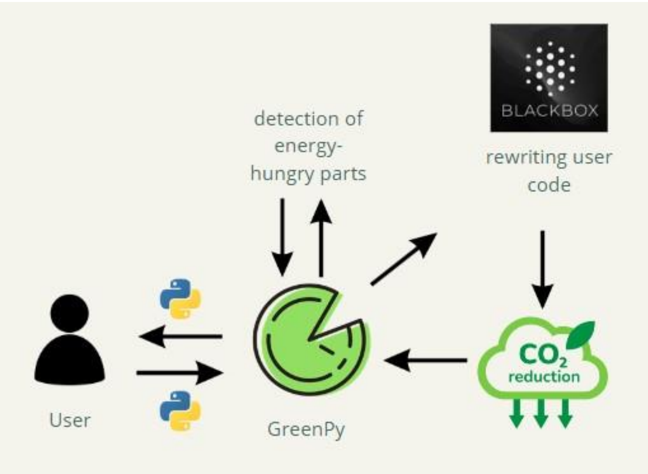

Figure1: GreenPy proof of concept

IV. SOLUTION PROPOSED :

The solution developed by GreenPy revolves around optimized GPU utilization, algorithmic efficiency, and the incorporation of Green IT practices. The project aims not only to provide a functional Python code editor but also to educate and raise awareness within the academic community about the importance of considering environmental impact in software development. The organization of the project involved collaboration between international teams, each focusing on specific aspects, and regular bi-weekly meetings to ensure consistency and coordination.

V. RESOLUTIONS METHOD:

GreenPy addresses energy-intensive parts of user code by identifying "while" loops. This study takes place in France and we use an Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz 2.59 GHz processor.

To see the result of our application we take a simple code with some “while” loop:

```
def example_code():
    i = 0
    while i < 5:
        i += 1
        j=0
        while j<3 :
            j += 1
            v = 0
            while v< 100000 :
                v += 1
example_code()
```

The Abstract Syntax Tree (AST) method analyze code users to find the “while” loops. An AST(figure 2) is a hierarchical data structure that represents the grammatical structure of a program in an abstract and organized manner. This tree-like structure, generated from the source code by the Python interpreter, facilitates a detailed analysis of the code's syntactic components, enabling targeted optimization efforts.

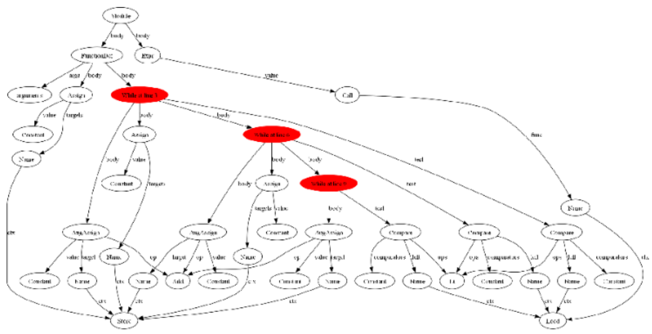

Figure 2: AST of the simple code with while in red

After find the while loop, we send prompt on Blackbox.ai to return an optimize code with for loop instead of “while” loop. Blackbox.ai is an open-source artificial intelligence that allows the generation of code in any programming language based on queries provided by the user.

We can now calculate the carbon footprint saved between the initial code and the optimized code. To do this, it is necessary to know the user's processor specifications and their country. The processor used here is an Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz 2.59 GHz with a power of 45W (table 1):

Processor Lines (Sheet 1 of 2)

Processor Line[1]	Package	Processor Base Power (a.k.a TDP)	Processor IA Cores	Graphics Configuration	Platform Type
U $_{v1}$ -Processor Line	BGA1528	15W	2	GT2	1-Chip
			4		
			6		
			2	GT1	
U $_{v2}$ -Processor Line	BGA1528	17W	6	GT2	1-Chip
			4		
			2		
H-Processor Line	BGA1440	45W	8	GT2	2-Chip
			6		
			4		
H-Processor Line XeonW	BGA1440	45W	8	GT2	2-Chip
			6		

Table1: power of intel processor [1]

The user's country for this study is France; however, for greater accuracy, two other European countries are added, each with a different carbon footprint taken at a specific moment in time on public website of “Reseau de Transport d’électricité”(RTE) for France [2] and for the other country we use open source data of ElectricityMaps [3].

Country	Eq gCO2/kWh	Date
France	50g/kWh	01/17/2024
Germany	605g/kWh	01/17/2024
Greece	430g/kWh	01/17/2024

Table 2: carbon footprint per country on Equivalent gram CO2.

Once these two characteristics are established, the Python module psutil.py is used to obtain the percentage of processor usage during user and optimize code execution. To determine the CO2 equivalent generated by codes, the processor usage percentage is recorded before and during user code execution, along with the program's runtime. Then, to calculate codes CO2 equivalent, the following formula is applied:

$$Eq\ gCO2_{code\ user} = \frac{\Delta\%cpu_{usage} * P_{processor} * t * eq\ gCO2_{country}}{C_{convertion}}$$

Figure: calculus of Eq gCO2 for a code

$\Delta\%cpu_{usage}$ *: Percentage difference in CPU usage before and during user program execution.*

$P_{processor}$ *: power of processor (W)*

t *: User program runtime. (s)*

$eq\ gCO2_{country}$ *: Gram CO2 equivalent of the user's country's electricity production. (gCO2)*

$C_{convertion}$ *: Conversion constant = 1000x3600; to obtain the result in gCO2.*

We use this formula for user’s code and optimize code and GreenPy make the different to obtain the gain.

However, the article acknowledges flaws in the method used to calculate the carbon footprint. We neglect the energy expended in data storage in the cache memory and in RAM. Moreover, most processors today have an automatic overclocking mode to increase their performance, which varies the maximum power. To address this issue, it is suggested to use an alternative approach using RAPL and JRAPL packages under Linux for more accurate results, obtaining the energy expended in joules by the processor during code execution [4].

VI. CONCLUSION

the GreenPy project represents a significant stride towards the intersection of innovation and sustainability in the dynamic landscape of technology. This six-month endeavor at ICAM Strasbourg not only aimed to create a functional Python application but also aspired to instill a mindset that integrates environmental consciousness into software development practices.

In moving forward, it would be advantageous to expand GreenPy's capabilities by detecting other energy-intensive code structures, such as nested loops. Additionally, incorporating a database with specifications of various processors would enhance result accuracy by increasing the diversity of user scenarios. Further, adding a database with CO2 equivalent data for electricity production from a broader

range of countries would provide a more comprehensive environmental perspective. These future enhancements will contribute to the ongoing pursuit of sustainable and conscientious software development practices.

References

[1] Intel®, “10th Generation Intel® Core™ Processors Datasheet, Volume 1 of 2,” February 2022 Revision 008, Document Number: 615211-008

[2] Réseau de transport d’électricité, “éCO2mix“ 01 january 2024.

[3] ElectictyMaps.

[4] Rui Pereira, Marco Couto, Francisco Ribeiro, Rui Rua, João Saraiva,Jácome Cunha,João Paulo Fernandes, “Energy Efficiency across Programming Languages”, SLE’17, October 23–24, 2017, Vancouver, Canada © 2017 Association for Computing Machinery.

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I2E2 Network

Bio Inspired Silent Drones

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***Abstract*—The 'Bio Inspired Silent Drone' project is addressing the issue of noise pollution from drones. With the upward trend of increased of drone usage, this issue becoming more relevant. Focused on innovating with propellors, using biomimicry, the aim is to reduce the noise by 3 dB or more. Key objectives include designing various propellors, conducting simulations and keeping patentability in mind. The innovations of the different designed propellors show promise in reducing noise and are possibly obtainable for patentability. With this innovation the project aims to increase the operating window for less sound of drones, with a particular focus on applications like wildlife photography and last-mile delivery. The wider-perspective goal is to show a propellor innovative solution that fills the current market gap by making the drones more user-friendly by significantly reducing noise levels.**

***Keywords*—biomimicry, drone, quadcopter, propellors, noise reduction, silent innovation, Von Karman vortex street**

I. Introduction

With the ‘revolutionary’ increase in drone usage, which has a projected rise from 110,000 in 2016 to 2,679,000 in 2025 [1], a key challenge of noise pollution arises. The 'Bio Inspired Silent Drone' project is aiming to explore the different innovation possibilities to decrease the noise output, by focusing on the main sound source, propellors. Nowadays, drones are being evolved into incredibly efficient equipment for several industries, think of wildlife photography as well as last-mile delivery. There is a gap in the usability of drones, mainly due to legislation and ‘victims’ of excess generated noise. It is therefore an opportunity to fill that market gap with the relatively quieter propellors in comparison to the currently commonly used. Therefore, this project is centered on aerodynamic sound effects, aims to create a quieter drone by using a self-built, demonstrative platform for testing and validation. Employing the TRIZ method, the journey begins with extensive patent and theoretical selection, followed by problem analysis and a more in-depth market demand anticipation. The patent search, which is guided by the V-model phases, is helping to inspire existing ideas into a tailored innovative solution for the project’s particular situation. Finally, deep evaluation with testing and reviewing is ensuring alignment with the project criteria, leading to conclusions and recommendations.

II. Project definition

This chapter delves deeper into the assignment and provides an overview of the project's objectives and the clients expectations.

A. Problem definition

As drone technology advances, challenges emerge. Therefore, the project's goal is to enhance drone capabilities by emulating nature's designs. The project aims to enhance drone capabilities through biomimicry, integrating efficient biological mechanisms for improved performance. Initially, the project focused on develop an entire drone to implement the innovation on. The focus shifted halfway to purely developing the silent innovation alongside creating a test set-up.

B. Occurrence

The challenge spans various situations, exploring innovative drone uses for consumers and industries. The project involves discovering practical and marketable ideas to enhance drone applications safely and align with technology, demand, and safety. Two key use-cases within this project are using silent drones for wildlife photography as well as last-mile delivery. For both these cases, noise is obviously a decisive nuisance, which stops the acceleration of using drones.

C. Assignment

The project focuses on innovating drone applications for consumer and industrial use, proposing practical ideas that elevate functionalities with safety in mind.

The assignment expects deliverables in the form of innovative use-case concepts, feasibility assessments, and recommendations that strike a balance between innovation, feasibility, and safety. The goal is to bridge the gap between imagination and feasible implementation, addressing market needs and advancing drone technology safely [2]. In particular, the project is aimed to deliver, an innovation, propellor, which decreases the sounds levels relatively with 3 dB in comparison to the current commonly used propellors for e.g., commercial quadcopters. A reduction of 3 dB, might not seem significant to the human ear, however by doing this, the acoustic power, air pressure, is close to being halved. Reducing noise with this value, thus represents a 'halving' of the perceived loudness and vice versa [3].

III. DESIGN

This chapter will capture the why and how of the design phase of the project. Here the methods of system and module design are explained with the reasoning behind them.

A. System design

To make appropriate design choices there must be certain methods in place. First of which is the morphological map where all concept ideas are gathered and divided into functions. These functions include but are not limited to patent research for sound reduction, propeller material, size and shape, motors, power supply and flight controller. Each functions contains multiple concepts, of which one or more will be chosen for a conceptual design. To make a substantiated choice another design methodology is introduced, being the Kesselring method. This method picks three designs based on level of silence, material quality and power efficiency respectively. The silent design optimizes noise control and durability while facing trade-offs in material quality and power efficiency. The material quality design focuses on using top-quality materials and ensuring durability but struggles with controlling noise levels and shows only average power efficiency. Lastly, the power efficiency design excels in power efficiency but sacrifices noise reduction and durability. For each of these designs the best the function is chosen and is weighted on a scale of 1 through 5, with a higher score being optimal. An overview can be seen in Table 1.

Table 1: Kesselring method

Criteria	Weight	Silent Design	Materials quality	Power efficiency
Noise Level	5	3	1	1
Materials/Structure	4	1	3	2
Efficiency	4	2	2	3
Cost-effectiveness	3	3	1	1
Safety	3	3	1	1
Durability	2	2	3	1
Total Score		49	37	33

Given the budget limitations on making further improvements the silent design was chosen with its superior noise reduction and reasonable durability. While constraints might prevent enhancements in material quality and power efficiency, this design aligns most closely with the goal of silencing drones within the given budget and limitations.

With the tight budget restrictions in place the unfortunate decision was made to abandon the design of a full drone and prioritize the propeller design. However, some of the findings from this chapter were used to create a setup for the testing of the propellers.

B. Module design

As established in the previous chapter the focus is put on the propellers. This chapter will elaborate on different propeller designs and how they are optimized for sound reduction. On top the design itself, noise simulations of those propellors will be explained as well. To finish of this chapter a schematic overview of the test circuitry is given.

The first design is a model based the professionally produced propeller of the T4943. Unfortunately, there are no CAD-models of this propeller readily available, so it had to be modelled by hand with the use of pictures. This propeller serves as a base comparison between a 3D printed propeller and a produced one. With this an estimation can, be made on the influence of the material on sound performance. [4]

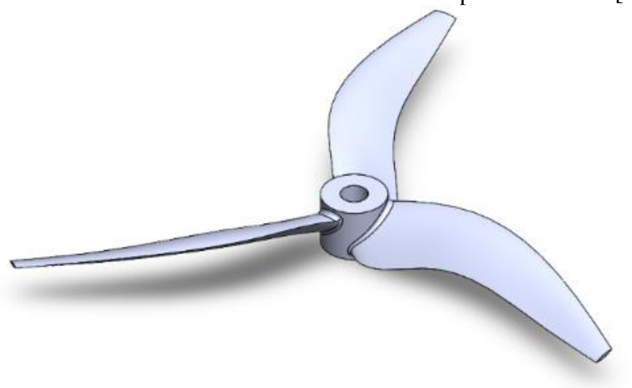

Figure 1: Replica of T4943 propeller

The second design is inspired by the anatomy of owl wings. Owls are known to be able to fly silently towards their prey, without alerting them. This makes it a perfect inspiration for a silent propeller design. Exactly recreating an owl wing is almost impossible, so to make it feasible it must be simplified. The biggest pressure difference is near the end of the propeller blade, this creates the most disturbance and thus the loudest. To counteract the pressure, difference a small plate has been added at 80% of the length of the blade. Although it seems to be a minor change, it gives multiple important benefits. It distributes the air better and in turn lowers the difference in pressure. On top of this it should also increase the amount of lift the propeller will produce, while also decreasing the amount of drag. [5]

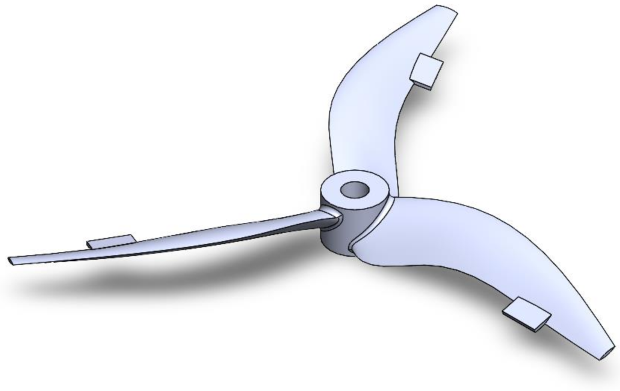

Figure 2: Owl wing T4943 propeller

Again, taking inspiration from the anatomy of owl wings, the improvements introduce the inclusion of ridges along the length of the propeller blades and addition of a slit with shark teeth. This helps improve efficiency by disrupting and breaking up the vortices that occur during operation. By changing the airflow, it avoids the adverse effects of vortices which in turn minimize noise generation. This design has a larger center, so it is also compatible for a Parrot Bebop 2 drone, this makes it more versatility while still being useful for testing with the 5 mm hole in the middle.

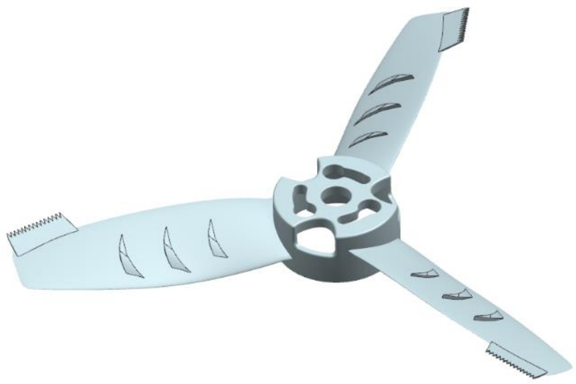

Figure 3: PC fan & owl wing propeller

Finally, there is the submarine turbine design. Like a submarine's propulsion system, this design capitalizes on wind drag generated along the edges of the blades. The semi-circular shape of the blades effectively minimizes drag, thereby reducing the impact on subsequent blades as they rotate.

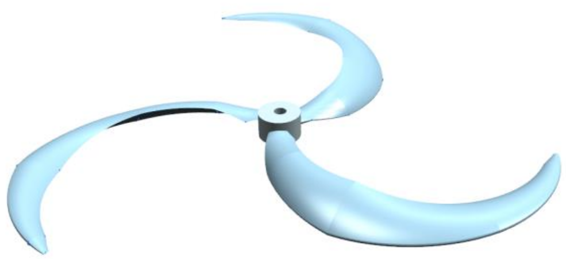

Figure 4: Submarine turbine propeller

Next up are the flow simulations. In Figure 5, a flow trajectory of the T4943 can be seen. In the figures the produced sound shown, is based on the displaced vectors of the propeller rotating through air at a speed of 6154 RPM's (The RPM count used during testing). By analyzing the picture, the propeller does not dissipate or allow the air to exit smoothly from the blade, thus a lot of sound is produced along the outside perimeter of the blades.

The affected vectors can be seen in red, orange, and yellow. With values ranging from 67 to 75, 58 to 67 and 50 to 58 dBs respectively. As one can imagine this is quite loud, and beyond that the simulation also suggests that the sound/vectors are not dissipating as the orange and yellow vectors can be seen making a full circular motion.

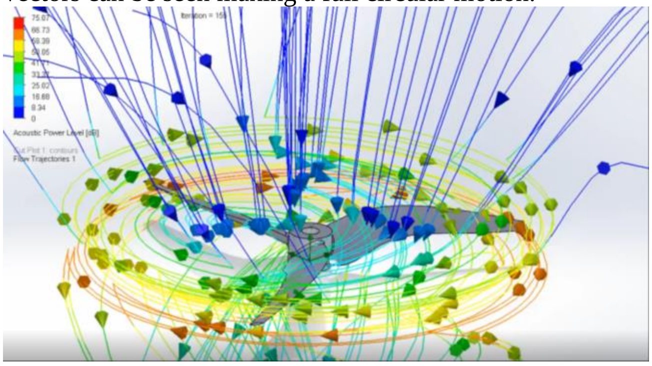

Figure 5: Simulated flow trajectory of T4943 replica

In Figure 6, the flow trajectory of the Owl Wing propeller can be seen. At first sight it is distinctively clear that most of the sound is created around the plate tips. This means that the design purpose of the propeller is effective, as an average reduction of around 1 to 2 dB's can be seen in the flow trajectories of the Owl Wing in comparison to the T4943. Thus, based on the simulations, the Owl Wing is worth implementing and testing.

The values of the simulation are considerably accurate, as the Owl Wing propeller showed an average sound output of 84.84 dBA (called 'Avg Slim Near' in the test result graphs) at around 6000 RPM's during testing.

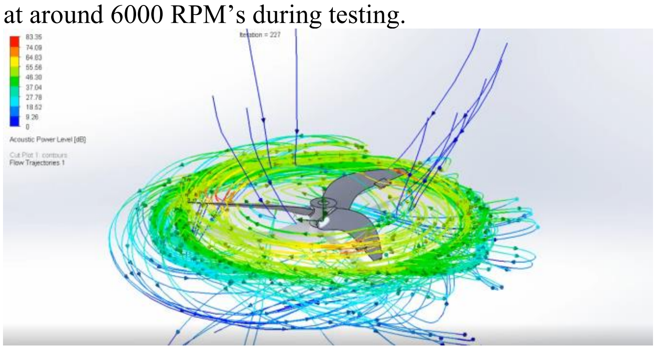

Figure 6: Simulated flow trajectory of Owl Wing

The last step of the system design is the test circuitry. It creates an overview of all electrical components of our test set-up and which I/O (inputs and outputs) are connected. The test circuitry differs from the drone circuitry the focus of the project shifted to only making the test infrastructure and not the entire drone. In the appendix is the drone circuitry which is the exemplary platform to which our innovation is going to be applied to.

The electrical components within the drone consist of:

- Flight controller: The flight controller dictates how much power is going to each motor to create the desired flight pattern (roll, yaw, pitch)
- ESC: Distributes the power to the motors according to orders from the flight controller.

- Motors: Creating lift by rotating (torque and rpm) with propellors attached.
- Receiver: Corresponds to a remote controller which sends orders from the user to the flight controller.
- Battery: Powers the entire system by using the ESC as distributor.

IV. RESULT

This chapter presents the outcomes of testing conducted to evaluate the performance of a newly designed propellers in comparison to the original propeller designed for a motor. The focus of the analysis is on sound levels, and the results aim to guide decisions for the optimal implementation of the propeller design.

A. *Testing methodology*

The testing involved three different propellers: the original (Red), the printed design with ridges and a heavier base (Printer), and the owl-inspired propeller with a slimmer design (Slim). Two subtests were conducted, varying the current input into the motor. The first test provided 2.2 A, generating 20% of the maximum motor throttle, while the second test provided 3.2 A, generating 40% of the maximum throttle. The positions of the measurement device were strategically chosen under the propeller, directly 62 centimeters below, and 90 centimeters away on the same level as the motor of a propeller. The 20 and 40 percentage of motors throttle were chosen due to the maximum current output of the power supply available for our testing.

The data collected from the measurement device focused on the LAF dB component, aligning with A-weighting to reflect the frequency sensitivity of the human ear. A-weighted measurements are commonly used in noise regulations due to their correlation with human annoyance and health effects.

B. *Results at 2.2 A (Figure 7)*

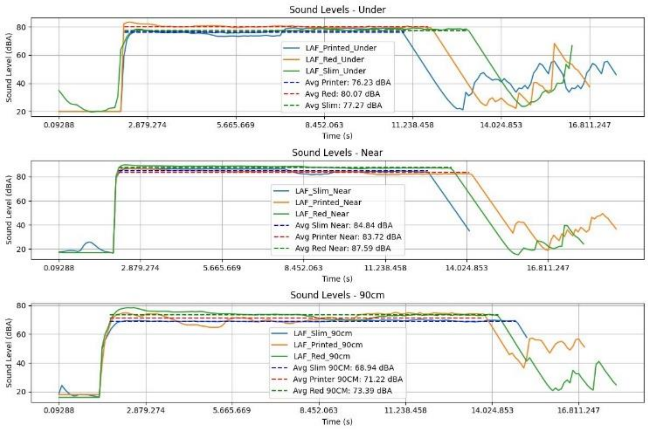

Figure 7: 2.2 A Average dB Graph

The graph illustrates the propellers' performance at 20% throttle, emphasizing noise levels. Both propellers developed by the team showed an average noise reduction compared to the Red (original for the motor) ranging from 2 dB to 5 dB. Notably, the Printer version demonstrated decreased noise levels beneath and near the motor, while the slim version outperformed in terms of noise reduction at a distance of 90 cm to the side.

It is crucial to acknowledge the limitations of these results, including the absence of propeller mass considerations and thrust measurements. The focus remains on noise levels under similar motor loads.

C. *Results at 3.2 A (Figure 8)*

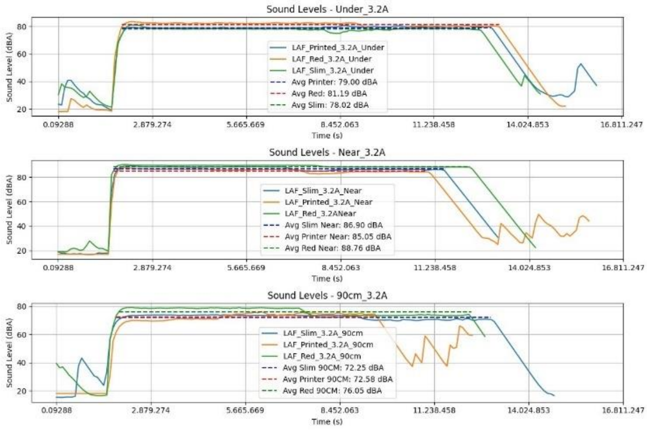

Figure 8: 3.2 A Average dB Graph

The graph presents propeller performance at 40% motor throttle, showing higher average noise levels across all propellers compared to the previous test. Both the Slim and Printer versions exhibit lower noise levels compared to the Red (original for the motor) version within the range of 2-4 dB. The Slim version, while maintaining reduced noise levels at a consistent height of 90 cm, produces more noise in proximity and beneath the propeller.

Testing at higher throttle settings was not feasible due to equipment limitations. Nevertheless, the observed progression of results suggests that the team's propellers would likely continue to outperform the original propellers at higher throttle settings.

D. *Evaluation*

The positive outcomes from evaluating the Printer and Slim versions at 20% and 40% motor throttle levels emphasize the potential and approval of these propellers. The consistent noise reduction of 2 dB to 5 dB, with each version showing specific advantages in different noise reduction aspects. Despite limitations, such as the absence of thrust measurement equipment and the need for a more comprehensive analysis considering propeller mass, the demonstrated superiority in noise reduction positions these propellers as promising alternatives. As the designs maintain an edge over the original propellers across varying throttle settings, the results contribute to the overall approval and validation of the Printer and Slim versions as effective solutions for noise reduction in propeller systems.

V. CONCLUSION

In conclusion, this project, which is aimed at reducing noise pollution from drones in commercial and industrial sectors, presents several key findings. The main objective was to achieve a 3dB noise reduction through a bio-inspired, patentable propeller design. This was accomplished through biological inspiration, patent research, prototyping, and testing while adhering to user and system requirements. To summarize, key findings that significantly influenced the project are as follows.

Research Focus, after patent and alternative research, emphasis shifted from von Karman Street vortices to owl wing dynamics due to feasibility issues. Testing confirmed the efficiency of the owl wing design, leading to the final propeller design including aspects of both theorems.

Sound Reduction, testing different designs yielded an average sound reduction of 2-5 dBs, meeting the project's requirements. Challenges consisted of budgeting and limited throttle testing, impacting propeller mass, and thrust considerations during testing.

Modular Test Setup, due to budget constraints, the original drone building requirement was changed. The current setup is a configuration consisting of a motor, flight controller, ESC, and propeller, allowing for future expansion to a full quadcopter.

Patentability, patent outlines support the design's patentability. Further testing, considering thrust measurements and propeller mass, is recommended to increase the success of the patent application.

Based on the aforementioned findings, a significant sound reduction of 3dB is achievable with propeller design modifications. This has the potential to change the development of propellers for commercial and industrial drones, causing broader drone acceptance in various applications. Furthermore, the project's success may inspire other engineers to further test and research silent propeller designs. The unique focus on plate tips sets our propeller apart from mainstream drone propeller designs. The project faced challenges such as budget limitations, which resulted in compromises in the test setup. Future considerations include possessing a thrust measurement device for more accurate test results.

VI. Recommendations

A. *Thrust Measurement and Propeller Mass:*

Incorporate thrust measurements to validate the design efficiency and trade-offs between sound emissions and lift.

B. *Higher Throttle Speeds:*

Test at higher throttle speeds (100%) to assess propeller performance under larger centrifugal forces.

C. *Expand Test Setup to Full Quadcopter:*

Expand the test setup to a full quadcopter, effectively emulating a more realistic system.

D. *Improve Budget:*

Gather additional funding to address budget constraints, enabling in-depth testing and the creation of a quadcopter.

E. *Optimize Owl Wing Design:*

Further optimize plate tips design to improve the efficiency of the propeller.

F. *Intellectual Property Consideration:*

Show a pro-active attitude towards maintaining intellectual property considerations for future protection of the innovative design.

G. *Engage in Public and Industry Discourse:*

Share project results to create collaboration, gather feedback, and contribute to advancements in the field of drone technology.

These recommendations shape our future efforts, such that continuous improvement and a broader impact in the field of drone technology can be facilitated.

VII. References

[1] K. Buchholz, "Commercial Drones are Taking Off," Statistica, 2019.

[2] E. Brokking, M. Gezuev, S. Gomez Rauw, W. Van Welie, A. Kishkoparov and J. Toonen, "Final Report Silent Drone," Fontys University of Applied Sciences, Eindhoven, 2024.

[3] Gracey & Associates, "Sound Level Calculations," Gracey & Associates, [Online]. Available: https://www.acoustic-glossary.co.uk/sound-level-calculations.htm. [Accessed 26 January 2024].

[4] Droneshop.nl, "T-motor T4943 Propellers," T-Motor, [Online]. Available: https://droneshop.nl/t-motor-t4943-propellers-4-stuks. [Accessed 26 Januari 2024].

[5] R. Noda, "Development of Bio Inspired Low Noise Propeller," Journal of Robotics and Mechatronics, Chiba, 2018.

Knee Orthosis

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***Abstract*— This paper presents a collaborative research endeavour between Fontys University of Applied Sciences and the Icam engieneering school of Strasbourg, focusing on pioneering advancements in knee orthosis design and functionality. This research paper centres on investigating and developing novel advancements in the design and functionality of knee orthosis specifically focusing on their application in assisting post-surgery knee osteoarthritis patients during their rehabilitation processes, while enhancing and promoting better structural cartilage recovery and therefore better knee motion recovery.**

Keywords—component, formatting, style, styling, insert (*key words)***

I. INTRODUCTION (*HEADING 1*)

Regardless of being one of the most vulnerable joints easily experiencing general wear and painful symptoms, the human knee is the key body part for sustaining activities of daily living. Due to trends in prolonged life expectancy, the vulnerability of the knee is furthered due to increased wear and tear of the joint, leading to knee pathologies being one of the most common complaints in the modern medicine. More generally, the aging population, coupled with a rise in sedentary lifestyles and sports-related injuries, has contributed to joint knee pathologies having variability of symptoms and unpredictability of development courses, needing an adjustable therapy to solve these medical pathologies.

Nevertheless, the current therapy solution for knee pathologies has several shortcomings. Firstly, passive knee orthoses are not a solution for a full range motion recovery, as they do not provide the needed support for the knee during different activities like walking and sitting down. Secondly, passive orthoses lack the ability of motor adjustment, thus not being able to account for different needs based on divergent patient symptoms. Lastly, the most commonly used passive knee orthoses i.e., unmotorized braces, require supporting efforts of therapists and orthopedicians, implying inconsistent and expensive prescribed therapy solution.

By presenting an orthosis supported by an actuator, our design not only aids in different types of daily activities by actively supporting even high-effort exertion, but also takes off load from knees. Secondly, the proposed electronics allows for a smart feedback system, enabling precise and personalized adjustments of the orthosis based on symptom difference and severity. Lastly, our design allows for minimal professional check-ups specifically for the physiotherapy, due to the ability of the design to self-initiate knee activity by having an actuator, thus starting off and actively supporting knee recoveries

II. DESIGN

A. Project Description

The project presents a novel knee orthosis design suitable for individuals experiencing different knee pathologies.

Overall, the design is of a prototype, that when produced, aims to treat three types of knee pathologies needing medical intervention: knee injuries, health conditions affecting muscles and/or joints, and idiopathic knee pain. The general objective of knee orthoses in all three pathologies is to ensure knee's (or its segments') stabilization through resisting external forces on the knee, preventing hyperextensions or abnormal/excessive movements, and overall controlling biomechanical knee alignment. Nevertheless, knee orthoses also have pathology-specific functions, making the appliance multi-purposeful. In the case of knee injuries, an orthosis commonly deals with injuries of a kneecap, otherwise called patellar injuries, i.e., injuries caused to the triangular bone in front of the knee that protects the knee joint. An orthosis can treat three types of patellar injuries: patellar instability, weakening of the patellar tendon in the knee (patellar tendinitis) and patellar dislocations. More generally, an orthosis treats knee ligament injuries and knee sprains. In the case of injuries, a knee orthosis is typically worn for a prescribed period and is most combined with other knee treatment options like physical therapy, injections, or anti-inflammatory medications. Therefore, the application of a knee orthosis in acute injury pathologies mostly revolves around supporting knee movement and preventing ligament injuries from worsening, thus having a short-term focus.

Contrarily, health conditions needing a knee orthosis treatment might need a long-term prescription due to chronic nature pathological symptoms like pain and stiffness. Some examples of health conditions treated with knee orthosis include osteoarthritis i.e., wearing away of the cartilage that caps the bones in joints and rheumatoid arthritis i.e., immune system attacking the joints. A knee orthosis also aids health conditions relating to knee deformity, like the outward curving of the knees i.e., Genu Varum and the inward curving of the knees i.e., Genu Valgum. Additional group of health conditions commonly treated by a knee orthosis refers to different genetic conditions that alter the strength of body tissues (e.g., Ehlers-Danlos syndrome) and joint flexibility (e.g., Joint Hypermobility Syndrome). In the case of health conditions, a knee orthosis is typically worn for a longer period, and aids with a chronic knee discomfort like swelling, muscle co-contraction and stiffness.

In the case of idiopathic pain, a knee orthosis is often self-demanded by individuals due to the general discomfort of the knee without a known cause, often resulting in orthopedic surgeons not prescribing conventional treatment options used in caused knee pain. Therefore, in the case idiopathic pain, a knee orthosis is used for different discomforts and knee pathologies and wearing period may differ per patient's needs.

<u>How the project solves the problem</u>

The objective of the project is to design a knee orthosis that can aid in recovery from the mentioned pathologies. This can be achieved by designing an orthosis that can perform these functions:

• The orthosis is an "active orthosis" and is power driven (electrical, pneumatic, etc.) to provide the user with mechanized assistance in their movement and reduce energy expenditure for the knee joints.
• Fix to the upper and lower leg and avoid migration, to ensure that the knees are properly unloaded
• Adjust to leg shape of the user
• Allow flexion-extension of the knee to achieve full range of motion
• Limit varus-valgus rotation to ensure proper knee fixation
• Constrain abnormal movements to prevent further deterioration
• The orthosis has different assisting levels which can be chosen to control the recovery pace

<u>Design Requirements</u>
Based on the theory and the analysis, requirements for the orthosis design can be defined. These are listed below:

1 The orthosis decreases pressure and compression on the knee
2 The orthosis follows the natural motion and biomechanics of the knee.
3 The orthosis does not cause any additional discomfort and pain to the user.
4 The orthosis is easy to put on.
5 The weight and size of the orthosis does not restrain or irritate the user in his movements.
6 The orthosis aids and assists the patient during movements requiring knee motions (such as leg flexion leg extension, internal and external rotations).
7 The orthosis does not function without the input of the user. Meaning that the orthosis does not initiate and achieve movements by itself.
8 The orthosis supports movement such as walking, sitting down, standing up, walking up or down stairs.
9 The orthosis secures the knee against over extension and over flexion.
10 The orthosis is size adjustable and can fit an average-size adult
11 The orthosis is working in favor of sustainability and follows ethical regulations of the industry.
12 The orthosis is comfortable to wear and use.
13 Be able to limit flexion-extension to individual preference

<u>Boundaries</u>
The project is about designing the prototype rather than its physical construction. Project is mostly focused on

the mechanical design (but have basics of the electrical and software). To reduce complexity and potential weight it was chosen not to design an orthosis that extends neither to the hip nor the foot. The dimensions of the design will be for an average-sized adult, thus excluding children and individuals with weight extremities.

B. Module Design

The orthosis consists of multiple main parts, the adjustable frame, the motor and the driving system, the batteries and the software.
The adjustable frame is the base of the orthosis, that is made of a metal alloy. Metals can be recycled without a decline in their material property values. Furthermore, the use of stainless steel contributes to the sustainability development goal [2]: responsible production. Stainless steel is a durable material, whit a high wear resistance and it makes part of a circular economy in which 100% of the material can be recycled [1], without the loss of their material properties. Tempered stainless steel is used for the frame not only for it is recyclability but also, because of the properties it has. The E-modules is 210.000 N/mm^2, while having a high toughness and a high corrosion resistance and it has a low maintenance [3].

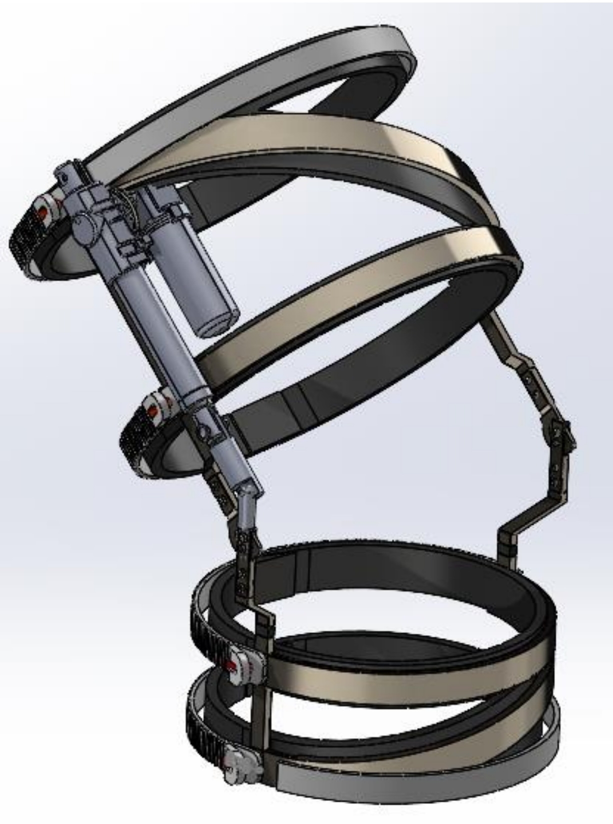

Figure 1: Orthose design

The orthosis is designed to be worn all day long, this is done by reducing the force applied to the leg on the contact surface with the orthose. The straps can easily be loosened by just pulling the strap connector up, this will reduce force on the leg while sitting down, without having to take off the whole orthoses.
Between the connection to the bottom and top leg is a damping component made out of rubber. It can absorb shocks and low frequency vibrations. There is a cushioning inside made from nylon which is breathable and feels soft against the leg, while reducing friction when moving.
the frame weight by using rectangular hollow tubes (15 x 8 mm) whit a thickness of 1 mm. By making the parts hollow, having the shape strength of the rectangular and use stainless steel as a material, the frame can easily support the body weight of the client and make it even more light to carry around all day. The weight of the whole frame including the motor, cushions and the straps to tighten the orthosis to the leg will be 4,3 kg.

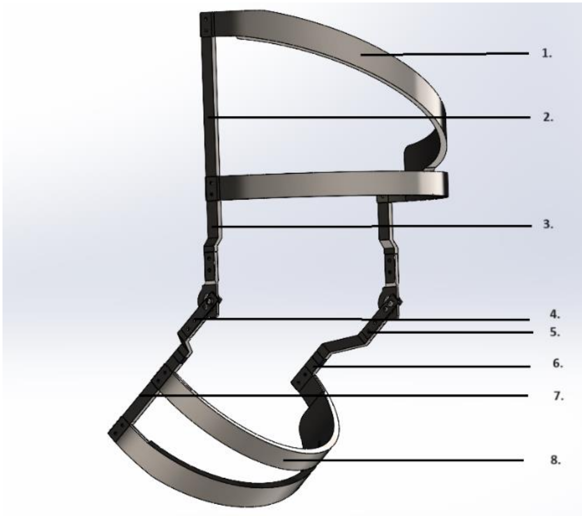

Figure 2: Orthoses frame

In figure 2 is a picture of the frame and their components. To make the frame adjustable in height and width it can be made suitable to fit adults. Components 2, 3, 6 and 7 are made in variable heights and components 1, 3, 4, 5 and 8 are made for different widths of the bottom and top leg, also by using different lengths on the x-axis for 3, 4 and 5 it is adjustable to the shape the patient's legs make.

All the components in the frame can be easily switched with the requested parts by simply unscrewing and replacing it. This will also ensure that worn down parts can be repaired or replaced, while leaving the rest intact. In figure 3 you can see that the “see trough” component slides in the attachment and can be bolted together with M4 boults through the holes.

The natural movements in a knee has multiple degrees of freedom, rotational, sliding and bending.

the rotational and sliding motion that a knee can naturally make are not replicated. This is because the rotational motion can cause additional instability when a patient wears it. After all, they wear the orthosis for a reason because they themselves do not have enough stability in the knee and cannot (almost) tolerate forces on the joint. The minimal rotation that the leg still makes during extension and flexion can be compensated for by the rubber damper located between the connection of the lower leg and the joint.

The sliding movement is possible to imitate, however, the shape of the sliding depends entirely on the dimensions of the contact surface of the tibial and femoral bones. The dimensions of this depend on the gender, bone structure, age and height of the person in question. If the sliding motion can be post-boosted in the hinge, it means that it will have to be custom-made, which will require a medical scan to determine its dimensions. This is a time-consuming and money-consuming process, moreover, it would have to be done for each individual [4]. So the sliding motion is not replicated.

Translated with DeepL.com (free version)
We can easily replicate the bending motion of the knee by letting the hinge rotate between 180 degrees (straight leg) to 40 degrees (fully bend leg). To ensure that the knee does not fold double or bend too far, there is an additional conductive groove in the hinge that limits movement through a pin connection. This hinge is shown in Figure 3.

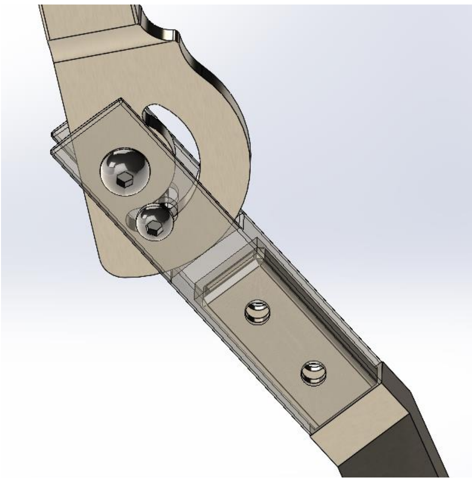

Figure 3: Hinge with rotation between 180 degrees and 40 degrees.

III. Business

The company offers a unique value proposition of advanced, comfortable, and user-friendly orthotic devices, especially aimed at people in need of orthopedic support. The product's distribution approach ensures widespread market accessibility by utilizing both healthcare provider and direct-to-consumer channels.

Consistent feedback methods are essential for maintaining customer connections and building loyalty and trust. The startup generates income from a variety of sources, including strategic alliances in the healthcare industry and direct sales. Securing its market position through patenting new discoveries and investing in state-of-the-art technology and intellectual property are crucial components of its strategy.

Strategies for market penetration, innovation, and ongoing product development are the main focuses of operations. Working together with healthcare organizations and professionals enhances its market reputation and facilitates product improvement. Maintaining financial health requires striking a balance between marketing and production expenses and capital expenditures for technology and market growth.

A key component of the startup's approach is its use of current and future technological advancements, which is achieved through continuous research and development work and the ability to patent the product in order to keep a competitive advantage in the quickly changing orthopedic market. This all-encompassing strategy highlights the business's potential for long-term growth and industry leadership.

IV. Conclusion

In conclusion, this study presents a significant advancement in the field of knee orthosis by introducing an innovative active orthosis design. This design addresses the limitations of traditional passive knee orthoses, offering enhanced rehabilitation support for patients with knee osteoarthritis and other knee pathologies. By integrating smart feedback systems and motorized adjustments, the proposed orthosis not only facilitates a more personalized and effective rehabilitation process but also reduces the dependency on continuous professional supervision. Furthermore, the focus on sustainability and user comfort in the design underscores the importance of practicality and environmental considerations in medical device development. This research marks a step forward in orthopedic care, suggesting a future where patients can experience more autonomous and efficient recovery journeys, ultimately improving their quality of life.

REFERENCES

[1] Outocompu, "Circulair economy," Outocompu, [Online]. Available:

https://www.outokumpu.com/en/sustainability/environment/circular-economy?gad_source=1&gclid=CjwKCAiAzJOtBhALEiwAtwj8tioME0j01cVBBlrndEtkQXeW-J9WI3QEJ62QmrOfwenJTBqtjDw2OBoCsm4QAvD_BwE. [Accessed 12 January 2024].

[2] United Nations, "The 17 goals," United Nations, 2023. [Online]. Available:

https://sdgs.un.org/goals. [Accessed 12 January 2024].

[3] Tosec, "Materiaaleigenschappen," Tosec, [Online]. Available:

.https://tosec.nl/nl/wiki/materiaaleigenschappen/#:~:text=Staal%20heeft%20ongeacht%20de%20variant,E%20%3D%20210.000%20N%2Fmm%C2%B2.. [Accessed 5 January 2024].

[4] "KNEE MOTION ANALYSIS OF THE NON-LOADED AND LOADED KNEE: A RE-LOOK AT ROLLING AND SLIDING," *Journal of physiology and pharmacology*, pp. 69-72, 18 December 2009.

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I2E2 Network

Building Facades with Algae

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I. Introduction

In today's context, where environmental preservation and sustainable development have become major concerns, it's essential to explore innovative solutions for integrating nature harmoniously into the urban environment. Our ambitious project aims to exploit the potential of bioluminescent algae as an ecological light source, by designing art deco lamps designed to embellish our interiors. In addition to their captivating aesthetic appeal, bioluminescent algae offer a sustainable, eco-responsible alternative to traditional lighting. This initiative represents not only a significant breakthrough in interior design, but also a contribution to the promotion of environmentally-friendly practices at the heart of our urban habitats. Through this project, we are committed to demonstrating that innovation can be synonymous with a symbiosis between design, sustainability and biodiversity, paving the way for an unprecedented aesthetic of light that is resolutely in line with the preservation of our planet.

II. Problem and Needs

A. Problematic

How can algae be effectively integrated into the urban fabric while exploiting their properties ?

B. Specification

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III. Our Path

Algae, long misunderstood, are now emerging as versatile and promising players in a variety of fields. Their use extends far beyond simple marine ecosystems, as researchers and innovators explore new applications in a variety of fields.
On the food front, algae are gaining in popularity thanks to their exceptional nutritional properties. Rich in proteins, vitamins and minerals, they are increasingly being incorporated into human diets, bringing benefits for both health and environmental sustainability.
In the field of bioenergy, algae represent a promising renewable source. Their ability to photosynthesize more efficiently than terrestrial plants makes them ideal candidates

for biofuel production and carbon dioxide capture, helping to mitigate climate change.

At the same time, algae have become key players in the cosmetics industry, providing natural components for skin care and beauty products. Their moisturizing, antioxidant and regenerative properties make them prized ingredients for manufacturers seeking to combine efficacy and sustainability.

This growing diversification of algae applications opens the way to new advances in a variety of sectors, underlining their emerging role in our daily lives.

A. *Well done seaweed and Definition*

Algae are living organisms capable of oxygenic photosynthesis, whose life cycle generally takes place in aquatic environments. They are a very important part of biodiversity and the mainstay of food chains in fresh, brackish and marine waters.

Existing solution:

- In Hamburg, the "Algae House", also known as BIQ, presents a bold innovation with a bioreactor integrated into its façade, offering an innovative approach to heating the building's fifteen apartments thanks to a bioreactor installed in BIQ's walls, where glass panels filled with a green liquid reveal gas bubbles rising to the surface. Stefan Hindersin, in charge of the reactor, explains that the movement of the bubbles is essential to agitate the algae, thus avoiding excessive exposure to sunlight and promoting regular growth.
- In 2013, Glowee tried to revolutionize urban lighting. Their innovative approach was based on the use of bioluminescence, a form of light emitted by natural organisms such as fireflies, glowworms, as well as over 80% of marine organisms such as jellyfish, squid and plankton. This original, environmentally-friendly concept aimed to illuminate store windows or facades at night, thanks to the genetic manipulation of bacteria that are harmless to humans. Several towns in France, including Rambouillet in the Paris region, had the opportunity to test Glowee's technology, with street furniture becoming the first pilot project for this promising start-up.
- - In 2015, CNRS and the University of Nantes jointly launched the AlgoSolis platform in France, dedicated to experimenting with the solar cultivation of microalgae. Occupying an area of 2,000 square meters, this facility enables researchers to evaluate various algae species through different bioreactor models. Investigations are aimed at determining the optimum technical set-up for algae cultivation, while fine-tuning the temperature, pH and nutrient parameters specific to each plant species.

B. *Our choice*

After much brainstorming, we decided to explore the bioluminescence of algae. Our approach was to select 10 words associated with the themes of algae in the urban environment, also soliciting suggestions from people outside the project. This is how bioluminescence emerged as the main topic, leading to our decision to integrate it into the field of urban lighting.

The initial idea was to replace bulbs and LEDs in public lighting and billboards with bioluminescent algae. This seemed a promising proposition, as it would considerably reduce electricity consumption for street lighting, while allowing the algae to absorb CO2, thus helping to improve the environment. What's more, the aesthetic aspect of algae bioluminescence added an artistic dimension to urban spaces. However, after extensive research and meetings, it became clear that this solution was not as viable as we had hoped. The costs associated with implementing this technology seemed higher, and the ecological performance didn't surpass that of LEDs, known for their low energy consumption. So we shifted our focus to aesthetics, realizing that bioluminescence was a remarkable innovation that had yet to find its way into home furnishings, offering a fresh and attractive perspective.

IV. Solution

Bioluminescence offers innovative opportunities in a variety of fields. It can revolutionize urban lighting, reducing dependence on electricity and adding a unique aesthetic to architecture. In the home, it could create soothing sources of natural light. Bioluminescence also has applications in environmental signage, biotechnology research, art and design, and education. It thus represents a versatile avenue combining functionality, aesthetics and sustainability.

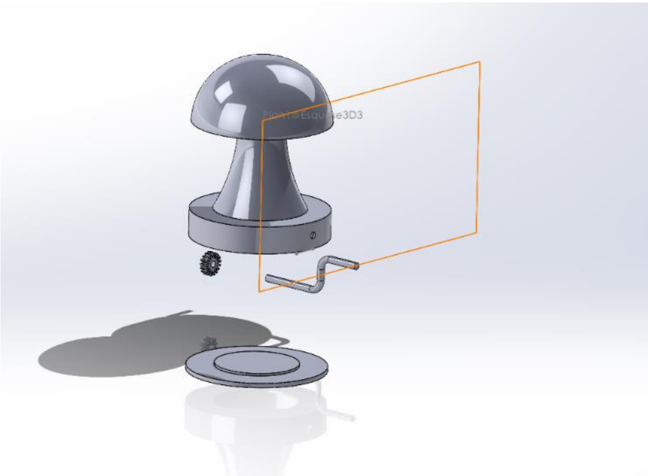
Bioluminescence is the production and emission of light by a living organism via a chemical reaction in which chemical energy is converted into light energy. This natural phenomenon involves the use of an enzyme called luciferase, luciferin, oxygen and other cofactors. Organisms such as fungi, bacteria, jellyfish, glowworms and even some algae use this mechanism for various functions such as hunting, communication and mate attraction.

A. *Chemical component , how does it work ?*

An ideal solution for the development of bioluminescent algae must provide an environment conducive to their growth and ability to produce light. To achieve this, the growth medium must be specifically formulated to provide all the essential nutrients, such as nitrogen, phosphorus, potassium, and micronutrients like iron, required for their development. The light source must be adequate to promote photosynthesis, and appropriate light cycles must be set up to stimulate light production. The temperature and pH of the solution must be controlled to maintain optimum conditions for growth. In addition, aeration and agitation of the solution are preferable to ensure a sufficient supply of oxygen and to prevent the accumulation of toxins. Regular monitoring of algal growth and bioluminescence enables the solution conditions to be adjusted to maximize their luminescent potential. Finally, the solution must be kept free of microbial or chemical contaminants that could compromise the health and luminosity of the algae. In short, the use or reproduction of seawater creates a solution conducive to the development of bioluminescent algae.Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

B. Movement

It's well established that bioluminescent algae require movement to activate their ability to produce light. In this process, the user plays a crucial role by turning a specially designed crank. This crank is directly connected to a wheel, creating a motion-transmitting mechanism. When the user activates the crank, the wheel starts moving, transmitting this kinetic energy to the solution containing the bioluminescent algae. This movement agitates the solution, stimulating the biochemical processes inside the algae that are responsible for light production.



C. Design

The initial objective for the lamp's design was to create Art Deco models accessible to the general public. We set out to design a lamp that would be as popular and universal as the lava lamps that were very much in vogue from the 70s onwards. This style of lamp was appreciated by everyone and was present in many homes. We therefore opted for a vintage style, with the aim of accentuating the impact of bioluminescence. For this, we drew inspiration from the famous designer Giancarlo Mattioli, renowned for his innovative lamps of the 1970s. Drawing on this artistic heritage, we worked to create lamps that not only evoke the retro aesthetic of that era, but also incorporate the modern technology of bioluminescence, offering a harmonious marriage of tradition and innovation.

Thanks

First of all, we'd like to thank Mr. Turko, our project teacher, for his support, invaluable advice and commitment in guiding us through this process. His expertise and dedication were invaluable to the success of this project.

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In addition, we are deeply grateful to the company who generously offered us their expertise and assistance in understanding the complex workings of bioluminescence. Their contribution was essential in deepening our understanding of the subject and enriching the quality of our work.

Finally, we would like to express our gratitude to all those who have contributed in any way to this project, and to our loved ones for their unfailing support throughout.

References

[1] G. Hislain, researcher at Woodlight, a company specializing in bioluminescent plants, unpublished.

[2] S. Rey Co-Founder of the french company Glowee.

[3] P.Fortin, “Glowee invente la lumière biologique”, in press.

[4] J-B. GANGA, “Woodlight, la deeptecj qui cultive l’éclairage de demain”, in press.

[5] Wilson T. and Woodland Hasting J. (1998) Bioluminescence. Annual Review of Cell And Development Biology. Vol 14. P 197-230.

[6] Morse D. and all. (1989) Circadian Regulation of Bioluminescence in Gonyaulax Involves Translation Control. Proceedings of the National Academy of Sciences of the United States of America. Vol 86. P 172-176.

[7] Cussatlegras A.-S. and all. (2001) Planktonic bioluminescence measurements in the frontal zone of Almeria–Oran (Mediterranean Sea). Oceanologia Acta. Vol 24. P 239-250.

[8] Philander G. S. (2012) Encyclpedia of Globa; Warming and Climate Change, Second Edition, SAGE Publication Inc., P 1416 – 1420.

Bionics in logistics – the use of swarm intelligence

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***Abstract*—Potential improvements were analyzed regarding the use of swarm intelligence in logistics, alternative solutions were developed and finally change projects were carried out in order to increase the efficiency and sustainability of the company partners' logistics processes.**

***Keywords*—bionics, innovation, intelligence, logistics, swarm**

I. Introduction

The innovation project deals with the use of bionics in logistics and, in particular, with the use of swarm intelligence. The research focuses on two main areas: area logistics control using ant algorithms and spatial logistics control, which focuses on swarm control algorithms for drones.

In both scenarios, the aim is to investigate the efficient coordination of individual transport resources to optimize logistics processes using swarm intelligence. In swarm intelligence, the focus is on optimizing the cooperation of resources such as drones and driverless transport systems to generate synergy effects and provide services that the individual resources could not achieve.

First, bionics in technology and logistics will be discussed in order to provide an overview of the topic. Then comes the focus of the innovation project, swarm intelligence in logistics.

This is followed by the areas of application, divided into drone and AGV application areas. The areas of application refer to specific fields of application of the company partners. Potential improvements are listed, and alternative solutions are presented about the use of swarm intelligence in the respective areas of application. These serve to potentially increase the efficiency and sustainability of logistics processes.

Finally, an assessment of the results, a conclusion for the use of swarm intelligence in logistics and a conclusion follow.

II. Bionics in Technology and Logistics

A. *Basics of bionics*

Bionics describes the interdisciplinary cooperation between biology and technology and its potential technical application [1]. Based on a conceptual definition, bionics looks at structures and processes in nature to find innovative solutions to technical problems [2]. Nature serves as inspiration for the development of new technologies and systems that are more efficient, sustainable and resource-saving [3].

Differentiating between biological and technical systems is essential for understanding bionics, as they have different system properties. Biological systems develop randomly and focus their development on optimizing the overall system. In nature, the generation of material, energy and organization takes place according to certain rules, mechanisms, and principles. Biological systems are also usually characterized by multifunctionality and are characterized by a close interplay of material and structure as well as form and function, which usually cannot be separated from each other. An observed phenomenon must therefore be precisely understood [2].

In contrast, technical systems are developed in a targeted manner. The focus is on optimizing individual functions. There is no compelling link between form and function, as there is in biological systems, in technology. A household appliance, for example, can vary greatly in design and form, even if the function remains the same [2].

For the fundamentals of bionics, it is noted that an abstraction of knowledge gained from biological models is required to be able to deal with the diversity and complexity of nature in bionics. The abstraction of biological findings also represents a challenge, both in the understanding of biological systems and in the process of bionics. It should be noted that there are three different levels of abstraction. The degree of abstraction differs depending on the observed natural phenomenon, the respective organism, and the underlying principle [2].

The degree of abstraction 1 can be explained by the Velcro fastener, the development of which was inspired by the adhesive force of the Velcro fruit [2]. The adhesive force is based on the sickle-like shape of the hooks of the Velcro fruit. Following a modeling process, the technical derivation was obvious: a system consisting of a hook tape is joined together with a fleecy tape [4].

Degree of abstraction 2 is illustrated by the self-purification of the lotus. In contrast to abstraction level 1, a deeper understanding of surface functionalization in nature is required. Through the evaporation of water, the lotus plant deposits waxy substances on the surface of its leaves, which organize themselves into a characteristic surface structure [2].

In the third level of abstraction, the findings about biological systems are abstracted into general innovative principles that primarily serve to generate ideas. For the third level of abstraction, it is crucial that today's technical possibilities such as X-ray structure analysis and electron microscopy enable a deep understanding of biogenic materials and structures. The third level of abstraction is important for the innovation project, as swarm intelligence is understood as an innovative principle [2].

B. *Understanding of bionics*

Bionics is an approach for product development and opens access to a solution space that would otherwise not be used. Existing bionic products can be used to solve an existing problem or improve a product. There is the classic way of bionics. In addition, there is creative bionics as an idea generation and innovation strategy, whereby it should be noted that all paths always involve a creative process in which new ideas for development work are found across existing boundaries [2].

In all paths, different disciplines work on a technical problem in an interdisciplinary manner and attempt to integrate nature and its principles into the solution-finding process. Depending on the level of abstraction chosen [5]. The path of creative bionics is decisive for the innovation project. Bionics is not only seen as a classical science, but also as a creative technique. The aim is to develop an innovation strategy for an area of application in logistics. Based on a previously generated idea. The innovation strategies should therefore provide the next best solution to the previous application of bionics [2].

Finally, for the understanding of bionics, it is noted that it is understood on the one hand as a science and problem-solving strategy and, crucially for the innovation project, as a creative technique and innovation strategy.

III. Swarm intelligence in logistics

A. *Basics of swarm intelligence*

Swarm intelligence is also known as collective intelligence or group intelligence. Groups of individuals make decisions by working together. In the animal kingdom, there are many species that act as a swarm. Ants, bees, fish, and birds, among others, live in a swarm. By living in a group, these animal species can, for example, procure food more efficiently or are better protected from predators. A swarm is based on the existence of a swarm intelligence. This in turn stems from a conceptual perspective that is focused on certain ideals. This requires an understanding of agent, behavior, and agent system. The terms are explained in the context of information technology, as this determines whether swarm intelligence can be used in logistics or not [6].

The terms "agent" and "behavior" are important for the basics of swarm intelligence. In computer science and technology, an agent is a delimit able (hardware and/or software) unit with predefined goals. The agent strives to achieve its goals through self-determined action and interacts with its environment and other agents. What is important is the state of self-determination, i.e. autonomy [6]. Autonomous means that the agent can weigh up its actions independently, considering inputs and models, and make goal-oriented choices [7].

An agent in logistics can be a robot, a drone, or a driverless transport vehicle (AGV), for example. Or it is the program in which the swarm intelligence is stored. The drone or AGV must be able to independently recognize a situation and react to it. The respective software responsible for the drone's and AGV's actions must be programmed for swarm intelligence.

For the areas of application in the innovation project, this means that, on the one hand, the technical framework conditions of the respective agent must enable swarm-intelligent work, but that appropriate programming must also be considered.

Behavior is everything that can be perceived externally with or without technical aids. These are primarily the movements of the body, special postures, changes to the body surface or other interactions with the environment [6].

In computer science or mobile robotics, both (robotics depending on the field of application) components in logistical processes, behavior corresponds to the (software) module that fulfils a self-contained function. One example is the collision avoidance behavior of a mobile robot or AGV. The robot or AGV uses its sensors to detect obstacles at an early stage and then avoids a collision by turning or performing an evasive maneuver. The ethogram would correspond to the set of behavior modules of the robot [6].

A swarm is defined as a group of autonomous agents that act in a coordinated manner through interaction. The interaction enables a swarm as a whole to develop capabilities that go beyond the individual agents, for example in the collective perception of information. Agents, as separable units in hardware or software, exhibit varying degrees of autonomy and complexity. Their behavior ranges from simple reflexes to swarm-intelligent patterns.

B. Swarm intelligence using the example of the ant trail

In an ant swarm, it is neither the queen nor a dominant worker caste that makes the decisions for the entire colony. It is the collective of workers that tries to make the best possible decision through intelligent behavior. The dynamics and adaptability of this collective behavior allow ant swarms to adapt precisely to local conditions, seasons, current weather conditions and the needs of the colony. The key role here is played by the organizational structures within the colony, in which the individual members communicate with and influence each other according to clear rules. Each individual worker plays her part in keeping the colony in optimum condition [8].

The interactions within the colony lead to feedback from scouts, which is crucial for the collective abilities of the ants. Food sources and suitable nesting sites lead to recruitment efforts by scouts. As a result, more workers are gradually led to these sites. The resulting feedback creates the basis for collective decisions [8].

Feedback within ant colonies and other insect swarms is made possible by scents known as pheromones. By pressing its rear end against the ground, the ant can leave a pheromone behind via a gland. An ant leaves a simple pheromone trail to find its way back to the nest when exploring [8]. When it has found a feeding place or a suitable nesting site, it leaves a stronger pheromone trail. The other ants react to this trail and follow it. Shorter paths have more pheromones on the trail and are more attractive [9].

C. Five basic principles of swarm intelligence

Five basic principles of swarm intelligence can be derived from the ant trail: The principle of neighborhood, the principle of quality, the principle of diverse response, the principle of stability and the principle of adaptability [8].

(1) *Principle of neighborhood*
The individuals of the swarm should only be able to carry out their actions and their perception within a limited local radius, which means that they "offset" the locally available environmental stimuli with their behavior without exception.

(2) *Principle of quality*
The swarm should be able to react to environmental stimuli in an adapted manner.

(3) *Principle of diverse response*
The swarm should have a sufficiently varied behavioral repertoire.

(4) *Principle of stability*
Not every (tiny) change in the environmental stimuli should lead to a change in the swarm's behavior.

(5) Principle of adaptability
The swarm should be able to change its behavior in response to sufficiently large changes in the environment, provided that this leads to an improved configuration.

IV. INNOVATION

As noted in Sections II. and III., the term "innovation" is used in relation to bionics and swarm intelligence. In colloquial language, the term is used in the sense of new ideas and inventions. This definition is sufficient for a basic understanding of bionics and swarm intelligence. An expanded understanding of the term innovation in relation to bionics and swarm intelligence in logistics is necessary for the areas of application presented in Section VI.

An innovation is an invention that has established itself on the market. In the case of innovations, a distinction is made between the degree of novelty and the potential for improvement and based on this, different types of innovation - from incremental to radical innovation, in some cases disruptive innovation. Depending on the type of innovation, a different number of attempts are required. As radical innovations create something new, their development is more extensive [2].

Changes brought about by radical innovations are far-reaching and not only reshape markets and products, but also the company itself and how it works. The changes can range from a new corporate culture and new (production) processes to new business areas and models, which subsequently create new jobs and make old ones redundant [10].

In addition to radical innovation, disruptive innovation is sometimes further differentiated. Disruptive innovations are a subset of radical innovations and occur less frequently. Like radical innovations, disruptive innovations are based on new knowledge and technologies. However, the aim is to create something completely new [11].

If a swarm-based solution for a use case in the innovation project could create the possibility of completely changing a logistics area, this would be referred to as a disruptive innovation. In principle, however, swarm-based solutions should be classified as radical innovations.

V. OVERVIEW OF APPLICATION AREAS

Fig. 1. provides an overview of the areas of application in the innovation project.

Overview of the areas of application	
Partner company	***Area of application***
Alfred Kärcher SE & Co. KG	Ant swarm intelligence for use in packaging
Kaufland Logistik GmbH & Co. KG	Pick-by-drone
Alfred Kärcher SE & Co. KG	Last-mile delivery using drones
Fritz Logistik GmbH	Support for a transshipment hall with AGVs in a swarm
Alfred Kärcher SE & Co. KG	Mobile picking robot with bionic gripper arm
Kaufland Logistik GmbH & Co. KG	Route planning in the palletizing area based on ant swarm intelligence
Fritz Logistik GmbH	Drone surveillance with swarm intelligence

Fig. 1. Overview of the areas of application

VI. DRONE APPLICATION AREA

A. Pick-by-drone

The implementation of future-oriented technologies such as drones brings many advantages. Many companies rely on Logistics 4.0 technologies, as a survey from 2022. A continuous increase can be observed [12].

In this project area in cooperation with Kaufland Logistik & Co. KG based in Neckarsulm, the implementation of a bird swarm intelligence for the transportation of articles from the warehouse areas is presented. The aim is to improve the efficiency and time optimization of the delivery process using autonomous drones at the Geisenfeld Ilmendorf logistics center.

As drones travel directly by air to their destination and can therefore avoid congested roads, the delivery time is greatly reduced. The drones are autonomous flying devices equipped with bird flock intelligence. Inspired by the coordinated dynamics of flocks of birds, this intelligence enables coordinated and adaptive navigation of the drones through the warehouse. Picking and transporting products can lead to improvements in logistics and warehouse management. It is also possible to increase processing speeds and improved picking efficiency.

Each drone has sensors and special mechanisms for gripping, such as the "delivAIRy" developed by the Fraunhofer Institute [13].

The hinges close and lock the goods in a similar way to the shutter mechanism of a camera. The advantage is that a QR code is attached to the adapter, turning image information into control information. Communication between the drones takes place via an intelligent interface system that includes 4/5G and RFID technology. Signals are transmitted regarding the storage location, the item to be picked and optimum flight routes to the area.

In the order picking sector, drones are set to replace the tasks of order pickers. It is common knowledge that there is a large and growing shortage of industrial workers in logistics. "This shortage will continue to increase due to demographic trends and the work-life balance sought by young professionals. This is why more and more companies are experimenting with different technologies to make goods delivery less dependent on people [14].

Drones with the pick principle are to be used here. This innovative solution achieves a dynamic and flexible adaptability that uses resources efficiently and minimizes delays in the dispatch process. The project aims to ensure the seamless integration of bird swarm intelligence into the logistics process and to optimize the overall efficiency of the storage and packaging process.

In the current logistics hall, order-orientated picking of goods is currently carried out manually by human workers on route vehicles. Sorting is a challenge and leads to a loss of time when picking goods correctly. In addition, the tugger trains cover long distances, which impairs efficiency.

The integration of drones aims to sustainably improve the time efficiency of order picking and thus increase the overall efficiency of the warehouse process.

The current loading processes are organized as follows: Loading begins with picking up the unit from a pallet. This process takes a lot of time. This process is carried out with the help of an employee on a small tugger train vehicle, each equipped with two folding pallets. In the case of empty pallets, these must be provided again for seamless picking using a forklift truck. This leads to further obstacles and a blockage of the aisle. This situation can be remedied by using a drone, as it utilizes the airspace, and the ground vehicles can carry out their function without interference.

Due to the extensive automation of processes in the hall, the use of drones could be considered. "Logistics will utilize airspace wherever it is efficient and ecologically justifiable by using drones and possibly cargo airships." [15]

The focus is on the safe and reliable transport of items between storage areas and the delivery point. In this context, it is crucial to select a drone that fulfils the specific requirements for robust performance and excellent stability. The selection of a suitable drone requires a thorough analysis and evaluation of various criteria, which, in addition to load and stability, should also consider aspects such as flight range, battery life, navigation accuracy, maneuverability and the ability to integrate sensor technologies.

In more detail, intelligent swarms of drones will operate using the pick principle. Since the swarm principle is being considered, platooning will become more important here. "In platooning, several vehicles can be driven in close succession by one person with the help of a control system." [12]

It would be possible to implement a control system in which a human operator monitors the entire hall and coordinates all processes via an interface.

It is essential that any use of drones complies with the applicable legal requirements. This includes national and local regulations, data protection laws and aviation regulations. See section Last Mile Delivery. Implementation is proving challenging due to the applicable legal provisions in Germany and the significantly high initial costs.

Nevertheless, the use of drones could be a promising approach in the future. Especially regarding the logistical challenge within a 3D space. The integration of drone intelligence in swarms for handling larger quantities can revolutionize the entire order picking sector. In addition, swarm technologies can offer versatile and promising solutions. Such a success would clearly emphasize a future-oriented approach.

B. Last-mile delivery using drones

The global exploration of autonomous drones for Last-Mile-Delivery is underway in various projects, including Jedsy in Germany [16], the Royal Mail in the UK [17], and Amazon's international Prime Air drone delivery service [18]. In Germany, laws such as the Air Traffic Act and the EU Drone Regulation govern the legal framework for drone operations. Drones are categorized based on weight and purpose, with specific rules for different environments like residential properties, airports, and traffic routes [19] .

The focus is on the potential implementation of Last-Mile-Delivery via drone at Alfred Kärcher SE & Co. KG, a German company. The delivery of spare parts to service technicians is particularly intriguing. The idea leverages drones' limitations in terms of payload to efficiently deliver spare parts to remote or inaccessible locations. The Wingcopter 198 Delivery Variant drone is considered a promising solution, capable of carrying up to three packages [20] .

The potential implementation of this idea could bring benefits such as increased efficiency, environmental friendliness, and improved supply to remote areas. However, substantial regulatory challenges stand in the way, especially the requirement for line-of-sight during drone operations. Security concerns and privacy issues, particularly with drones equipped with cameras, demand clear guidelines and advanced technologies.

A more in-depth analysis of the current situation in spare part procurement by service technicians reveals a process through the internal Enterprise Resource Planning System (ERP), where the logistics department packs and dispatches orders by 7:00 PM. Possible enhancement of this process through drone deliveries could mean significant time and cost savings.

The legal framework for deploying autonomous drones in Germany is dictated by the Air Traffic Act and the EU Drone Regulation. The legislation categorizes drones based on weight and purpose, including the "open" category for drones under 25 kilograms, the "specific" category for advanced applications, and the "certified" category for heavy drones carrying passengers or dangerous goods.

The EU Competency Certificate for remote pilots is now mandatory for drones with a takeoff mass of 250 grams or more and varies depending on the drone category. National regulations in Germany emphasize operational approval, line-of-sight and remote control, data protection, liability insurance, as well as special permits and exemptions. Restrictions apply to geographical areas such as residential properties, airports, and traffic routes, with special approvals and minimum distances required [21].

The presented concept for Last-Mile-Delivery via drone envisions a potential landing site allowing drone placement for takeoff and landing operations. With the autonomous drone from Wingcopter, delivery within a radius of 30 km could be realized.

Implementing this idea would not only mean significant efficiency gains and cost reduction but also environmentally friendly deliveries and improved supply to remote areas. Nevertheless, regulatory challenges such as the demand for line-of-sight and privacy concerns are in focus. The future development of EU regulations could bring positive change for the feasibility of this idea. A detailed cost-benefit analysis and quotes from drone manufacturers are crucial for assessing profitability and the timing of implementation.

The feasibility of the idea requires overcoming these challenges through potential regulatory adjustments and advanced safety measures. A careful balance between potential benefits, such as efficiency gains and environmentally friendly deliveries, and existing hurdles is crucial. Prospects for future EU regulations could potentially bring changes to facilitate implementation. The decision for implementation also necessitates drone manufacturer quotes to assess investment costs and the amortization timeframe.

C. Drone surveillance with swarm intelligence

The proposal describes the creation of a sophisticated surveillance drone system that utilizes bionic swarm intelligence principles to improve monitoring and detection of hazardous substances in Warehouse 9 at Fritz Logistik. The autonomous system uses swarm intelligence to efficiently cover the entire warehouse area. It communicates collaboratively and responds quickly to potential threats such as hazardous material leaks. Integrating advanced technologies such as obstacle detection, human presence identification, and instant communication capabilities can enhance warehouse safety measures.

The primary objective is to improve safety in Warehouse 9, a facility dedicated to storing hazardous substances within Fritz Logistik. Due to the unique nature of the warehouse, it is crucial to minimize risks associated with handling and storing dangerous materials. The goal of the proposed monitoring system is to proactively manage risks by continuously monitoring for hazardous substances, quickly detecting potential leaks, and ensuring immediate response to mitigate hazards and ensure the safety of personnel and the overall warehouse environment.

The system's key features include Bionic Swarm Intelligence, which allows the drones to imitate the collective behavior of biological organisms.

This enables them to operate autonomously and communicate with neighboring drones to optimize surveillance coverage and resource distribution.

Additionally, the system is equipped with LiDAR, obstacle detection sensor, which utilize advanced sensors and computer vision technology to ensure smooth navigation and efficient coverage in warehouse environments [22].

The system can also detect human presence. By integrating Passive Infrared sensor, drones can differentiate between human and non-human entities, preventing collisions and enabling targeted surveillance, especially in areas with hazardous substances [23].

Drones are also equipped with integrated sensors capable of detecting hazardous substance leaks. If a leak is detected, neighboring drones are immediately notified to confirm the incident.

Additionally, cooperative communication is employed.

Drones maintain constant communication with each other to facilitate real-time information exchange about their surroundings.

In case of hazardous substance leaks, the central communication center will be automatically triggered if two or more drones confirm the presence, and an alarm will initiate for the immediate evacuation of personnel from Hall 9.

In the event of an alarm activation, an automated emergency response will provide personnel with 23 seconds to evacuate, close doors, isolate the warehouse, and activate the CO_2 fire suppression system.

Actual State:

This is the current situation at Fritz Logistik. Hall 9 is designed specifically for storing highly hazardous substances. To prevent incompatible materials from being stored in proximity, the hall is divided into three compartments. Although these precautions are in place, unforeseen incidents such as substance leaks still pose significant threats. Strategically placed stationary safety sensors are programmed to activate an alarm system in case of substance leakage. This facilitates a swift evacuation within a 23-second timeframe.

Proposed State:

A warehouse surveillance system uses seven drones operating in strategic cycles to ensure continuous and effective coverage. The drones operate in pairs, with each pair covering one and a half rooms in the three-room Hall 9. Flight time is limited to 45 minutes, after which the drones autonomously return to the docking station for a 90-minute recharge. Two backup drones take over after 45 minutes, ensuring a seamless inspection cycle.

In the event of a hazardous spill, the reporting drone communicates with its partner for a rapid response. The drones then transmit precise location data to the control room using LiDAR sensors, activating the alarm system and emergency protocol. While the original detection drones search the affected area, two additional drones search the unaffected chambers. Once personnel safety is confirmed within 23 seconds, all drones return to the docking station. Simultaneously, the doors and gates of the affected room close, triggering the CO_2 extinguishing system to eliminate the hazard. Upon completion, the doors reopen, and the monitoring cycle resumes, ensuring a continuous and vigilant system. An additional backup drone is on standby to replace any malfunctioning unit, increasing system reliability.

Assessment of the Swarm Intelligence Surveillance Drone Idea:

The proposed swarm intelligence system is innovative. However, due to the size and characteristics of Warehouse 9 at Fritz Logistik, it may not be cost-effective considering the rarity of incidents. For a smaller warehouse, stationary sensors could fulfill the surveillance needs more affordably. However, in larger warehouses, particularly those with high shelves, the swarm drone system is more cost-effective, providing improved surveillance in expansive and complex environments. Implementation should be customized to meet the specific requirements of each warehouse, achieving a balance between cost and safety efficiency.

VII. AGV APPLICATION AREA

A. *Ant swarm intelligence for use in packaging*

The presented use case outlines the concept of swarm intelligence for the packaging of commissioned items in warehouses, particularly within the context of the Alfred Kärcher factory. The implementation involves the use of Autonomous Mobile Robots (AMRs) with swarm intelligence, operating autonomously and coordinating movements through the warehouse. Each AMR is equipped with sensors and a gripper arm to automatically transport grid boxes. Communication between AMRs is facilitated through an intelligent interface system [24].

The MiR250 Hook serves as an example of such an AMR capable of autonomously transporting grid boxes [25]. Traditional logistics methods involving human employees and forklifts currently dominate Kärcher's warehouse operations. The integration of swarm intelligence and bionic principles holds the potential to significantly enhance logistics efficiency [26].

The idea is well-suited for Kärcher as it promises efficiency gains, minimization of human errors, flexibility, reinforcement of the innovation image, and contributions to sustainability [27]. Swarm intelligence enables effective coordination of AMRs to identify the quickest routes and timely transport of grid boxes to the packaging area.

Spatial requirements include a structured layout, safety zones, and effective communication systems [28]. Technical considerations involve the size, dimensions, weight, and safety features of the AMRs. Feasibility is supported by efficiency improvements, resource savings, and seamless integration into existing systems but could face challenges due to high initial investments, complex infrastructure integration, and the need for employee training. A thorough analysis and adjustments are necessary to overcome potential obstacles and ensure successful integration [29].

B. *Support for a transshipment hall with AGVs in a swarm*

The basic idea of this project is that the staff in the transshipment hall are supported by automated guided vehicles (AGVs), thus promoting automation in this area of logistics. It should be noted in advance that this application is designed exclusively for standardized Euro pallets (with 100mm overhang, dimensions 1300x900mm).

The process is as follows: Lorries are unloaded by personnel and the pallets are placed under a camera system. This checks whether the supplier dimensions match the reality and whether the load unit is suitable for transport by an AGV. The recorded information is stored in the cloud. Suitable pallets are placed in a pick-up area, from where a vehicle transports them to the buffer zone. Unsuitable consignments are processed by staff. In the transshipment hall, cameras monitor the loading and unloading as well as the tracking of goods, but do not provide any control for the AGVs or similar. The means of transport draw information from the cloud and can store feedback. As soon as a lorry is ready for loading, the AGVs transport the pallet to the corresponding buffer zone, from where it is loaded into the lorry by an operator using a forklift or high-speed truck.

The framework conditions for the project are divided into spatial, technical and process-orientated conditions and are presented here in brief. The basic spatial conditions include a clear room structure, a flat, smooth floor surface, stable lighting conditions and walkways for the personnel. From a technical point of view, the AGVs are equipped with 3D cameras to create a map of the surroundings and know where they are in the room. The simultaneous localization and mapping process is used for this. The AGVs are also equipped with an ultrasonic sensor at the front in the direction of travel in order to reliably recognize obstacles and people [30]

. Position and weight sensors are used to check whether the loading unit is correctly positioned on the fork. The process-oriented and organizational conditions include the fact that there must be training for workers in the handling of AGVs. Furthermore, the material flow must be adapted so that camera checks and just-in-sequence delivery to the gates are taken into account. The creation of work instructions, error logs and maintenance plans are also helpful.

Swarm intelligence is used here in that the AGVs communicate with each other and agree who should take on which job from the cloud. The vehicles act independently and actively receive orders from the cloud. A means of transport can also request help and support by sending a signal to others. In such cases, the AGVs communicate with each other and decide which vehicle can best help based on who is closest or has just completed a job. When there is no more work, the vehicles return autonomously to their charging stations. If they detect that sensors or other systems are not working properly, they send a signal so that an employee can fix it.

In principle, it is possible to implement the idea, provided the general conditions are met. However, it should be noted that the use of swarm intelligence can slow down the process somewhat and is not necessarily more efficient than the conventional, non-automated version with labour. In addition, extending the scope of application is challenging, especially in transshipment centres where a large number of different items are dispatched. For each of these cases, the AGVs would have to have different, additional gripper or suction arms, which is costly and time-consuming.

C. *Mobile picking robot with bionic gripper arm*

The idea of developing a mobile picking robot with a bionic gripper arm for picking goods came about after visiting a warehouse at Alfred Kärcher SE & Co. KG in Obersontheim. The use case is supported by Kärcher, which is a world-renowned company for cleaning solutions [31].

The aim of the use case is to replace the current conventional picking processes with innovative cyber-physical conveyor technology. A cyber-physical conveyor system consists of individual modules with their own decentralized control systems. The picking robot is considered an integral part of this cyber-physical system. Its gripper arms are designed to precisely identify, pick up and place various items in a container using state-of-the-art sensors, image processing technologies and artificial intelligence. By using these technologies, the robot can act autonomously and intelligently by continuously exchanging data and information.

Currently, goods are still picked manually, which poses various challenges. Manual picking processes are prone to human error, can be time-consuming and require a high level of manpower to meet precision and speed requirements.

In view of this manual approach, the development and implementation of mobile picking robots with bionic gripper arms appears to be a promising solution. This is seamlessly connected to Kärcher's warehouse management system. As soon as the system sends the order with the destination to the robot, it independently calculates the optimum route. It uses its ability to use 2D and 3D cameras in the grippers to scan the contents of the shelf.

The bionic gripper is designed to adapt to different item types and grip them precisely, enabling optimal handling of small parts in the warehouse top speed (LTS) area.

The robot can interact with its environment in real time. It has a laser protective field and sensors to detect obstacles and unforeseen blockages and react accordingly. It can also be combined with various gripping tools to perform a variety of tasks [32].

Depending on the goods to be picked, a jaw gripper, an articulated finger gripper, a suction cup gripper or a magnetic gripper can be used to carry out the gripping process. It is imperative that no items are damaged during the gripping process. Therefore, sensor-controlled image processing is integrated into the gripping device to facilitate the gripping process [33]. A jaw gripper could be inspired by the functioning of a beetle's gripping mechanism, which can grip efficiently through its jaws. An articulated finger gripper could borrow from the flexibility and precision of the joints of a human finger. A suction cup gripper could be inspired by the suction ability of squid or other marine life. A magnetic gripper, on the other hand, could be inspired by the magnetic adhesion of some animals or by magnets in nature.

The idea of using a mobile picking robot to optimize the picking process represents a promising opportunity for Kärcher. By linking to a warehouse management system, the robot can independently receive orders, calculate routes and scan the contents of shelves to find the required items and place them in a container. Precise product and position recognition enables accurate handling of even disordered items. Real-time interaction with the environment enables the robot to react to obstacles and achieve a similar range of action as a human operator. It can also use different gripping tools to adapt to different items.

In terms of linking with swarm intelligence, the idea could be extended by coordinating several such robots to work together on order picking. Such swarm intelligence could further increase efficiency by allowing the robots to work together on complex tasks and support each other.

D. *Route planning in the palletizing area based on ant swarm intelligence*

Kaufland Logistik GmbH & Co. KG planned to expand its Ilmendorf site, Geisenfeld logistics center, into one of six regional administrations in 2016. This was achieved by the end of 2023 through the construction of two new halls and the implementation of automation technologies in a new, highly automated distribution center. These investments are aimed at replacing and facilitating heavy physical activities, which optimizes both the work for employees and the handling of goods [34].

From 2024, Kaufland plans to have 80% of its non-refrigerated food range picked automatically at the Geisenfeld logistics center. This will be made possible using picking robots, autonomous shuttle vehicles and pallet transport systems. In the new distribution center, the robots are programmed to pack the pallets according to the specific layout for the stores, which reduces the workload for employees and shortens their walking distances [35].

Autonomous mobile robots (AMR) are used in the new Geisenfeld logistics center. They take over the transportation of the specially developed Kaufland folding pallets. This results in traffic jam and waiting times during the regular operation.

The lack of intelligence and the congestion and waiting times in regular AMR operation make it suitable as an application for the use of bionics and swarm intelligence. The idea is to use swarm intelligence to achieve more efficient, adaptable, self-organized and congestion-resistant AMR route planning. In addition, the AMRs should act and interact intelligently in the future, i.e. interact with each other. Part of the idea is to draw on swarm intelligence using the example of the ant trail (see section III. C.).

The idea is to transfer the natural intelligence and adaptability of ant colonies to the route planning of the AMR.

The AMR should be able to transmit positive or negative feedback to other AMRs, just like ants' customers.

To ensure a more precise hold, metal strips are attached to the floor of the transport zone in which the AMRs move. They guide the AMR into position. Part of the idea is that an "AMR of the future" can also move precisely without the metal strips and can therefore use the entire space [36].

(1) What should the AMR of the future look like?

The AMR of the future should also be equipped with artificial intelligence to be able to operate autonomously and adaptively in complex warehouse environments. This requires new navigation technology that implements artificial intelligence and swarm intelligence and enables the AMR to move freely in space and calculate the best route to its destination (pallet pick-up or unloading point) [2].

To avoid traffic jams and waiting times, a continuous and independent exchange of data between the AMRs is required. In addition, the AMR should be able to interact with people and other vehicles in the area [37]. For example, the AMR should not only stop in good time in the event of obstacles, such as a person on the route, but also drive around them with foresight thanks to real-time route optimization [38].

In addition, the AMR was to fulfill a variety of tasks in the future. Up to now, it has usually only transported pallets or other containers from one location to another and unloaded them at the unloading point, as is the case at Kaufland's Geisenfeld logistics center [38]. The AMR of the future, on the other hand, should often be equipped with grippers that have an exchange system. An interchangeable system would allow AMRs to be equipped with different grippers and other tools depending on where they are used. The AMR could then, for example, carry out palletizing directly on site if the palletizing robots have no capacity due to high workloads [39].

(2) How can AMR and route planning be optimized inspired by nature?

As mentioned at the beginning of the section, the AMR and its route planning could be optimized inspired by the example of the ant trail. Derived from the ants, decentralized communication between the AMRs, in which each vehicle acts autonomously but shares information with others, could also be introduced [8]. The aim is to promote coordination and improved communication for more efficient route planning [9].

In addition, pheromone-like markings could be integrated into the AMR data exchange. This would allow alternative routes to be marked by individual AMRs. This information would lead to positive feedback for routes with stronger markings [8]. Like a swarm of ants, an "AMR swarm" could explore different routes and use positive feedback to discover the best possible route. Rapidly adapting route planning in response to disruptions could minimize existing congestion and waiting times [6].

Furthermore, the principle of negative feedback from swarms of ants could be used [8]. The use of negative feedback mechanisms could ensure that overloads and blockages in the palletizing and depalletizing areas are avoided if the individual routes are distributed effectively. A large number of AMRs could be used simultaneously, thus reducing throughput times [6].

(3) How can AMR and route planning be optimized inspired by nature?

In addition to the possible equipment with grippers listed in (1) and the idea of route optimization based on ant swarm intelligence explained in (2), movement across several floors is also conceivable. This would require the integration of automatic doors and elevators [38].

Finally, it can be stated that the use of ant swarm intelligence in AMR would be of great benefit in preventing traffic jams and waiting times. Route planning would also be optimized, which would save even more time. The possible implementation of a gripper arm would make Kaufland even more flexible when it comes to palletizing and picking. This would put the company in a secure position for the future and enable it to handle significantly higher pallet and goods handling volumes.

VIII. Conclusion

Using the example of the ant line and the areas of application, the advantages of swarm intelligence in logistics can be identified in comparison to conventional control systems.

Swarm intelligence enables rapid adaptation to changing conditions (e.g. higher pallet and goods turnover). Another advantage is decentralized decision-making. There is a faster response to disruptions in the process as there is no need to wait for a central instruction.

Conventional control is static and hierarchical and offers less flexibility than swarm-based control. In addition, resources are used more effectively with swarm-based control. The units adapt their actions to the situation, which leads to more efficient use of transport routes, for example.

Other advantages include self-organization (less manual effort) and robustness. If one unit fails, another in the swarm can replace it immediately.

IX. References

[1] K. Liggieri und O. Müller, Mensch-Maschine-Interaktion: Handbuch zu Geschichte – Kultur – Ethik, Stuttgart: J.B. Metzler, 2019.

[2] K. Wanieck, Bionik für technische Produkte und Innovation: Ein Überblick für die Praxis, Wiesbaden: Springer Spektrum, 2019.

[3] J. C. Schmidt, „Bionik und Interdisziplinarität: Wege zu einer bionischen Zirkulationstheorie der Interdisziplinarität," in *Bionik*, Berlin, Heidelberg, Springer, 2005, p. 219–245.

[4] BIOKON – Forschungsgemeinschaft Bionik-Kompetenznetz e.V., „Solarabsorber FracTherm® – Energie effizient übertragen," 2014. [Online]. Available: biokon.de/solarabsorber-fractherm-energie-effizient-uebertragen/. [Accessed January 10, 2024].

[5] W. Nachtigall, Bionik als Wissenschaft: Erkennen - Abstrahieren - Umsetzen, Berlin, Heidelberg: Springer, 2010.

[6] H. Hamann, Schwarmintelligenz, Berlin, Heidelberg: Springer Spektrum, 2019.

[7] Verein Deutscher Ingenieure e.V., VDI/VDE 2653 Blatt 1: Agentensysteme in der Automatisierungstechnik - Grundlagen, Düsseldorf: Beuth Verlag GmbH, 2018.

[8] T. Schmickl, „Schwarmintelligenz am Beispiel der Ameisenstraßen,“ *Denisa,* Bd. 25, pp. 141-155, 2009.

[9] T. Bogon, Agentenbasierte Schwarmintelligenz, Wiesbaden: Springer Vieweg, 2013.

[10] C. Müller, „Was ist eine radikale Innovation?,“ Heppenheim, 2021.

[11] C. Müller, „Was ist eine disruptive Innovation?,“ Heppenheim, 2021.

[12] E. H. Grosse, Logistik 4.0: Stand der Forschung und Praxis, Heidelberg: Springer Verlag, 2022, pp. 6-20.

[13] Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA, „Was ist DelivAIRy?,“ 2023. [Online]. Available: iml.fraunhofer.de/de/abteilungen/b1/verpackungs_und_handelslogistik/innovationen/DelivAIRy1.html. [Accessed January 11, 2024].

[14] I. Göpfert, Logistik der Zukunft - Logistics for the FutureLogistik der Zukunft - Logistics for the Future, 9. Hrsg., Wiesbaden: Springer Gabler, 2023.

[15] P. H. Voß, Die Neuerfindung der Logistik: Wie sich die Logistikindustrie für das Zeitalter der Volatilität rüstet, Wiesbaden: Springer Gabler, 2023.

[16] startupticker.ch, „New delivery drone technology put to the test,“ 2023. [Online]. Available: startupticker.ch/en/news/new-delivery-drone-technology-put-to-the-test. [Accessed November 14, 2023].

[17] S. Hartmann, „264 Kilometer in die Zukunft: UK „baut“ in nächsten 2 Jahren den größten automatisierten Drohnen-Highway der Welt,“ 2022. [Online]. Available: nordisch.info/england/uk-baut-in-naechsten-2-jahren-den-groessten-automatisierten-drohnen-highway-der-welt/. [Accessed November 16, 2023].

[18] N. Groll, „Amazon erweitert Drohnen-Lieferung international,“ 2023. [Online]. Available: stores-shops.de/technology/e-commerce/amazon-erweitert-drohnen-lieferung-international/. [Accessed November 18, 2023].

[19] Bundesministerium für Digitales und Verkehr, „EU-Regelungen für Drohnen,“ 2021. [Online]. Available: bmdv.bund.de/SharedDocs/DE/Artikel/LF/drohnen.html. [Accessed November 14, 2023].

[20] Wingcopter GmbH, „Einkäufe aus der Luft: Wingcopter-Drohnen liefern erstmalig in Deutschland Güter des täglichen Bedarfs,“ 2023. [Online]. Available: wingcopter.com/odenwald_liefermichel2. [Accessed November 14, 2023].

[21] F. Markert, „Drohnengesetze in Deutschland: Diese Vorschriften gelten in der Bundesrepublik,“ 2023. [Online]. Available: drohnen-camp.de/drohnen-gesetze-in-deutschland/#nationale-besonderheiten-in-deutschland. [Accessed November 16, 2023].

[22] M. Alpers, „Lidar,“ 2023. [Online]. Available: dlr.de/rd/desktopdefault.aspx/tabid-5626/9178_read-17527/. [Accessed on December 6, 2023].

[23] Elektrohandel Wandelt GmbH, „Wie funktionieren eigentlich Bewegungsmelder?,“ 2023.

[24] IPH – Institut für Integrierte Produktion Hannover gGmbH, „Fahrerlose Transportsysteme (FTS) für Produktion und Logistik,“ 2023. [Online]. Available: iph-hannover.de/de/dienstleistungen/automatisierungstechnik/fts-fahrerlose-transportsysteme/. [Accessed on December 20, 2023].

[25] Mobile Industrial Robots A/S, „MiR Hook 250,“ 2023. [Online]. Available: mobile-industrial-robots.com/de/losungen/aufsatzmodule-und-zubehor-von-mir/mir-hook-250/. [Accessed December 2, 2023].

[26] HUSS-MEDIEN GmbH Technische Logistik, „Automatisierter Materialtransport mit Anhängern,“ 2021. [Online]. Available: technische-logistik.net/automatisierter-materialtransport-mit-anh%C3%A4ngern. [Accessed on December 10, 2023].

[27] Visable GmbH, „Materialfluss & Intralogistik: Intralogistische Konzepte der Zukunft: Schwarmintelligenz nutzen,“ 2021. [Online]. Available: wlw.de/de/inside-business/branchen-insights/materialfluss-intralogistik/schwarmintelligenz. [Accessed on December 27, 2023].

[28] Pilz GmbH & Co. KG, „Sicherer Einsatz von fahrerlosen Transportfahrzeugen und -systemen,“ 2023. [Online]. Available: pilz.com/de-DE/trainings/articles/229377. [Accessed December 4, 2023].

[29] Verein Deutscher Ingenieure e.V., „Fahrerlose Transportsysteme Leitfaden Phasen, Rollen und Akteure,“ Düsseldorf, 2022.

[30] microsonic GmbH, „Ultraschallsensoren,“ 2023. [Online]. Available: microsonic.de/de/service/ultraschallsensoren/prinzip.htm. [Accessed December 11, 2023].

[31] M. t. Hompel , T. Bauernhansl und B. Vogel-Heuser, Handbuch Industrie 4.0, Bd. 3. Auflage, Berlin: Springer Verlag, 2020.

[32] K.-H. Wehking, Technisches Handbuch Logistik 1, Stuttgart: Springer Vieweg, 2020.

[33] M. t. Hompel, V. Sadowsky und M. Beck, Kommissionierung Materialflusssysteme 2 - Planung und Berechnung der Kommissionierung in der Logistik, Heidelberg: Springer-Verlag, 2011.

[34] G. Kohlhuber, „Geisenfeld: Maschinen statt Menschenhand,“ *Donaukurier,* 2021.

[35] Kaufland Dienstleistung GmbH & Co. KG, „Logistik digital bei Kaufland – Neubau Automatische Kommissionieranlage,“ Neckarsulm, 2023.

[36] Vanderlande Industries B.V., „Übersicht AMR Total,“ Geisenfeld, 2021.

[37] D. Hamberger, „Robotik 2030: So sieht die Zukunft aus," *Das Österreichische Industriemagazin,* 2023.

[38] Baumüller Nürnberg GmbH, „Autonome Mobile Roboter: Baumüller Systems – Ihr zuverlässiger Partner für innovative AMR-Systemlösungen," Nürnberg, 2023.

[39] M. Bayerdörfer, „Schnellwechselsystem mit IoT-Anbindung und automatisierter Greiferwechsel," Marburg, 2020.

Digital twin of the knee

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***Abstract*—Advanced Diagnostics and Management Strategies for Anterior Cruciate Ligament Injuries: A Digital Twin Approach**

***Keywords*— ACL Injury, Digital Twin[1], Sensor Integration, Machine Learning, User Interface, Sports Medicine.**

I. Introduction

The Anterior Cruciate Ligament (ACL) is crucial for knee stability, with injuries leading to serious long-term effects. The prevalence of these injuries necessitates advanced diagnostic and treatment methods. Our study presents a novel system integrating digital twin technology and sensor-based diagnostics to address this need.

The project is a collaborative effort between ICAM and Fontys, merging biomechanical engineering, computer science, and clinical medicine. Our goal is to create a platform that not only detects ACL injuries with precision but also offers personalized rehabilitation plans.

A. Project Overview

The digital twin of the knee project is at the intersection of biomechanics, data science, and orthopedic research. It focuses on developing a detailed digital model of the knee joint, incorporating real-time sensor data for precise modeling and analysis. This initiative seeks to improve traditional ACL diagnostics[2], providing a system that is predictive and adaptable to individual patient needs.

The concept of a digital twin in medical applications is a groundbreaking approach, allowing for a virtual representation of a patient's knee to be, created, and analyzed in real-time. This model offers unprecedented insights into the biomechanics of knee injuries, enabling clinicians to diagnose and treat ACL injuries with greater accuracy and efficiency. By simulating different scenarios and treatment outcomes, the digital twin model empowers healthcare providers to make more informed decisions and tailor treatment strategies to the specific needs of each patient. After analyzing the objective, we had set for the project considering a state-of-the-art review, it became apparent that the digital twin was not suitable. This is because it would require operating on the patient before any injury occurred as a preventive measure. Conducting numerous scans for this approach would result in a very costly solution, which contradicted our intended goals. Therefore, to still address our issue, we have opted for a competitive and innovative technology.

B. Technological farmework

The project utilizes advanced sensor technologies, including the Movella[3] sensor, comprising a gyroscope, accelerometer, and shift sensor. These tools capture detailed knee joint movements and stress dynamics, enhancing the accuracy of ACL injury detection. This technology provides critical data to guide rehabilitation strategies and offers the potential to significantly improve patient-specific recovery outcomes.

The integration of these sensors into our system marks a significant advancement in ACL injury diagnostics. By monitoring the kinematics of the knee in real-time, these sensors provide a level of detail and high repeatability that surpasses traditional diagnostic methods.

Furthermore, the use of machine learning algorithms in our system facilitates the analysis of vast amounts of data measured by the sensors. These algorithms can identify patterns and predict outcomes, thereby enhancing the decision-making process in ACL injury management. The implementation of these advanced technologies signifies a shift towards more personalized and data-driven approaches in sports medicine, leading to better patient outcomes.

II. Context

A. Abrevation and acronym

ACL: Anterior Cruciate Ligament
RDBMS: Relational Database Management Systems
UI: User Interface
CSS: Cascading Style Sheets
HTML: HyperText Markup Language
PHP: Hypertext Preprocessor
SQL: Structured Query Language
MRI: Magnetic Resonance Imaging
BT: Bluetooth
BMI: Body Mass Index

B. Importance of the anterior cruciate ligaments (ACL) in knee stability[4]

The anterior cruciate ligament (ACL) plays a crucial role in knee stability, serving as an essential link between the femur and tibia and preventing excessive forward sliding of the tibia. Although strong, the ACL is prone to injuries that may require medical intervention, ranging from physiotherapy to surgery, depending on the severity of the tear. The representation in the associated graphic (see Figure 2) illustrates not only the location of the ACL within the knee joint, but also the nature of the injuries that can affect it. These images underline the protective role of the ACL in dynamic knee movements, such as pivoting, acceleration and deceleration, which are essential to an athlete's agility and balance.

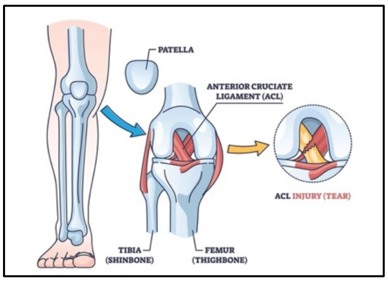

Figure 1:Scheme of ACL injuries

C. Frequency of ACL injuries and impact on athletes'health[5]

ACL injuries are particularly common in sporting activities and can have a considerable impact on athletes' long-term health. The data presented in the graph (see Chart 1) indicate a worrying increase in ACL injuries over an extended period, with the rate rising from 5.5 to 8.2 injuries per 100,000 exposures among high school athletes between 2007-10 and 2019-22[7]. This highlights the importance of early and accurate detection of ACL injuries for appropriate management. The implementation of prevention programs, such as specific injury risk reduction training and the use of advanced diagnostic methods, is therefore essential to reduce the frequency of ACL injuries and their consequences on health and athletic performance.

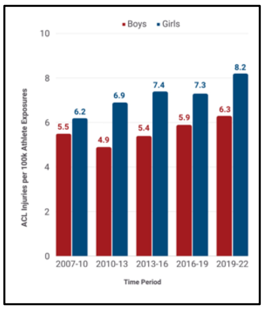

Figure 2: Improvement of ACL injuries' graph since 2007

D. Existing machines for measuring ACL defects

1) GNRB Arthrometer

The GNRB is a device using the LDA method for objective assessment of knee stability. Adapted to X-ray technology, it performs non-invasive dynamic tests. It features automatic calculation of the difference in tibial displacement and the slope of compliance curves, recording the fixation force of the patella and the distance between the patient's foot and the base of the machine for precise reproducibility. Supplied with a PC and LDA software, it offers a thrust force from 1 to 200 N and automatically saves patient data, with results exportable as XLS. files or PDFs for excellent communication. The GNRB's dimensions of 845 x 270 x 400mm, and weight of 15kg, make it easy to manage for clinical use.

2) KT1000 Arthrometer

The KT1000 is a device developed to measure anterior and posterior translation of the tibia in relation to the femur. Positioned supine with the thighs on a support to keep the knees at around 30° flexion, it uses two sensors to measure translation. Results are displayed to the nearest half-millimeter, with tones indicating different forces applied during the test. Although less advanced than the GNRB in terms of dynamic technology, the KT1000 remains a valuable tool, offering a more accurate clinical assessment of ACL instability than an MRI. It can also track post-operative results, an important feature for monitoring ACL graft healing.

III. Methodology

Before delving into the technical details, it is essential to outline the methodology guiding the Digital Twin of the Knee project. This section elucidates the step-by-step approach employed to achieve the project's objectives.

A. Project Resources and Management

Our project was empowered by combining the expertise of ICAM and Fontys, focusing on revolutionizing ACL diagnostics. We utilized Movella sensors, capable of accurately tracking knee movement, to bridge the gap between traditional methods and advanced technology. The project followed a structured timeline, emphasizing critical milestones like sensor integration, web platform development, and data analysis.

B. Sensor Integration and Data Collection

We chose Movella sensors for their advanced capabilities in capturing the nuanced movements of the knee joint. These sensors, equipped with gyroscopes and accelerometers, allow us to gather detailed data beyond what is possible with conventional physical examinations. This rich data is crucial for our goal of providing a more comprehensive understanding of knee dynamics.

Figure 2: Movella sensors

C. Web Interface and Database Implementation

The project's web interface stands as a testament to meticulous design, offering an intuitive navigation experience through the incorporation of innovative web technologies. This user-friendly interface not only facilitates the seamless management of patient profiles and the viewing of diagnostic results but also places a premium on ensuring user privacy. The interface excels in generating realistic diagnostics based on the patient's BMI and physical condition, considering intricate details such as the frequency and nature of physical activities. Supporting this user-centric approach is a robust database system, which securely stores and analyzes patient data. Employing advanced machine learning techniques ensures a continuous refinement process, enhancing accuracy over time and solidifying the platform's position at the forefront of innovative ACL diagnostics.

D. Traditional Testing and Limitations

A comprehensive analysis of traditional ACL tests revealed significant limitations, notably the subjective nature of the Pivot Shift Test[7] and the reliance on examiner skill in the Lachman Test. In response, our project adopts an innovative approach bolstered by sensor technology, aiming to transcend these limitations and deliver an objective and consistent assessment. By doing so, we set a new standard in ACL diagnostics, mitigating the inherent challenges associated with traditional testing methodologies. For instance, the Lachman Test often faces variability due to differences in examiner technique, while the Pivot Shift Test's subjectivity can be a hindrance to accurate diagnostics.

E. Sensor Data Analysis and Interpretation

The heart of the project lies in the utilization of sophisticated algorithms to interpret sensor data, converting raw measurements into meaningful diagnostic insights. This real-time analysis, an integral component of our technological arsenal, provides an unparalleled level of detail when assessing knee joint health. For instance, our sensors, integrated with Movella technology, incorporate gyroscopes and accelerometers to deliver precise measurements essential for evaluating ACLs. This transformative approach in sensor data analysis marks a change in thinking, offering a nuanced and comprehensive understanding of knee health.

F. Integration of Cutting-Edge Scientific Findings

Our project seamlessly integrates the latest scientific knowledge into our approach. This not only ensures alignment with current scientific understanding but also serves as a testament to our commitment to evidence-based practices. For example, studies on knee instability after ACL reconstruction have influenced our methodologies, shaping the direction of our project and reinforcing its scientific rigor.

G. Grading of ACL Injuries

Our grading system for ACL injuries, a culmination of sensor data and traditional tests, establishes a comprehensive framework for assessing injury severity. This sophisticated system considers nuanced factors, including the extent of movement in the Lachman Test and the qualitative aspects of the Pivot Shift Test. For instance, the incorporation of Movella sensors with gyroscopes and accelerometers provides detailed metrics on knee movements, enabling a more refined and accurate grading system. This comprehensive approach enriches our understanding of ACL health, allowing for a more personalized and effective diagnosis.

IV. Conclusion

This comprehensive investigation has elucidated a profound understanding of anterior cruciate ligament (ACL) injuries, signifying a substantial paradigm shift in both diagnostic and management methodologies. The amalgamation of cutting-edge technologies, specifically digital modelling, and motion sensors, within our system epitomizes a transformative leap in ACL injury detection precision. Furthermore, it proposes meticulously tailored rehabilitation plans, heralding a new era in proactive and personalized sports medicine.

Our meticulous exploration and exposition of the limitations intrinsic to traditional ACL testing methods, exemplified by the Lachman and Pivot Shift tests, have revealed inherent challenges, including subjectivity and the variability of results. In response, the seamless integration of motion sensors serves as a methodological breakthrough, facilitating an objective and reproducible assessment of knee biomechanics that transcends the limitations of conventional approaches.

The user-centric web interface, meticulously architected for an enriched experience, serves as an instrumental tool in the seamless and efficient management of patient profiles and clinical results. Its intuitive design and user-friendly navigation empower healthcare professionals to channel their focus towards diagnosis and treatment, eliminating undue complexity in tool manipulation.

The robust database, fortified by cutting-edge machine-learning algorithms, emerges as the backbone of our system, ensuring a dynamic and personalized real-time analysis of patient data. This continuous adaptive mechanism enhances the accuracy of diagnoses and amplifies the relevance of treatment recommendations, placing our scientific approach at the vanguard of innovative medical technologies.

In the culmination of our endeavours, grounded in an intricate understanding of ACL pathology, we leverage the latest technological advances to elevate athletes' health and performance. The positive impact of our interdisciplinary approach to sports medicine reverberates, paving the way for ongoing research and innovation in this scientific domain.

The evaluation of existing machines, such as the GNRB Radio and the KT1000, for their accuracy and ease of use, serves as a cornerstone in contextualizing our research within the broader scientific landscape. This meticulous examination not only provides invaluable context for our study but also delineates clear avenues for refinement in the accurate detection of ACL injuries.

In concluding this scientific endeavour, our project underscores not only the paramount importance of an integrated approach to diagnosing and managing ACL injuries but also accentuates the invaluable role of interdisciplinary collaboration. It reinforces the urgent need for continued innovation and integration of novel technologies into sports medicine. As we advance, sustaining the momentum of this research is pivotal, ensuring that athletes globally benefit from the pinnacle of medical care, founded on robust scientific data and steadfast analysis. Our project, standing as a groundbreaking achievement in ACL injury treatment, emerges as a pivotal model for the trajectory of future developments in the realm of sports health.

ACKNOWLEDGMENT *(Heading 5)*

Acknowledging the collaborative efforts and invaluable contributions of the individuals involved in this project is paramount. Our sincere appreciation extends to Professor Jorge Uquillas Paredes, whose visionary leadership and medical expertise laid the foundation for this endeavor. Professor Paredes' interdisciplinary insight, spanning biochemistry to artificial intelligence in medicine, guided the project with unwavering precision.

The resolute team from ICAM and Fontys played a pivotal role in the project's success. The general engineering expertise brought by the ICAM students, crucial to project management, was complemented by the diverse skills of the Fontys team, specializing in mechatronics, mechanics, electricity, and biomedicine. Their collaborative spirit and commitment significantly enriched the project's quality and breadth.

A special acknowledgment is extended to Mr. Seigneuret, the on-site supervisor at ICAM, whose guidance and support were instrumental in navigating the challenges of inter-university collaboration. His expertise and commitment to fostering effective communication underscored the importance of seamless teamwork in achieving our project goals.

The indispensable role of Mr. Turko, the on-site aide at ICAM, is also recognized with gratitude. His assistance in overcoming logistical hurdles and ensuring the smooth integration of the project within the ICAM framework was invaluable.

This project was made possible through the collective dedication and collaborative spirit of all involved, from the students to the professors and supervisors. Everyone's unique expertise and commitment have left an indelible mark on the success of this innovative venture.

REFERENCES

[1] Jakob Trauer, Sebastian Schweigert-Recksiek "*WHAT IS A DIGITAL TWIN? – DEFINITIONS AND INSIGHTS FROM AN INDUSTRIAL CASE STUDY IN TECHNICAL PRODUCT DEVELOPMENT*" Proceedings of the Design Society DESIGN Conference, May 2020

[2] *Daniel DM, Malcom LL, Losse G, Stone ML, Sachs R, Burks R: Instrumented measurement of anterior laxity of the knee. J Bone Joint Surg Am 1985*

[3] *Movella "Document XD0502P" , Revision I, 16 March 2023*

[4] *Janne Spierings, Marloes Van den Hengel , Rob P. A. Janssen, Bert Van Rietbergen, Keita Ito and Jasper Foolen, "Knee instability caused by altered graft mechanical properties after anterior cruciate ligament reconstruction: the early onset of osteoarthritis?", Frontiers ,Aug 24, 2023*

[5] *Yuji Yamamoto, Shugo Maeda, Eiichi Tsuda, Satoshi Toh, "Comparison betwwen clinical grading and navigation data of knee laxity in ACL deficient Knees", Sport medecine Arthroscopy Rehabilitation Therapy & Technology, november 2010*

[6] *Leitze Z, Losee RE, Jokl P, Johnson TR, Feagin JA: Implications of the pivot shift in the ACL-deficient knee. Clin Orthop Relat Res 2005*

[7] *Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ: Relationships between objective assessment of ligament stability and subjective assessment of symptoms and function after anterior cruciate ligament reconstruction. Am J Sports Med 2004*

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I2E2 Network

Brew-Up : Industrial beer for amateurs

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Amateur beer brewing is a hobby that, since the COVID-19 era, is in growth in France. More and more people and groups are venturing into the realm of beer brewing and thus the issues present in beer brewing are touching an ever-larger market. One of these issues is the use of CO2 in beer bottling, the unoptimized use of CO2 leads to waste, beverage deterioration and reduced beverage yield.

I. INTRODUCTION

In 1810 Paris, Nicolas Appert published "Le livre de tous les ménages ou l'art de conserver pendant plusieurs années toutes les substances animales et végétales," marking the start of modern food preservation methods. Before Appert, preservation relied on drying, smoking, or using preservatives like sugar and honey. Appert's method involved sealing food in bottles or jars, corking them, heating them in a bain-marie, and then cooling them. This process was the early form of sterilization, showing that heating to 100°C could preserve food if it wasn't exposed to external germs, a concept later validated by Louis Pasteur. However, this method also cooked the food, sometimes degrading its quality.

A century later, the "Controlled Atmosphere Storage" (CAS) technique was developed in California. It involved creating a CO2-rich environment for storage, improving upon Appert's method by controlling the air in the storage jars to further inhibit microorganism growth. CAS was particularly effective in meat preservation, as demonstrated by longer-lasting pork under CO2 conditions. This paper will firstly provide background information about brewing, whereafter the approach of the project will also be elaborated on. The design of the device is the third chapter, both the hard- and software will be explained, this includes the actual 3D model of the device and the first prototypes. The fourth chapter will give an explanation on the test results, and it will verify that the device meets the requirements. The paper will be concluded with a conclusion, discussion and finally a recommendation.

II. CONTEXT

A. Market context

In France, the craft brewery and home brewing market are rapidly expanding, with over 2,500 craft and microbreweries contributing to a dynamic segment of the beverage industry. This growth reflects an increasing consumer interest in unique, locally produced beers. Alongside these professional ventures, a thriving community of unregistered home brewing enthusiasts adds to the richness and innovation of the French brewing scene.

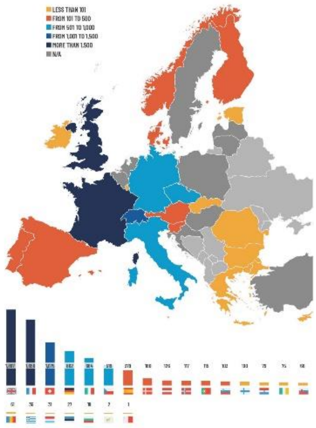

Figure 1 - Map of European countries by brewery amount.

B. *State of the art*

Gravity filling: This is the simplest and most basic filling method, where the product flows into the bottle by gravity. It is typically used for low-viscosity liquids, such as water and soft drinks.
This technic suffers from low accuracy, slow filling speeds and is susceptible to contamination.

Metered flow filling: This method uses a pump to control the flow of product into the bottle. It is more precise than gravity filling and can be used to fill a wider range of products, including viscous liquids and carbonated beverages.
This technic requires precise equipment, is susceptible to blockages and can damage bottles.

Counterpressure (isobaric) filling: This method is used for carbonated beverages to prevent the loss of carbonation. It works by pressurizing the bottles with carbon dioxide before filling, and then the pressure is maintained during filling to prevent the CO_2 from escaping.
This technic requires expensive equipment, can be difficult to control and can cause foaming.

Fill-to-level filling: This method uses a sensor to detect the fill level of the bottle. The filling valve is then closed when the desired level is reached.
This technic is dependent on sensor accuracy, can be sensitive to changes in product viscosity and is not suitable for all products.

Overflow filling: This method is typically used for carbonated beverages. The bottle is filled until the liquid overflows, and then the excess liquid is returned to the reservoir.
Waste a lot of beer and can introduce air into the bottle.

III. Device Concept and Design

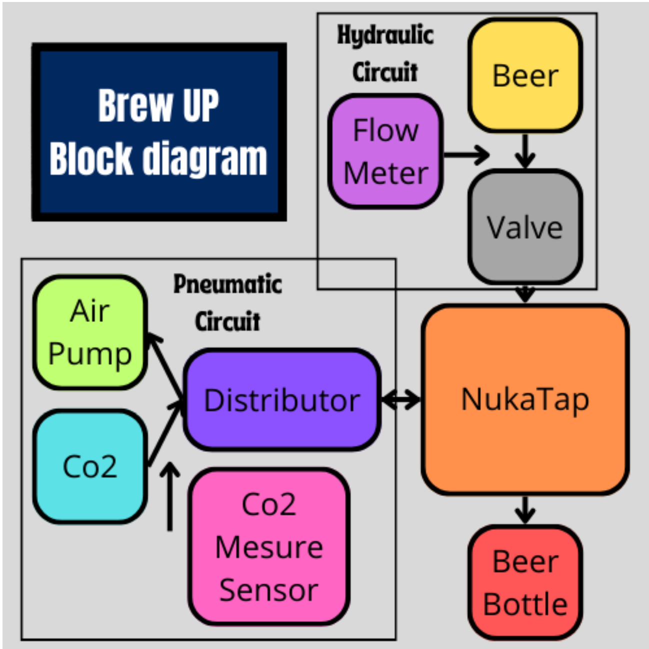

Figure 2 – Block diagram

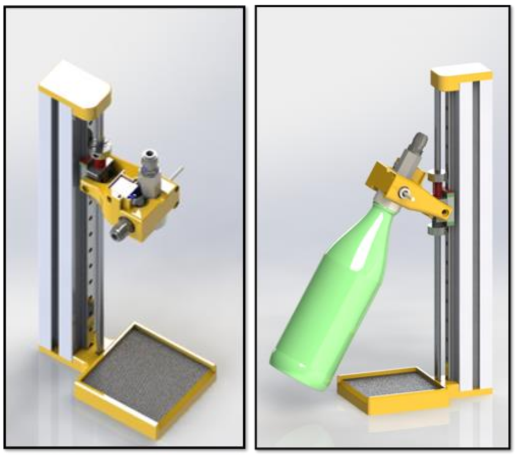

Figure 3 - CAD design of the final product

Our product presents itself like so. It consists of beer purge and filling mechanism for the purely beverage part of the product and a mechanical support that hosts the beer bottle filling system. The aim of this prototype is to give industrial levels of beer bottling to amateurs, this works by purging the bottle of air as much as possible, then making sure the beer has the least amount of contact with oxygen as possible. This is to ensure industrial levels of sanitation, quality and CO_2 use.

A. *Approach*

At first, we identified a system of bottle filling on which we could develop on. A Counterpressure beer bottle filler is a type of beer tap specifically designed for dispensing draft beer. Counterpressure beer bottle fillers often have a forward-sealing design. In traditional beer taps, the valve that stops the flow of beer is located at the rear of the tap, which can leave beer residue in the nozzle that dries out and can affect the taste of the beer and the cleanliness of the system. Forward-sealing designs have the valve at the front, which means the interior of the nozzle stays coated with beer, keeping it fresher and reducing the risk of bacterial growth. However, we have determined that it would greatly increase the quality of the beer if we purged the bottle before filling it with beverage.

Then we looked at the needs of the amateur brewer and microbrewer and determined a list of requirements for this new device.

Requirement	Constraint
Adaptability to all bottle sizes	A slider or modifiable system
Ease of bottle swopping	A simple mechanism to free the bottle from its holding
High pressure system	A sufficiently high force applicator to stop the bottle from removing itself
Inexpensive construction	Using cheap materials and common parts
Ability to send it in a kit	Using easy to assemble parts

Figure 4 – Proof of Concept

B. Construction

- To build the Brew up prototypes, a lot of parts have been printed with 3D Printers. Doing that allow an impressive adaptation to the bought parts with complex geometry or with no place to be fixed. Printing complex parts is a way to get a light, appealing and ergonomic design.
- Assembly has been done with inserts and screws.

C. Issues encountered during the assembly

Assembly of the prototype has been well done, but in a Plan, Do, Check, Act process, there were still some issues in the organization and the assembly itself. Most of the parts needed a reworked to be perfectly assembled.

D. The futur version

For the next version, we will change the architecture to have something stronger. This next architecture will also prevent the Counterpressure beer bottle filler from lifting due to the pression inside, making sometimes gas leaks.

IV. RESULTS EXPLAINATIONS

In this critical section, the findings derived from comprehensive analyses will be delved into. To enhance the understanding of these conclusions, this section has been structured into five distinct parts, each aimed at exploring specific aspects of the subject. The first, titled Adaptability, will scrutinize the system's ability to adapt to diverse environments, including its capability to accommodate various bottle models. The second, dedicated to Ergonomics, will assess the efficiency and user comfort of the solution. The third, focused on Physical Constraints, will highlight potential physical limitations of the device. The fourth, Assembly, will analyse the ease and effectiveness of the assembly process. Lastly, the Price section will examine the economic viability of the innovation. These subdivisions will facilitate an in-depth exploration of the results, providing a holistic understanding of the performance and features of the solution.

A. Adaptability

The design of brew up has been as designed adapable to the 3 mains kind of bottles used by the amateurs :

33 cl bottles – around 22 cm height
50 cl bottles – around 25 cm height
75 cl bottles – around 30 cm height

Our available space is 32.5 cm height, and after being tested, it can be testified Brew up can work with a wide range of bottles. Beside this, the design of the product enables high diameter of bottles:

33 cl bottles – around 6.5 cm wide
50 cl bottles – around 7 cm wide
75 cl bottles – around 8 cm wide

Our available max diameter is 10 cm wide.

Dimensions of botles being the main criterias in the adaptibility of Brew Up, the sysem is adapable to a wide range of bottle and can be used by every amateurs.

Brew Up can also be used with can. You just neet to plug a can adaptator.

B. *Ergonomics*

First, how to characterize ergonomics?

Ergonomics can be characterized by several aspects aimed at making products, environments, and systems more suitable and user-friendly. Here are some key characteristics of ergonomics:

1. Ease of Use: Ergonomic products are easy to understand and operate, even for novice users. Interfaces and controls should be intuitive, minimizing the need for extensive training.

   Brew up is composed of spring and has intelligent use of the gravity allowing an automated return to initial position. To use the system, a button must be pushed, and a potentiometer must be turned to adjust beer volume that need to be in the bottle. Then, a swift and simple movement to put the bottle in the counterpressure beer bottle filler nozzle must be made. There is nothing more to do. With a counterpressure beer bottle filler, you need 3 hands, with Brew up, you need only one.

2. Comfort: Ergonomic products are designed to provide an optimal level of comfort. This includes considering physical aspects such as posture, preventing muscle strains, and reducing fatigue. With the smart use of gravity, user don't have to hold the counterpressure beer bottle filler while filling bottles.

3. Efficiency: Ergonomics aims to maximize the efficiency of interactions between the user and the system. This involves minimizing unnecessary steps, streamlining processes, and reducing the time required to perform tasks. Thanks to the electronic of the system, everything is done by the machine. The filling is done accordingly to the volume asked by the user, and the cycle of CO2 filling is done without human interaction. The only thing that the user must do is launching the cycle, adjusting wanted volume and prepare the bottle.

4. Clear Feedback: Users should receive clear feedback on their actions. This can include visual, auditory, or haptic signals to indicate the success or failure of an action, facilitating the understanding of the interaction. With a screen showing the state of the filling, the user has clear feedback and know exactly what he must do. A sound would be designed to alert the human if there is issue of if the filling is finished while he is away.

5. Aesthetics: While subjective, aesthetics play an important role in ergonomics. Visually well-designed products can positively impact user perception and willingness to use them.

In summary, ergonomics aims to create systems that are user-friendly, easy to use, efficient, safe, and comfortable and brew up respect the ergonomic criteria.

C. *Physical Constraints*

Applying pressure in a bottle create a counter force that push any system in its neck outward. This physical phenomenon must be countered, as it breaks the sealing and open the road for microorganism and uncontrolled air to get into the bottle. The pressure injected in the bottle doesn't exceed 1 bar. With a diameter of the neck of 26 mm, and with the application of the following formula:

$$F = P * A$$

With F = the force leaving the bottle in Newton (N).
P = the pressure inside the bottle in Pascal (Pa).
And A = the area of the neck.

53 N push the counter pressure beer bottle filler. With the current design, only 48 N are applied to counter the pressure. A new design with torsion springs and more mass of the handler is necessary to guarantee sealing of the system.

D. *Cost of production*

The current prototype had a cost of production of 415,62 euros. Nevertheless, production in series should cost 345 euros. One of the main strengths of our product is it should bring semi-industrial quality to amateurs who don't have 1the same budgets as giants like Kronebourg or any industrials. In the market, there is 3 categories:

- Industrial bottle filler: Theses systems cost minimum 6000 euros. It guarantees Production ratee AND quality. Only wrong side is the cost.
- Semi industrial bottle filler: Theses systems cost minimum 2000 euros. These systems guarantee a high production rate but not the quality.
- Amateurs bottle filler: Theses system costs 100 euros. They guarantee neither Quality, neither production rate.

In the whole market, where do Brew Up is placed?
Brew up can fill a bottle with an industrial rate for 415 euros and has quality, when 2000 euros systems can fill 4 bottles with industrial rate without quality. It means 500 euros are used for one bottle without quality. We are then placed between the industrial bottle filler and the semi-industrial bottle filler in term of $Production\ Rate * Qualiy \big/ _{price}$. Our place in the market crushes every other builder.

E. *Plug and Play system ?*

Brew up is a system easy to install. With the current design, everything can be fixed with less than 15 screws. In addition to that, wiring is easy. Only one cruciform screwdriver and no more than 30 min is needed for the assembly of Bew up.

V. CONCLUSION

This study delineates the expanding domain of amateur beer brewing in France, highlighting its rising prominence and creative advancements. Central to this discourse is the conceptualization and development of an innovative beer bottling apparatus, brew up, specifically engineered to cater to the nuanced requirements of amateur brewers and microbreweries. The primary objective of this device is to refine the utilization of CO2 in the bottling phase, a crucial factor for maintaining the integrity of the beer and minimizing resource wastage.

The architectural design of Brew up represents an amalgamation of classical brewing techniques and contemporary technological innovations. Incorporating mechanisms such as the Counterpressure beer bottle filler and an advanced CO2 purging system, the device significantly elevates the quality of the beer by minimizing oxygen exposure and adhering to sanitation standards comparable to industrial benchmarks. The versatility of Brew up, accommodating various bottle sizes, and its economical production, facilitated by 3D printing technology, highlight its practicality and accessibility for the target demographic of amateur brewers.

The assembly process and the iterative developmental approach of Brew up have illuminated various challenges, particularly in achieving precision in component assembly and managing internal pressure to avert gas leaks. These observations have been pivotal in informing the design alterations for the subsequent iteration of the device, which will encompass a robust architecture for augmented strength and stability.

In summation, Brew up signifies a notable advancement in the field of amateur and microbrewery beer bottling. By addressing critical aspects such as the optimization of CO2 use and ensuring high-calibre, sanitary brewing conditions, this invention not only aids in reducing waste and enhancing yield but also substantially contributes to the evolution of the beer brewing process. As the amateur brewing community in France continues to flourish, innovations like Brew up are expected to play an integral role in supporting and further enriching this dynamic sector.

ACKNOWLEDGMENT

We express profound gratitude to Mr. TURKO for his exceptional services, unwavering availability, generous provision of equipment, and insightful guidance, all of which have significantly influenced the success of our project. His professionalism and dedication have been instrumental, surpassing our expectations. We also extend thanks to ICAM Strasbourg for facilitating our fruitful collaboration with expert professors and for their crucial financial support in realizing the prototype. Lastly, our appreciation goes to the ICAM's fablab managers for their pivotal role in information exchange and providing necessary resources, contributing significantly to the success of our project. The collaboration with the fablab has enriched our experience, strengthening the quality and success of our prototype.

REFERENCES

https://en.wikipedia.org/wiki/Homebrewing

https://byo.com/article/counter-pressure-techniques/

https://www.icfillingsystems.com/wp-content/uploads/Counter-Pressure-Isobaric-Filling-by-Giovanni-Solferini-v2.pdf

https://learn.kegerator.com/counter-pressure-bottle-filler/

https://brewersofeurope.org/uploads/mycms-files/documents/publications/2021/european-beer-statistics-2020.pdf

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Waste & Material sorting for recycling and up-cycling - (Project No 13)

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***Abstract*—This paper describes the improvement of the recycling process of polycarbonate pieces at the Dutch company Vink, by introducing a new sorting machine, using cutting-edge green light technology. This project took place in cooperation between students of EUSS - School of Engineering and Fontys - University of Applied Sciences. The focus of this paper is on the environmental impact of the current recycling cycle in comparison with the impact of the improved cycle that results in more recycled plastic and less waste, hereby also analyzing the impact of production, maintenance and end-of-life of the sorting machine.**

I. Introduction

Plastic waste is a ubiquitous environmental challenge. These materials, derived from polymers, resist decomposition and can persist in the environment for hundreds of years. The global surge in plastic production has led to a corresponding increase in plastic waste, posing severe ecological threats. Improper disposal and inefficient recycling contribute to the accumulation of plastic waste in landfills, oceans, and ecosystems, impacting wildlife and human health.

As part of an Eco-Product Design class at EUSS School of Engineering, a team of EUSS-students collaborated with Fontys University of Applied Sciences and Vink, a company focused on plastic production. The project was started with the goal to reduce plastic waste by improving Vink's recycling process. The project took place at EUSS and Fontys in Eindhoven, with Fontys responsible for conceiving and constructing the separator system, while the Spanish team was tasked with studying the environmental impact of the machine. Despite having individuals in the Spanish team who were involved in both the conception and Life Cycle Assessment (LCA) aspects, the primary goal was to determine the machine's utility in terms of energy efficiency, raw material usage, and other environmental factors. The compiled report provides insights into the LCA, even though challenges such as limited information about the machine's status and Vink's recycling process were encountered during the assessment.

II. The Company

Vink Holdings, a dynamic enterprise based in the Netherlands, boasts a rich legacy dating back to its inception in 1954. Originally a federation of over 100 independent businesses across 19 European countries, Vink has evolved into a prominent force with a vast inventory exceeding €80 million. Operating in diverse sectors such as graphics, signage, building, construction, chemical, storage, manufacturing, automotive, public transport, and medical, Vink caters to the unique needs of over 120,000 customers [1].

At the core of Vink's success is its commitment to providing top-notch plastics materials, specialized fabrication, and machining services. As a member of the Plastics Family, one of the world's largest independent plastic businesses, Vink leverages its extensive network to source and deliver a wide range of plastics materials from global leaders. This strategic approach ensures that Vink's outlets, equipped with processing facilities, can meet the diverse requirements of industries spanning Europe [1].

In response to the escalating challenges posed by plastic waste, Vink, a forward-thinking company, has undertaken a project focusing on the differentiation of plastics. This innovative venture aligns with global efforts to enhance waste management practices and reduce environmental impact.

Vink's commitment to sustainable solutions is evident in this initiative, aiming to revolutionize the recycling process and contribute to a circular economy. By developing a cutting-edge separator system with green laser technology, Vink strives to streamline plastic waste separation, fostering a more efficient and eco-friendly approach to plastic recycling [1].

III. First ideas

Before agreeing on the final project in cooperation with Vink, different ideas where raised by the EUSS-team. Engaged in an eco-design initiative, the Spanish team employed Life Cycle Assessment (LCA) as the primary decision-making tool, recognizing the significant environmental impact of plastic waste. Even in recycling efforts, plastics often undergo a process of "downcycling," transitioning from high-value, durable products to lower-value, short-lived items. This occurs due to the need for distinct recycling processes for each plastic type, making contamination a significant risk that can compromise desirable properties like strength.

Initially, the team explored three innovative ideas for addressing plastic waste:

- Filters for Microplastics
- Smart Container
- Green Light Separation

After deliberation, the group leaned towards the first two concepts, conducting preliminary research to identify potential challenges. However, as part of the collaboration with Fontys University of Applied Sciences in Eindhoven, a strategic decision was made to focus on the third theme, Green Light Separation. The subsequent segment will discuss the research conducted on the first two projects before providing a detailed exploration of the chosen final project, the green light separator.

A. Filters for Microplastics

Microplastics are one of the major environmental issues due to their high capacity to find their way into water systems firstly and then into the sea secondly were they pose great danger to ecosystems but also human health. This is why the project of a filter at the entrance to the water network is a good idea.

Plastic could be filtered by playing on the difference in density with water but here again plastic is a material which poses a problem because it can have densities higher and lower than that of water. The filter will therefore not be effective on 100% of micro plastics.

Research also showed that different complex micro plastic filters are already developed and sold by different companies, indicating that it would be hard to find an innovative and competitive solution. Due to these problems, this idea was ultimately discarded.

B. Smart Container

The main principle of a Smart Container is fusing the traditional trash container with the plastic separator. In this case, the green light is implemented as the optical scanner.

This separator will work classifying the different types of plastic with the help of a mechanical-electronical assembly, which will be capable of recognizing and separating the different types of recyclable plastic into different compartments.

When one of them is full, it can show an “alarm” to be collected by the different services of the city. Working from the point of view of an urban zone, whose main proposal is to make the separation of plastics easier from the first instance, reducing the transportation lines, due to the different location of the treatment plants.

Furthermore, one of the objectives of these Smart Container is to promote recycling to Spanish citizens, enabling social and economical benefits like other countries in the European Union. Due to the different uses of different types of plastic, we come to the conclusion that dimensioning the different compartments as one wouldn’t be profitable. Also the development of a reasonable sized technology that can separate and identify every type of plastic is very unrealistic.

C. Green Light Separation

The fundamental principle underlying Green Light Separation is the application of a specialized process to segregate rigid plastic components. Specifically, this project targets circular plastic pieces produced by Vink from polycarbonate (PC), characterized by its transparency and exceptional hardness, akin to glass. There are 3 different types of plastic produced, Lexan Exell-D, Lexan 9030 and Lexan Margard, that have different coatings that protect them from scratching and UV. Of those three types, only two, Exell-D and 9030, are recyclable. Margard must be discarded [1].

All PC pieces sold by Vink have a protective foil that contains information about the type of plastic (Exell-D, 9030 or Margard). After the customers return the used pieces of plastic to Vink, a Circular Plastics Factory (CPF) sorts them by hand by this color-coded foil. Therefore, if a customer removes the entire protective film from a piece, the resultant plastic becomes ineligible for recycling because the type cannot be identified and therefore has to be discarded. Due to this difficulty even plastic pieces that could be recycled are not, resulting in unnecessary waste [1].

The project's core objective is the development of an innovative product proficient in identifying and mechanically/electrically separating PC pieces independently of the protective foil. This is achieved through the implementation of cutting-edge green light reflection technology. The precision of this process ensures the efficient separation of plastic pieces, optimizing the recycling potential of high-value polycarbonate while adhering to stringent quality standards.

Due to the practical nature of this third idea, the potential to use data from Vink and the realistic scope, it was selected for further pursuit.

IV. Collaboration on the final idea

The collaboration between EUSS and Fontys University of Applied Sciences prompted a strategic focus on the third theme, Green Light Separation, for the final project. Fontys students were assigned the task of designing a system utilizing a green laser to differentiate between different types of PC, aiming to separate them into specialized boxes with load cells providing weight data. This innovative approach aligns seamlessly with the overarching initiative to address plastic waste, emphasizing the significance of collaboration in crafting sustainable solutions.

Teamwork between the Dutch and the Spanish team was complicated by the distance and as a solution proposal, it was suggested to implement a collaborative effort where Fontys students predominantly handle the mechanical and electrical engineering aspects, while the Spanish team focuses on studying the environmental impact of the product. This approach ensures an optimized product and reinforces the essence of working together towards a common goal. The following paper will focus on the analysis of environmental impact, the Dutch team will publish a separate report discussing the mechanical and electrical design.

V. Project objective

The overall goal is the improvement of the plastic recycling process by developing a machine to optimize the sorting process.

The goal of the Spanish sub-project is to evaluate the environmental impact of the separation system throughout its life cycle and to compare it to the current plastic cycle. This way it can analysed if the production and implementation of the machine is sensible from an environmental standpoint. Furthermore, opportunities for environmental optimization in the design, construction, and operational phases can be identified.

Firstly, it is necessary to specify what the improved process will look like.

A. Improved process

1) Collection:

Companies dispose of their plastic waste pieces into a centralized container, where the sheets are collected.

2) Detection:

Upon reaching the detection unit, the plastic pieces undergo scanning, employing green light technology for identification. This scanning process allows for the precise separation of individual pieces from each other.

3) Separation:

With the information gathered through scanning, the device discerns the different layers and coatings on the PC pieces of each piece and directs it to the designated container. The segregation ensures that plastic pieces are sorted based on their respective materials.

4) Recycling:

Subsequently, the containers, now holding separated plastic pieces, can be transported to Sabic, a recycling company. This company has the capability to transform the plastic into reusable components, contributing to a sustainable and circular approach in the management of plastic waste [1].

B. Mechanical-Electronical Assembly

To reach the specified objective the machine must include the following components:

- Source of power (access to electricity network)
- Opening for entering plastic pieces
- Step feeder
- Separator from different kinds of plastic (green light technology)
- Collection Containers
- Conveyor belt
- Power train: cables between Source of Power and other components
- Control Unit: controls function of Compressor and Separator.

VI. LCA Specifications

A. Goal and Scope:

The primary objective of this Life Cycle Assessment (LCA) is to determine the environmental feasibility of implementing a plastic separation machine for enhanced plastic recycling [2]. Key considerations include assessing the comparative environmental impact of recycling with and without the machine, evaluating the reduction in plastic landfill disposal, and understanding the trade-off in building and operating the machine.

The LCA will be conducted with the software SimaPro, which contains extensive data bases and is used as a tool to quantify the environmental impact of products and processes. ReCiPe (H) is used as the impact methodology for converting by-products of processes and products into comparable impact units in different categories [4]. The impact categories will be identified based on relevant environmental aspects, such as energy consumption, emissions, and waste generation. SimaPro evaluates the environmental impact in specific mid- and endpoint categories, which will be used in this analysis.

This analysis is directed towards Vink, the entity responsible for plastic treatment. The findings are also intended for communication with the students from Fontys who are involved in the project.

The LCA aims to compare two recycling processes:

1. The current process, where unidentified plastic is discarded.
2. The process with the new machine, wherein all plastic pieces are identified and if possible recycled.

The functional unit is defined as kilograms of plastic. This unit allows for a quantitative evaluation of the efficiency of plastic recycling with the new machine. Temporary limits extend to approximately 5 years, representing the expected lifetime of the machine. The geographical limits encompass everything involved in the process within the Netherlands.

B. Flowcharts

1) Current Process

The current process without the separation machine involves the following steps [1]:

1. Collection: Unidentified plastic is collected, including Lexan Exell-D, Lexan 9030, and Lexan Margard.
2. Visual Check: Vink visually inspects incoming pallet boxes to ensure proper separation without contamination.
3. Transport to CPF: Full Truck Load (FTL) with material is transported to the Circular Plastics Factory (CPF) in Putte, NL.
4. Manual Sorting: CPF workers manually sort plastic by identifying the protection foil colour (9030: blue, Exell-D: red, Margard: green).
5. Shredding: Lexan Exell-D and 9030 are shredded by CPF and put into big bags.
6. Delivery to Sabic: Big bags are delivered to Sabic as raw material to produce Lexan Exell-D or 9030 PC pieces.

7. Delivery to landfill: Margard and pieces without identifying foil are discarded because they cannot be recycled.

The LCA will integrate this flow chart and assess the changes introduced by the implementation of the plastic separation machine in terms of environmental impact.

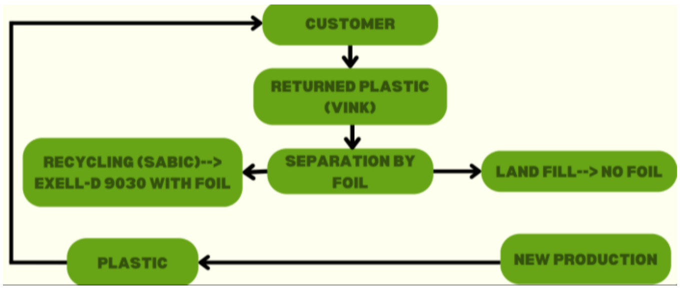

Fig. 1. Flowchart of cycle 1

2) Improved Process

The improved process with the separation machine involves the following steps:

1. Collection: Unidentified plastic is collected, including Lexan Exell-D, Lexan 9030, and Lexan Margard.
2. Visual Check: Vink visually inspects incoming pallet boxes to ensure proper separation without contamination.
3. Sorting by machine: all PC pieces regardless of foil are sorted into the three types (9030, Exell-D, Margard).
4. Production of the machine: includes development, production and transport of the machine
5. Shredding: Lexan Exell-D and 9030 are shredded by CPF and put into big bags.
6. Delivery to Sabic: Big bags are delivered to Sabic as raw material to produce Lexan Exell-D or 9030 PC sheets.
7. Delivery to landfill: identified Margard pieces are transported to a landfill.

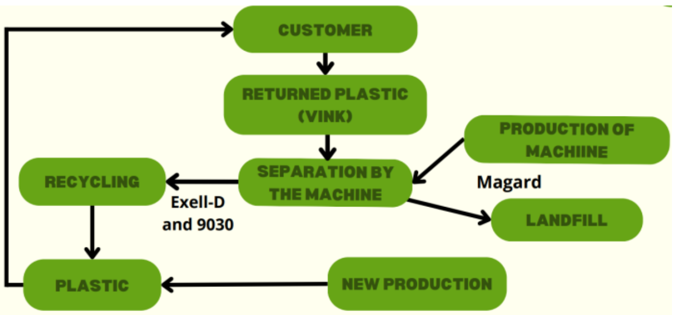

Fig. 2. Flowchart of cycle 2

VII. LCA of the Machine

The machine as an assembly is made up from several different subassemblies and components. The Spanish team required detailed information about these from the Dutch team, which unfortunately could not always be provided in time for the LCA. Therefore, some parts of the machine are based on educated assumptions, which do not provide exact data but still give a general idea about the impact distribution of the machine.

The SimaPro entries of the step feeder, the separator, and the conveyor belt are directly based on the Dutch prototype. All of these are subassembly-entries made up of different components and also contain information about the production and therefore energy consumption of the parts [3].

Due to a lack of information, all other parts of the machine are based on assumptions, including transport, maintenance and waste management, to be sure to be able to grasp its impact compared to its influence on the recycling process. These remaining parts are: the hull, the gears, the cables, the controller and the stepper motor.

However, despite the assumptions, the impact of the machine is comparatively small when juxtaposed with the plastic processing, ensuring overall correctness in the broader perspective. This impact on the second cycle is based on the life span of the machine, that the Dutch team determined at 5 years. Calculating with a 40 hour week of machine usage, 50 productive weeks a year, that leads to a life span of 10000 hours.

For the energy consumption, the calculation involved determining the electricity consumption based on a 24 Volts and 6 Ampere power supply [3], multiplied by the assumed lifespan of 10,000 hours, resulting in 1440 kilowatt hours.

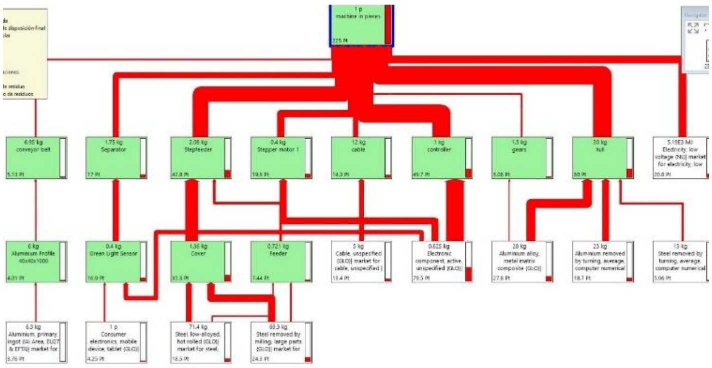

Fig. 3. Network analysis of machine

Fig. 3 shows the network analysis of the machine, where all parts are evaluated on their general impact. The red arrows indicate the assembly structure of the machine and the thickness is a measure for the amount of impact. Endpoint impact is evaluated in Points (Pts), which is a unit used by SimaPro to compare total environmental consequences. A higher point score means a higher overall impact [4].

The assessment indicates that the highest impact contributors to the machine were the hull, controller, and step feeder, as Fig. 3 shows. This gives insight into potential improvements of the machine in the future because these specific components should be targeted. The inclusion of additional elements like change parts, while considered in the analysis, did not significantly alter the overall impact. The main influenceable aspect of the machine concerning its environmental impact is its lifespan because a higher lifespan leads to a proportionally lower impact. This information should also be regarded in future versions of the sorting machine.

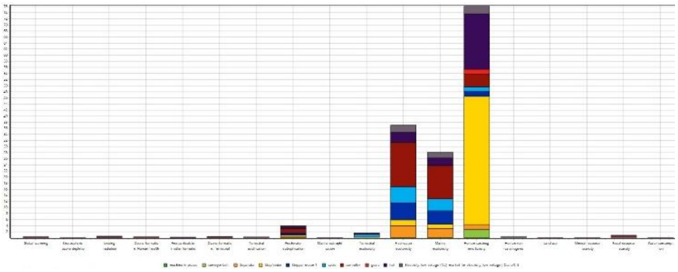

Fig. 4. Midpoint impact of the machine

Fig. 4 shows the midpoint impact of the machine in the 18 categories applied by SimaPro. These are from left to right: global warming, stratospheric ozone depletion, ionizing radiation, ozone formation human health, fine particulate matter formation, ozone formation terrestrial, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, mineral resource scarcity, fossil resource scarcity and water consumption [4].

The diagram shows the most important categories being human carcinogenic toxicity, freshwater, and marine ecotoxicity. Notably, the step feeder (yellow), the hull (dark blue) and controller (dark red) were identified as having the highest impact in these categories.

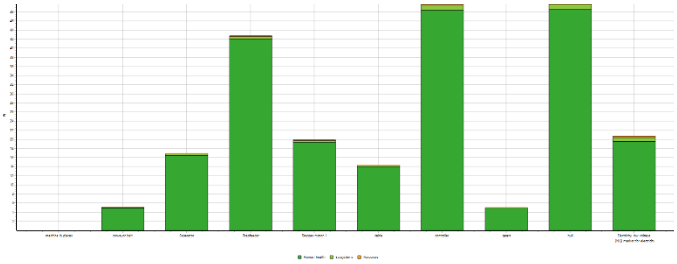

Fig. 5. Endpoint impact of the machine

Upon evaluating the endpoint impact (Fig. 5), which considers the overall effect on human health (dark green), resources (orange) and ecosystems (light green), the hull, controller, and step feeder emerged as the most significant contributors, having by far the highest impact on human health. This analysis sheds light on the key components influencing the environmental footprint of the machine, emphasizing the importance of minimizing the impact of these elements for a more sustainable recycling process.

VIII. LCA Comparison

The following part of the LCA compares Cycle 1, the current plastic recycling cycle with the sorting at CPF based on the foil and Cycle 2 with the improved sorting process by machine and including the machine impact.

A. General Assumptions

Unfortunately, the Spanish team did not receive sufficient information about the complete plastic recycling cycle, more specifically ratios and amounts, and therefore had to rely on educated assumptions to be able to conduct the LCA.
These assumptions are:

- the amount of plastic is constant over the analyzed time period.
- the quality of the recycled plastic pieces does not decrease, meaning that recyclable plastic stays in the cycle forever.
- The types of the returned plastic pieces are evenly distributed: one third of each plastic type (Exell-D, 9030, Margard) and 50% without foil.
- 10% loss of plastic occurs during the recycling process.

B. Cycle 1

For Cycle 1 the aforementioned assumptions mean, that two thirds of all recycled plastic have to get discarded, either because it is Margard or returned without foil. Since all the returned plastic stays in the cycle and factoring in the assumed 10% loss of material during the recycling process, that means that both Exell-D and 9030 are made up from 30% recycled and 70% newly produced PC.

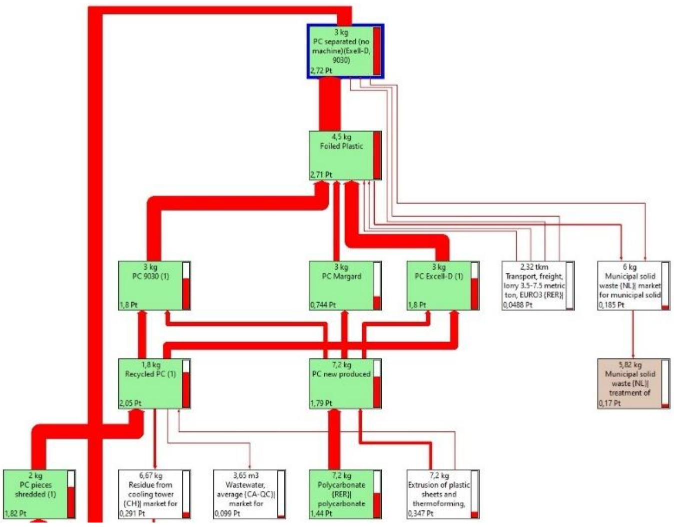

Fig. 6. Network analysis of Cycle 1

Fig. 6 shows the closed loop of the entire recycling process. While Margard is only made from newly produced PC, Exell-D and 9030 are made up from both newly produced and recycled PC, with the aforementioned ratios. Unfortunately, SimaPro does not have detailed information on the recycling process of PC, which therefore had to be substituted with the recycling process of PET, thereby assuming enough similarity between the two processes.

Same as with the network analysis of the sorting machine the thickness of the red arrows indicate the level of impact, similar to the Points (Pts) for every component of the cycle. This network also includes the production processes of newly produced/recycled PC but only shows the aspects with the highest impacts. Notably it also displays the plastic that gets thrown away to a landfill (Municipal solid waste in the Netherlands) and the transport.

The transport for Cycle 1 consists of 4 different aspects. First all of the PC pieces get transported from Vink to CPF in Putte, NL. After they were sorted by hand at CPF, 50% of pieces get thrown away because they lack the identifying foil and therefore have to get transported to a landfill. The two thirds of the remaining pieces that are recyclable get transported from CPF to Sabic, where they get recycled, while the other third (Margard) also gets transported to the landfill.

While the distances between Vink, CPF and Sabic are accurate, the distance from either company to the landfill is assumed, as well as the method of transportation, which was chosen to be standard transport lorry with a capacity of 3.5 to 7.5 tons.

C. Cycle 2

In the Cycle 2, we maintained similar recycling ratios, yet PC without foil was assumed not to be discarded, leading to a better recycling outcome. Non-recyclable Margard was the only material considered to be thrown away (assumed to be one third), resulting in Exell-D and 9030 to be comprised from 60% recycled material and 40% newly produced, due to the assumed 10% loss during the recycling process.

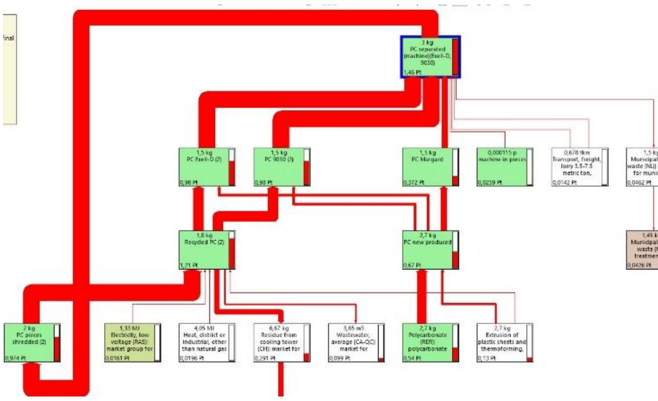

Fig. 7. Network analysis of Cycle 2

The most notable differences between the network of Cycle 1 and Cycle 2 (Fig. 7) are the change in recycling ratios, the reduced amount of newly produced PC and discarded plastic, and the introduction of the sorting machine (here called ‚machine in pieces‘).

The network analysis shows the impact for a small amount of plastic in the cycle, due to insufficient information about the actual amount of plastic in the cycle and can be appropriately scaled. Since the machine can sort more than the 4.5 kilograms (resulting in 3 kilogram usable sorted plastic) of PC, that are shown in the network, it is necessary to figure out how much to correctly scale the impact of the machine on the cycle.

For this consideration of the machine’s utilization, the sorting capacity was required. The machine is assumed to have a lifespan of 10000 hours. With a sorting speed of 65 grams per minute [3] the machine needs 256.4 hours to sort 1000 kilograms of PC pieces. Therefore, that amount of plastic requires 0.02564 machines and the 4.5 kilograms shown in the network require 0.000115 machines.

The energy consumption of the machine is 1440 kilowatt hours for 5 years as explained before. The data for the transport is calculated similarly to Cycle 1 even though the details changed. In Cycle 2 the plastic does not get transported to CPF for sorting by foil and instead is sorted by machine at Vink which eliminates this transport. Instead the two thirds recyclable plastic pieces are transported from Vink to Sabic, while the remaining third goes to the landfill, also assumed to be 100 kilometres away from Vink. The assumed transport method also stays the same.

These calculations and assumptions offer a preliminary assessment and give us a good understanding of the ratios and relations but also highlight the need for accurate data to improve the analysis's precision in future studies.

D. Comparison results

The network analyses already show that the overall environmental impact of Cycle 2 is smaller than that of Cycle 1, because the sorted 3 kilograms PC in Cycle 1 have an impact of 2.72 Points, while it is only 1.45 Points in Cycle 2, showing that the implementation of the sorting machine reduces the impact of the entire process to almost half.

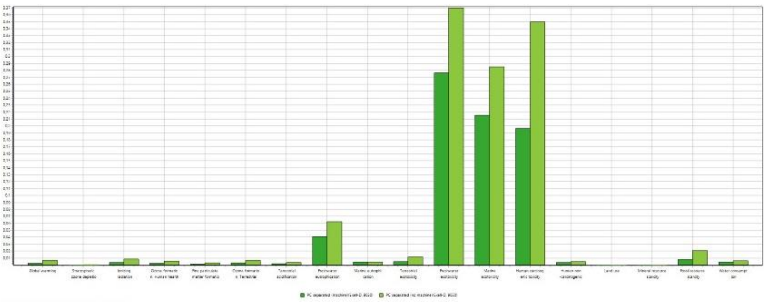

Fig. 8. Midpoint comparison of the two cycles

SimaPro also offers a comparison tool for the Midpoint and Endpoint analyses. Fig. 8 shows the Midpoint comparison, again regarding the following categories from left to right: global warming, stratospheric ozone depletion, ionizing radiation, ozone formation human health, fine particulate matter formation, ozone formation terrestrial, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, mineral resource scarcity, fossil resource scarcity and water consumption. Hereby is Cycle 1 represented by light green, while Cycle 2 is dark green.

This comparison further supports the conclusion, that Cycle 2 is largely improved concerning the environmental impact, because Cycle 1 exhibits a higher impact in every single category, with the highest midpoint impact in freshwater and marine ecotoxicity, as well as human carcinogenic toxicity.

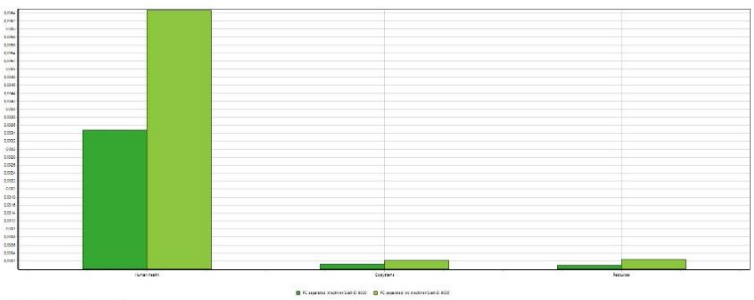

Fig. 9. Endpoint comparison of the two cycles

The Endpoint comparison shows the categories Human Health, Ecosystems and Resources, with the same colour coding of Cycle 1 and Cycle 2 as before.

Upon examining the results, it is evident that Cycle 1 shows higher figures, especially concerning human health. This trend is clearly depicted in the diagram, where the dark green columns are consistently and significantly lower than the light green ones in all categories. Therefore, despite the entire impact of the machine in Cycle 2, the fact that Cycle 2 recycles a significantly larger amount of plastic and produces less waste contributes significantly to reducing its environmental impact both in a midpoint and endpoint analysis.

IX. CONCLUSION

Our comprehensive study on the plastic recycling project has uncovered valuable insights into the current state of plastic recycling practices. However, it is crucial to acknowledge certain limitations and challenges that affect the overall realism and accuracy of our findings.

A significant hindrance to the realism of our study lies in the lack of critical information, notably pertaining to concrete information about the recycling process and the machine and its components.

The use of SimaPro, while a powerful tool for life cycle assessments, has posed challenges due to missing and inaccurate data. Substituting the recycling process of PET for the actual plastic PC due to non-available information about the PC recycling process and the absence of information on the shredding process, causing the use of a woodchipper instead of a plastic chipper in the process specification, have introduced variations that compromise the precision and reliability of our analysis.

An overarching concern is the ongoing development status of the machine. Incomplete information about its specifications and processes directly translate to limitations in our ability to conduct a realistic assessment. The combination of incomplete machine details, uncertainties in transportation data, and discrepancies in SimaPro inputs collectively impacts the realism of our study. It underscores the importance of having accurate, up-to-date, and comprehensive information to ensure a faithful representation of the environmental impact of the plastic recycling process.

In our analysis of Cycle 1, representing the process without the sorting machine, and Cycle 2, which incorporates the sorting machine and emphasizes more recycling, along with a separate examination of the machine, several assumptions were made due to the lack of precise information about the machine's components. It is important to note that while these assumptions were necessary, the overall impact of the machine on the plastic recycling process was found to be relatively small compared to the plastic process, providing confidence in the broader accuracy of the assessment.

Keeping this in mind, the team is still confident that although the used and produced data is not entirely accurate and numerous assumptions were made to finish the analysis, the overarching result is accurate because none of the assumptions are deemed critical. Especially the improvement in Cycle 2 is a very important and useful realization.

Future studies should prioritize obtaining complete and accurate information about all aspects of the recycling process, including machine specifications, transportation logistics, and material inputs. Another focus should be making sure that SimaPro inputs closely mirror the actual processes and materials involved, because this is paramount for a more realistic life cycle assessment. This includes avoiding substitutions, such as using PET instead of the specific plastic PC. Also, regular updates on the development and operational status of the machine are essential for maintaining the realism and relevance of the study.

In conclusion, our study has provided valuable insights into the plastic recycling project. It clearly shows the improvement of Vink’s plastic cycle by introducing the sorting machine and also indicates which components of the machine have the most potential for future optimization. However, the identified information gaps, especially in the recycling process and SimaPro inputs, necessitate a cautious interpretation of our findings. The pursuit of accurate, complete, and up-to-date data will be pivotal in conducting more realistic assessments in future studies related to plastic recycling initiatives.

REFERENCES

[1] Vink holdings, J. Steltenpool, 2023.

[2] I. Florensa Ferrando, “LCA Methodology”, Barcelona: EUSS-School of Engineering, unpublished, 2023.

[3] D. Cornea, T. de Louw, R. Heeren, and G. Crone, “Plastic Separation by specific wave length”, Eindhoven: Fontys-University of Applied Sciences, unpublished, 2024.

[4] PRé Sustainability, “SimaPro Tutorial”, version 6.0, April 2023.

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Learning physics through 3D printing

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***Abstract*— This university project aims to develop 3D-printed toys for effective physics education and sustainability promotion. These toys provide an interactive experience, fostering curiosity and active experimentation, while also encouraging problem-solving skills through physical challenges. Sustainability is integrated into the project using reusable and biodegradable materials, energy-saving practices, and smart packaging. This holistic approach not only seeks to innovate in education but also advocates for responsible and sustainable practices in the creation and utilization of toys. Introduction**

I. Introduction

In the landscape of education, the synergy between traditional subjects and developing technologies has become a central point for innovation. This project embarks on a journey to search for the convergence of physics education and cutting-edge technology, particularly investigating the transformative role that 3D printing can play in elevating comprehension. We aim to close the gap between theoretical and practical concepts, enriching the educational experience for students.

Furthermore, this project focuses on finding creative methodologies to motivate and get involved children and youth involved in the learning process. With a particular emphasis on encouraging playful exploration, we seek to organize methods that seamlessly integrate education and recreation, creating a dynamic and satisfying learning environment. The exploration of these innovative approaches not only motivates the advancement of physics education but also contributes to a broader vision of stimulating a lifelong love for learning among the younger generation.

II. Objectives

A. *Effective Physics Education:*

Effectively convey fundamental physics concepts through interactive 3D-printed toys, facilitating a hands-on understanding of physical principles.

B. *Stimulate Curiosity and Experimentation:*

Foster curiosity in children by creating toys that encourage exploration and active experimentation.

C. *Promote Active Learning:*

Encourage children's active participation in the learning process, motivating them to experiment and dynamically analyze physics concepts.

D. *Develop Problem-Solving Skills:*

Contribute to the development of problem-solving skills in children by presenting physical challenges through the toys. This practical experience will strengthen their ability to address and overcome obstacles.

III. Ideas to Develop

1) Archimedes' Principle:

Understand that any object in a fluid experience an upward buoyant force equal to the weight of the fluid it displaces.

2) The Law of the Lever:

Explore the balance of moments of force around a pivot point.

3) Gearbox:

Grasp concepts of mechanics, gears, torque, rotational speed, and ratios through calculations and participation in this educational kit.

4) Slope with Ball:

Explore concepts of mass, gravity, forces, time, acceleration, and speed through calculations and participation in this educational experiment.

5) Laser Deflection:

Acquire knowledge about lasers, light, mirrors, and lenses in an enjoyable way. The goal is to create multiple starting configurations to generate various problem-solving games.

IV. Educational Model Designs

About Archimedes principle and the Law of the lever design:

In this design, each toy is connected in a manner resembling puzzle pieces. The parts fit together without problems, creating a cohesive and combined structure. The versatility of this design is highlighted by its applicability to multiple games.

The cube can serve a dual purpose, accommodating different gameplay scenarios or activities.

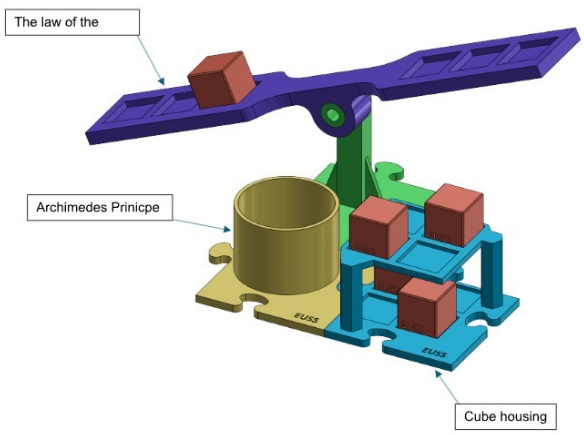

Image 1: Archimedes and law of the lever design

About the Laser deflection design:

This design focuses on developing a system that enables controlled deviation of a laser to reach a predetermined target. The key lies in accurately calculating the entry and exit angles of the laser, ensuring effective impact. Additionally, the determination of the power needed to activate the sensor at the target is addressed, considering the efficiency of the mirror used in the system.

This comprehensive approach not only aims for precision in the laser's direction but also emphasizes energy efficiency by considering the reflective capability of the mirror. The result will be a system that ensures controlled and accurate deviation of the laser, optimizing both the angles of incidence and the power required for effective sensor operation at the designated target.

Image 2: Laser deflection design

About the Slope with ball design:

This design introduces an innovative educational proposal by rolling a ball down a slope, while sensors measure the time of travel. This experience combines physical activity with sensor technology, generating measurable data. The design, focused around an educational kit, also integrates a 3D-printed model for a comprehensive hands-on and theoretical learning experience.

Image 3: Slope with ball design

About the Gearbox Project:

This project introduces an educational kit that is assembled gradually by adding parts at each step to increase complexity. This approach enables students to learn both the fundamentals and advanced skills, addressing complex gearbox problems progressively and comprehensively.

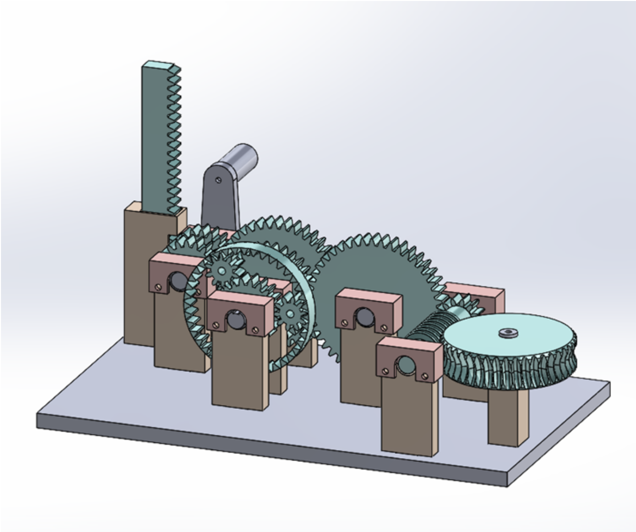

Image 4: Gearbox design

V. Manufacturing process

All parts are manufactured through 3D printing. When the customer purchases the product, they have two options:

1) Self-Printing:

- The customer prints the parts themselves and receives detailed instructions on how to print, assemble, and execute the practical.
- We provide all necessary files, instructions, and non-printable parts.

2) Printing by us:

- We print all parts using the 3D printers at the school or in a future company.
- We deliver the 3D-printed parts, non-printable parts, and provide clear instructions to the customer.

VI. Sustainability

Guided by sustainability principles, our strategic decisions span every phase of the product lifecycle. The preference for reusable or biodegradable materials minimizes our environmental impact, while local production reduces carbon emissions associated with transportation. Our modular and reusable designs aim to extend the longevity of the products. Additionally, smart packaging optimizes space, contributing to a significant reduction in carbon footprint during transportation. This approach underscores our steadfast commitment to sustainability in the creation of educational toys.

VII. Future planning

In our strategy for the future, the development of a comprehensive business plan is proposed, encompassing essential components such as market analysis, organizational structure, and sales and financing strategies. Recognizing the importance of anticipating and managing risks, there is a proposal to conduct a detailed analysis to identify potential challenges and establish preventive measures. Market research will focus on thoroughly understanding our target audience and evaluating competitors. Additionally, legal aspects will be carefully considered to ensure compliance and protection for the business. This comprehensive planning aims to position us strongly to face future challenges and seize opportunities, guiding us toward a successful and sustainable future.

VIII. Conclusions

The project highlighted several key outcomes:

The fusion of fundamental physics theories with 3D printing technology resulted in a seamless integration of theoretical knowledge and practical application.

The practical application of principles such as those of Archimedes and the lever law within 3D designs showcased their immediate relevance and real-world applicability.

Direct engagement in the 3D printing process fostered an active and participatory learning environment, facilitating the development of both theoretical understanding and hands-on skills.

The utilization of innovative technologies, particularly 3D printing, underscored the significance of educational innovation, sparking a sustained interest in scientific exploration.

The connection of physics principles to tangible objects like gearboxes demonstrated the direct transferability and real-life relevance of acquired knowledge.

The project's emphasis on applying physics principles and leveraging 3D printing techniques encouraged collaborative efforts across disciplines, promoting the development of interdisciplinary skills for holistic problem-solving.

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I2E2 Network

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Keywords—Smart Tooling, Industry 5.0, Lean Management

I. Abstract

This study investigates the application of Industry 5.0 technologies to improve efficiency and reduce assembly errors in conveyor assembly lines, focusing on a collaborative project with Vanderlande. Through a six-month innovation project within the I2E2 Network, we explore the integration of smart tooling solutions and lean manufacturing principles to modernize assembly processes.

II. INTRODUCTION

The advent of Industry 5.0 has heralded a new era in manufacturing, emphasizing human-technology collaboration. This pape r presents a research project undertaken in partnership with Vanderlande, aiming to enhance conveyor assembly lines through smart industrial tooling. The project's scope, objectives, and the significance of integrating Industry 5.0 technologies are discussed..

III. THE CONCEPT

A. *Transport of the product during assembly*

1) Modular Design for Versatility and Adaptability

The foundation of our assembly line lies in its modular design, which underscores its adaptability to a diverse range of customer needs and products. This approach ensures versatility without confinement to a specific product, prioritizing independence in development, testing, and maintenance. The ease of replacing or upgrading modules minimizes disruptions, contributing to a more efficient and responsive system.

2) Uniform Table Heights for Operational Efficiency

In the operational context, achieving uniform table heights within the modular system becomes crucial for ensuring a seamless workflow. This emphasis on alignment is instrumental when multiple tables are used together, enhancing the overall efficiency of the system. The uniformity in table heights not only streamlines the assembly process but also facilitates a cohesive operation.

3) Categorization of Functions and Manual Transport

To optimize cost-effectiveness and ease of implementation, functions within the assembly line are categorized. In this context, manual transport, particularly utilizing a guided rail and wheels system, emerges as the optimal choice. Despite potential ergonomic concerns associated with manual transport, the lightweight nature of the products makes this method manageable. This aligns with the broader objectives of the modular design, promoting an efficient yet ergonomic approach to product transport.

B. *Pick to light*

Pick-to-Light technology has emerged as a transformative solution in modern warehouse and manufacturing operations, leveraging visual cues to guide workers through the picking process. In this section, we delve into a thorough examination of both the advantages and potential drawbacks associated with the implementation of Pick-to-Light systems in industrial settings.

1) Impact of Pick-to-Light Systems

Pick-to-Light systems significantly enhance operational efficiency through two core features: precision in picking accuracy and real-time monitoring.

a) Precision in Picking Accuracy

The standout advantage of Pick-to-Light systems is their ability to improve picking accuracy. Outfitting each storage location with light modules enables precise item identification, minimizing errors during picking. This leads to increased operational efficiency, as workers swiftly locate and select correct items, reducing fulfillment times and enhancing overall productivity.

b) Real-time Monitoring for Workflow Optimization

Complementing accuracy, Pick-to-Light systems provide real-time monitoring capabilities. Supervisors can actively track picking progress, identify bottlenecks, and manage workflow efficiently. This fosters a more streamlined and responsive warehouse or manufacturing environment, optimizing overall operation efficiency.

2) Implementation Challenges and Considerations

a) Initial Implementation Cost

One potential drawback associated with Pick-to-Light systems is the initial implementation cost. The installation of light modules, displays, and system integration may require a significant upfront investment. Organizations must carefully evaluate these costs against the anticipated benefits, considering factors such as improved accuracy, reduced errors, and enhanced operational efficiency. Despite the initial investment, the long-term gains in productivity and accuracy may justify the upfront expenses.

b) Integration Complexity

Another consideration is the potential complexity of integrating Pick-to-Light systems into existing warehouse or manufacturing processes. Adapting assembly procedures or interfacing with other management systems may pose challenges, potentially requiring adjustments that could temporarily impact productivity. Careful planning and seamless integration strategies are crucial to mitigating any disruptions and ensuring a smooth transition to Pick-to-Light technology.

c) Training Requirements and Workforce Adaptation

As with any technology, training workers to effectively use the Pick-to-Light system is essential. Initial learning curves or turnover of staff may influence productivity during the early stages of implementation. Organizations should invest in comprehensive training programs to familiarize workers with the system, minimize disruptions, and optimize the benefits of Pick-to-Light technology.

3) Future Considerations and Recommendations

a) Scalability and Long-term Viability

A crucial consideration for organizations implementing Pick-to-Light systems is their scalability for future growth and expansion. Assessing the long-term viability of the technology in evolving warehouse and manufacturing environments is essential to ensure continued success.

b) Technological Advancements and Evolving Standards

Exploring potential technological advancements in Pick-to-Light systems is vital. Considering evolving industry standards and their impact on system upgrades and compatibility will be crucial for staying ahead in a rapidly changing technological landscape.

C. Detection of the product during and after assembly

The movement of the product along the rail system and through various assembly stations is crucial for ensuring smooth production. Knowing precisely where the product is in the assembly line is of paramount importance for the proper functioning of the system.

1) QR Scanner

The use of a QR scanner mounted under the rail provides an effective solution for tracking the product's position. At each assembly step, the scanner reads the QR code under the carriage, allowing the system to track the product's progress along the line.

The system's functionality focuses on carriage movement and QR code scanning. This information is then relayed to operators to provide them with the appropriate instructions at each assembly station, ensuring an efficient and error-free process.

Confirmation of the end of the assembly line is a crucial process, and the system is designed to indicate any errors in the assembly. This ensures the accuracy of finished product counting and the overall quality of assemblies.

The carefully chosen specifications for the scanner favor a compact and fast RF (Radio Frequency) model. This technology offers increased accuracy, real-time data transmission, and operational efficiency essential for effective production management.

2) RF Scanner Specifications

The selection of the RF scanner is based on carefully evaluated specifications, emphasizing compactness and speed. Compactness ensures easy integration under the rail, while scanning speed allows for quick and efficient capture of QR codes, minimizing downtime in the assembly process.

The preference for an RF model stems from its advantages in terms of accuracy and real-time transmission. This technology ensures reliable data collection, contributing to more efficient production management and increased responsiveness of the system.

The chosen RF scanners are selected for their reliability in demanding production environments. This reliability contributes to the accuracy of product tracking along the assembly line, ensuring smooth production management.

D. poka yoke

Poka-yoke, or mistake-proofing, involves more advanced strategies to ensure even more reliable error prevention in processes. This can include sophisticated systems that automatically adjust operations based on real-time feedback, ensuring that errors are not just caught but prevented from occurring in the first place. For instance, in an assembly line, a poka-yoke device might not only stop the line if a part is missing but also reorder the missing part automatically. This deeper integration of poka-yoke into systems helps create a more resilient and efficient manufacturing environment, further reducing waste and improving quality.

IV. PROJECT MANAGEMENT

The project employed an agile-like approach with monthly collaborative sprints between Fontys and Vanderlande, supplemented by weekly steering meetings for detailed discussions. Without a designated leader, the team adopted participative management, fostering collective engagement. A Gantt chart was crucial for mapping and tracking the project timeline, milestones, and responsibilities, enhancing communication and oversight within the team.

V. DIFICULTIES ENCOUNTERED

The project faced challenges with international collaboration, differing work methods, and limited meeting time, leading to difficulties in workload distribution and decision-making. Communication issues with the client and a language barrier further complicated the project, impacting the efficiency of solution discussions and overall project progress.

VI. OUTLOOKS AND REFLECTIONS

Reflecting on our project, we'd consider a more gradual approach to solution selection, starting with an in-depth analysis of the current assembly line. This could reveal that advanced technologies might not be necessary for Vanderlande's small-scale assembly, leading us to explore more cost-effective and simpler solutions like process standardization and enhanced training, potentially improving productivity and reducing errors without significant investment in new technologies

VII. CONCLUSION

This project taught us the value of collaboration, adaptability, and communication in a diverse, international team, beyond just technical skills. We embraced the lean methodology, emphasizing incremental progress, which shaped our problem-solving and project management strategies. Engaging closely with the client from the start proved vital, enhancing project understanding and outcomes. These experiences have prepared us for future challenges in industrial engineering, highlighting the importance of a collaborative, adaptable approach and effective communication.

VIII. ACKNOWLEDGMENT

Our heartfelt thanks to the I2E2 Network, Fontys University students, our mentor Mr. Reheisser, and Vanderlande for their invaluable support and collaboration on this project, enhancing our academic and practical skills in industrial engineering.

REFERENCES

[1] ICAM Lean Team

[2] The Toyota Model by Jeffrey Liker