Examensarbete

HÖGSKOLAN
I SKÖVDE

DESIGN FOR ASSEMBLY CONSIDERATIONS OF A BATTERY CELL MODULE IN A ROBOTIC CELL.

Bachelor Degree Project in Product Design Engineering
G2E, 30 credits
Spring term 2024

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Abstract

The project aims to improve the design for the assembly and fabrication of a cell module in a robotic cell. This report presents a structured design process covering the approach, methods, results and conclusions. Problems related to the geometrical complexity of the module are addressed and key objectives for the improvement of the assembly and fabrication are established. Secondly, an investigation of the product and relevant aspects in the current market is carried out. Next, the architecture, functions and requirements to be fulfilled by the battery module are developed. The list of requirements is key and essential as it serves as a guideline for the following phases. During the concept generation stage, a brainstorming process is used to sketch out ideas, followed by an evaluation of the final concept using the information from the interviews, a checklist of the guidance table and the spider diagram. This process allows to identify which concept can best meet the proposed objectives. Furthermore, the final result is presented through renderings and modelling for a complete visualisation. Finally, the report includes conclusions highlighting the positive and negative aspects of the project, as well as areas for improvement and achievements.

Certification

This thesis has been submitted by Carmen Belda Torró and Evelyn Rodríguez Castellón to the University of Skövde as a requirement for the degree of Bachelor of Science in Product design Engineering.

The undersigned certifies that all the material in this thesis that is not my own has been properly acknowledged using accepted referencing practices and, further, that the thesis includes no material for which I have previously received academic credit.

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Skövde 2024-06-02
School of Engineering Science

Acknowledgements

We would like to thank those who contributed to the development of this project in a significant way.

First and foremost, we thank Nathanaël for his guidance and constant support throughout this process. His knowledge and direction were instrumental in achieving our goals, and we are sincerely grateful for her dedication.

We would also like to thank Aitor Iriondo Pascual for his collaboration and help during this project. We appreciate his willingness to assist us when we needed it most.

Finally, we extend our thanks to the other teachers whose teaching was essential for the completion of this work. Their teaching has been fundamental for our academic and professional growth.

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1. Introduction

The last decade has witnessed a significant shift in the automotive industry, driven largely by the growing demand for electric vehicles. This shift has been motivated by the need to reduce emissions and promote sustainability in transportation. As a result, progress is being made in the development and refinement of technologies related to electric vehicle (Zimm, 2021).

One of the components of electric vehicles is the battery system. According to Arora et al., (2016) among the most prominent innovations is the "cell module", a unit that integrates multiple battery cells which provide the energy necessary for a vehicle to move. This evolution has led to a greater focus on the design and optimisation of these modules, with the aim of improving their performance, durability and safety (Figure 1).

According to Nogueira et al., (2022) sales of electric vehicles have grown significantly in the last decade, and by 2030, these sales are expected to account for 20-30% of the total. This further underlines the importance of cellular modules in electric vehicles.

In this context, the need arises to consider Design for Manufacture and Assembly (DFMA) principles in cell module design, which focus on simplifying and optimising manufacturing and assembly processes to reduce costs and improve efficiency (Nogueira et al., 2022).

This work focuses on the redesign of the electric vehicle cell module, considering the evolution of batteries and taking advantage of the advantages of design for manufacturing in a robotised environment and DFMA principles. This project is related to two colleagues: one specialising in production engineering and the other in mechanics engineering. The three projects are interrelated. One of the projects focuses on the redesign of a gripper by the mechanical specialist, while the other is dedicated to the development of robot programming for cell assembly by the robotics specialist. The three projects will be combined in order to carry out cell assembly. In collaboration with ASSAR, a leader in innovation and technology, the aim is to improve the quality, efficiency and competitiveness of electric vehicles in today's market, thus encouraging the adoption of more sustainable mobility.

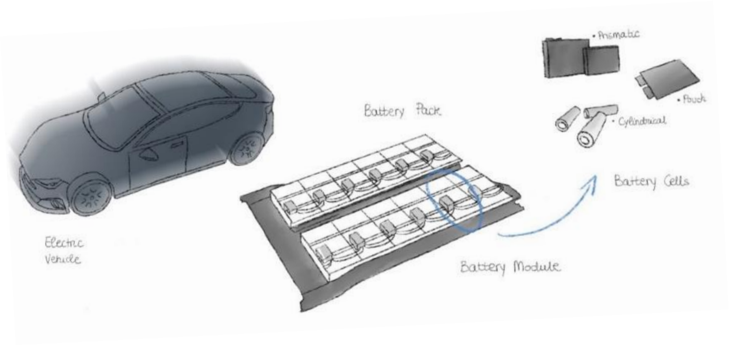


Figure 1. Graphical representation of battery structure.

1.1 Background

ASSAR is a meeting and collaboration space designed to drive development and innovation in the manufacturing and technology industry connected to University of Skövde, Aurobay and Volvo. Here, professionals and companies can network, participate in activities that strengthen their companies and access resources such as seminars, workshops and networking to address the challenges and opportunities of the global market. In addition, ASSAR plays a crucial role in driving automated production processes and provides an environment conducive to the demonstration of innovative technologies and practices. In short, ASSAR provides a dynamic environment for the exchange of ideas and business growth.

1.2 Problem Statement

In the context of automated production, the main challenge lies in optimising the assembly process with robots, especially in the case of the battery module, by using Design for Assembly (DFA). It addresses the fundamental question: What factors hinder the efficient handling and assembly of components by robots and what actions can be taken to improve the situation?

Identifying these factors becomes the main challenge, where geometrical complexity, optimisation of gripping characteristics, reduction in the number of parts, limited accessibility of the robot and other features that hinder gripping must be thoroughly analysed. In addition, it is essential to integrate sustainability considerations into this redesign process, asking how to design battery module components that are both easy for robots to assemble and sustainable in terms of materials, energy and resources used.

1.3 Aims and Objectives

The main objective is to optimise the design of the battery module casing to improve the ease of assembly using robots. This involves identifying the factors that hinder the efficient handling and assembly of components during the automated production process, including a final redesign with less geometric complexity and adapted to the gripper's gripping characteristics.

In addition to this main objective, there are several secondary objectives:

1- Investigate and apply Design for Assembly (DFA) principles to optimise the automated battery module assembly process.

2- Integrate sustainability considerations into the battery module redesign process, such as design for the environment (DFE). This includes the application of Design for Disassembly (DFD) principles to facilitate recycling and reduce waste.

To achieve these objectives, design iterations, simulations, and tests are carried out. The aim is to demonstrate the tangible impact of DFA principles in the robotic production process.

1.4 Limitations

For the implementation of this project, it is essential to consider some limitations:

1- The present work does not include the exact material for the cell module housing, therefore a material analysis is not required

2- The project does not take into account electrical considerations and is therefore focuses exclusively on the exterior design of the housing.

3- The bus bar and heater film are not included in the redesign of the cell module housing due to company considerations. This is relevant but is not taken into account in the assembly process of this redesign, it will have to be considered later in another process.

4- The batteries inside the cell module have been previously selected, which means that the dimensions of the space to house them are already defined. The specific characteristics of these batteries are:

    3.1 Dimensions: 174x170x43 mm.

    3.2 Weight: 2.85 kg.

5- The grip of the robot has certain limitations that must be considered:

    4.1 The gripper has a maximum load capacity of 5 kg.

    4.2 The robot is equipped with only one gripper.

    4.3 The gripper is able to perform 360 degree movements.

    4.4 The maximum opening of the gripper is limited to a specified value of 45 mm.

    4.5 The minimum opening of the gripper is limited to a specified value of 13 mm.

1.5 Overall methodology

The engineering and redesign process approach proposed by Otto and Wood (2001), establishes a systematic methodology that guides project development from initial assessment to market implementation of the redesign (Figure 2). It begins with a thorough evaluation of an existing product on the market, identifying possible areas for improvement based on market demands or current constraints. This engineering process involves anticipating the functions that the product should fulfil, followed by modelling, analysis, breakdown and testing of its actual performance. Subsequently, redesign is carried out through a reverse engineering methodology, evolving the product in response to market demands towards its next iteration or market version.

The reverse engineering and redesign process is divided into three fundamental stages:

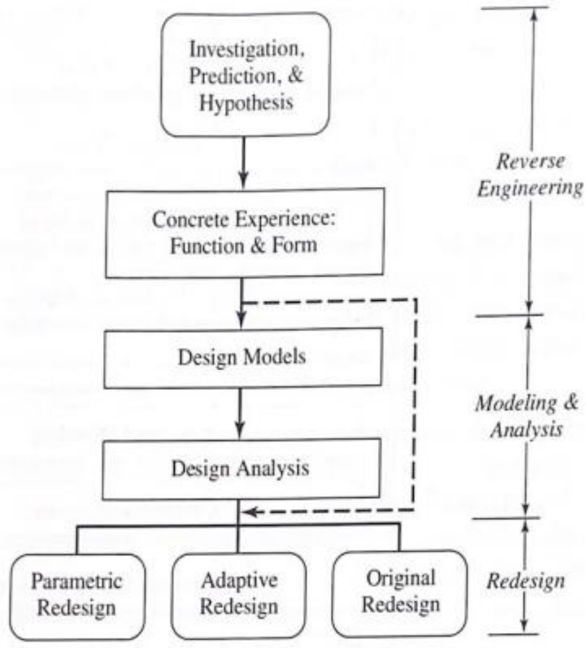


Figure 2: General reverse engineering and redesign methodology (Otto & Wood, 2001).

- Reverse engineering: This begins with the evaluation of the existing product on the market, taking it apart or analysing it in depth to understand its construction and operation. During this process, market and customer needs analysis is conducted to identify opportunities for improvement by understanding the strengths and weaknesses of the current product (Otto & Wood, 2001).

- Modelling and analysis: Once the reverse engineering phase is completed, the redesign is developed using modelling and analysis tools to explore new concepts and assess their feasibility. Detailed analyses are conducted to assess the performance of the new designs and ensure that they meet market requirements and expectations (Otto & Wood, 2001).

- Redesign: The most appropriate redesign concept is selected for implementation, introducing changes in aspects such as manufacturing or the use of new materials or technologies. The new design is subjected to rigorous testing to ensure functionality and performance (Otto & Wood, 2001).

Based on the design process proposed by Otto and Wood (2001), a variant of this design process, adjusted to fit the specific aims of the project, has been defined and carried out (Figure 3).

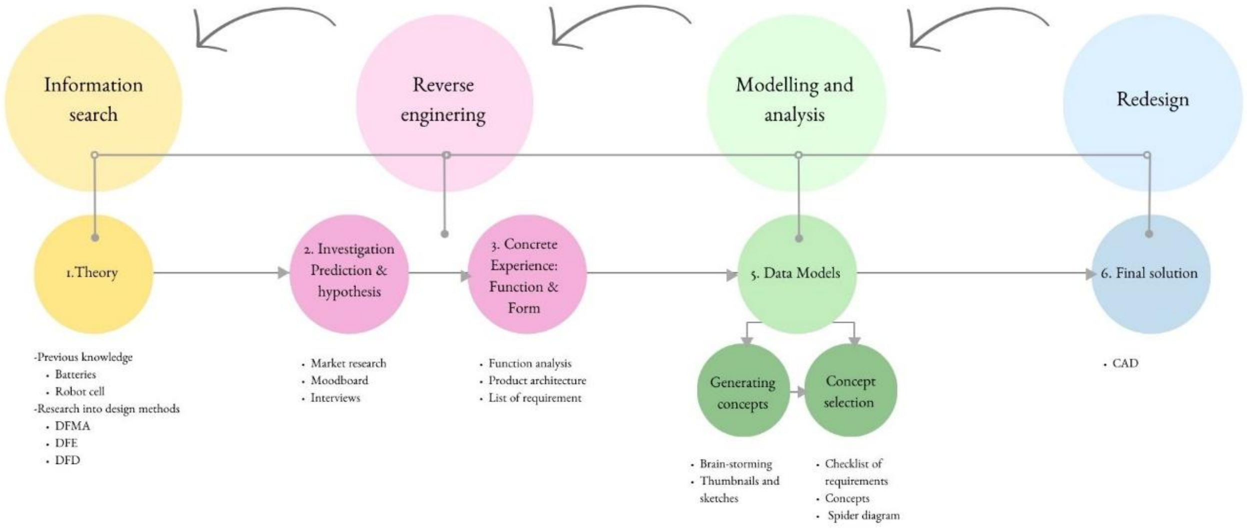


Figure 3. Design process.

This design process has been adapted for the redesign of a cellular module housing, incorporating several significant modifications. One of the changes is the adoption of an iterative approach, which allows for continuous adjustments and improvements as the process progresses. In addition, an initial step focusing on theory has been introduced, as this project is oriented towards DFMA (Design for Manufacture and Assembly) principles. It was considered essential to obtain detailed information on these principles as a starting point.

The design process starts with the information search, divided into two sections: "previous knowledge" and "research into design methods ". This stage involves gathering information about the robot and the battery, as well as specific details about Design for Manufacture and Assembly (DFMA), Design for Environment (DFE) and Design for Disassembly (DFD) guidelines. This information provides a solid foundation for understanding how to apply these principles in the design of the cell module.

The next step is reverse engineering, which is divided into two stages. In the first stage, market research is conducted to understand the product and analyse its position in the market, complemented by interviews to expand knowledge about the robot gripper and battery. This stage helps to identify common features and practices in similar products, allowing the design to be placed in a realistic and competitive context. In the second stage, functional analysis is crucial to identify all functions of the cell module. Through the product architecture, these functions are related to each part of the product, allowing the essential parts of the module to be identified. This information is vital to create the list of requirements.

The next step is modelling, which is divided into two parts: "concept generation" and "concept selection". Concept generation includes brainstorming, sketching and outlining, where several preliminary concepts are developed. Using the list of requirements, three main concepts are selected to be evaluated by means of a spider diagram and the final concept is chosen. It is decided to limit the selection to three concepts because this number provides an optimal balance between diversity and simplicity. Having three concepts allows an adequate range of solutions and approaches to be explored, offering sufficient perspectives and alternatives for the redesign. Furthermore, working with three concepts simplifies the analysis in the spider diagram, making possible a detailed and clear comparison of each option against the set criteria. This number ensures that assessments can be made without the process becoming overly complex or difficult to manage.

The last phase of the process is the redesign, where the final solution is developed based on the selected concept. This involves the creation of the detailed design using CAD software. In this phase, the solutions identified in the previous steps are implemented, optimising each component to facilitate robotic assembly and improve the overall efficiency of the module. In addition, the gripper is verified to be compatible with the redesigned design by taking photos of the gripper with the batteries in the cell module. The redesign phase culminates with the implementation of the final solution, representing the outcome of the design process and ensuring that the final product is competitive and efficient.

1.6 Overview

The following chapters discuss the key aspects of the work done: Chapter 2 discusses the general theory, including the background, such as the study of stacks and the robot. In addition, it focuses on conducting a detailed investigation of the DFA, DFE and DFD. Chapter 3 details the methods used to carry out the project, describing the market research in which batteries, the GoFa CRB 15000 5 robotic arm, materials and assemblies are investigated. In addition, a moodboard, function analysis, product architecture, interviews, requirements list, concept generation and concept selection have been conducted; chapter 3 also presents the implementation of the methods, highlighting how the process was executed; Chapter 4 discusses and presents the results obtained, highlighting the most relevant findings; Chapter 5 discusses whether the objectives set at the beginning of the project have been met, as well as describing the methods used, the difficulties encountered and the sustainable development of the project; chapter 6 presents the conclusions of the work, highlighting achievements and possible areas for improvement; and finally, chapter 7 provides recommendations for future work, based on the results and inputs of the project. Each chapter is designed to provide a clear understanding of the battery module redesign process and the results obtained, as well as to suggest possible future directions for research in this field.

2. Theory

2.1 Batteries

Lithium-ion batteries are fundamental to the advancement of electric vehicles, representing a key part of their development. According to Pesaran et al., 2009, these batteries have the potential to meet the essential requirements for electric vehicles, such as high performance, low cost, long life and safety. However, their integration into modules and packs must be done with caution to avoid performance, durability and safety issues, while keeping costs under control.

There are three main types of lithium-ion batteries, depending on their shape (Pesaran et al., 2009).

- Prismatic cells: They have a flat rectangular shape, like a box. They are common in applications where high energy density and compact design are required.
- Pouch cells: These are flexible and can be adapted to different shapes and sizes of storage spaces. They are mainly used in applications where flexibility and adaptability are important.
- Cylindrical cells: These are cylinder-shaped and are commonly used in applications where high current capacity and good heat dissipation are required.

The cell types are as follows (Figure 4).

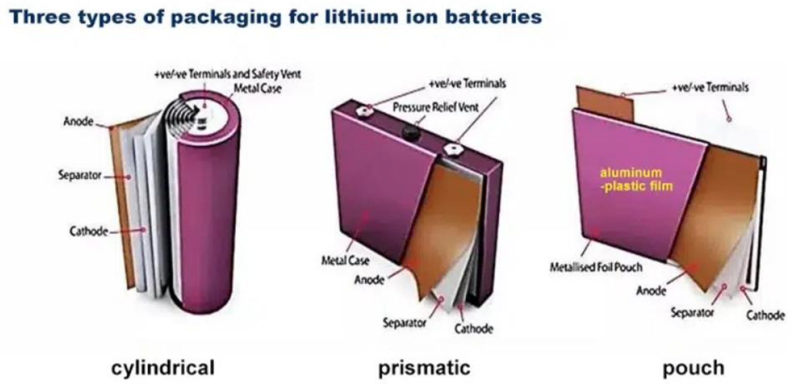


Figure 4. The three forms of battery cells (“ Lithium-ion battery cells and chemistry” n.d.)

In terms of the division of battery packs, it is essential to consider various levels of integration, from the individual cell to the complete pack, with the lithium-ion battery cell being the most basic unit (Pesaran et al., 2009).

Here you can see the three levels of division (Figure 5):

- Battery cell: The basic unit that stores energy chemically and can come in a variety of shapes, such as prismatic, pouch and cylindrical cells. They are the fundamental components of any battery system (Pesaran et al., 2009).

- Cell module: The next level of organisation after individual cells. A cell module is composed of several battery cells connected in series and/or parallel to achieve the desired voltage and energy capacity. This is the part that is the focus of this study (Pesaran et al., 2009).
- Cell Pack: The complete structure that supplies power to the electric vehicle and usually contains multiple cell modules (Pesaran et al., 2009).

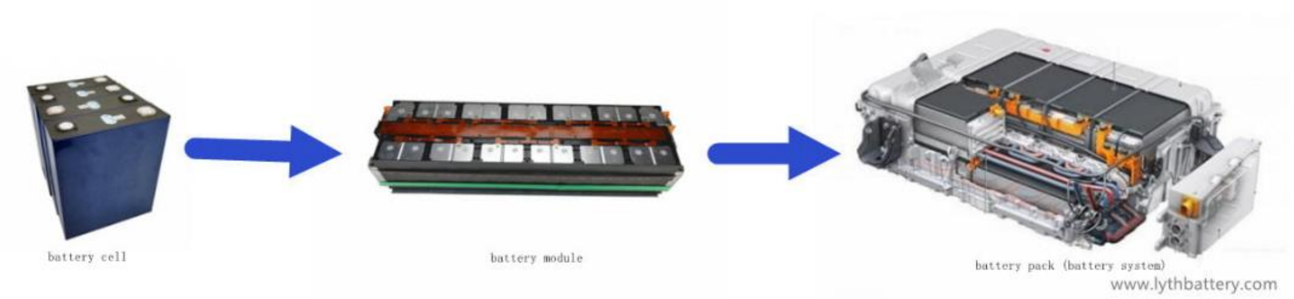
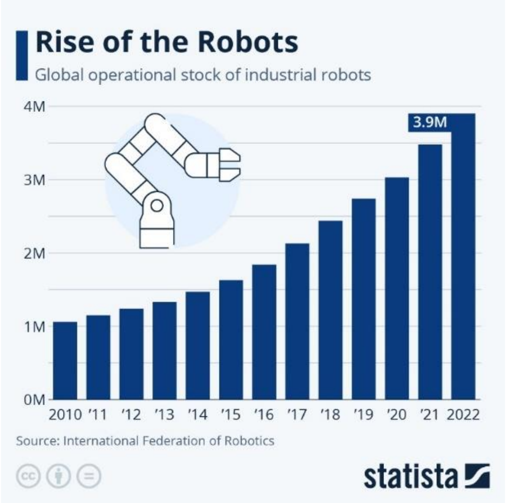


Figure 5. Battery pack division levels ("What is the battery module?," n.d.)

2.2 Robot cell

Today advances in robotics are ushering in a new era of automation with several notable benefits. It is estimated that automation can increase productivity globally by 0.8% to 1.4% annually. According to McKinsey & Company (2017), some industries could experience productivity gains of up to 30% through automation. This change is radically transforming the way work tasks and industrial processes are carried out by reducing errors and improving the quality of work. This trend indicates a significant change in the way manufacturing and design tasks are conceived and performed, as automation is increasingly required to be considered in assembly processes when designing products.

According to (Robotics, n.d.) the International Federation of Robotics (IFR), all industrial robots has tripled in the last decade, reaching almost four million robots by 2022 (Figure 6). This trend reflects the growing role of industrial robotics in transforming manufacturing, with benefits such as increased efficiency and productivity.



Source: International Federation of Robotics

Figure 6. Statistics on all operational industrial robots in the global marketplace ("Infographic," 2023).

2.3 DFMA

Design for Manufacture and Assembly (DFMA), as an approach used in product engineering, is based on the optimisation of the manufacturing and assembly process. The Design for Manufacturing (DFM) component involves the adaptation of parts to make them easier to produce, including aspects such as ease of moulding and the application of part-forming models, while Design for Assembly (DFA) focuses on simplifying the assembly process through the use of appropriate fastening methods (Otto & Wood, 2001).

In addition to this, design for assembly involves the development of instructions and fastening methods that facilitate the process of joining different parts of the product. This can be made easier, for example, by designing parts that are easy to attach using press-fits rather than machine screws. In this context, design for assembly involves the application of models that consider the time and complexity of joining, which can be derived from basic rules and tables based on simplified time studies or full-time industrial engineering and motion studies (Otto & Wood, 2001).

There are several significant benefits to implementing DFMA. Firstly, cost reduction is evident, as by making the manufacturing process more efficient, the time required to produce the product is reduced, which in turn reduces the costs associated with labour and resources used. In addition, by simplifying the production process, the number of potential errors is minimised, as each reduced step means a lower probability of failure. Finally, DFMA also contributes to improving the quality of the final product, since a simpler and more efficient design tends to be more consistent and less prone to manufacturing errors, resulting in higher product quality (Otto & Wood, 2001).

2.3.1 Design guidelines method.

The most basic approach to design for manufacture and assembly is to use design guidelines (Table 1). According to Otto and Wood (2001), once a design concept has been conceived, it is necessary to review each of these guidelines and adjust the design to conform to them. It is important to keep in mind that these guidelines are heuristic, meaning that they are practical principles that are often effective. However, as with any rule, there may be exceptions. Therefore, these guidelines should be used flexibly, evaluating their application in terms of design objectives and ensuring that their implementation enhances the design concept in relation to those objectives.

These are the main guidelines:

1. Reduce the number of components by combining several functions in a single part
2. Divide components into simple, modular sub-assemblies
3. Assemble in open areas, avoiding narrow spaces.
4. Design parts to clearly indicate their orientation for assembly.
5. Standardise components to reduce the variety of parts.
6. Avoid parts that can become entangled with each other.
7. Prevent pieces from fitting into each other.
8. Design features to facilitate the insertion of parts.
9. Increase symmetry of parts as much as possible.
10. Position parts from the top of the assembly.

11. Ensure that parts are inserted from the same direction or from a few directions, avoiding having to rotate the assembly.
12. Minimise or eliminate the use of fasteners.
13. Position fasteners in unobstructed areas.
14. Provide flat surfaces for even and easy fastening.
15. Ensure sufficient space to use a fastening tool.

Table 1. Design for manufacture and assembly guidelines (Otto & Wood, 2001).

According to Otto and Wood (2001), a fundamental point that emerges from this analysis is the need to balance design complexity with production feasibility in the DFMA and DFA framework. While DFA and DFM guidelines generally seek to simplify designs to reduce costs and improve quality, it is crucial to recognise that in certain cases the inclusion of multiple functions in a single part can result in excessive complexity. This situation demands careful evaluation and, sometimes, splitting the part into simpler components to optimise manufacturability and reduce associated costs. This approach underlines the importance of considering not only the efficiency of the design but also its feasibility in terms of production and cost within the context of product development.

2.3.2 Modularity

The concept of modularity in product design, according to Otto and Wood (2001), refers to creating parts that are independent, each fulfilling a specific function. This idea is based on using individual blocks or parts that can be combined in different ways to make the whole product work. Although modularity in mechanical design is often considered at later stages of product development, its implementation from the beginning can lead to a faster process and cost reduction in future designs. For example, the observation that product components have other potential uses can guide future product development. This premise is based on the idea that, if properly identified and designed from the beginning, modularity can directly benefit immediate product design.

2.4 DFE

The introduction to Design for the Environment (DFE), based on the theory of Otto and Wood (2001), highlights the importance of this activity in the design process, underlining that much of the environmental impact of a product is determined in the early stages of its development (Figure 7). It is emphasised that customers are now demanding products with a lower environmental impact, which has become a competitive advantage in the marketplace. In addition, government agencies are setting increasingly stringent standards to reduce the environmental impact of products. To address these demands and meet regulatory standards, it is essential to implement design for the environment.

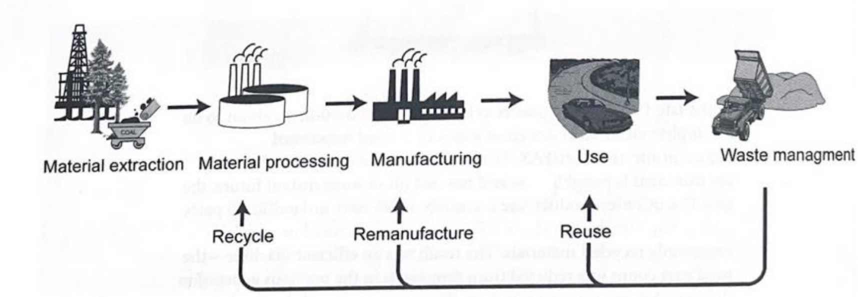


Figure 7. Product life cycle phases (Otto & Wood, 2001).

2.4.1 Design guidelines

The Design for Environment (DFE) considers environmental objectives, including biosphere protection, sustainable resource use, and waste reduction and elimination Otto and Wood (2001). These principles provide guidelines for minimising the release of pollutants, using raw materials sustainably, reducing waste, and promoting the rational use of energy, among other aspects (Table 2).

These are the most highlighted guidelines in the design for environment:

Guidelines	Reason
Reduce the number of components by creating parts with multiple functionalities.	Decrease time and resources needed for disassembly.
Avoid using separate springs, pulleys or harnesses.	Reduce time and resources spent on disassembly.
Design in a modular way, separating the different functions.	Facilitate maintenance, upgrading and recycling.
Locate non-recyclable parts in subsystems that can be easily removed.	Speed up the disassembly process.
Place the most valuable parts in easily accessible locations	Facilitate disassembly
Design parts to remain stable during disassembly.	Makes manual disassembly faster and more efficient
Avoid the use of metal inserts or reinforcements in plastic parts	Eliminate the need to grind and separate materials
Make access and breakage points clearly visible	A logical structure facilitates disassembly
Group individual parts that are made of the same material	Eliminate the need for disassembly during recycling

Table 2. Design for environmental guidelines (Otto & Wood, 2001).

2.4.2 Life cycle

Life cycle analysis becomes a fundamental tool, according to Otto and Wood (2001). It is a systematic process to assess the environmental impact of a product throughout all its stages, from raw material extraction to final disposal. Incorporating the DFE into the life cycle implies a holistic approach that seeks to minimise the environmental impact at each stage of the product life cycle.

A crucial part of this approach is the selection of materials, as suggested by Otto and Wood (2001). This involves assessing not only the mechanical and aesthetic properties of materials but also their environmental impact in terms of embodied energy, greenhouse gas emissions, natural resource consumption and ease of recycling at the end of their useful life.

When considering the entire life cycle, design for manufacture also becomes important. Here, the aim is to minimise the consumption of energy and resources during the manufacturing process, as well as to reduce the generation of waste and emissions (Otto & Wood, 2001)

Furthermore, as Otto and Wood (2001) point out, design for energy consumption focuses on optimising the performance of the product during use, which implies reducing its energy consumption and, thus, its environmental footprint during the operational phase. This aspect of design may include optimising energy efficient systems, implementing energy management technologies and adopting design practices that reduce the energy demand of the product.

Finally, design for end-of-life refers to planning for the final disposition of the product once it has reached the end of its useful life. This involves designing products in a way that facilitates the disassembly, recycling and reuse of components and materials, thus promoting a circular economy and reducing the amount of waste sent to landfills (Otto & Wood, 2001).

2.4.3 Techniques to reduce environmental impact.

As mentioned above, in the context of product design, there is a growing awareness of the importance of adopting sustainable practices that minimise environmental impact throughout the product life cycle, as emphasized by Otto and Wood (2001). In this regard, they propose a number of techniques that can be incorporated into the design process to improve the environmental sustainability of products.

One of the key techniques proposed by Otto and Wood (2001) is "design to minimise material use", according to their research. This involves reducing the number of materials used in the manufacture of a product. This approach not only contributes to resource efficiency but can also reduce the costs associated with materials procurement and handling.

Another key technique is "design for disassembly", which involves designing products so that they can be easily disassembled at the end of their useful life. This practice facilitates the reuse and recycling of components, thus promoting the circular economy and reducing the amount of waste generated (Otto & Wood, 2001).

In addition, "design for recycling" is essential to maximise the ability of a product to be recycled at the end of its useful life, according to Otto and Wood (2001). This involves selecting materials that are easily recyclable and designing the product in a way that facilitates the recycling process.

"Design for remanufacturing" is another significant technique proposed that promotes the reuse of products by disassembling them, cleaning and repairing the components, and then reassembling them for reintroduction into the market. This practice not only reduces the demand for new materials but also minimises waste generation (Otto & Wood, 2001).

Furthermore, Otto and Wood (2001) suggest a "design to minimise hazardous materials", which seeks to eliminate or reduce the use of materials that may pose a risk to the environment or human health. By selecting safer and eco-friendly alternatives, product safety and environmental impact can be improved.

"Energy efficiency" is also an important consideration in sustainable product design, as highlighted by Otto and Wood (2001). By optimising energy use during product manufacture, use, and dismantling, greenhouse gas emissions and natural resource consumption can be significantly reduced.

Finally, "design to regulations and standards" ensures that products comply with environmental regulations and sustainability standards set by competent authorities, according to Otto and Wood (2001). This ensures that the products are not only environmentally safe but also legally compliant.

The implementation of these techniques proposed by Otto and Wood (2001) in product design can lead to a significant reduction of environmental impact, promoting sustainability and environmental responsibility in the manufacturing industry.

2.5 DFD

Design for Disassembly (DFD) is an essential strategy employed by engineers and designers to simplify the product disassembly process, as pointed out by Abuzied et al. (2020) This methodology primarily aims to facilitate product demanufacturing, reduce the costs and time associated with disassembly, and promote the recovery of valuable components and materials. Ultimately, DFD seeks to develop products that can be easily disassembled at the end of their useful life, thus encouraging the reuse, remanufacturing and recycling of materials.

The Design for the Disassembly concept aligns closely with the principles of green manufacturing, where the full life cycle of products is considered. By designing products with disassembly capabilities, waste is significantly reduced, and the recovery of valuable resources is maximised, contributing to more efficient waste management and the promotion of a circular economy (Abuzied et al., 2020).

Design for Disassembly guidelines, according to Bogue (2007), cover various aspects, from the selection of materials to the definition of the product architecture, including the appropriate choice of fasteners and joints (Figure 10). It is crucial to consider the final destination of each component, whether recycling, reuse or disposal, as well as the associated costs and benefits resulting from each stage of the disassembly process.

Successful DFD involves the proper use of materials, the efficient design of components and product architecture, as well as the proper selection of fasteners and joints (Bogue, 2007).

These disciplines are detailed in the following (Table 3).

Influences on the disassembly procedure	**Suggestions for enhancing disassembly**
Structure of the products	Design in a modular way Reduce standardisation of components Reduce product variants
Materials	Reduce the variety of materials used Use of recyclable materials Eliminate harmful or toxic materials
Fastening elements, connections, and junctions	Reduce the number of joints and connections Ensure gaskets are visible and accessible; avoid hidden ones Use joints that are easy to disassemble Clearly mark hidden joints Opt for fixings instead of adhesives
Features of components for disassembly	Easy to access Lightweight Sturdy with few fragile components Safe and non-toxic Ideally unpainted
Requirements for disassembly	To design for the automated disassembly Avoid the need for specialised disassembly procedures Implement design for disassembly with simple, standard tools.

Table 3. DFD Guideline (Otto & Wood, 2001).

It is essential to recognise the importance of materials, especially plastics, and the need to consider their compatibility in order to facilitate post-disassembly processes such as separation and recycling (Bogue, 2007)

On the other hand, according to Bogue, (2007) it is also essential to consider the aspect of joints, as a considerable part of the time spent on disassembly is often related to the removal of fasteners and connectors.

3. Methods and Implementation

3.1 Market research

Benchmarking is an initial stage in reengineering efforts in design processes and serves to study existing products on the market. According to Goodman et al., (1996) benchmarking is an essential element of re-engineering. It describes benchmarking as a process that determines industry best practices and provides guidance for improving a product or process. Once the target is identified, companies embark on re-engineering efforts to reconfigure their processes and improve productivity. It notes that benchmarking has gained increasing acceptance as a technique that enhances re-engineering efforts within organisations.

3.1.1 Battery

For the manufacture of the cell module compartment , it is essential to define the batteries to be housed inside (Figure 8). In this case, it is the battery previously defined by the company, a 120 AH LIFEPO4 lithium battery. The cellular module has 6 batteries like this one in its interior.

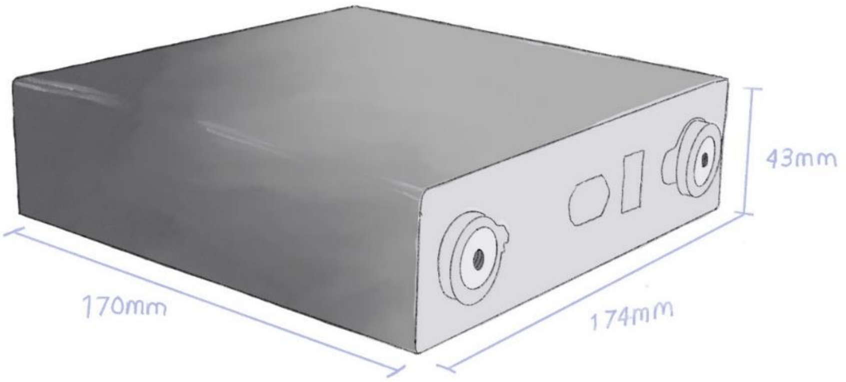


Figure 8. Used battery.

The battery has the following characteristics (Table 4):

Model: LiFePo4 3.2V 120AH	Rated capacity: 120AH
Nominal voltage: 3.2V	Maximum Discharge Current: 360A
Max Charge Voltage: 3.65V	AC Impedance Resistance: ≤0.0mΩ
Charging temperature: -5-60ºC	Discharging Temperature: -30-60ºC
Weight: 2.86+0.05Kg	Dimension (L*W*H): 174*43*170)mm

Table 4: Feature of the batteries.

This battery comes equipped with busbars and bolts to facilitate the connection between the cells and to distribute the current evenly and efficiently. In addition, this configuration helps to ensure a more solid structure within the cell module compartment. (“3.2V Rechargeable Prismatic Cell 120Ah Deep Cycle Lifepo4 120Ah Lithium Ion Solar Battery,” n.d.)

It is important to note that these batteries must be equipped with a heating film between them to maintain the temperature within the optimal operating range. Therefore, adequate space between the cells should be taken into account to accommodate the film heater.

3.1.2 GoFa™ CRB 15000 5

The GoFa CRB 15000 5 robot is used to assemble the cells in the module, offering a combination of efficiency, speed, ease and safety (Figure 9), ("GoFa CRB 15000 Collaborative Robot", n.d.).

This robot allows safe integration with workers, eliminating the need for barriers or fences. It is capable of handling payloads up to 5 kg and is equipped with torque sensors at each of its six joints. Installation and configuration are simple thanks to the graphical applications available from FlexPendant ("GoFa CRB 15000 collaborative robot," n.d.).

Over the TPC speed of 2.2 m/s, more operations can be performed in less time. In addition, it has a reach of up to 1.62 m. In terms of energy efficiency, it saves 20% in electricity consumption, which not only benefits the environment, but also economically.

Figure 9. GoFa CRB 15000 5 (“ABB expands GoFa family of cobots - Metalindustria,” n.d.).

These are the characteristics of the robot (Table 5) to be taken into account for the assembly process of the cellular module (“GoFa CRB 15000 collaborative robot,” n.d.):

Model: GoFa CRB 15000 5	Reach: 950 (wrist); 1050 (flange)
Load: 5 kg	Number of axies: 6
Protection: IP54	Functional safety: Safe Move
TPC maximum speed: 2.2 m/s	TPC maximum acceleration: 36.9 m/s2

Pose repeatibility: 0.02 mm	Robot base dimensions: 165 x 165 mm
Axis arm rotation 1: -180° a 180° Velocity: 125 °/s	Axis arm rotation 2: -180° a 180° Velocity: 125 °/s
Axis arm rotation 3: -225° a 85° Velocity: 140 °/s	Axis wrist rotation 4: -180° a 180° Velocity: 200 °/s
Axis curve 5: -180° a 180° Velocity: 200 °/s	Axis turn 6: 270° a 270° Velocity: 200 °/s

Table 5: Robot's specifications

In terms of applications, the GoFa CRB 15000 5 can perform welding, palletising, assembly, screwing and many other industrial tasks depending on the type of gripper inserted. In this case, the gripper used is the Co-act EGP-C 40-N-N-GoFa, which is used in assembly processes (Figure 10), ("GoFa CRB 15000 collaborative robot," n.d.).

Figure 10.Co-act EGP-C 40-N-N-GoFa.

The most important features of the gripper are as follows (Table 6):

Stroke per jaw: 45 mm	Power supply: 24 V DC
Min. gripping force: 35 N	Max. total current: 2 A
Max. gripping force: 140 N	Max. ambient temperature: 55 °C

Table 6: Gripper's specifications.

3.1.3 Materials

The selection of materials is an important part of the design of any product. As mentioned above, an analysis of materials is not necessary, as the choice of materials is not within the scope of this project, but the materials most commonly used by other companies have been analysed without going into detail. The following is an overview of the materials used by some brands in this design (Table 7).

Vehicle´s company	**The materials utilized for the battery casing**
Tesla	Aluminium
Honda	Steel
Chevrolet Voltio	Steel
Chevrolet Spark	Composite
Bmw i3	Aluminium

Table 7. Material used by companies for the cellular module.

Each material brings distinctive characteristics:

According to de la Figal, J. G., & Ramos, P. A. R. (2007), composites are combinations of materials that offer superior properties to traditional materials, such as greater stiffness and strength, and have the advantage of being lighter. They are used in a wide range of engineering applications and allow products to be designed in various shapes and sizes. They are also recyclable, making them a sustainable option for the future.

On the other hand, steel is strong, durable and versatile, being used in a variety of industries. It also provides the strength needed to protect battery cells against impact and fire hazards. It is eco-friendly, cost-effective and easy to fabricate. Its durability and reasonable cost make it an economical choice in the long term, while its high strength and recyclability make it essential for many applications (Jack, 2013).

Finally, aluminium contributes to weight reduction and offers excellent thermal conductivity, efficiently dissipating the heat generated by the cells and prolonging their lifetime. In addition, its corrosion resistance makes it ideal for demanding environments (Delgado, F. M., García, D. P. S., & Flórez, J. J. O. , 2015).

3.1.4 Assemblies

The investigation of assemblies is fundamental for the redesign, so an investigation of different types of assemblies has been carried out.

Firstly, a hinge type assembly has been found, this type of assembly is characterised by allowing a rotational movement around a fixed axis, similar to the operation of a hinge on a door (Figure 11). This assembly could be implemented in the lid part of the cell module.

Figure 11. Example of hinge type ("Unfinished wooden box with hinges and latch-8x6x3-unfinished wooden box-ready to finish-engravable wooden box-customised laser engraving - Etsy España," n.d.).

Another type of assembly is the sliding assembly (Figure 12). This assembly allows two parts of the device to slide over each other in a linear fashion, as found in the drawers of a cabinet. This could be done for the lid mechanism or for the insertion of the cells into the structure.

Figure 12. Example of sliding type assembly ("jonaxel-combination-storage-white__0703637_pe732231_s5.jpg (600×600)," n.d.).

On the other side, the pin type assembly (without screws) This type of assembly is based on the use of a pin or a stick that acts as a central axis to allow rotational movement between two parts without the need for screws (Figure 13). For the cell module design, a non-screw hinge could be an efficient solution to facilitate assembly/disassembly. By using a pin as the connecting element, the assembly and disassembly process is simplified, allowing the user to easily access the internal components of the device for repairs or upgrades. This modular approach promotes design flexibility and adaptability.

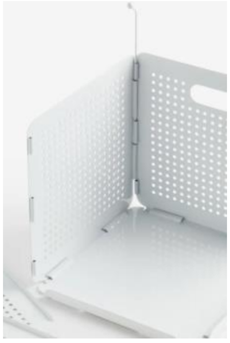


Figure 13. Example of pin type assembly ("Perforated metal box - White - HOME | H&M ES," n.d.).

Finally, another relevant component has been identified: a cover lock made of sheet metal. It is suggested that this alternative could be suitable for the battery module. The main advantage of this component lies in its manufacturing process, which involves machining and punching the sheet metal to shape both the lid and the case (Figure 14). This allows the desired closure to be created in a cost-effective and simple manner.

Figure 14. Lock assembly ("Tall metal box | Gift presentation items," n.d.).

3.2.1 Implementation

The market analysis has drawn on a variety of sources available on the internet. Industry reports, academic articles, manufacturer websites and relevant news stories have been searched to understand the current landscape of battery modules for electric vehicles. This research has been necessary to keep abreast of the most recent developments giving a clearer idea of how our redesign could be oriented in the future.

On the other hand, when approaching the research on assembly, the assembly mechanisms found in everyday objects have been inspiring. They have closely observed how simple elements in everyday life are assembled, such as the mechanism of a drawer or the structure of a piece of furniture. In addition, physical shops have been visited to examine efficient assemblies.

This information has been used to create the moodboard shown below.

3.3 Moodboard

According to Garner and McDonagh-Philp, (2001), moodboards are a crucial tool in the product development process. Their main function is the ability to condense information through the combination of images and words. These visual and textual representations allow to express and communicate the emotions that the product under development intends to convey.

Therefore, a moodboard is created based on the information obtained from the market research (Figure 15).

3.3.1 Implementation

Figure 15. Moodboard of assemblies, materials, examples.

A multi-faceted approach has been used for the moodboard, including an internet search for information on the latest trends in battery modules for electric cars. In addition, most of the information used in the moodboard has been collected from previous market studies. This method has been used to group all relevant information from the previous method in a visual and easy to understand way.

3.4 Function analysis

According to Baxter (1995), it starts with a thorough brainstorming to identify all product functions from the customer's perspective and then organises into a hierarchical tree starting from the main product function down to basic and specific functions. By structuring the functions in a hierarchical tree, logical coherence is established to understand how each function contributes to the main function and how they relate to each other. Validation of the tree is done by asking how and why the functions are performed, ensuring relevance and consistency with the customer's perception. This systematic, user-driven approach provides a detailed understanding of the product, facilitating the identification of areas for improvement or innovation in the design.

Consequently, the execution of the function tree is crucial to the redesign of the cellular module due to its ability to dissect and understand the fundamental functions perceived by users (Figure 16). By following an organised method that involves identifying the main functions and breaking them down into more specific details, a solid framework is created to ensure that the cellular module design meets the needs and expectations of the users (Baxter, 1995).

3.4.1 Implementation

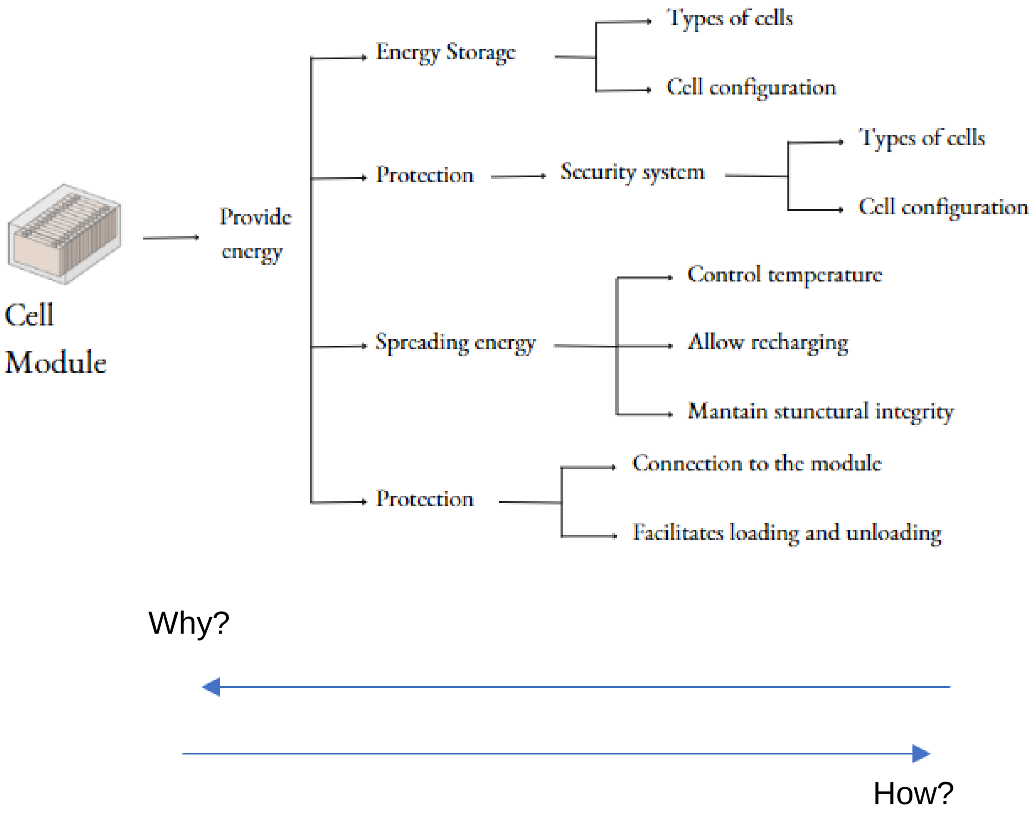


Figure 16. The hierarchical tree of functions of the battery module.

A function tree approach was used to develop the design of the battery module for the electric vehicle. This method allowed the system to be broken down into main functions and sub-functions, which provided a clear understanding of the various parts of the battery module and their contribution to the overall system performance.

Firstly, a search of relevant scientific sources was carried out to understand the fundamental functions that battery modules must fulfil in electric vehicles. This data provided a solid basis for identifying the key functions of the battery module. Subsequently, the function tree was used to hierarchise these functions, dividing them into a main function and sub-functions. This hierarchisation allowed an initial product architecture to be developed, defining the overall structure of the battery module and the role played by each of its parts. By having a clear understanding of the functions and sub-functions, the redesign of the battery module can be approached more effectively.

3.5 Product architecture

Product architecture, at a basic level, begins with the creation of effective component and subsystem designs, where subsets of the product development team complete different tasks. According to Otto and Wood, (2001), during this stage, attempts to answer several questions: what alternative architectures exist? how the subsystems interacts? and how they interconnect? If we look a little more closely at the act of creating a product architecture, the focus is on transforming the function of the product into its form.

The product architecture provides a clear structure of the functions of the cell module, which is essential in the redesign process (Figure 17). By breaking down the main functions and understanding the interaction between the subsystems, the best design alternatives can be identified and ensure that the redesign adequately meets the users' needs and expectations. This approach allows us to distinguish the essential parts from those that do not provide functionality so that they can be eliminated in the redesign (Table 8). It also helps to visualise how the different elements of the cellular module are divided and connected, making it easier to optimise the design to improve efficiency, functionality and customer satisfaction (Otto and Wood, 2001).

3.5.1 Implementation

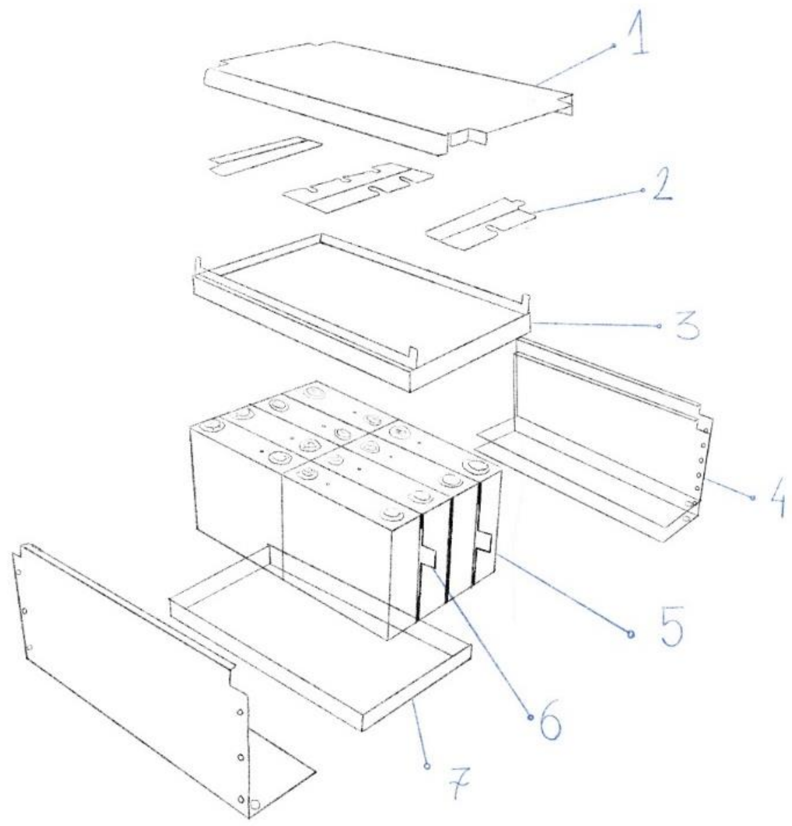


Figure 17.Explosion of module components.

Número	Componentes	Funciones
1.	Top cover	This part has several functions, such as protecting the battery cells and internal components of the module against mechanical damage, protecting against intrusion from external elements such as dust or moisture, and providing a structure for mounting and securing the module in its location within the system.
2.	Bus-bar	The bus bar provides a conductive path for the electrical current between the individual battery cells within the module. Basically, it connects the cells in series or in parallel depending on the design of the battery system.
3.	Cell cap	The cell cap seals and protects the top of each cell in the battery. It helps maintain the electrolyte and protects the internal components of the cell.
4.	All box	This part serves as a protective housing for the battery module, providing mechanical and thermal protection for the cells and other internal components.
5.	Batteries	They store chemical energy and supply electrical energy when needed.
6.	Heater film	These films have the function of heating the battery module when necessary to maintain optimal operating conditions, especially in cold environments where low temperatures can affect battery performance.
7.	Battery separator	This part has the function of separating the cells and keeping them in a fixed position.

Table 8. Parts of the battery module.

In order to improve the design of the battery module, the product architecture method has been carried out. Through research, a deeper analysis of each component of the module and its interaction within the system has been carried out. This method has provided a better understanding of the design, allowing the identification of parts that could be unified and possible improvements.

Firstly, the option of unifying the top cover and the cell cap is considered as a possible improvement to reduce the number of parts, secondly, unifying the two side parts of the module into a single part to reduce the use of screws and parts, and thirdly, unifying the two side parts of the module into a single part to reduce the use of screws and parts. Finally, another possible improvement would be to unify the cell organizer together with the two side parts of the box. These ideas are later reflected in the generation of miniatures. It should be noted that although these 7 main elements have been considered in this method, the redesign is focused on the module and does not take into account the bus bar or the heater films.

3.6 Interviews

According to Otto and Wood (2001), customer needs are essential in the process of redesigning a product, as it allows design teams to adapt and improve the product so that it truly meets the expectations and demands of the market. Interviews, therefore, stand out as an indispensable tool in market research and product development. This qualitative approach offers a unique opportunity for designers to interact directly with potential customers, allowing them to gain a deep and detailed understanding of their needs, wants and experiences in relation to the product in question.

Unlike questionnaires or surveys, which are often based on pre-determined answers, interviews allow for a freer and more flexible exploration of issues, making it easier to capture valuable and contextual information about customers' perceptions and preferences, (Otto & Wood, 2001).

According to Alshenqeeti, 2014) there are three main types of interviews that are commonly used:

- Firstly, structured interviews, these types of interviews are fairly rigid, with a predetermined set of questions that usually require short answers, often of the "yes" or "no" type.

- Secondly, semi-structured interviews, which have some predetermined questions, but also allow for new issues to arise during the conversation. This provides the opportunity to delve deeper into specific topics while maintaining a certain degree of organisation.

- And finally, unstructured interviews, also known as open-ended, are much more flexible. They are not constrained by a predetermined set of questions, allowing the conversation to flow freely and emerging themes to be explored in greater depth.

Furthermore, studies such as Griffin and Hauser, 1993) support the effectiveness of interviews as a primary method for capturing customer needs in the product design process. According to their research, interviewing a relatively small group of people over a limited period of time can provide significant insight into over 90% of customer needs. This highlights the effectiveness and efficiency of interviewing as a valuable way to gather detailed and valuable information about customer needs, enabling design teams to make more informed decisions and develop products that really satisfy the expectations of the market.

3.6.1 Implementation

In order to carry out the interviews, semi-structured questions were used, as they are the ones that best adapt to the type of information we want to collect, thus allowing the interviewee to answer freely, providing us with richer answers. This section of the interviews is used to collect information, and later on there will be another section of interviews focused on the selection of concepts.

These are the interviews conducted:

Person 1:

Name: Eire Climent Gimenez

Studies: Production engineering

Objective of the interview: To obtain relevant information about the robot and the factors to be considered for the design of the cellular module.

Interview Summary: During the interview with Eire, information about the robot was obtained and the constraints that need to be taken into account in the redesign of the Cell Module were understood.

Key Considerations:

- The robot has a base that can rotate 360 degrees and has a maximum reach of 950 mm.
- The maximum opening of the gripper is 2.5 mm, while the minimum opening is 1.3 mm, and it has only one single gripper.
- Its maximum load capacity is 5 kg.
- It has a speed of 2 m/s and a repeatability of 0.02 mm, which guarantees precision in delicate operations.

Conclusions : The information provided by Eire was instrumental in identifying the limitations of the robot that must be considered before designing the cell module. Without taking these considerations into account, the robot would not be able to carry out the assembly efficiently.

Person 2:

Name: Cristina Escobar Hidalgo

Studies: Robotic engineering

Aim of the interview: To obtain key information to ensure efficiency in the design of the cell module, especially with regard to the robot gripper.

Interview Summary: The interview with Cristina provided essential information on key considerations for the design of the cell module, with a focus on assembly efficiency and proper adaptation to the robot gripper system.

Key Considerations:

1- Simplicity in Design:

- It is essential to ensure that the cell module design does not consist of more than 4 parts.
- The total assembly time of the cell module should not exceed 3 minutes to ensure efficiency in the process.

2- Adaptation to the Robot Gripper:

- It is crucial to take into account the thickness of the robot gripper, which is 15 mm, when designing the cell module grips. This helps to avoid possible collisions with walls or parts during the assembly process.

Conclusion: The information provided by Cristina is essential to minimise the amount of testing required once the first prototype of the cell module is available. This optimises the design and development process by ensuring proper adaptation to the robot gripper system and efficient assembly.

3.7 List of requirements

According to Otto and Wood (2001), in the product design process, the Basic Specification Sheet Method is used to compile the essential product requirements. This method recognises that customer needs are fundamental to the design but does not provide a complete view of the task. It is crucial to complement customer needs with engineering requirements, also considering standards, ethics and manufacturing aspects that may not be directly perceived by the customer.

One strategy to complement customer needs is the generation of specification lists, which focuses on identifying relevant specifications that may be latent in customer needs, such as safety aspects, regulations and environmental factors. Designating each specification as a required demand or a desirable desire communicates its relative importance (Otto and Wood, 2001).

3.7.1 Implementation

Statement	**Units**	**Demand**	**Wish**	**References/comments**
Geometry				
Cell module casing dimensions	mm	400x200x156	354x176x135	Company
Maximum weight cell module casing with the batteries	kg	<25	<20	Company
Battery cell dimensions	mm	174x170x43	-	Company
Maximum weight cell	kg	2.85	-	Company
Numbers of cells	cells	6	-	Company
Structure resistant to mechanical and external damage.	Yes/No	-	-	Assumption
DFMA				

Number of components for the cell module casing	pieces	<6	<4	Interviews
Maximum time of assembly	min	<5	<3	Interviews
Multifunctional parts	Yes/No	-	-	System guidelines/ Delete non-functional parts
Maximum range of the robot cell	º	360	-	Interviews
Maximum weight supported by the robot cell	Kg	5	-	Interviews
Maximum opening of the robot cell	cm	2,5	-	Interviews
Minimum opening of the robot cell	cm	1,3	-	Interviews
Standardise to reduce the variety	Yes/No	-	-	System guidelines
Insert new parts into assembly from above	Yes/No	-	-	Insertion guidelines
chamfers to easy insertion	º	30<x<45	-	Insertion guidelines/ ISO 7455
Reduce fasteners	Fasteners	<8	<4	Joining guidelines
Access points should be at the top	%	<60	<80	Product structure guidelines
DFE				

Modular parts, with separation of function	Yes/No	-	-	Product structure guidelines/ separate parts which are easy to replace
Avoid metal details on plastic	Yes/No	-	-	Product structure guidelines
Eliminate adhesives	Yes/No	-	-	Fastening guidelines
Well ventilation	Yes/No			Assumption
DFD				
Use joints that are easy to disassemble (at the top)	Yes/No	-	-	Fasteners, joints and connections guidelines
Eliminate the need for specialised disassembly procedures	Yes /No	-	-	Disassembly conditions guidelines
Time to remove the fasteners	Seg	<120	<60	Assumption
Tools needed to remove fasteners	Tool	<3	<1	Assumption
Maximum time of disassembly	min	<5	<2	Interviews

Table 9. List of requirements.

To establish the project requirements, a series of interviews were conducted, in addition to the information previously collected on the DFMA, the DFE and the DFD. Based on this information, a list of requirements was drawn up, covering the customer's wishes and requirements as well as the technical specifications necessary for the realisation of the project (Table 9).

This list of requirements not only serves as a guide for the design and development of the battery module but is also decisive in the selection process of the final concepts. Subsequently, the list of requirements is used to evaluate each concept in terms of its ability to meet the set criteria. This ensures that the selected concepts are not only innovative and technically feasible but also meet the requirements specified in the table.

3.8 Generating Concepts

3.8.1 Brainstorming

To start the generating concept’s part, according to Otto and Wood (2001), the first thing to do is to implement traditional brainstorming. This intuitive and collaborative method focuses on the verbal communication of ideas over a given period of time, seeking to generate a wide variety of holistic solutions. The aim is to explore different approaches and perspectives, in the hope of discovering innovative and creative solutions.

However, it should be noted that while brainstorming can be powerful in generating concepts, it can also present challenges such as the possibility that the "right ideas" may not come at the right time or that certain team members dominate the discussion, so that thumbnails and sketches are still created to further work on idea generation (Otto & Wood, 2001).

3.8.2 Sketching

According to Hua, (2019), the design relies on the art of sketching, a fundamental skill that designers develop and refine throughout their training to enrich their creative work. From the earliest design texts to the most contemporary research, the ability to sketch ideas is widely recognised as vitally important for designers, and some even consider it the primary method in the design process. Sketching not only stimulates creative thinking but also helps to identify the emerging characteristics and properties of a design concept, thus facilitating changes of direction during the process and the dialogue between initial vision and practical implementation.

3.8.3 Implementation

To start the brainstorming process, it was decided to use post-its to write down all the ideas that emerged during the session (Figure 18). This made it possible to quickly capture thoughts and concepts on sticky notes that were then shared in a common space.

Figure 18.Brainstorming process with post-it notes (1).

Once the generation of ideas was complete, faces the challenge of organising them in a coherent and relevant way. It was decided to group them into three main categories: features to solve problems, ideas for components and assemblies (Figure 19). This classification allowed us to better understand the overall structure of the project, thus laying a solid foundation for the next phase: concept selection.

Figure 19.Brainstorming process with post-it notes (2).

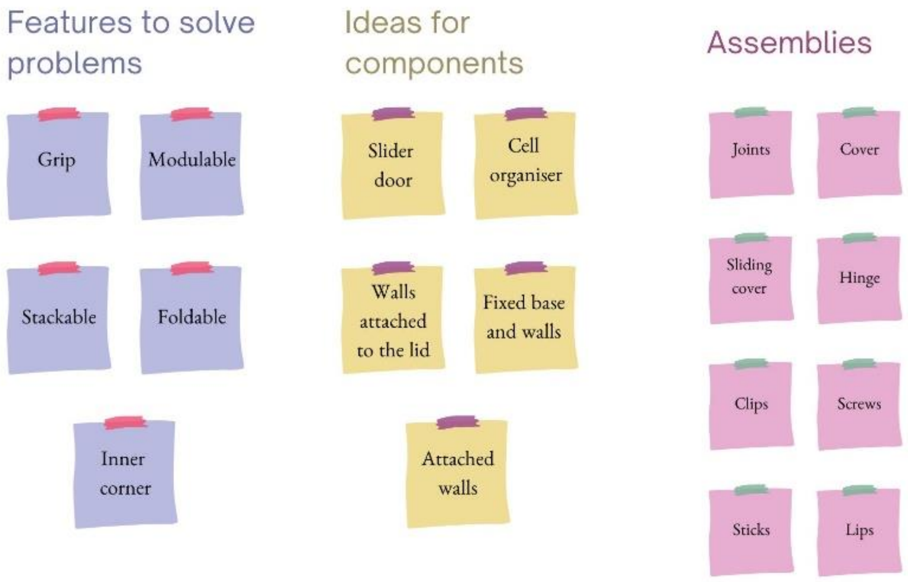


Figure 20. Digitalised Post-its brainstorming method.

Organising the ideas into these categories was central to the sketching process (Figure 20). This provides a clear structure to work from and identifies the key points to focus on when creating the thumbnails.

Once the ideas have been clarified, thumbnails are produced to generate clearer and more detailed visual representations (Figure 21). The choice is made to produce as many thumbnails as possible, in order to cover a wide range of ideas, as they are then submitted to a list of requirements. In the end, a total of 20 miniatures were compiled.

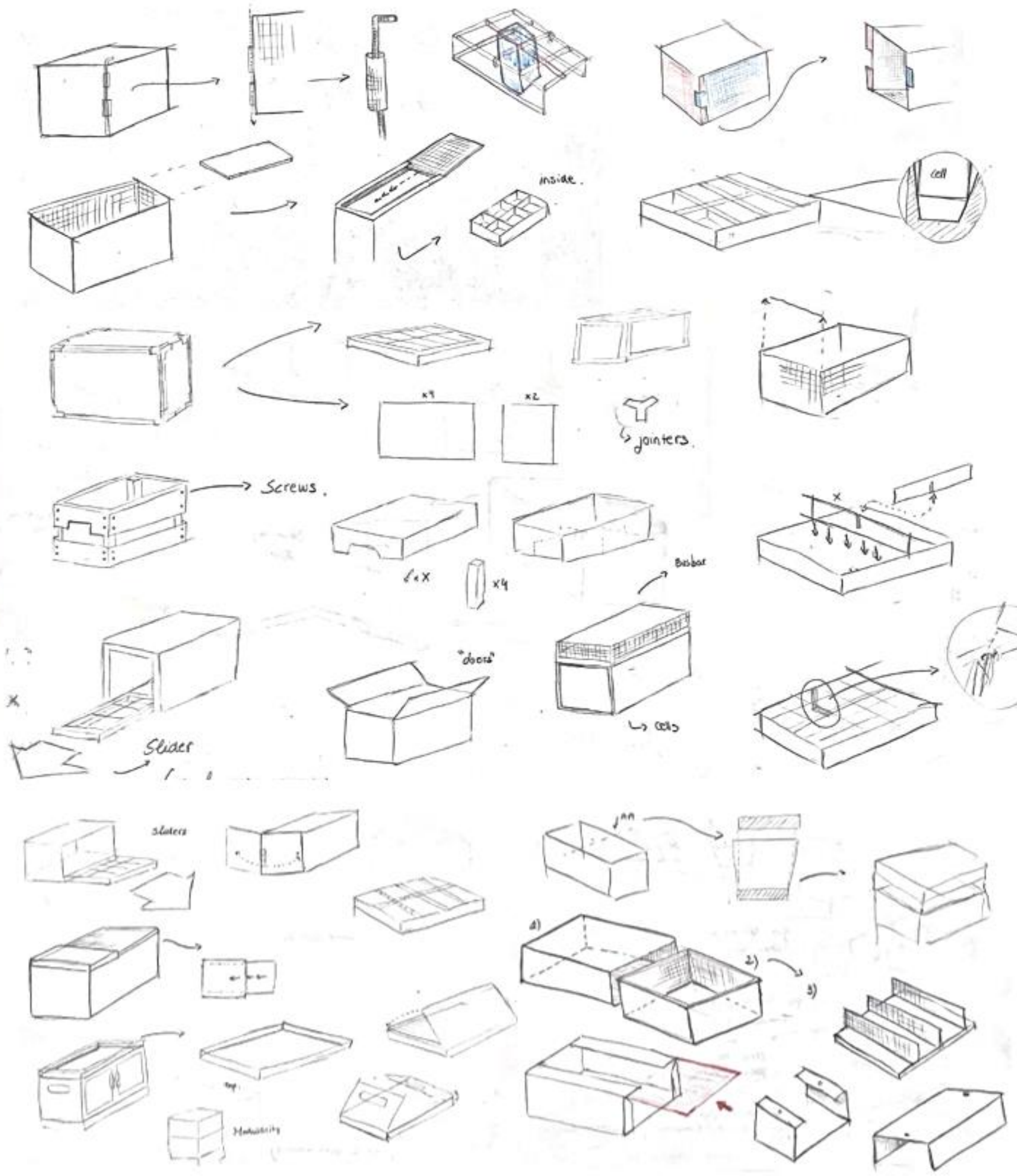
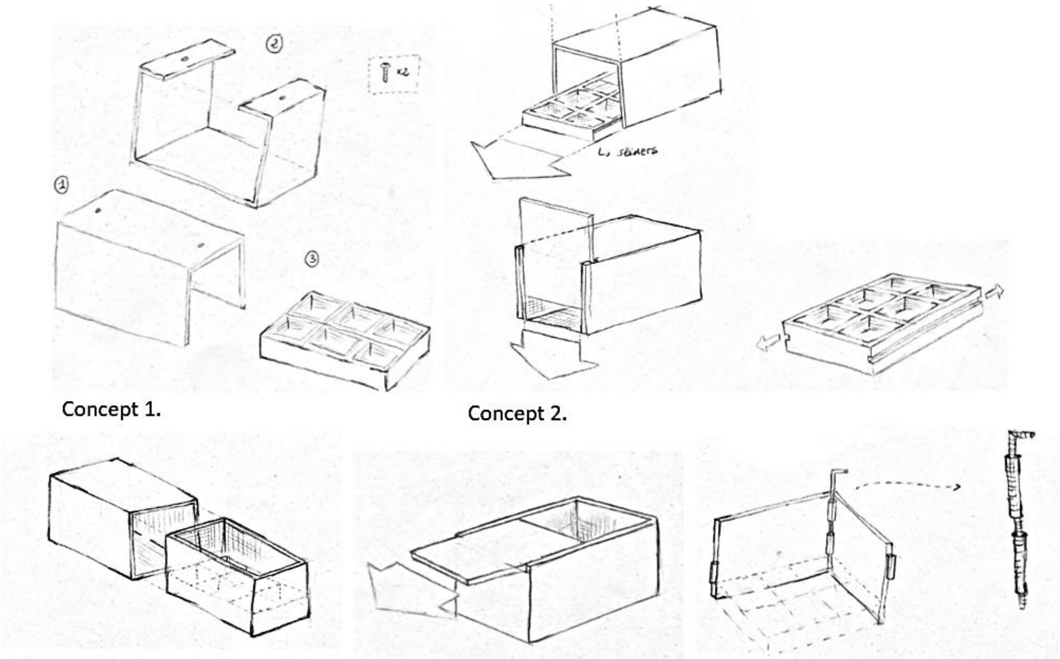


Figure 21.Thumbnails.

After the generation of the thumbnails, 5 final sketches have been made by unifying ideas taken from the thumbnails (Figure 22).


Concept 1.

Concept 2.

Concept 3.

Concept 4.

Concept 5.

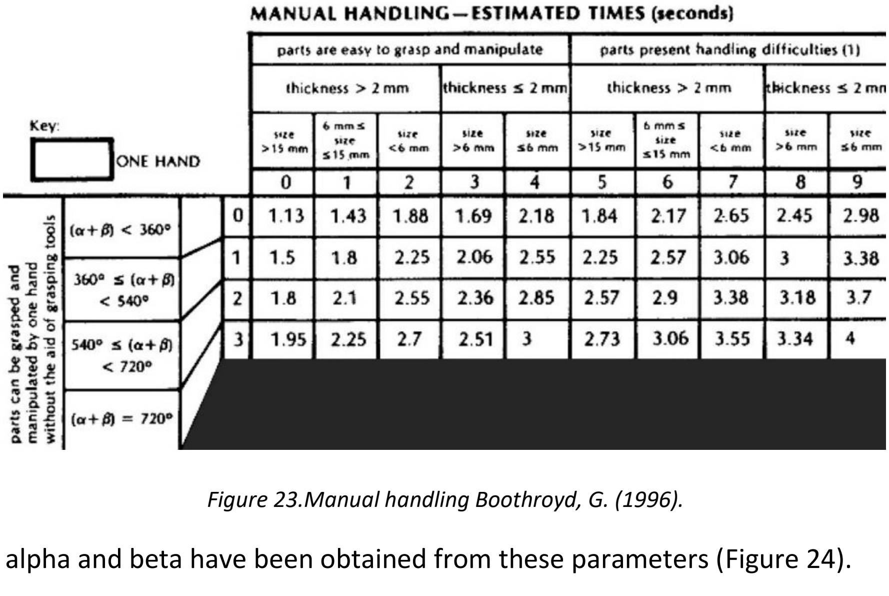
Figure 22. First concepts.

3.9 Concept Selection

3.9.1 Check list of requirements

The Checklist of requirements acts as an instrument to determine whether these elements comply with a set of requirements. In this project, it will allow the selection of the three final concepts to be further analysed.

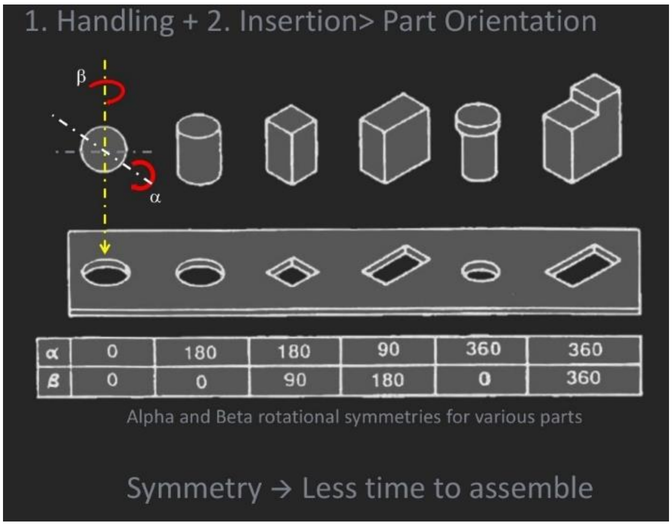
To evaluate the assembly time of each concept, the manual handling tool has been used to evaluate the maximum assembly time parameter found in the list of requirements (Figure 23).


MANUAL HANDLING—ESTIMATED TIMES (seconds)

			parts are easy to grasp and manipulate					parts present handling difficulties (1)				
			thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
Key: ONE HAND			size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm	size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm
			0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand without the aid of grasping tools	(α+β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
	360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
	540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
	(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

Figure 23.Manual handling Boothroyd, G. (1996).

The values of alpha and beta have been obtained from these parameters (Figure 24).



1. Handling + 2. Insertion> Part Orientation

α	0	180	180	90	360	360
β	0	0	90	180	0	360

Alpha and Beta rotational symmetries for various parts

Symmetry → Less time to assemble

Figure 24.Part orientation Boothroyd, G. (1996).

3.8.2.1 Implementation

After the generation of concepts, the concept selection part begins, in which the five concepts previously seen in figure 22 have to be evaluated and for this purpose a check list of requirements has been made with the list of requirements mentioned above (Table 10).

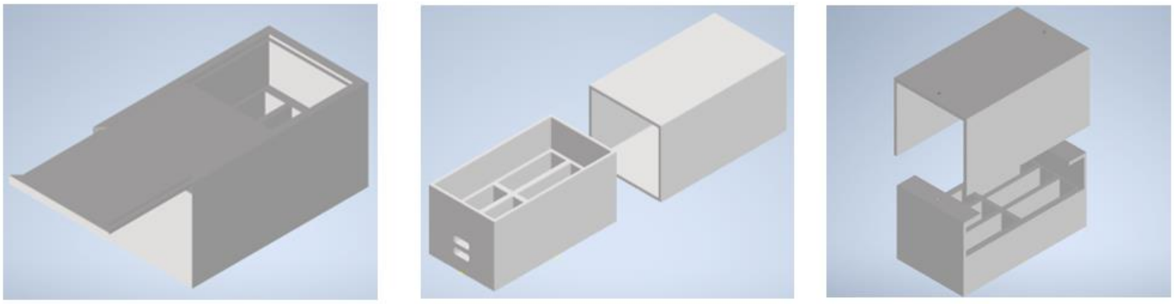
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Number of components for the cell module casing	3	3	2	3	13
Standardise to reduce the variety	Yes	Yes	Yes	Yes	No
Fasteners	2	0	0	0	0
Access points should be at the top	Yes	Yes	No	Yes	Yes
Modular parts, with separation of function	Yes	Yes	Yes	Yes	Yes
Use joints that are easy to disassemble (at the top)	Yes	No	No	Yes	Yes
Specialised disassembly procedures	No	No	No	No	Yes

Time to remove the fasteners	30	60	60	0	360
Tools needed to remove fasteners	1	0	0	0	1

Table 10. Check list of requirements (1).

Initially, concept 5 was discarded due to its large number of components and its inability to meet several requirements, such as the need for specialised disassembly procedures or the considerable time needed to remove the fasteners. After discarding one concept, there remains another to be discarded. As shown in table 7, the first three requirements are satisfactorily met by the remaining four concepts, although concept 3 does not meet the requirement that the access points must be at the top, nor the use of assemblies that are easy to disassemble (at the top), so the selected concepts are concept 1, concept 3 and concept 4.

For a better understanding of the three selected concepts, three simple CAD models have been made in order to better analyse their type of assembly (Figure 25).



Concept 4. **Concept 3.** **Concept 1.**

Figure 25.First concepts in CAD.

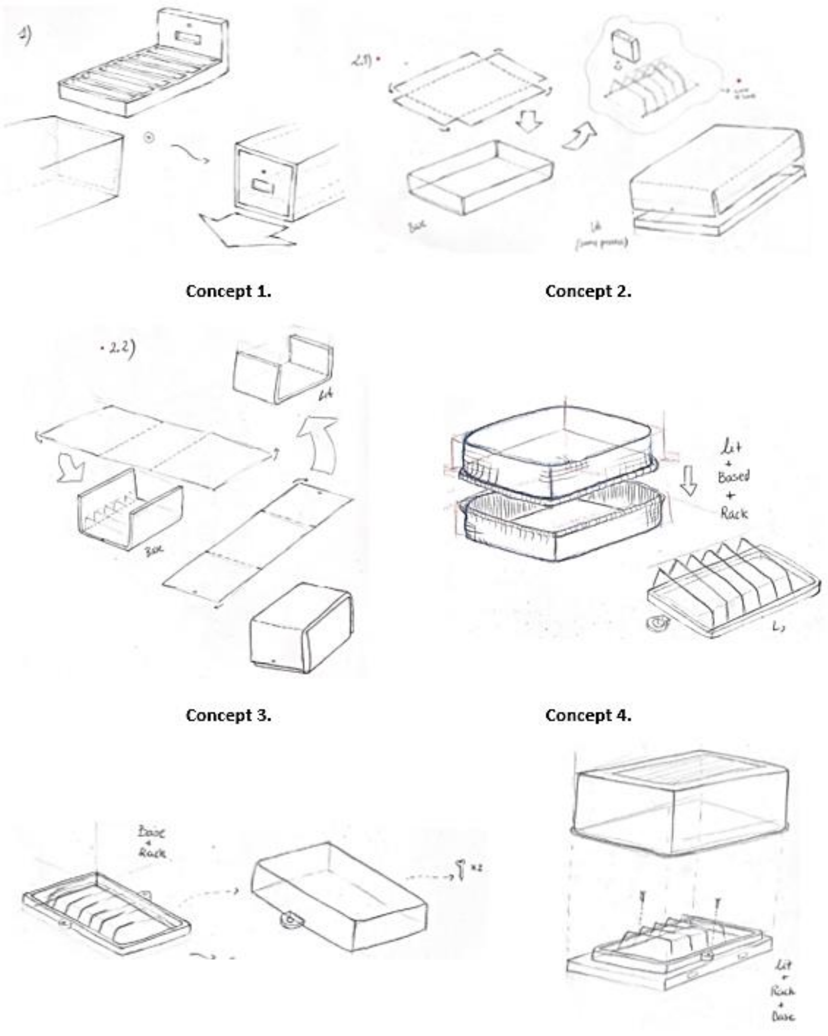
After the choice of the three final concepts, it has been determined to backtrack in the design process due to the perception that they do not adequately satisfy the criteria established by the theory analysed. Therefore, the concept generation phase is resumed.

Therefore, the concept generation phase is resumed due to the large amount of material used in the previous designs. The distribution of the cells has been changed as it causes the robot to make numerous movements, complicating the manufacturing process. In addition, the shape of the boxes and walls made accessibility difficult for the robot, so this has been taken more into account in this new generation of concepts. Although the assemblies were efficient, they were not feasible.

In the second generation of concepts, some ideas from concept 1 have been followed, keeping the design of the walls attached to the base and lid and the metal folding. Concept 3 retained the box design, but the amount of material was reduced and the cell layout was changed. Although the assembly idea of concept 4 was a good idea, it was discarded because it required a large amount of material to be used, which was to be avoided.

Eventually, more ideas were added, such as new assemblies, the position of screws, the arrangement of parts for efficient assembly, and parts designed to reduce material. Grips for the robot and the space required for its operation were also considered.

Second generation of concepts (Figure 26).



Concept 1.

Concept 2.

Concept 3.

Concept 4.

Concept 5.

Concept 6.

Figure 26. New concepts.

After this second generation of sketches, a new check list of requirements has been made (Table 11).

	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
DFMA						
Numbers of components for the cell module casing	2	3	3	3	3	3

Maximum time of assembly	1.13	1.13	1.13	1.13	1.13	1.13
Multifunctional parts						
Standardise to reduce variety	Yes	Yes	Yes	Yes	Yes	Yes
Fasteners	1	4	2	4	2	4
Access points should be at the top	Yes	Yes	Yes	Yes	Yes	Yes
DFE						
Modular parts, with separation of function	Yes	Yes	Yes	Yes	Yes	Yes
DFD						
Use joints that are easy to disassemble (at the top)	No	No	No	No	Yes	No
Specialised disassembly procedures	No	No	No	No	No	No
Time to remove the fasteners	30	60	60	0	60	120
Tools needed to remove fasteners	1	1	1	0	1	1

Table 11. Check list of requirements (2).

To carry out the assembly time study, the manual handling tool has been used, as illustrated in figures 23 and 24. This tool provides an overview of the estimated assembly time for the various conceptual designs. The corresponding table is used for a clearer and more detailed identification of the collected data (Table 12).

Concept	C.1	C.2	C.3	C.4	C.5	C.6
Easy/ Difficult manipulating	Easy	Easy	Easy	Easy	Easy	Easy

Thickness (mm)	>2	>2	>2	>2	>2	>2
Size (mm)	>15	>15	>15	>15	>15	>15
α + β	90+180=270 <360	180+90=270 <360	180+90=270 <360	180+90=270 <360	180+90=270 <360	180+90=270 <360
Total (seconds)	1.13	1.13	1.13	1.13	1.13	1.13

Table 12. Time estimation table.

It is observed that the same maximum assembly time is required in all cases. Therefore, it is concluded that the designs are effective in terms of the time required for assembly in all six cases. However, it is important to note that the application of fasteners has not been taken into account in these times; these elements have been addressed in another section of the table, specifically in the requirements checklist (Table 11).

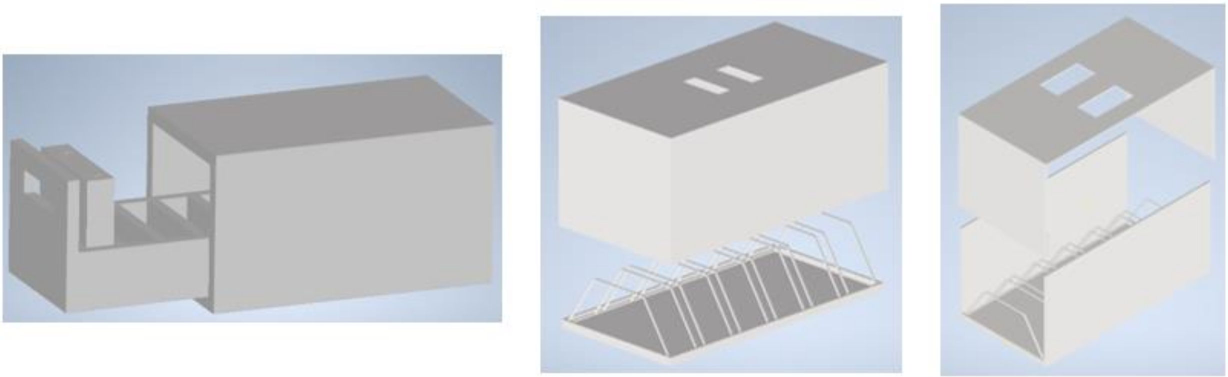
During the selection process in the check of requirements, concept 2 was discarded due to several factors identified as determining its exclusion. Among them, a greater use of fasteners and the complexity associated with their disassembly, given that no element is provided for the robot to grip the lid. In addition, it is considered that the time required to remove the fasteners could be considerable.

Concept 4 was discarded due to the number of fasteners required compared to other options, as well as the lack of adequate compatibility with the robot for disassembly.

Concept 6 was later discarded due to its somewhat complex design, the abundance of fasteners and the difficulty in removing them, especially as they are hidden under the cover.

Therefore, the three selected concepts are Concept 1, Concept 3 and Concept 5.

For a better understanding of the three selected concepts, three simple CAD models have been made to better analyse their type of assembly (Figure 27).



Concept 1 Concept 5 Concept 3

Figure 27. Final concepts in CAD.

3.8.3 Interview

At this stage of the process, interviews were conducted in order to obtain information on the three selected concepts, realised in CAD in a simplified form. It also provides guidance on the selection process and the information needed to move forward.

3.8.3.1 Implementation

Company:

Name: Artinox

What company is about Metal carpentry

Aim of the interview: To explore the industrial methods and processes used by Artinox in the manufacture of metal products, focusing on the sheet metal cutting, bending and assembly processes proposed for this project.

Interview Summary: During the interview with Artinox, three concepts proposed for the research on industrial processes in metal were presented. The proposed processes and associated techniques are summarised below:

Key Considerations: During the interview, several general processes applicable to the three concepts proposed for the research project were identified:

1- Sheet metal cutting:

- Sheet metal cutting or shearing is used for the creation of metal parts. All concepts require this process.

- Holes can be made by punching or CNC cutting. Concepts 5 and 3 with holes would be cut with this process.

2- Sheet metal bending:

- Sheet metal bending is done by press brake, with automated and manual options. It would be performed on concept 3, 1 and 5.

- Bending is used to reinforce the structure of metal parts.

- The plastic deformation of the material exceeds the elastic limit of the material and it is permanently deformed.

3- Welding:

- In some cases, welding is used to join metal parts, especially for structures such as shelving. In concept 1 and 5.

4- Finishing:

- A finishing process is carried out which may include edge rounding using specific tools to avoid sharp edges. This is done with a burr removal tool.

Conclusion: The interview provided a deeper understanding of industrial processes in the metal sector, highlighting the importance of precise cutting, proper bending and joining techniques such as welding in the manufacture of metal products. This knowledge gained serves to improve the project and develop a more complete understanding of industrial processes in metal.

3.8.4 Spider diagram

The spider diagram is used to evaluate concepts, especially in situations where multiple choices need to be made. These diagrams allow visual relationships to be established between concepts, making them ideal for making informed decisions. In this case, it is used to select the final concept by considering five important characteristics (Beynon-Davies, 2018).

The purpose of this method is to create a visual representation of which concept meets the five criteria: assembly, optimal production, material waste, assembly process stability, number of parts and robot accessibility. Each concept is evaluated by assigning a score from 1 to 5 to each criterion. The concept that receives the highest score or the largest area in the diagram is the winning concept (Beynon-Davies, 2018).

3.8.4.1 Implementation

The spider diagram was carried out to select the final concept (Figure 28). In the selection process, the Spider diagram was chosen because of its ability to clearly and concisely represent the most relevant characteristics identified from the interviews and the checklist. This tool made it possible to comprehensively visualise which concept best matched the required knowledge. The choice of this method was intended to provide the reader with a clear and quick understanding of how each concept aligned with the established criteria, thus facilitating decision-making.

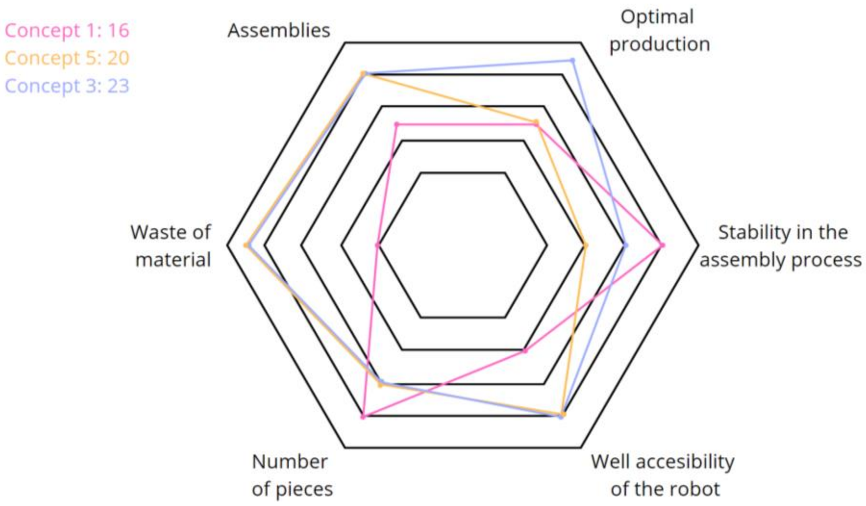


Figure 28. Spider diagram.

Concept one scored 16 points, concept three scored 23 points and concept five scored 20 points, so the winning concept is concept three as it is the concept that fulfils these criteria the most.

However, when analysing the diagram, it can be seen that the scores for concepts three and five are very similar. The decisive difference and the main reason for choosing concept three is that it does not require a welding process on any part of the enclosure shell. In addition, concept three provides greater stability during assembly, as it has two side walls that provide additional support. This ensures that the assembled cell inside the enclosure has more stability thanks to these side walls.

Thanks to the check list, the interviews and the spider diagram, it has been possible to arrive at this final concept. From concept 3, some changes have been added to be considered in the final result. Material has been added to the base and lid extremes for better stability in the assembly process. This is the final concept (Figure 29).

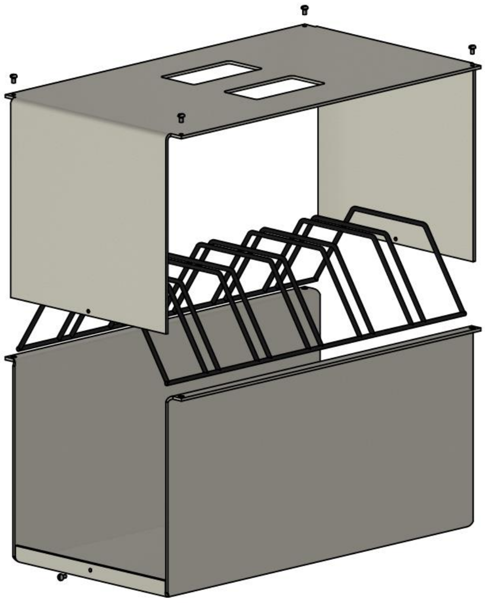


Figure 29. Explosion of the final concept.

4 Analysis and Results

For the verification of an effective and efficient design and assembly, 3Dsmax renderings are made by adding the robot gripper and simulating the assembly process, in this way it has been analysed that the design fulfils its main function.

The robot gripper has been programmed to apply the exact amount of force required during the assembly process. When placing the batteries, the gripper grips the batteries with just enough force to lift and place them in the box without damaging or deforming them. The force applied is sufficient to maintain a firm but controlled grip, avoiding the risk of slippage due to lack of friction or deformation due to excessive pressure. Similarly, when placing the lid, the gripper grips the lid of the box with a calibrated force to avoid any damage. The programming of the robot ensures that the force is adequate to handle the lid without causing deformation and to ensure its correct positioning on the box. (Figures 30 and 31).

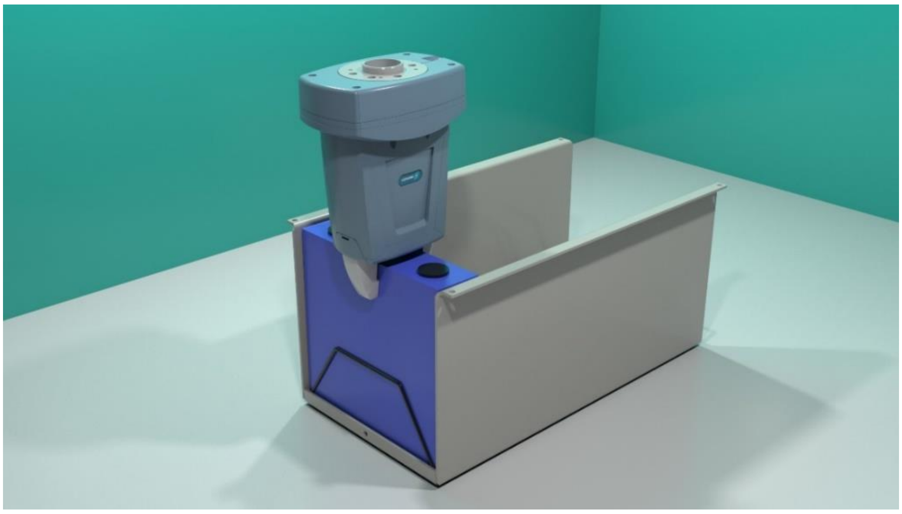


Figure 30. Assembly process simulation (1).

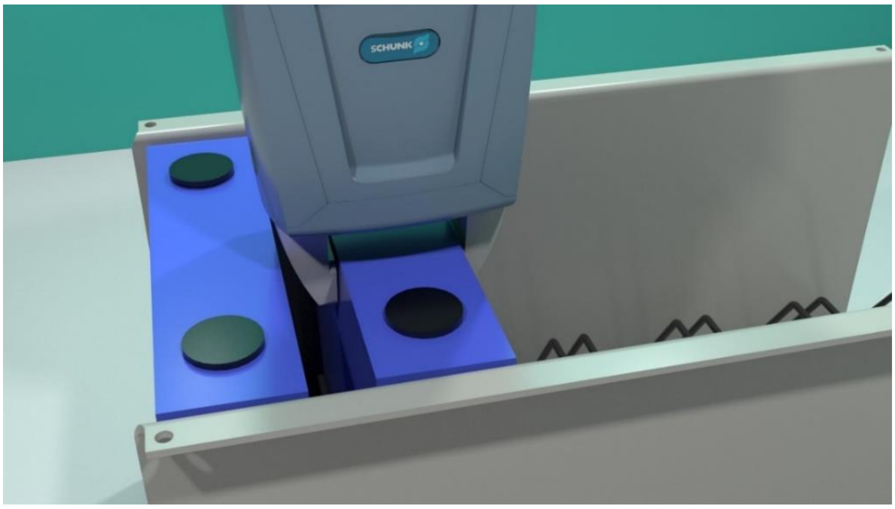


Figure 31. Assembly process simulation (2).

This is the final result rendered in 3Ds max, you can see the module in different ways, closed with its lid, open without lid and assembled with its cells organised (Figures 32, 33 and 34).

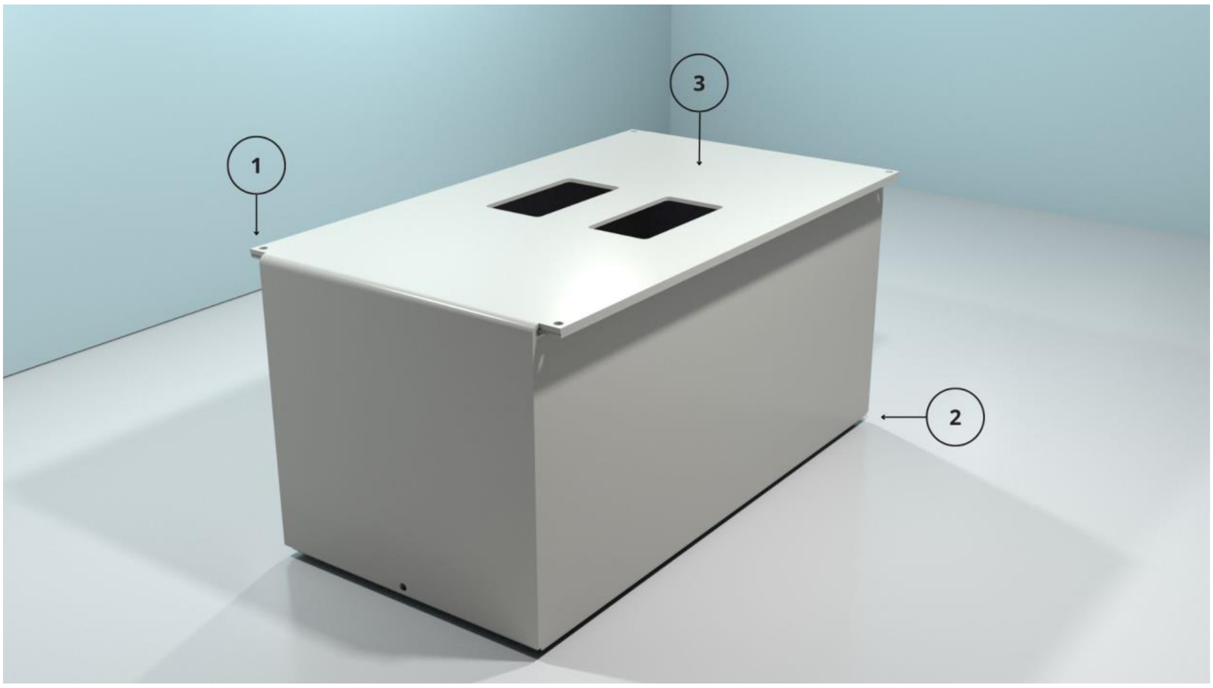


Figure 32. Rendering of the closed cell module.

1. Recycling and reuse of parts have been taken into account by avoiding welding or the use of adhesives to join the enclosure, which facilitates disassembly and recovery of materials at the end of the product's useful life.
2. The manufacture of the enclosure by metal folding minimises the environmental impact in terms of energy and recyclability, as this process does not produce toxic gases or consume an excessive amount of energy.
3. Holes are drilled in the lid of the battery module so that the robot can better grip it during assembly. This improves accuracy, increases safety by preventing slippage, and makes the process more efficient.

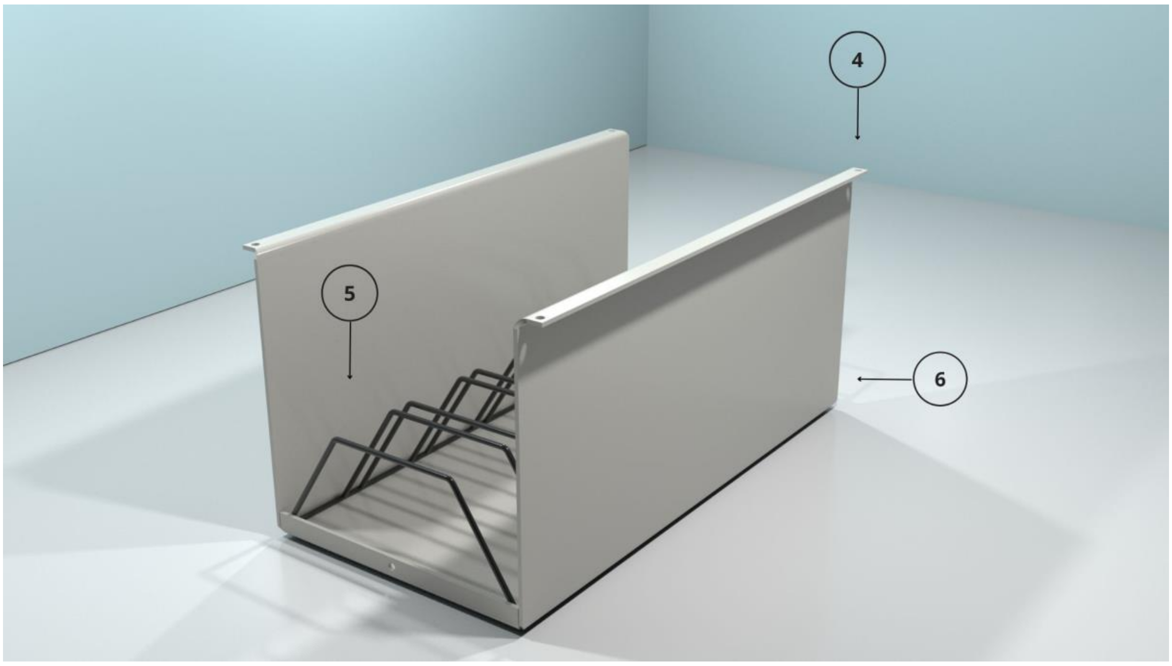


Figure 33. Rendering of the open cell module.

4. The base has been provided with a fold to help the stability of the assembly between the base and the lid. In addition, this fold has been made towards the outside so as not to hinder the assembly of the batteries.
5. The rack has been designed in a multifunctional way, not only to organise and hold the batteries, but also to leave space for the gripper to assemble efficiently.

6. The adoption of a base with two walls and a lid with the remaining two walls simplifies the manufacturing process by reducing the number of parts required, facilitating the moulding of the parts, as the main structure is produced only by bending the metal, which contributes to the efficiency of the manufacturing process. In addition, the arrangement of the base walls has been taken into account to facilitate the assembly of the robot and provide stability to the batteries during the assembly process, designing the module so that the assembly is carried out from the top to facilitate the assembly.

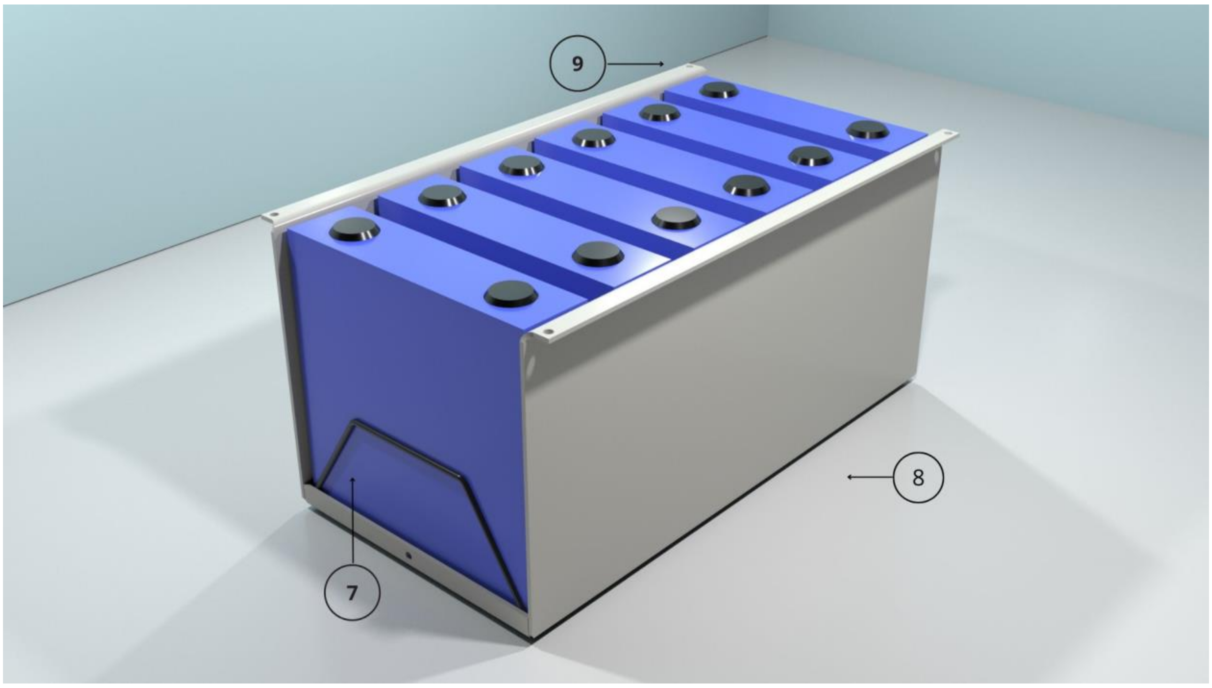


Figure 34. Rendering of the module with batteries inside.

7. During the assembly process, screw fastening for the battery separator has been eliminated, opting instead for the application of pressure. However, the upper and lower parts have to be screwed on afterwards.
8. A cell organisation grid has been implemented as an integral part of the design with the aim of reducing the material required for module manufacture. By using this grid, efficient metal distribution is achieved, minimising waste and maximising the strength-to-weight ratio of the component.
9. The reduction in the number of parts has been achieved by integrating multiple functions into individual parts. For example, the previous design had separate components such as the cell lid, top cover, housing sidewalls and battery separator, whereas the final design simplifies this assembly by including only the top and bottom of the housing and the battery separator. This strategy not only reduces the complexity of the assembly but also increases the functionality of the parts.

In summary, the integration of DFMA, DFE and DFD principles into the design of the cell module demonstrates an approach that prioritises efficiency, functionality and sustainability throughout the product life cycle.

5 Discussion

The initial question posed in the research problem focuses on the factors that can hinder the efficient handling and assembly of components by robots, as well as the actions that can be taken to improve this situation. Several critical issues were identified including geometric complexity of components, gripper optimisation, reduction in the number of parts, limited accessibility for robots and resource efficiency. These issues were analysed in detail to understand their importance in the automated assembly process, especially in the redesign of the battery module. The implementation of Design for Assembly (DFA) principles was highlighted as a key challenge in optimising the automated assembly process, as it ensures efficiency and ease of assembly.

In terms of the specific objectives of the study, the main goal was set to improve the ease of assembly of the battery module by optimising its housing design for use with robots. This main objective has been achieved thanks to the whole design process that goes from all the theory learned to the implementation of the methods and is reflected in the final product.

A highlight of the product design has been the inclusion of 7 components in the architecture, however, two key parts were omitted: the busbar and the heater film, both of which are technical in nature. This omission resulted in a deeper initial focus on the external design of the module as the process progressed. Priority was given to Design for Manufacture and Assembly (DFMA), as proposed by Assar at the start of the project.

Although the importance of this aspect was recognised, the focus was mainly on DFMA principles, to some extent neglecting Design for Environment (DFE) considerations. This is because, firstly, in exploring the literature, it was noted that many aspects of DFMA and DFE were interconnected, leading to a focus on the former. This observation suggested that by focusing on DFMA, some aspects of DFE could also be addressed indirectly, this is reflected in the redesign of the rack as the use of material has been significantly reduced. In addition, it was noted that by focusing more on DFE, other considerations were affected. For example, reducing material by drilling holes in the box increased the cost of production. Making holes required additional machinery and processes, which increased manufacturing time and costs. In addition, the edges of the holes need special finishing to ensure their quality and durability, which also increases costs. Thus, although material usage is reduced, the production process becomes more expensive and complex. This has been taken into account at the end of the design process, when research into production processes has begun.

It was a difficult task of having to discard concepts that, although they fulfilled some requirements, were not the most suitable in terms of the number of conditions obtained from the list of requirements. This decision-making process proved to be challenging, as there was no "perfect" concept that met all the criteria. However, a number of analysis tools were used to assist in the selection of the final concept. While this process has been difficult, it has provided a solid basis for arriving at a final result that, while not perfect, met the maximum fundamental requirements set out in the specification table.

In summary, while the main objective of improving the ease of assembly of the battery module has been achieved, the need for further exploration in the area of sustainability is recognised for future research. The selection of the final concept also presented challenges due to the need to balance multiple criteria and requirements, which highlighted the inherent complexity in making design decisions.

5.1 Method

During the development of the project, methods have been implemented that have proven to be valuable for the progress of the project, although some areas for improvement and method decisions that could have been more effective have also been identified.

The design process begins with market research, a method that has been fundamental for obtaining relevant information on both the battery and the robot, as well as providing information on the materials that are commonly used in existing battery modules and a small study of possible assemblies. It should be noted that obtaining specific data on battery modules has been limited as there is very little information on this.

Functional analysis has been crucial for the redesign of the product by identifying the main and secondary functions of the battery module, although, at the beginning of this method, the focus was only on the functionality of the external design of the module, without considering the module as a whole in a technical way. This approach proved to be an initial drawback that was corrected.

In addition, the study of the product architecture has provided an understanding of both the internal and external structure of the battery modules, which has been essential for the design process. Interviews with both students and professionals have been a valuable source of information, although difficulties have been encountered in contacting some interviewees. Initially it was hoped to conduct a larger number of interviews.

The Requirements List has been fundamental in our project, as it has allowed us to compile all the key requirements for the design of the module serving as our main guide, however, we have faced challenges such as frequent changes in the list throughout the process, due to the need to summarise a large amount of information from DFMA, DFE and DFD in a list that could not be too long, becoming the biggest challenge of the project.

Within the generating concepts, brainstorming has been useful to generate ideas and establish guidelines for the sketching process. Although sketching has facilitated the identification of solid concepts for analysis and selection, discarding less viable ideas has been a challenge as what were initially identified as the best ideas were later discarded as they did not meet as many requirements as expected.

The checklist has allowed us to assess which concept meets the most requirements, although difficulties have been encountered in eliminating requirements that were not as applicable as initially expected. Finally, the spider diagram has been useful in the selection process between the three final concepts by evaluating the key and most important concepts to consider in order to arrive at the final result.

During the iterative design process, some alternative methods that were not considered suitable for the project have been eliminated. 3D printing has been discarded because it has been considered irrelevant for a metal designed product and is not expected to add value to the project. On the other hand, the Pugh matrix has been omitted in favour of other more appropriate techniques in the concept evaluation.

In terms of the initial approach, the project lacked adequate planning in terms of method selection. Instead of considering what results could be achieved and how they could contribute to the redesign, methods were used without clear justification; it would, therefore, have been prudent to think from the outset about which methods might be most appropriate to the needs of the project. This would have allowed for a more informed and efficient selection of methods, ensuring that each method contributed to the overall objective, and would have saved a lot of time at the start of the project. Although some methods may not have been effective in the design process and may have been discarded, a more thorough prior assessment would have helped to minimise this risk and optimise the use of available resources and time, so more careful thought about method selection at the outset would have been beneficial to the effective development of the project.

5.2 Project Content, Development, and Results

During the development of the project, several difficulties were encountered that impacted both the generation of the initial concepts and the results obtained. One of the main difficulties encountered was the lack of consideration of the theory previously seen during the Sketching phase, which resulted in the generation of inefficient final concepts. It was observed that the first three final concepts had an inadequate amount of material and a less-than-optimal arrangement of cells, which made assembly by the robot difficult and generated excess material. Although assemblies such as a slider were considered as a potential solution to reduce the need for screws and simplify assembly, it was concluded that this alternative required a considerable amount of material. During this design selection process, it became apparent that it was necessary to discard ideas that, although they seemed good, did not fulfil the number of fundamental requirements.

In response to these difficulties, a review and recreation of the concepts was carried out, followed by a selection analysis in order to identify the most efficient solution using tools such as the checklist, interviews and the spider diagram. It was concluded that the final design had to meet the essential requirements indicated, as well as being compatible with the assembly by means of the robotic arm and the corresponding cells.

In addition, several factors were identified that complicated the process and affected the results in unexpected ways. Firstly, the scarcity of information available from internet sources posed an initial challenge, delaying the effective start of the project while an extensive search for information was conducted. Also, the lack of organisation in the selection of appropriate methods for the development of the redesign led to confusion and delays in the process. However, as the project progressed, a more robust and structured iterative process was established, allowing for greater efficiency in decision-making and the application and elimination of methods.

One of the aspects that has not been observed in accordance with expectations is the use of screws, given that initially it was foreseen in the list of requirements to use a maximum of 4 screws. However, during the process, it was found that it was not feasible to use less than 4, as this did not ensure a complete sealing of the box. It was therefore decided to use 6 screws.

Another challenge has been to address multiple issues, such as production cost, material quantity and environmental impact, without prioritising any of them. This situation complicated the process considerably, as it was virtually impossible to create a design that encompassed all of these elements equally.. Every small change in the design might improve one aspect, but as a consequence, another aspect worsens. To address this problem, it was decided that the main priority was to comply with the design principles for the assembly, and then consider the other aspects.

Finally, the organisation of the report proved to be another significant drawback, with points of confusion in terms of the layout of the theoretical information and the results obtained. Through weekly follow-up meetings, these doubts were addressed and a better clarity and coherence in the presentation of the report was achieved.

5.3 Sustainable Development

In order to address the question of how the relevant community objectives for sustainable development have been considered from different perspectives, it is essential to carefully analyse the economic, social and ecological aspects involved in the design and development of the project in question.

From an economic point of view, attention has been paid to the concept of Design for the Environment (DFE). This approach involves selecting industrial processes that allow for efficient and low-cost manufacturing. In this sense, research has been carried out to choose the most suitable industrial processes that not only reduce production costs but also minimise the associated energy consumption. In addition, a materials reduction strategy has been adopted, which not only reduces manufacturing costs but also contributes to a more efficient management of natural resources.

On the social side, priority has been given to the accessibility and user-friendliness of the product. Parts have been designed in such a way that they can be easily replaced, which not only prolongs the life of the product, but also reduces the need for complete disposal in the event of breakdown or wear and tear. This consideration provides a more durable and easier to maintain product and also helps to reduce the waste of resources.

Finally, from an ecological perspective, consideration has been given to resource efficiency and waste minimisation. The design of the robot, including the arrangement of the cells, has been made in such a way as to minimise unnecessary movements and optimise the direction and efficiency of movements, thus reducing energy consumption. In addition, special attention has been paid to the standardisation of components, such as the use of the same screws throughout the design, which facilitates the disassembly and recycling process.

In summary, the project has comprehensively integrated the relevant EU objectives for sustainable development, taking into account economic, social and ecological aspects at each stage of the product design and development process. This has been achieved through the application of strategies such as Design for the Environment, product accessibility and durability, and resource optimisation and waste minimisation.

6 Conclusions

This project has focused its efforts on the optimisation of the battery module assembly process, with the aim of improving efficiency, functionality and sustainability throughout the product life cycle. Throughout this study, the principles of Design for Manufacture and Assembly (DFMA), Design for the Environment (DFE) and Design for Disassembly (DFD) have been applied to achieve optimal results. In this conclusion, the key findings of the project are presented, highlighting both successful aspects and areas for future improvement.

- Minimising the number of parts in the final cellular module design by integrating multiple functions into individual parts has been successfully demonstrated, reducing assembly complexity and increasing part functionality.

- The arrangement of the base walls has been found to facilitate the assembly of the robot and provide stability to the batteries during the assembly process, which contributes to increased manufacturing efficiency.

- It has been recommended to improve the stability of the assembly between the base and the lid by optimising the outward folding to avoid difficulties in battery assembly.

- The adoption of a base with two walls and a lid has simplified the manufacturing process by reducing the number of parts required, thus improving the efficiency of the process.

- It has been proposed to join the top and bottom parts using screws during the assembly process to ensure greater structural integrity.

- The multi-functionality of the rack, which sorts and holds batteries, facilitates efficient assembly and has been designed to reduce material usage, has been demonstrated.

- It has been recommended to continue to prioritise the recycling and reuse of parts by avoiding welding or the use of adhesives to join the case, which contributes to the sustainability of the product.

- It has been found that manufacturing the enclosure by metal bending minimises the environmental impact in terms of energy and facilitates recycling at the end of its useful life.

7 Future Work

Despite the significant progress made in this project, there are a number of areas that could be explored and improved in future research and development. In this section, we identify several directions for future work

- Further testing and analysis to further optimise the folding design at the base of the module, with the aim of ensuring optimal assembly stability without compromising ease of assembly.

- Conduct life cycle analysis studies to more fully assess the environmental impact of the product at all stages, from raw material extraction to final disposal, and use these results to inform future design and manufacturing decisions.

- Conduct a comprehensive analysis of the materials used in the manufacture of the battery modules and assess the mechanical, thermal and electrical properties of the materials to ensure optimal performance and extended product life. In addition to this investigate the availability, sustainability and environmental impact of the materials used, looking for more sustainable alternatives.

- Research and develop alternative joining methods to improve assembly stability and structural integrity of the cellular module, exploring options such as specialised adhesives for metallic materials to replace any interior parts and be environmentally sustainable.

- Another improvement to be considered in the future is the incorporation of perforations in the cell module to facilitate ventilation.

- Deepen the application of design for the environment (DFE) from the early stages of the design process.

- Studying the degrees of freedom of assemblies is crucial to optimise the efficiency and accuracy of the design and manufacturing process.

- Complement this project with electrical and mechanical knowledge providing a solid basis for implementing improvements focused on these areas. With a deeper understanding of the relevant electrical and mechanical principles and concepts, more innovative and effective solutions can be developed to optimise battery module design and manufacturing.

- Including the heating film and busbar early in the design process ensures more complete and efficient planning. These components are critical to the performance of the battery module, and integrating them early in the design process allows their requirements and limitations to be taken into account from the beginning.

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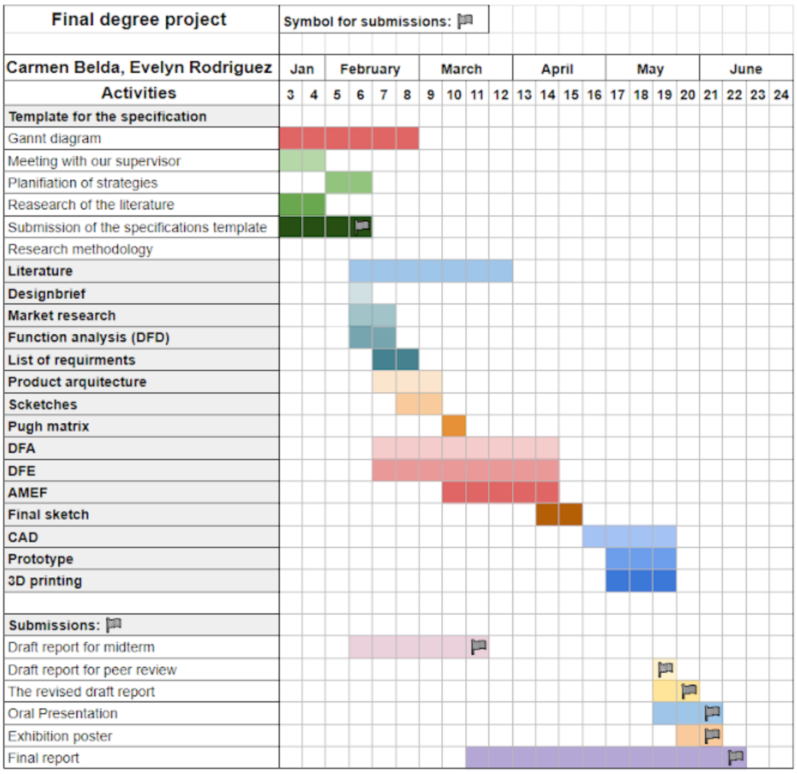
Appendices

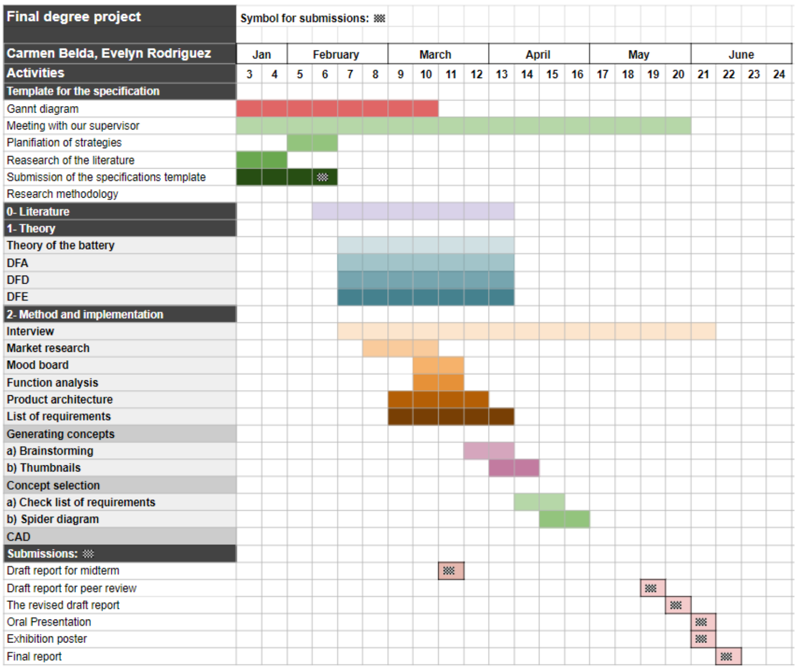
Appendix 1. Work Breakdown and Time Plan

This is the original Gantt chart.



Final degree project	Symbol for submissions: ⚑																					
Carmen Belda, Evelyn Rodriguez	Jan		February				March				April				May				June			
Activities	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Template for the specification																						
Gannt diagram	■	■	■	■	■	■																
Meeting with our supervisor	■	■																				
Planifiation of strategies			■	■																		
Reasearch of the literature	■	■																				
Submission of the specifications template	■	■	■	⚑																		
Research methodology																						
Literature				■	■	■	■	■	■	■												
Designbrief				■																		
Market research				■	■																	
Function analysis (DFD)				■	■																	
List of requirments					■	■																
Product arquitecture					■	■	■															
Scketches						■	■															
Pugh matrix								■														
DFA					■	■	■	■	■	■	■	■										
DFE					■	■	■	■	■	■	■	■										
AMEF								■	■	■	■	■										
Final sketch												■	■									
CAD														■	■	■	■					
Prototype															■	■	■					
3D printing															■	■	■					
Submissions: ⚑																						
Draft report for midterm				■	■	■	■	■	⚑													
Draft report for peer review																	⚑					
The revised draft report																	■	⚑				
Oral Presentation																	■	■	⚑			
Exhibition poster																		■	⚑			
Final report									■	■	■	■	■	■	■	■	■	■	■	⚑		

Here you can see the updated Gantt chart.



Final degree project	Symbol for submissions: ▩																					
Carmen Belda, Evelyn Rodriguez	Jan		February				March				April				May				June			
Activities	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Template for the specification																						
Gannt diagram	■	■	■	■	■	■	■	■														
Meeting with our supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Planifiation of strategies			■	■																		
Reasearch of the literature	■	■																				
Submission of the specifications template	■	■	■	▩																		
Research methodology																						
0- Literature				■	■	■	■	■	■	■	■											
1- Theory																						
Theory of the battery					■	■	■	■	■	■	■											
DFA					■	■	■	■	■	■	■											
DFD					■	■	■	■	■	■	■											
DFE					■	■	■	■	■	■	■											
2- Method and implementation																						
Interview					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Market research						■	■	■														
Mood board								■	■													
Function analysis								■	■													
Product architecture							■	■	■	■												
List of requirements							■	■	■	■	■											
Generating concepts																						
a) Brainstorming										■	■											
b) Thumbnails											■	■										
Concept selection																						
a) Check list of requirements												■	■									
b) Spider diagram													■	■								
CAD																						
Submissions: ▩																						
Draft report for midterm									▩													
Draft report for peer review																	▩					
The revised draft report																		▩				
Oral Presentation																			▩			
Exhibition poster																			▩			
Final report																				▩		

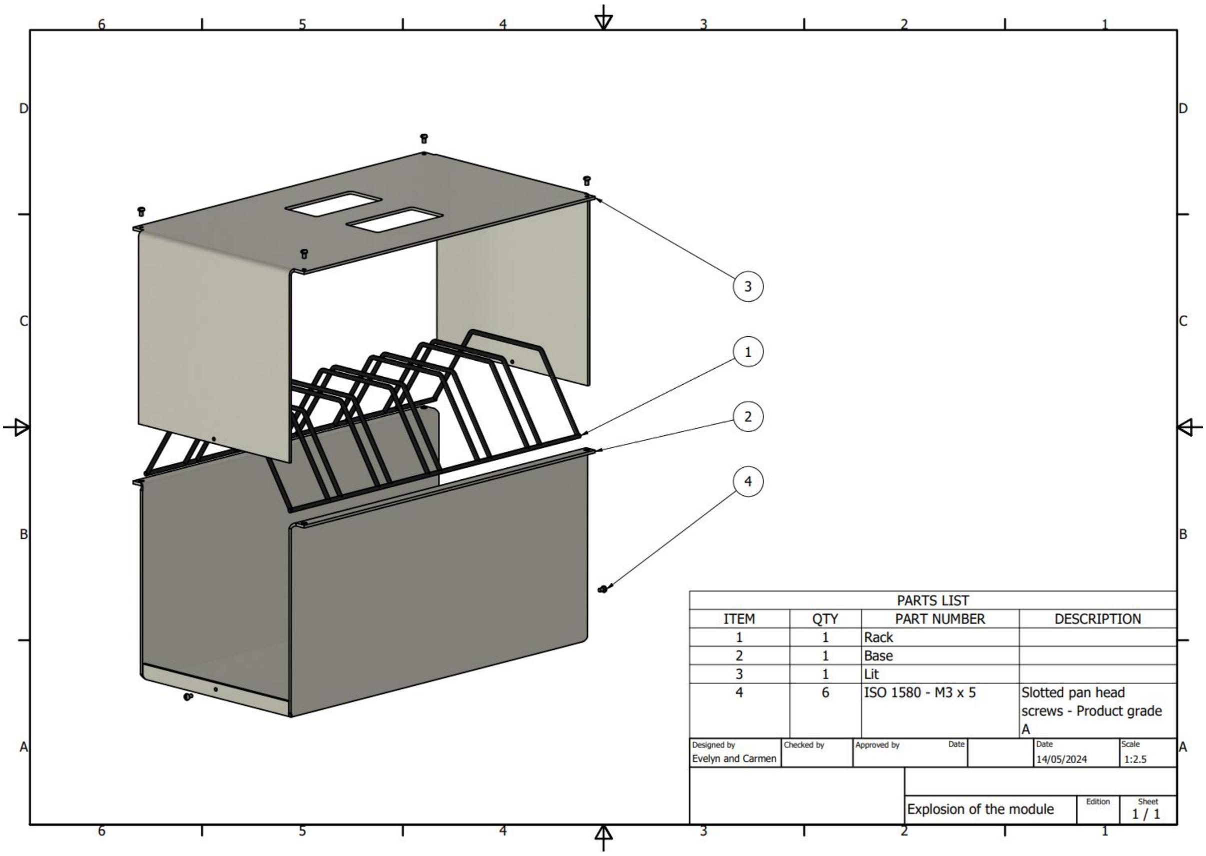
The project underwent several significant changes during its development, some of which had a notable impact on its direction and execution.

The most prominent change centred on the reorganisation of the time plan, where it was noted that the initial order was not considered appropriate. It was identified that both the understanding of the product architecture and the exploration of literature related to DFMA, DFE and DFD should precede the elaboration of the list of requirements. This restructuring was crucial for a deeper understanding of the project from its inception.

Furthermore, the decision was made not to carry out 3D printing of the final product. This choice was based on the material of the product, which is metal. This adaptation in the manufacturing process was made to optimise resources and focus on more suitable methods for the production of the final product.

Finally, a change was made in the evaluation methodology from the Pugh matrix to the spider diagram. This modification was based on the need for a clearer visual representation of the evaluated parameters. The spider diagram provided a more intuitive perspective and allowed for a better comparison of the different criteria analysed.

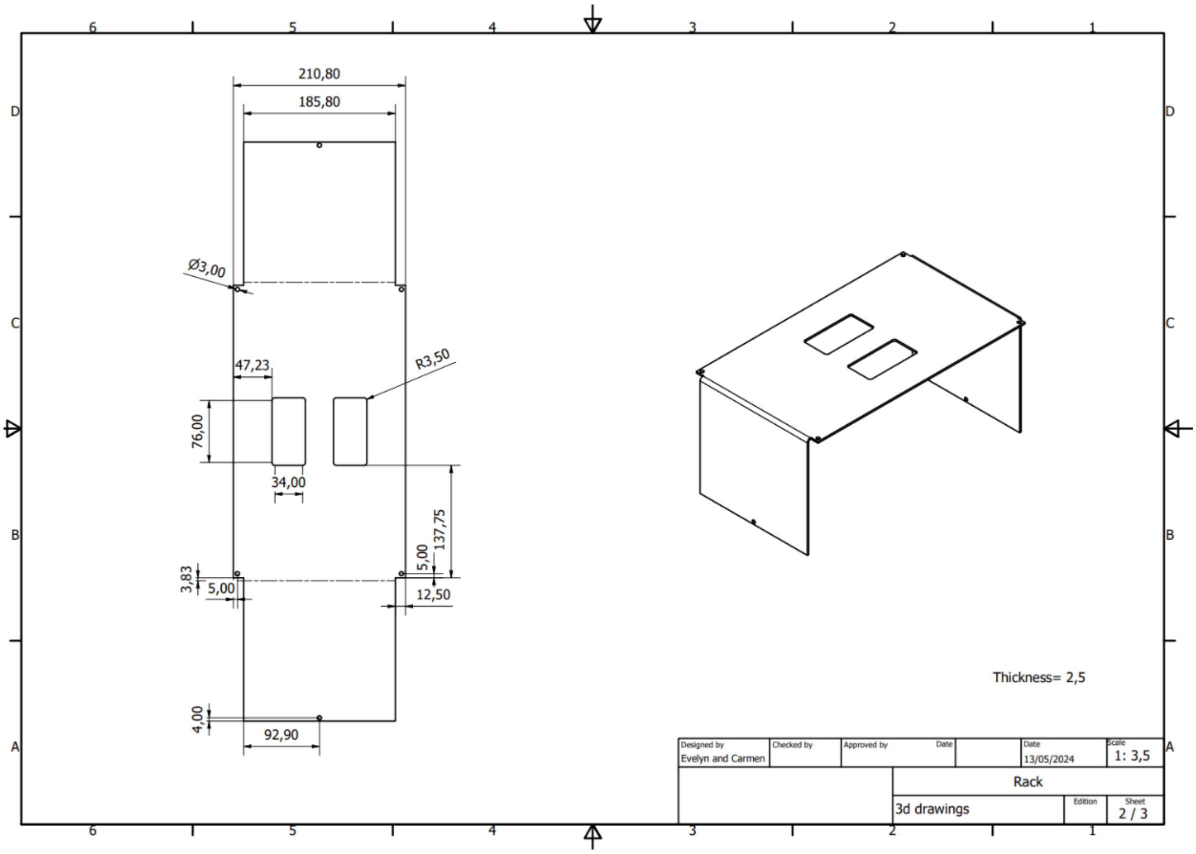
Appendix 2. 3D drawings



PARTS LIST

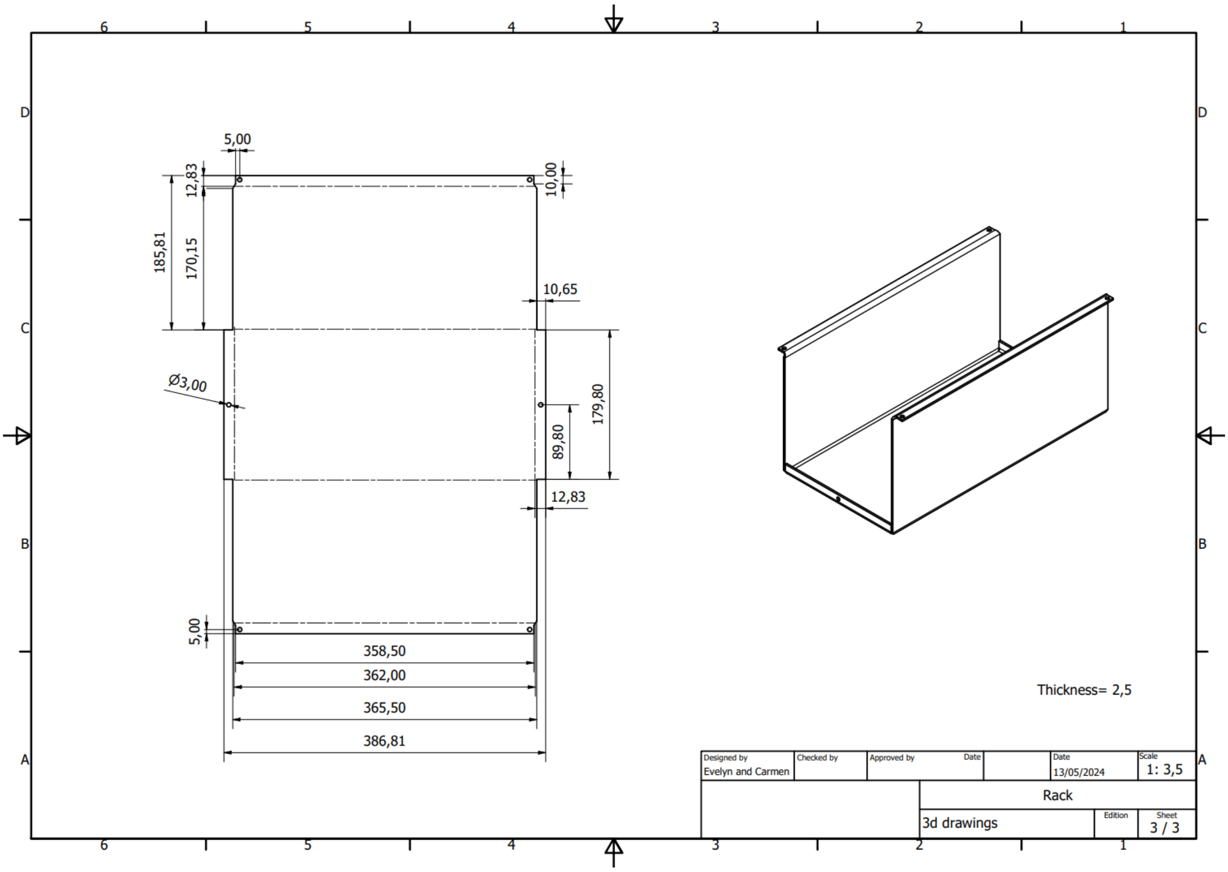
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Rack	
2	1	Base	
3	1	Lit	
4	6	ISO 1580 - M3 x 5	Slotted pan head screws - Product grade A

Designed by: Evelyn and Carmen
Checked by:
Approved by:
Date:
Date: 14/05/2024
Scale: 1:2.5
Explosion of the module
Edition:
Sheet: 1 / 1

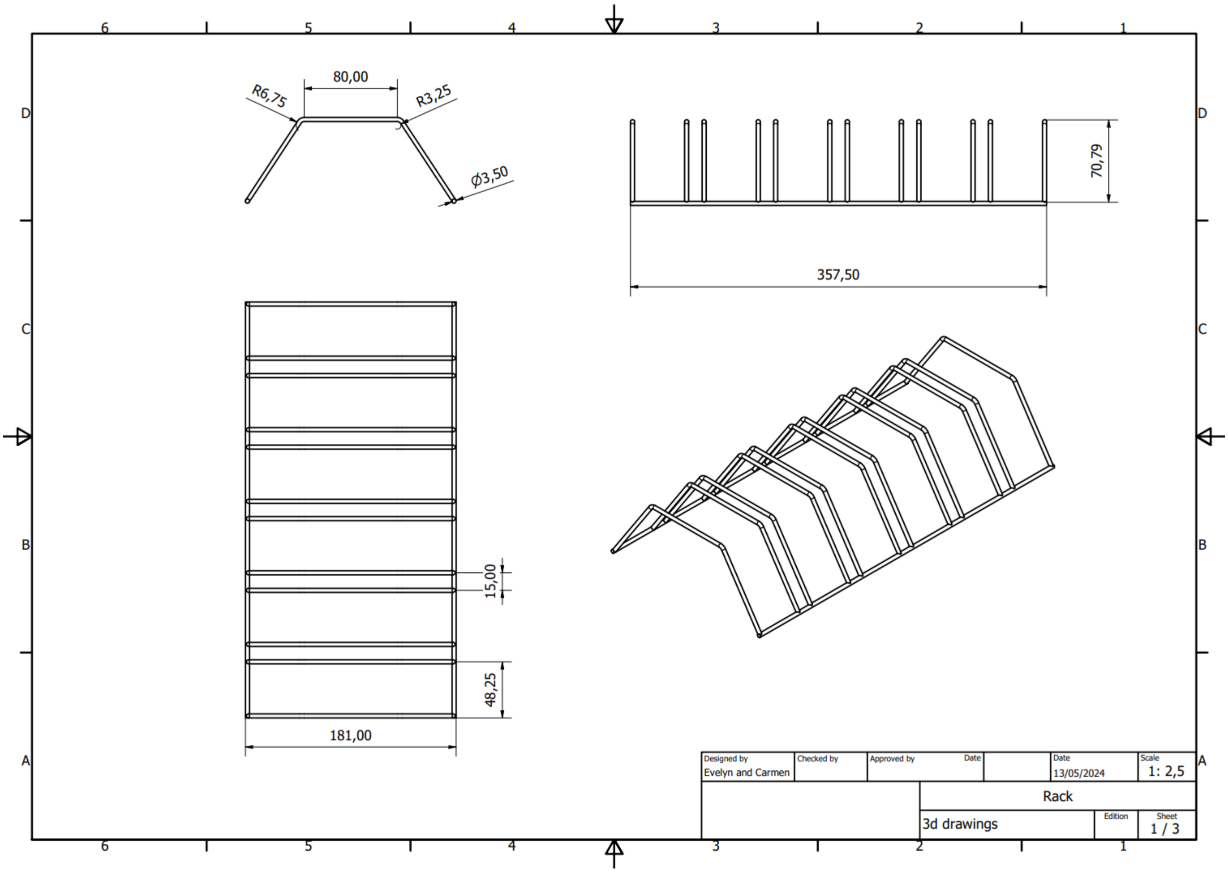


Thickness= 2,5

Designed by: Evelyn and Carmen
Checked by:
Approved by:
Date:
Date: 13/05/2024
Scale: 1: 3,5
Rack
3d drawings
Edition:
Sheet: 2 / 3



Designed by: Evelyn and Carmen
Checked by:
Approved by:
Date:
Date: 13/05/2024
Scale: 1: 3,5
Rack
3d drawings
Edition:
Sheet: 3 / 3



Designed by: Evelyn and Carmen
Checked by:
Approved by:
Date:
Date: 13/05/2024
Scale: 1: 2,5
Rack
3d drawings
Edition:
Sheet: 1 / 3