UiT The Arctic University of Norway

FACULTY OF ENGINEERING SCIENCE AND TECHNOLOGY

DEPARTMENT OF COMPUTER SCIENCE AND COMPUTATIONAL ENGINEERING

FRAME AND CASING DESIGN OF SECOND LIFE BATTERY ENERGY STORAGE SYSTEMS

A PRODUCT DEVELOPMENT PROJECT

ANIRUDH KURUP

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Abstract

The design of the frame and casing for two types of battery storage systems was carried out through a product development process on behalf of RePack AS. The primary design objectives were clarified using an objective tree method. The main functions of the designs were explored, and the product requirements was compiled stating the various demands and wishes pertaining to the products. Design concepts were generated for each type of product presented which resulted in two detailed concepts, with one having a prototype made at labs in UiT Narvik. The concepts presented are supported with calculations, finite element analysis using ANSYS R1 2021 academic and material selection using ANSYS academic Granta.

Acknowledgement

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Abbreviations

AC	Aleternating Current
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BMS	Battery Management System
BTMS	Battery Thermal Management System
BMs	Battery Cell Modules
BRs	Battery Module Racks
DC	Direct Current
EMS	Energy Management System
ES	Energy Storage
ESS	Energy Storage System
EES	Electrical Energy Storage
EV	Electrical Vehicle
OEM	Original Equipment Manufactur

PCS	Power Conversion System
PE	Power Electronics
PV	Photo Voltaic
SES	Stationary Energy Storage
SOC	State Of Charge
TBD	To be decided
TBC	To be checked

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1. Introduction

This chapter presents a comprehensive review of recent knowledge regarding reuse of electrical vehicle [EV] batteries for energy storage purposes. The current scenario in the energy market is explored along with the present challenges for repurposing EV batteries for energy storage technology. Some background theory on battery energy storage systems [BESS] from the perspective of reusing EV Lithium-Ion batteries is provided to emphasize the theme of this report. From this information, the problem statement is derived, the limitations are listed followed by a time plan for the project.

1.1 Theory

Technological advancements in the electrification of vehicles are directly resulting in expanding numbers of EV batteries[1] . The cost of batteries for electric vehicles is falling rapidly, industry reports show that sales-weighted battery pack prices in 2019 were an average of 1344.34 NOK per kilowatt-hour, down from more than 9476.83 NOK/kWh in 2010 [1] (The volume and value of EV batteries are measured in kilowatt-hours, which allows a one-to-one comparison between different types of batteries). The average battery pack size across electric light-duty vehicles sold (including battery electric vehicles and plug-in hybrid electric vehicles) continues an upward trend; the battery of electric cars in most countries are in the 50-70 kWh range [1]. It is estimated that 100-120 GWh of electric vehicle batteries will be retired by 2030[2]. More than 50% of new vehicles sold globally in 2030 will be electrified[2]. Adoption of BEVs, the vehicles with the highest battery capacity, will increase by an average of 25% per year through 2030, and recent evidence shows that sales momentum has not slowed appreciably as a result of the COVID-19 pandemic[2]. By 2030, the number of passenger EVs on the road globally is likely to exceed 300 million[2]. Nearly 4 million EVs are expected to be retired in calendar year 2030, with a combined originally rated capacity of nearly 100 GWh, and that number will increase significantly in subsequent years[2].

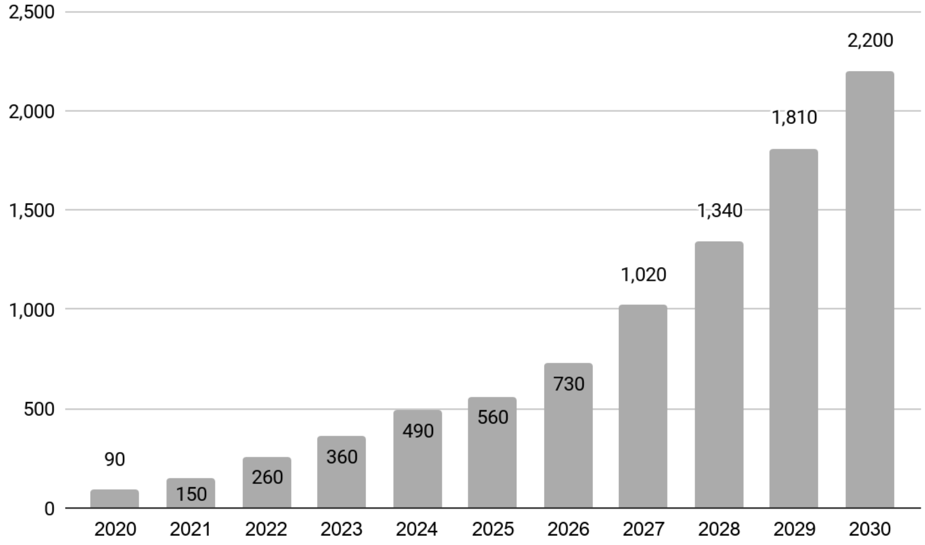


Figure 1: MWh used EV batteries being scrapped p.a., 1. Compounded Annual Growth Rate, Source: TØI - Norwegian Centre for Transport Research, 2020, RePack presentation deck.

All EV batteries are typically assumed to reach endof-life when they retain 80% of their initial capacity[1]. The average useful life of lithium-ion batteries is around ten years and all lithium-ion batteries degrade over time, afte they fall below around 80% of their originally rated capacity, they no longer offer a sufficient level of performance to power a vehicle. When a battery at the end of its first life is removed from a vehicle, it has three possible destinations: a recycling facility, a second-life application, or a waste management facility: In **recycling**, the valuable metals are recovered, in a **second-life application**, a specialized company repurposes the battery cells for a new use without dismantling them, often in combination with a new set of power electronics, software, and housing structure[2]. The new application is typically stationary, rather than mobile[2]. If placed into a **waste stream**, the battery enters a landfill or other disposal facility with no recovery of any of its remaining value[2]. Increasingly, regulations are mandating that lithium-ion batteries enter the circular economy rather than being discarded[2]. For a 60kWH BEV battery pack that is designed for 1,500 cycles; this capacity can still offer 18 MWh of electrical load, or enough electricity to power a typical home for more than 15 years [2]. Hence, repurposing an EV battery as stationary storage is estimated to extend its lifetime by 5-15 years, depending on its initial state of health and the characteristics of the second-life[2].

Extending the useful life of automotive batteries contributes towards positive environmental impacts, reduces emissions and costs of manufacturing new batteries[2]. Second-life batteries have various applications such as services for electricity grid operators, electric utilities, and commercial or residential customers[2]. Peak shaving, black-start, uninterrupted power supply, frequency regulation and optimising energy from variable renewable energy sources [wind, PV cells] are some of the main applications of today[2]. It is estimated that demand for batteries in the SES market alone will reach 120 GWh annually by 2030[2]. From a technical standpoint, batteries manufactured for use in an EV can satisfy most of the applications mentioned above[2]. In fact, one can argue that EV batteries are overdesigned for use in relatively relaxed stationary environments, as the conditions in which batteries are used in vehicles are far more rigorous[2].

Some of the challenges for BESS are: **Manufacturing;** the production process for repurposing a battery is complex[2]. The battery must be disassembled; the cells must be tested, graded, and matched; the casing must be rebuilt; the cells must be integrated with an inverter and software; and the repurposed battery must be reassembled before it can be resold[2]. But manufacturing isn’t the only challenge[2]. **Labor;** disassembling, grading, and reassembling batteries is a time-intensive, largely manual process, and it is further complicated by limited knowledge about how the battery had been used and its current cell-level performance[2]. Moreover, many batteries depend on nonstandard chemistries and packing designs[2]. Over time, however, digital advances and product standardization may help to reduce labor costs[2]. For example, recent research indicates that the time required to grade a battery pack could be reduced from days to a few minutes[2].**Valuation;** questions persist on how to assess the remaining life of a battery and assign a book value to it[2]. The full history of the battery’s prior usage is an important input to calculating remaining value[2]. **Price;** the price that customers are willing to pay for a second-life solution is typically no more than 60% of the price of a new battery solution—and as prices of new batteries continue to decrease, so will those of second-life batteries[2]. **Liability;** uncertainty as to how a battery was used in its first life may encourage repurposers to overdesign the second-life version to ensure that it meets the specifications for its new use[2]. Moreover, navigating the regulatory codes and certifications needed for specific applications can be more complex with a second-life battery[2]. Second-life batteries must also compete with several alternatives[2]. The first is the large number of battery-pack designs on the market that vary in size, electrode chemistry, and format (cylindrical, prismatic, and pouch). Each battery is designed by the battery manufacturer and automotive OEM to be best suited to a given EV model, which increases refurbishing complexity due to lack of standardization and fragmentation of volume[2]. Up to 250 new EV models will exist by 2025, featuring batteries from more than 15 manufacturers[2]. **First-Life Batteries;** in terms of total cost of ownership (TCO), first-life batteries are often more competitive, except for use cases that require a low number of annual cycles[2]. A new BESS battery pack represents just 30% to 50% of the total price of the application, so the second-life battery must be heavily discounted in order to significantly lower the total price[2]. Moreover, a second-life battery may use technology that is 10 to 15 years old, placing it at risk of obsolescence given the steady pace of advances in the energy density, safety, and lifespan of new batteries[2]. **Recycling;** many EV manufacturers are building out their own battery supply chains and ensuring continued access to in-demand materials such as nickel and cobalt[2]. Recycling allows automotive OEMs, for example, to keep used batteries and reclaim these materials, rather than selling them into the stationary storage supply chain[2]. **Vehicle-to-Grid;** there is increasing optimism that over the longer term, second-life batteries will need to compete against “grid-able” vehicles—vehicles that can store electricity and discharge it when needed for use at home or send it back to the grid without compromising their primary function of mobile transport[2]. Once the number of EVs in use reaches sufficient scale, a vehicle-to-grid offering could effectively reduce the market size for other energy storage needs—making the business case for second-life applications even more challenging[2]. Because of these challenges, as well as the attractive economics of recycling at scale, fewer than 20% of batteries will be used in a second-life application before being recycled and that the great majority of first-life batteries will go directly to recycling[2].

To <u>overcome the challenges,</u> **the designer of such a second life battery energy storage system could develop standardized, modular solutions, create scalable and standardized processes to lower the cost of repurposing**. The BESS providing company must secure exclusive access to batteries from high-volume vehicle models, learn to test and process the battery pack efficiently, and gain scale in the design, integration, and certification processes[2]. To reduce disassembly costs and cell-matching challenges, designed solutions should use the full battery module[2]. The BESS could be customizable from the standard offerings to meet special customer deamnds[2]. A design offering could include mixing and matching used and new battery modules to optimize the design for specific customer needs[2]. **This report explores the design of such ideal second life battery energy storage systems.**

1.1.1 Understanding a Battery Energy Storage System [BESS]

BESS components are grouped according to function into battery components, components required for reliable system operation, and grid connection components [if connected to the grid]. The main components of a BESS are:

a) Energy Management System [EMS]
b) Battery System
c) Power Conversion System [PCS]

The primary focus of this report will be on the battery system, EMS and PCS will only be studied briefly as it is outside the scope of this report. The battery system consists of the battery pack, which connects multiple cells to appropriate voltage and capacity; the battery management system (BMS); and the battery thermal management system (B-TMS). The BMS protects the cells from harmful operation, in terms of voltage, temperature, and current, to achieve reliable and safe operation, and balances varying cell states-of-charge (SOCs) within a serial connection. The B-TMS controls the temperature of the cells according to their specifications in terms of absolute values and temperature gradients within the pack. The components required for the reliable operation of the overall system is the system control and monitoring, the energy management system (EMS), and system thermal management. System control and monitoring is general (IT) monitoring, which is partly combined into the overall supervisory control and data acquisition (SCADA) system but may also include fire protection or alarm units. The EMS is responsible for system power flow control, management, and distribution. System thermal management controls all functions related to the heating, ventilation, and air-conditioning of the containment system. The power electronics can be grouped into the conversion unit, which converts the power flow between the grid and the battery [if the system is connected to a grid], and the required control and monitoring components— voltage sensing units and thermal management of power electronics components [5].

1.1.2 EV Li-Ion Batteries

Li-ion battery chemistries have the highest energy density and are considered safe. No memory or scheduled cycling is required to prolong battery life[5]. Some other advantages include high specific energy and high load capabilities with power cells, long cycle and extended shelf-life, maintenance-free, high capacity, low internal resistance, good coulombic efficiency, simple charge algorithm and reasonably short charge times[5]. Some disadvantages are need for protection circuit to prevent thermal runaway if stressed, degradation at high temperature and when stored at high voltage, impossibility of rapid charge at freezing temperatures [5]. The Li-Ion batteries used in EV vehicles smaller cells which are packed into cell modules as shown in figure 1. The cells can be of 3 types [Cylindrical, Prismatic, Pouch] as shown in figure 2.

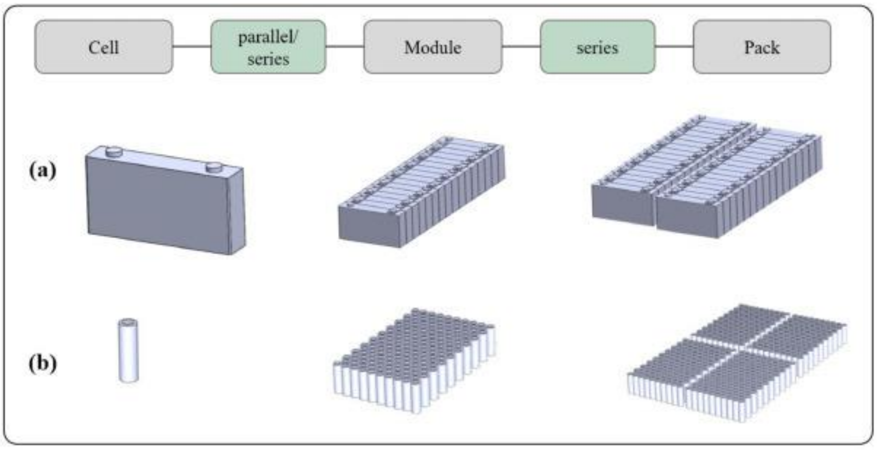
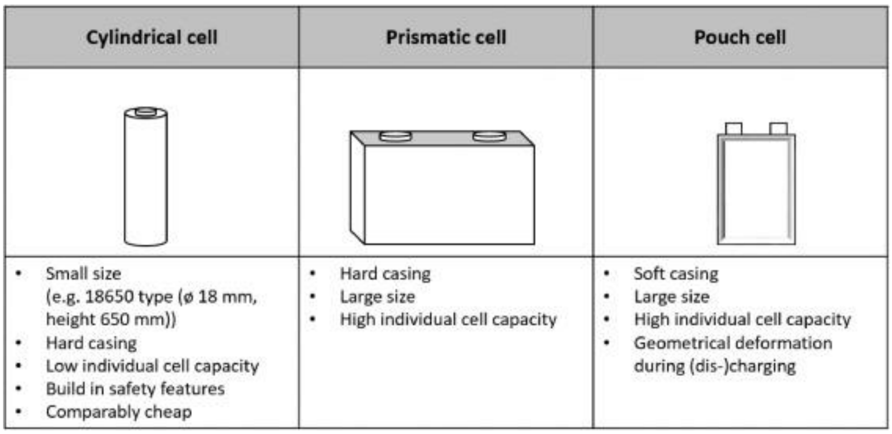


Figure 2: Overview of battery packs indicating two constructions with (a) cylindrical and (b) prismatic cells.Source: Automotive battery pack manufacturing – a review of battery to tab joining, Journal of Advanced Joining Processes [4].



Cylindrical cell	Prismatic cell	Pouch cell
• Small size (e.g. 18650 type (ø 18 mm, height 650 mm)) • Hard casing • Low individual cell capacity • Build in safety features • Comparably cheap	• Hard casing • Large size • High individual cell capacity	• Soft casing • Large size • High individual cell capacity • Geometrical deformation during (dis-)charging

Figure 3: Overview of different cell types used in automotive battery applications: (left) cylindrical cell, (middle) prismatic cell, (right) pouch cell.Source: Automotive battery pack manufacturing – a review of battery to tab joining, Journal of Advanced Joining Processes [4].

The battery modules considered in this report are from VW E-Golf and Nissan Leaf, the dimensions and weight are listed in table1.

Table 1 Type of battery modules considered in this report. Source: https://www.secondlife-evbatteries.com/

Module	External Dimensions [l × w × h]	Cell type	Capacity	Weight
VW E-Golf	335 x 150 x 105 mm	Prismatic	1.6 kWh	11 Kg
Nissan Leaf	300 x 222 x 68 mm	Pouch	1.6 kWh	8.7 Kg

The images of these battery modules are attached in the **Appendix I.**

1.1.3 Competitors

The following competitors were studied as an inspiration and to thoroughly understand the types of energy storage systems available in the market:

Competitor	Remarks
1. Coffman BESS [7]	Large shipping containers
2. MTU BESS [8]	Large shipping containers
3. RePurpose Energy [9]	Large shipping containers, specially designed modular battery packs
4. Batteryloop [10]	Large containers

5. ECO STOR [11]	Unique frame and casing design
6. EATON BESS [12]	Well designed frame and casing for large energy storage
7. Powervault [13]	Modular & scalable frame, aesthetically pleasing casing
8. Eldrift [14]	Neat exterior casing
9. Mercedes Benz Energy [15]	Unique frame for easy installation of battery modules
10. Voltfang [16]	Well-designed aesthetically pleasing frame and casing
11. Corvus [17]	Neat battery module arrangement in container
12. Fluence Energy [18]	Outdoor stackable casings
13. Chainpro Energy [19]	Neat frame and assembly of battery modules using a sliding system
14. Wattsun [20]	Simple, small, rugged, stackable, scalable solutions
15. Polarium [21]	Well-designed exterior casing, modular inner casing

Table 2: Competitor study.

1.1.4 Possible solution categories

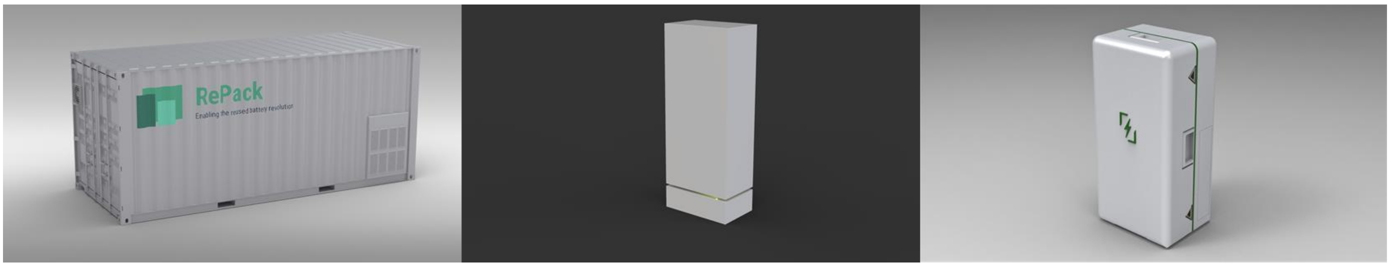


Figure 4: Categories (left to right) 1,2,3 of energy storage systems for representative purposes. Source: Own.

Following the competitor study and a market study, the three main categories of BESS were identified based on energy requirement as shown in figure 3 above.

- **Category 1**: Large container type BESS which consists of around 288 BMs [460kWh]. These are usually commercial, industrial and utility scale systems [100 kWh – 1MWh].
- **Category 2**: BESS for houshold purpose which consists of around 20 BMs [32 kWh]. These are considered as private systems.
- **Category 3**: Portable BESS which consists of 1 BMs. [1.6 kWh]

1.2 Background and problem description

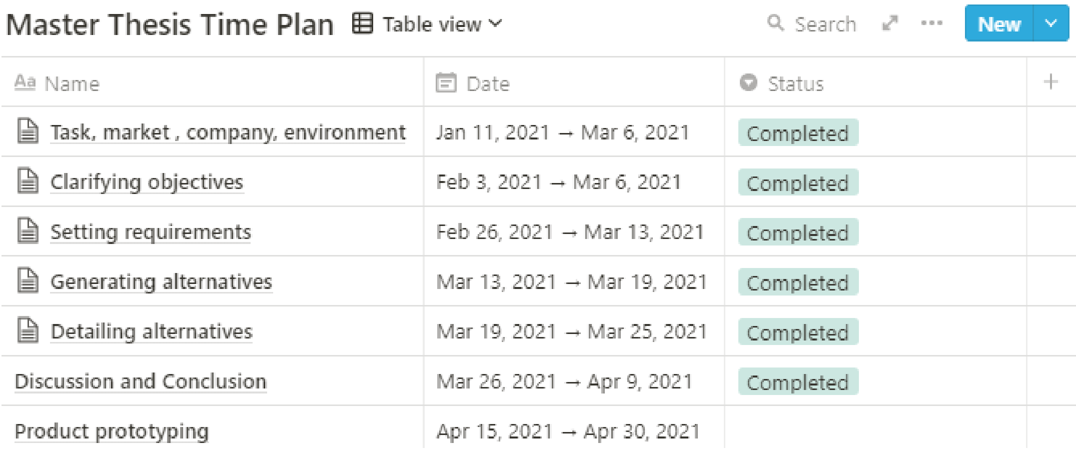
The purpose of this project is to, on behalf of RePack AS [6], develop a frame and casing for the battery energy storage systems. RePack is developing technology for enabling the reuse of electric car batteries in second-life applications. One of the key technologies needed by RePack's Battery Energy Storage System (BESS) is the frame in which the second-life battery modules will be arranged. RePack is looking to optimize the battery frame to maximize customer value, system maintainability, module compatibility. All the above while making certification straightforward. This will be key to minimize cost and footprint. The complexity in geometry and material selection, plus the uncertainty relating to the optimal operational envelope of the Lithium-Ion batteries warrants an in-depth study of the problem. RePack has identified an attractive use case for **category 2 and 3** solutions. The product design task will mainly deal with **category 2** energy storage systems for cabins in Norway**. Category 3** solution, viz, a portable handheld BESS will be designed for technical demonstration purposes. The deliverables of the project will include the analytical work and literature review, shortlisted concept options, full CAD models of the most promising concept, engineering drawings and BOMs with estimated costs.

1.3 Limitations

1. Detail design of all 3 categories of solutions mentioned above may not be carried out due to time constraints.
2. Design of BMS, BTMS, EMS, PCS, PE, electrical architecture etc are outside the scope of this report and hence will not be carried out.
3. Detail design of casing will not be carried out, only conceptual designs will be presented due to time constraints.

1.4 Time Plan

The project was limited to the spring of 2021, starting January 11 and ending May 15. A time plan was made on notion.so. Since a user id is required to login, a brief picture of the time plan is provided below with the detailed time plan in the **Appendix B**.



Master Thesis Time Plan

Name	Date	Status
Task, market , company, environment	Jan 11, 2021 → Mar 6, 2021	Completed
Clarifying objectives	Feb 3, 2021 → Mar 6, 2021	Completed
Setting requirements	Feb 26, 2021 → Mar 13, 2021	Completed
Generating alternatives	Mar 13, 2021 → Mar 19, 2021	Completed
Detailing alternatives	Mar 19, 2021 → Mar 25, 2021	Completed
Discussion and Conclusion	Mar 26, 2021 → Apr 9, 2021	Completed
Product prototyping	Apr 15, 2021 → Apr 30, 2021	

Figure 5: Time Plan.

2. Design Methodology

The design methodology of the thesis is based on Engineering Design Methods: Stratergies for Product Design by Nigel Cross [22]. Two different approaches have been carried out for both the different category of solutions. A detailed approach is carried out for **category 2** solution (figure 6) for a mass production purpose, while a much more simplified approach is considered for **category 3** solution for a technical demonstration purpose (figure 7).

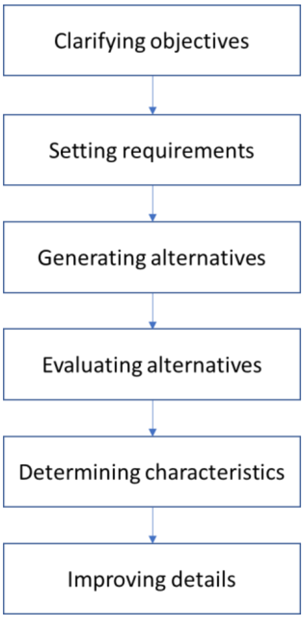


Figure 6: Design methodology for category 2 solution.

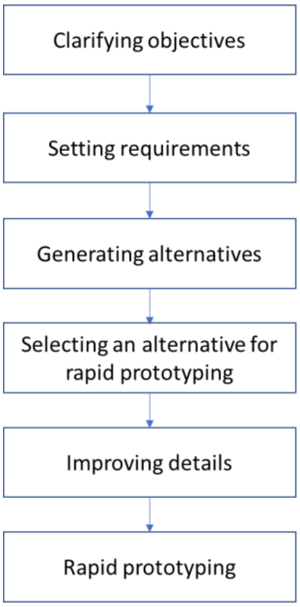


Figure 7: Design methodology for category 3 solution.

3. Clarifying Objectives

An Objectives Tree Diagram for the product belonging to both categories [category 2,3] can be seen in **Appendix L,M** . Looking from top to bottom in the diagram provides answers to how the different objectives can be fulfilled. Similarly, looking from bottom to top in the diagram motivates why each sub objective is necessary. Some sub-objectives answer to multiple objectives.

4. Setting requirements

A requirement specification was compiled for both category 2 and 3 solutions, differentiating compulsory “Demands” (D) and desired but not necessary “Wishes” (W). The wishes and demands are scored on a scale of 1-10 with 10 being the highest wish or demand.

System/equipment = Frame + Battery modules + PE, BMS, inverter etc + Casing.

4.1 Requirements for category 2 solution are:

#	Requirement	Demand	Wish	Remarks
1	Dimensional requirements			
1.1	Must fit battery modules of **Length = 400-500mm, Breadth = 150-300 mm, Height = 100 – 200mm [VW E-golf, Nissan leaf battery modules]**	8	0	*Leaf modules have a very different form factor (much thinner)*
1.2	Fit other types of battery modules, Good if possible	0	8	
1.3	Overall System dimensions not to exceed : **60 cm wide, 50 cm deep and 80 cm tall [without inverter] or 150 cm tall [with inverter]**	10		
2	Weight requirements			
2.1	System to accommodate 28 Nissan Leaf battery modules of Total weight = **145 Kg**	10		
2.2	or System to Accommodate 18 VW E-golf battery modules Total weight = **195 Kg**	10		
2.3	Weight of the frame to be selected for best strength/ cost ratio and not to exceed **50Kg**	8		
2.4	Light weight frame and casing	7	0	
3	Strength requirements			
3.1	Frame to be designed for handling the weight of upto **500 Kg**	9		
4	Input, output requirements			
4.1	Display for SOC, module temperature etc	3	0	*TBD whether on local screen or through app only (likely latter?)*
4.2	Power switch/ master switch/ kill switch	10	0	*Emergency stop button? to check DSB reg/NEK*

4.3	Easily replaceable input, output zones [ex: panel having slots for input / output]	0	0	*of power outlet slots and power inlet slots of the casing.*
4.4	Number of output sources [what type ex: usb, type c power outlet]	4	0	*This is standard per product. Depending on design might be slot-in for inverter module.*
4.5	Number of input sources [for charging] = **1**	6	0	
5	Temperature and humidity requirement			
5.1	Active thermal management	0	8	*TBD – question for outdoor systems in cold weather*
5.2	Passive thermal management	0	8	
5.3	Humidity level or 0% humidity inside casing	0	0	*TBC – there doesn't seem to be an issue with operation in humid environment*
5.4	No Condensation	9	0	*Should have condensation prevention or mitigation*
6	Service and maintainability			
6.1	Space for maintenance access	10		
6.2	Service life	10	0	*App-dependent. 5-10 years*
6.3	Installation by a non-specialist	0	8	*Should be easy but non-specialist access is not allowed / encouraged.*
6.4	Maintenance interval	7	0	*minimal*
6.5	Maintenance by a non-specialist	0	8	*Monitoring-only, via software (at least officially)*
6.6	Waterproof	1	0	*From rain*
6.7	Shockproof	6	0	*Only for transport reasons. 2X 5-10G*
6.8	Corrosion-proof	8	0	
7	Production requirement			
7.1	Production: Large scale production, batch size if any	9	0	*Batches of 10-100*
8	Safety requirements	10	0	
8.1	No sudden movement during transportation	10		
8.2	No overturning of frame, falling of battery modules	10		
8.3	Guards to prevent touching of high voltage components			*TBD*
8.4	High mechanical safety	10		
8.5	Active fire suppression system	0	0	*Likely not*
8.6	Passive fire suppression system	0	0	*Likely not*
9	Other requirements			
9.1	Scalable	9	0	
9.2	Stackable/ modular construction	0	0	
9.3	Easy to disassemble and re assemble	4	0	*TBD*

9.4	Convertible into fitting on a wall or free-standing	4	0	*Yes for cabin/home systems*
9.5	Lock for casing	10		
9.6	Appealing outer casing design and surface finish	10		*Professional looking, something you want in your living room*
9.7	Lifting assist for entire system[ex: forklift, crane, helicopter]	3		
9.8	Lifting assist for battery modules	3		
9.9	System can be placed outdoors	2		
9.1	Usage of standard components wherever applicable	5		
9.11	Insect proofing	1		

Table 3: Requirements for category 2 solution

4.2 Requirements for category 3 solution are:

1. Geometric requirement: Accommodate 1 **VW E-golf battery module** of size 350 mm X 150 mm X 105 mm [D]

2. Strength requirement: Structure to handle weight of up to 20 Kg [D]

3. Fit Raspberry pi 7-inch screen in landscape mode [D]

4. Output panel to include 4 usb modules, one switch, 2 LEDs [D]

5. Ergonomic handle [W]

6. See through window [D]

7. Mounting points for the wiring inside [D]

8. Charging port [D]

9. Rubber shock absorbing base [D]

10. Appealing visual design [W]

11. Loops for shoulder strap [D]

12. Hinged cover for outlet panel [W]

13. Lock [W]

5. Establishing functions

The primary function of the frame in category 2 solution is to facilitate module compatibility w.r.t various EV battery modules available in the market.

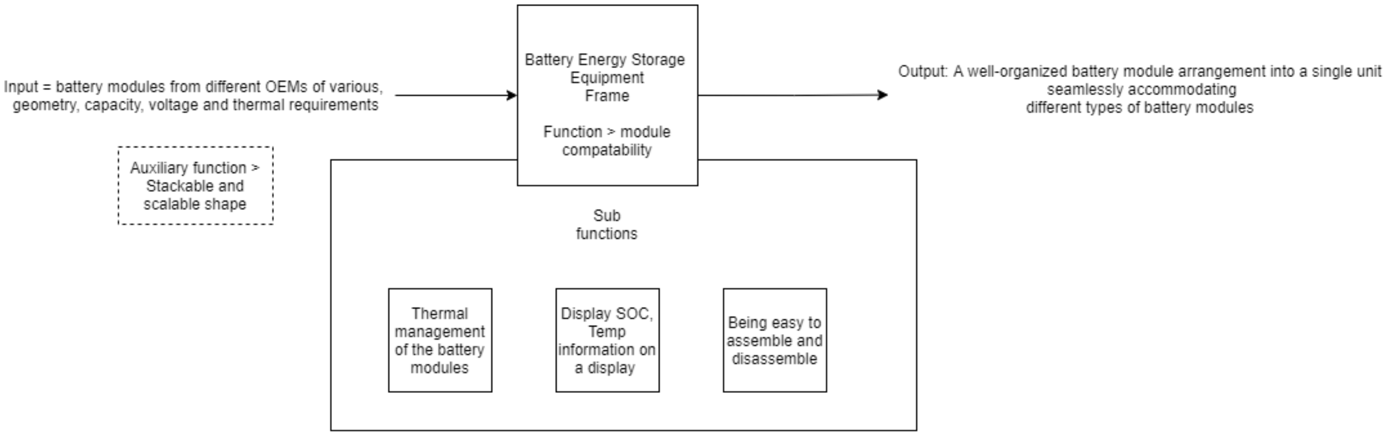


Figure 8: Establishing functions for category 2 solution.

The primary function of category 3 solution is to facilitate portability and technical demonstration of one specific battery module.

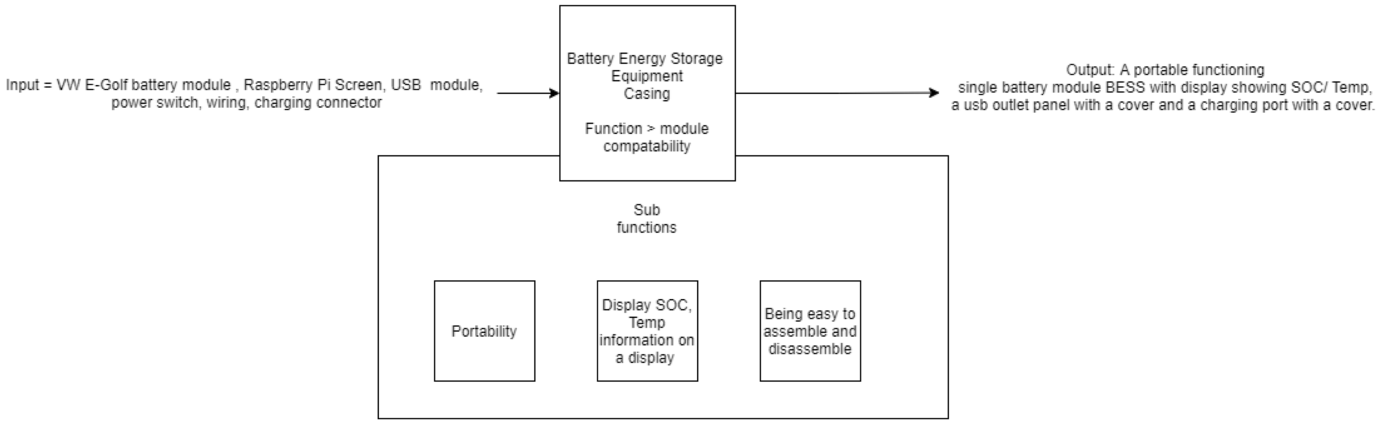


Figure 9: Establishing functions for category 3 solution.

6. Generating alternatives – Category 2

This section is divided into two parts:

1. <u>Generating sub-concepts</u>: The sub concepts are generated for the purpose of mounting the battery modules onto the frame. Various methods of mounting the battery modules are explored in this section. The concepts explored applies to all battery modules mentioned.

2. <u>Generating system concepts</u>: The main concept is an overall solution consisting of the sub concepts and solving the weight issue (battery modules are quite heavy to be installed in large packs).

6.1 Generating sub-concepts

Some sub-concepts were generated and studied for category 2 battery module frame: 1.1 Tilted module arrangement (figure 10): The arrangement shown below can accommodate both VW E- Golf and Nissan Leaf battery modules. This arrangement constraints the modules with the assistance of gravity and unique geometry. The zig-zag shape also maximizes surface area for heat transfer. Advantages include: Easy maintainability, simple assembly. Disadvantages include: The trays with unique geometry occupy large amount of space, busbar connection is going to be difficult.

Figure 10: Tilted module arrangement.

1.2 Bookshelf arrangement: This arrangement (figure 11) is similar to the tilted module arrangement but can accomodate more battery modules, enable busbar connection. This arrangement also constraints the modules with the assistance of gravity and a L-profile stopper. Advantages include: Simpler than tilted module arrangement. Disadvantages include: Battery modules are not thoroughly fixed in place hence a strong movement might displace them.

Figure 11: Bookshelf arrangement.

<u>1.3 Bolted through horizontal arrangemement:</u> This arrangement (figure 12) utilizes the mouting points present on the battery module to constrain the battery module. The modules are stacked together with a long bolt going through the modules and resting on the frame or casing of the system. Advantages include: Convenient module production, supporting rods [bolts] can be adjusted vertically, efficient utilization of space. Disadvantages include: Mouting problems, to replace one module entire set of modules need to be removed, rods or bolts need to be strong enough to handle the weight of the modules.

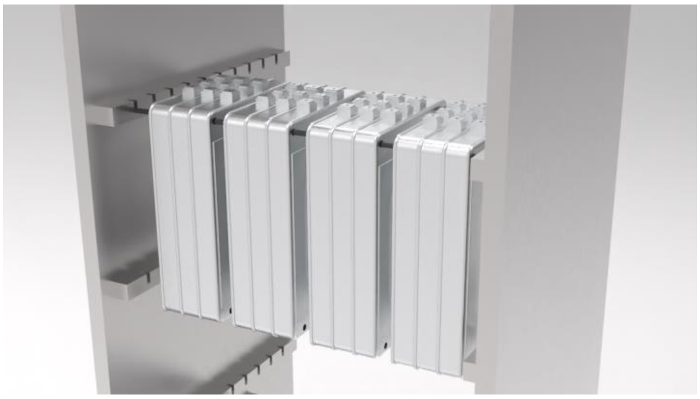


Figure 12: Bolted through horizontal arrangement.

<u>1.4 Bolted through vertical arrangement:</u> In this arrangement (figure 13) , the battery modules are stacked vertically on a platform with a unique distribution of hole system to accodmodate both Nissan Leaf and E-Golf battery module. The stacked modules are bolted through the

mounting holes and held in place. Advantages include: Easy to replace small group of modules. Disadvantages include: vertical stacking not as efficient as horizontal stacking and difficult to stack large number of modules vertically.

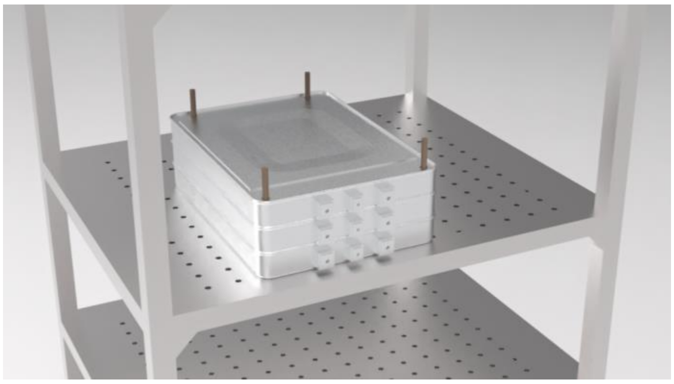


Figure 13: Bolted through vertical arrangement.

1.5 Simple rack with vertically adjustable shelves: In this arrangement (figure 14), the battery modules are simply placed on a platform without being constrained. The platforms are vertically adjustable to accomodate different module arrangements. The battery modules are arranged in a casing prior to placing on the shelf. Advantages include: modular design, modules pre fitted with bus bars, allows assembly line production of battery modules. Disadvanatges include: difficult to stack large pack of battery modules vertically.

Figure 14: Simple rack.

1.6 Tightly packing the battery modules: This concept (figure 15) secures the battery modules by applying force and tightly packing them into the trays. In the figure below, the battery modules are arranged in the tray to snug fit, the plexi glass applies a small amount of force sufficient to arrest the battery modules in the tray. Advantages include: simple and effective method. Disadvantages include: force may not be applied to battery module terminals [in case of Nissan leaf modules]

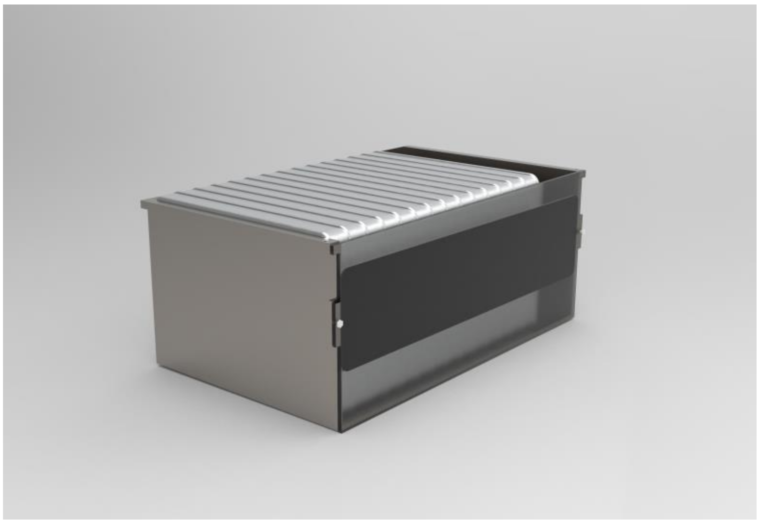


Figure 15: Tightly packed battery modules.

6.2 Generating system concepts:

1. Concept 1 : A combination of subconcepts 1.5 and 1.3 was generated. This concept [concept 1](figure 16,17) has a unique arrangement of Nissan Leaf modules inside a casing. This system concept consists of trays on which th battery modules are bolted and constrained. A wheel system is added to slide the trays in and out of the casing. The trays can accomodate and lock 14 Nissan leaf modules or 8 E-Golf modules into place. Disadvantages include: difficult to stack a 70Kg + tray filled with battery modules during assembly, casing made to handle structural loads can be an expensive option.

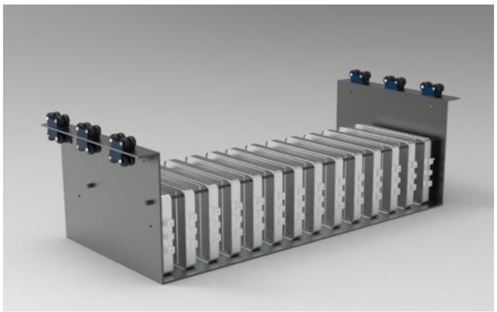


Figure 16: Tray with wheels [Nissan Leaf battery modules].

Figure 17: System concept 1 Case + Frame.

2. Concept 2 : This concept is same as concept 1 but the trays are further split into separate units for ease of assembly. Disadvantages include: Larger number of parts due to the trays being split into smaller units.

3. Concept 3: In this solution (figure 18), the battery modules are packed into movable units with wheels attached. This makes assembly and maintenance easy. Disadvantages include: the concept occupies a larger floor space.

Figure 18 Concept 3.

4. Concept 4: This concept utilizes a frame to handle all the structural loads, and a simple casing to be designed as a separate unit. The battery modules are individually assembled into trays which are fixed onto the frame. Disadvantages include: time consuming assembly.

Figure 19: Concept 4.

7. Evaluating alternatives - Category 2

Clarifying objectives of category 2 solution was scored based on the relative importance as shown in figure below.

Design objectives	**Relative importance**
1. Module compatibility	10%
2. Handling and maintainability	5%
3. Thermal management	5%
4. Safe	10%
5. Rigid, robust, Strong, Lightweight	10%
6. Transportable	10%
7. Ease of assembly of frame/casing	8%
8. Energy Dense	5%

9. Cost effective	10%
10. Smart	2%
11.Scalable	10%
12. Aesthetically pleasing	5%
13. Simple component production	10%
14. Easy to operate	5%

Table 4 Priortizing design objectives.

The concepts were then scored based on how well each of the concept satisfied the design objectives.

Alternative	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
Concept 1	**9**	**3**	**3**	**9**	**6**	**6**	**6**	**5**	**3**	**0**	**0**	**5**	**3**	**4**	**62**
Concept 2	**9**	**3**	**3**	**9**	**6**	**6**	**7**	**5**	**2**	**0**	**0**	**5**	**3**	**4**	**62**
Concept 3	**9**	**3**	**3**	**9**	**6**	**7**	**7**	**5**	**3**	**1**	**7**	**5**	**3**	**5**	**73**
Concept 4	**9**	**3**	**3**	**9**	**9**	**9**	**5**	**5**	**7**	**1**	**9**	**3**	**9**	**4**	**85**

Table 5: Scoring concepts based on design objectives.

Concept 4 was selected from the list of system concepts based on the overall score. The determining characteristics table (**Appendix J**) was referred to while designing the alternative.

8. Detailing the alternative - Category 2

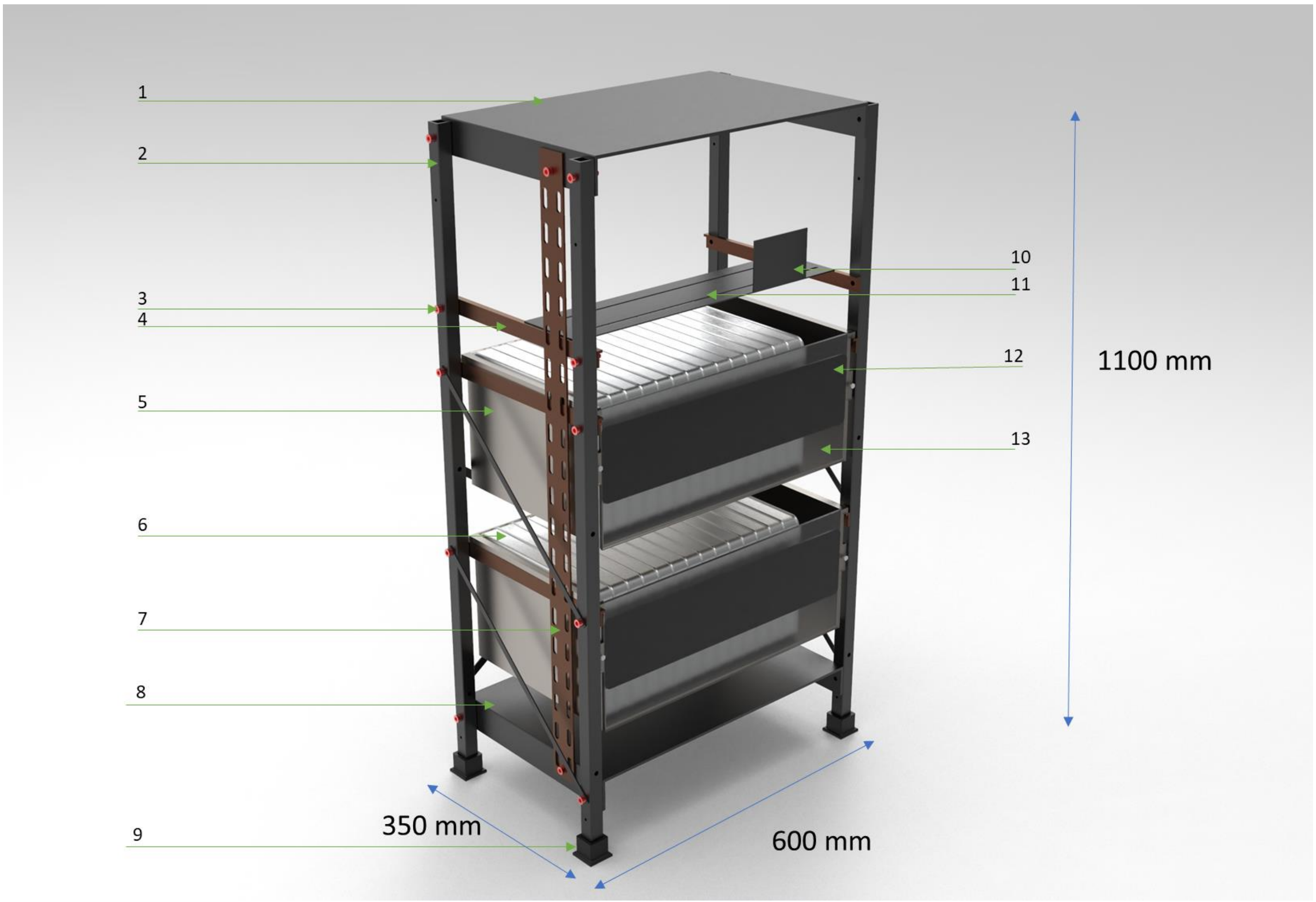


Figure 20: Detailing the alternative - Category 2 solution

The final concept is detailed with the following components:

1. Top cover: A plate made of sheet metal to provide structural rigidity.

2. Columns: Square tubes or uprights that sustain the vertical loads of the structure. There are 4 such uprights in this frame which are primarily attached to 1. and 8..

3. M8 bolts: M8 bolts are used for most of the joints in this structure.

4. Horizontal rails/supports: These members transfer the loads onto the columns/uprights and are firmly held in place by the M8 bolts.

5. Trays: The trays house the battery modules. Depending upon the type of battery module, each moudle is mounted on to the tray in a different manner. The most commonly used example for representation will be the Nissan leaf modules.

6. Battery modules: The battery modules are placed in the tray such that they have a snug fit. It is easy to install and remove a battery module from this arrangement.

7. Wire mount: This panel is used for cable management. All the wires coming out of the bus bars will be neatly secured to it.

8. Bottom cover: A plate made of sheet metal to provide structural rigidity.

9. Rubber bushings: These are added for prevention of damage to floors and to absorb shocks while the system is being placed on the floor.

10. Vertical panel: This panel houses the led screen, switches etc for ease of access to the user.

11. Power electronics tray: This section houses the power electronics such as BMS, relays etc.

12. Bus bar connectors: These connect all the terminals of the battery modules [depends on the type of battery module being used]

13. Plexi glass: The plexi glass packs the battery modules into the tray by applying a small pressure to hold the modules in place.

Figure 21: Bracing the structure.

To add further structural rigidity to the system, and to mitigate the parallelogram effect, the following braces were added:

1. Z- braces: Z braces were selected as they maximise stiffness for vertical loads, and also for ease of assembly of this particular system. Z braces provide stiffness for loads in the X direction.
2. Spine braces: Spine braces provide stiffness in the Y dirction.[24]

Stress analysis of various structural members:

For stress analysis Ansys R1 2021 Academic was used, with maximum amount of nodes = 50000. The columns, the horizontal beams/rails, the trays and the braces of the frame were chosen for investigation through finite element analysis.

1. Columns:

Material chosen: Aluminium alloy

Nodes: 15718, Elements = 8168

Fixed: bottom surface of the column, top end is free.

Bearing loads of – 377.5 N applied onto both hole number 3 and 4 counting from the bottom end of the column.

Deflection = 2 mm observed for thickness of 4 mm

Column thickness	Max. total deflection
4 mm	2 mm
5 mm	1 mm

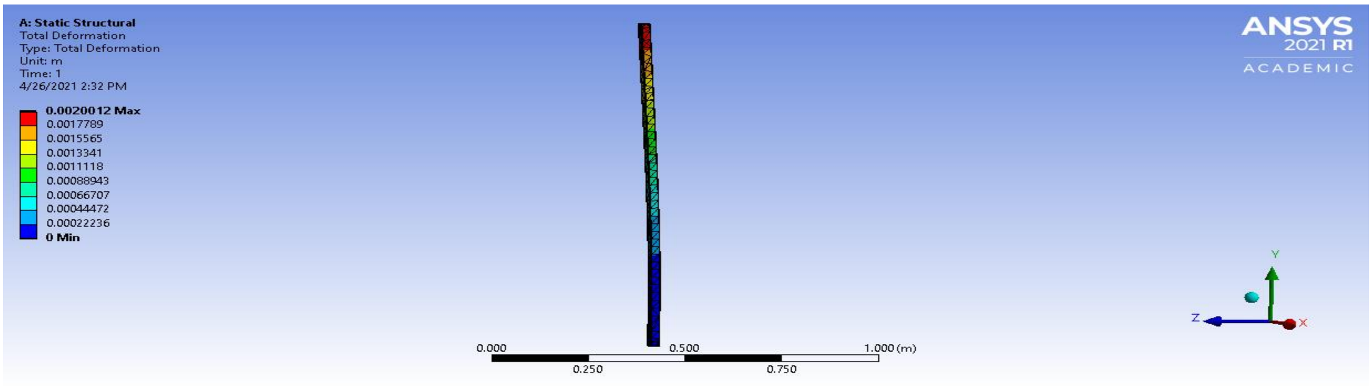


Figure 22: Deflection of 4mm thick columns.

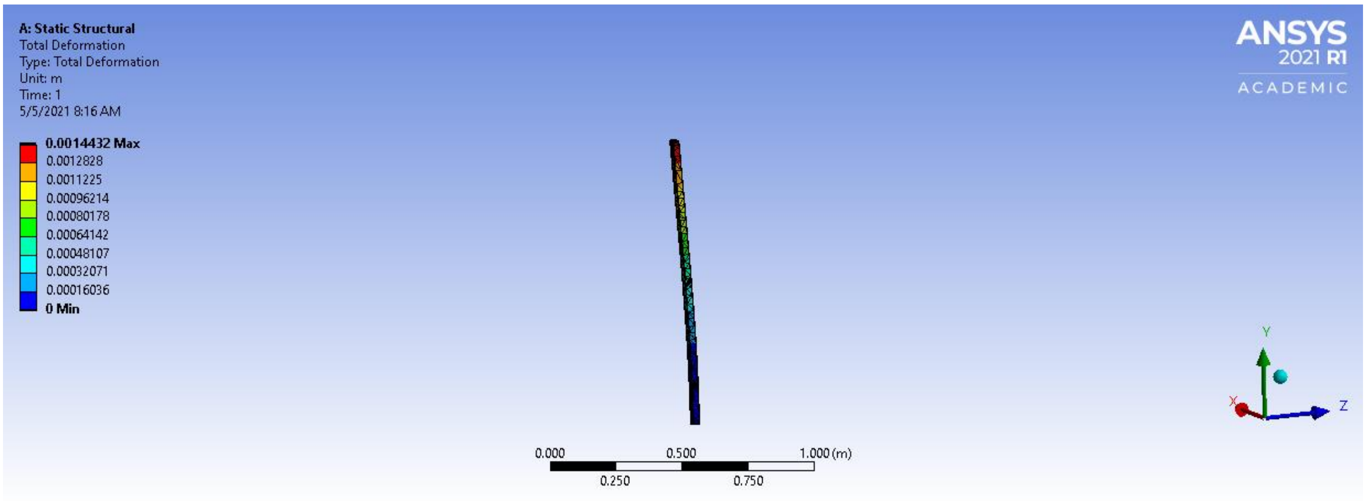


Figure 23: Deflection of 5mm thick columns.

Determining critical load for the column:

Outer width = 25mm

Inner width = 17 mm

Length = 1100 mm

E [Youngs modulus] = 71000 N/mm^2

Moment of Area I = 25592 mm^4

Effective length L_e = 2200mm [one end fixed and other end free]

Crippling load $P_{cr} = \pi^2 E I / [L_e]^2$ = 3705.24 N or 377 Kg

The weight on each column is at max 50 Kg which is less than P_{cr}

2. Horizontal supports/rails:

This part is considered as a simply supported beam.

Material chosen: Structural steel

Nodes: 4036, Elements = 1933

Fixed support: surfaces on both ends are fixed such that it is similar to a beam fixed at both ends

Force of 1510 N applied onto the top face as uniformly distributed load.

Deflection = 0.4 mm observed for thickness of 4 mm

Beam thickness	Max. total deflection
4 mm	0.4 mm
5 mm	0.1 mm
2 mm	0.7 mm

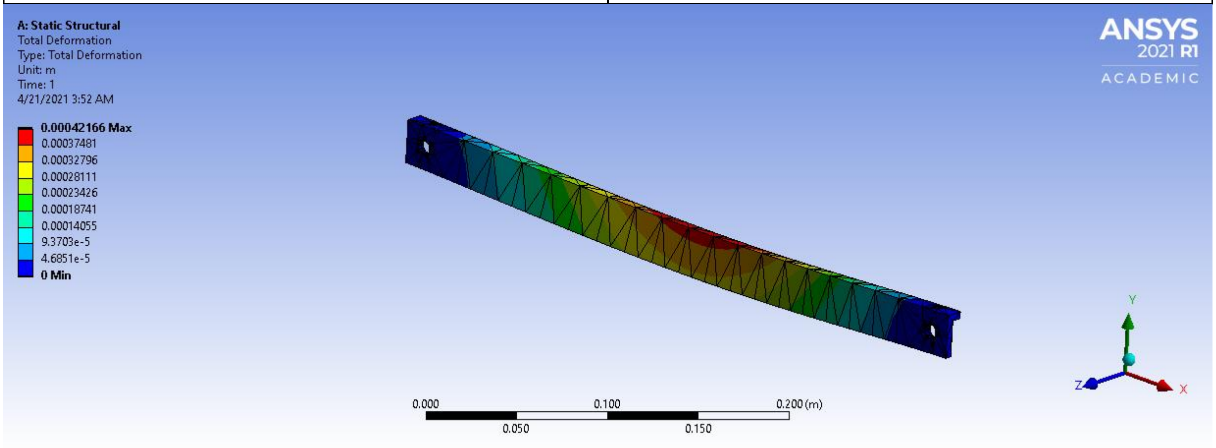


Figure 24: Deflection of 4mm thick beam.

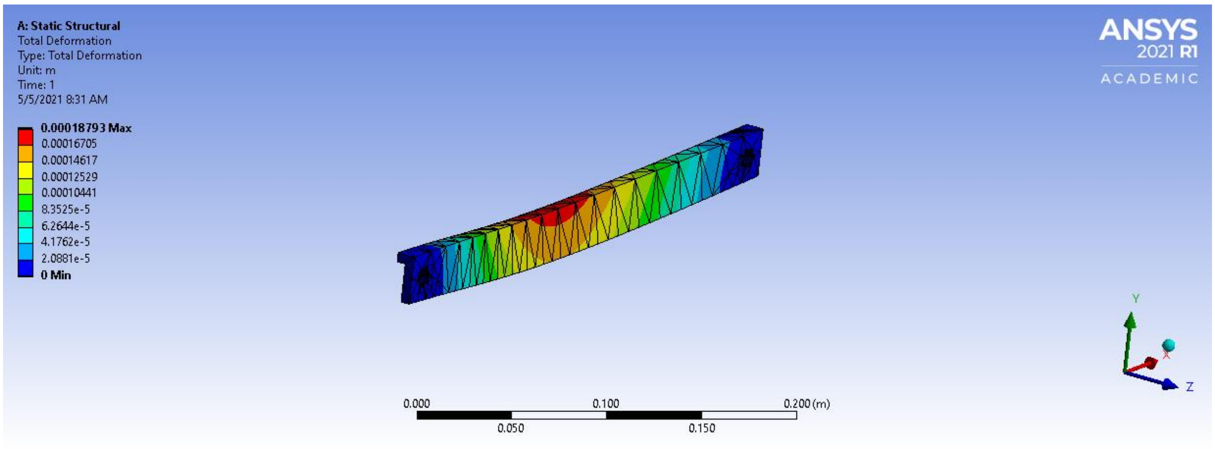


Figure 25: Deflection of 5mm thick beam

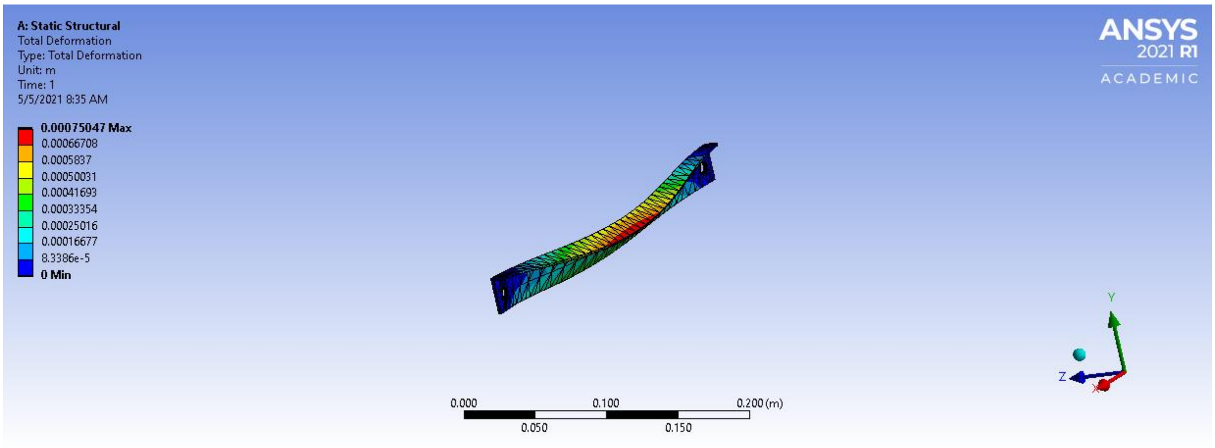


Figure 26: Deflection of 2mm thick beam.

Determining max deflection for 4mm thick beam

L = 350 mm

I = 10195 mm^4

E = 200000 N/mm^2

P = 1510 N

Deflection = $P L^3/48 EI$ = 0.6 mm which is comparable to the simulation result 0.4 mm.

This part can be further reduced in thickness for reduction in weight without compromising the strength.

3. Trays:

Material chosen: Aluminium alloy

Nodes: 7846, Elements = 3716

Fixed support: surfaces on both ends are fixed such that it is similar to a simply supported beam

Force of 1510 N applied onto the middle surface as uniformly distributed load.

Deflection = 2 mm observed for thickness of 5 mm

Tray thickness	Max. total deflection
5 mm	2 mm
7 mm	0.9 mm

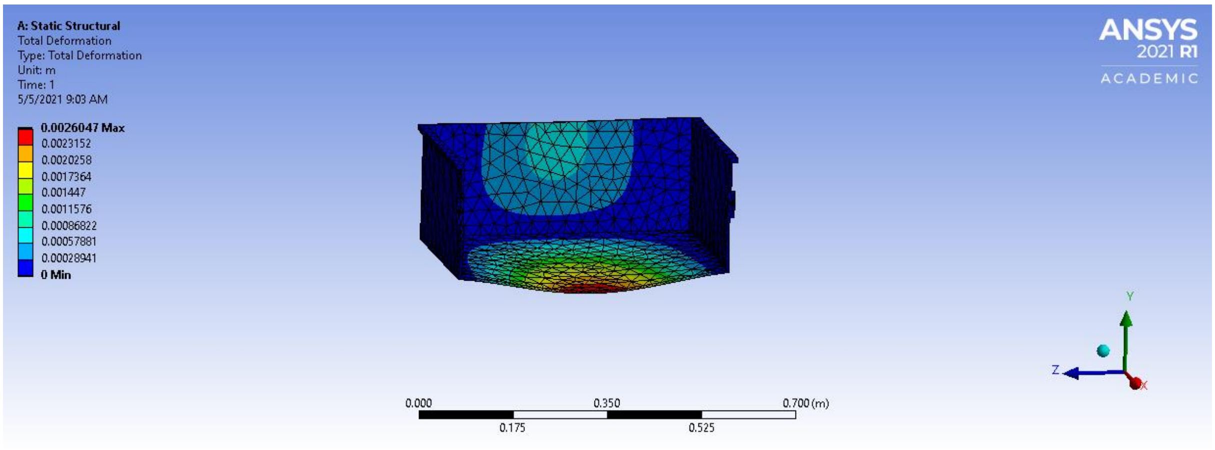


Figure 27: Deflection in 5mm thick tray

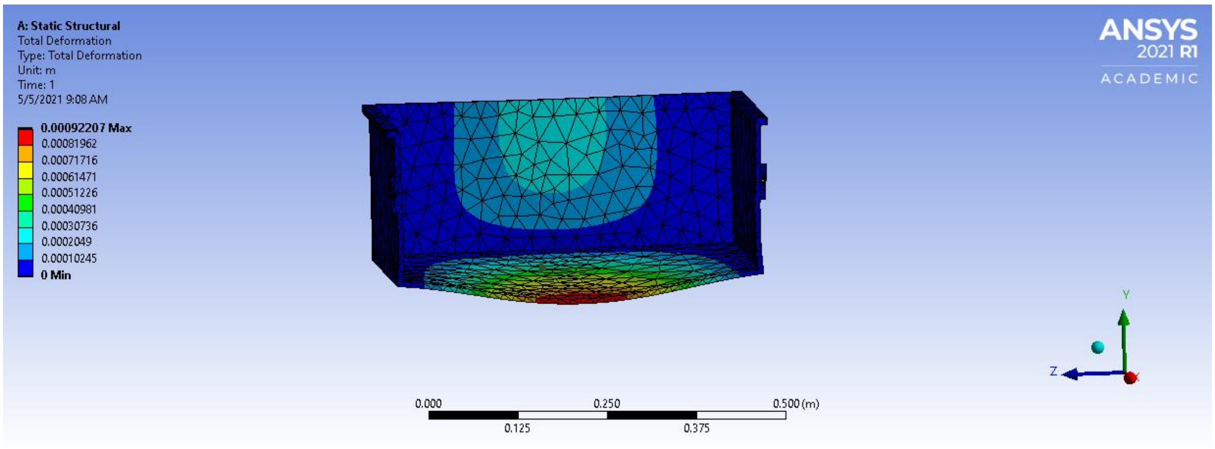
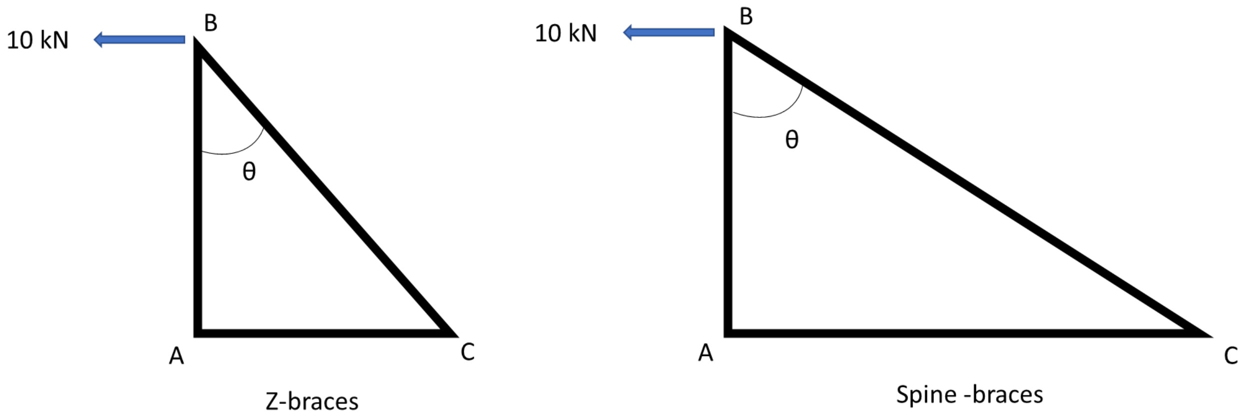


Figure 28: Deflection in 7mm thick tray.

4. Braces:

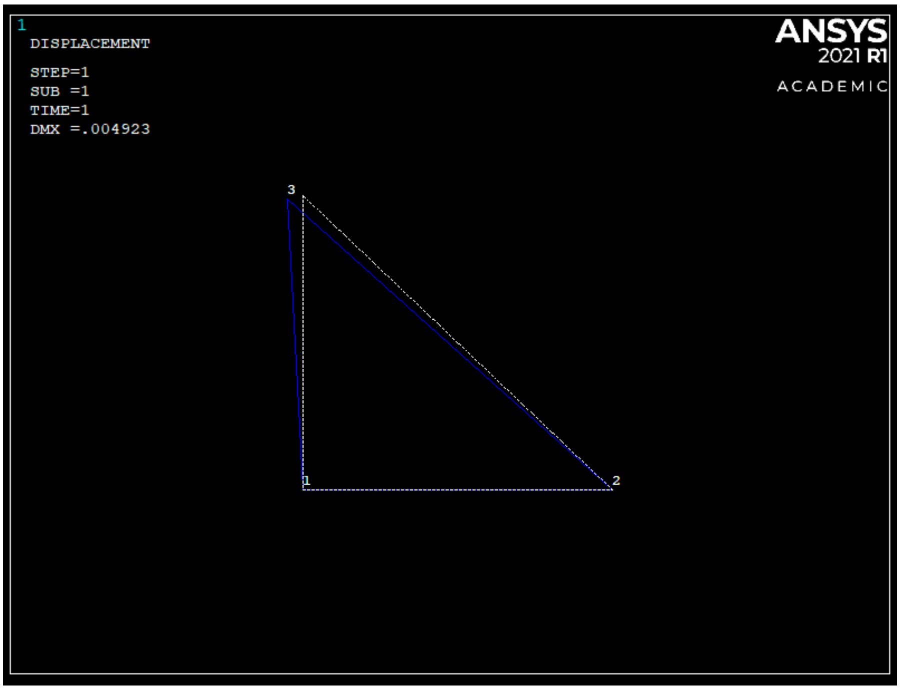


Z-braces

Spine -braces

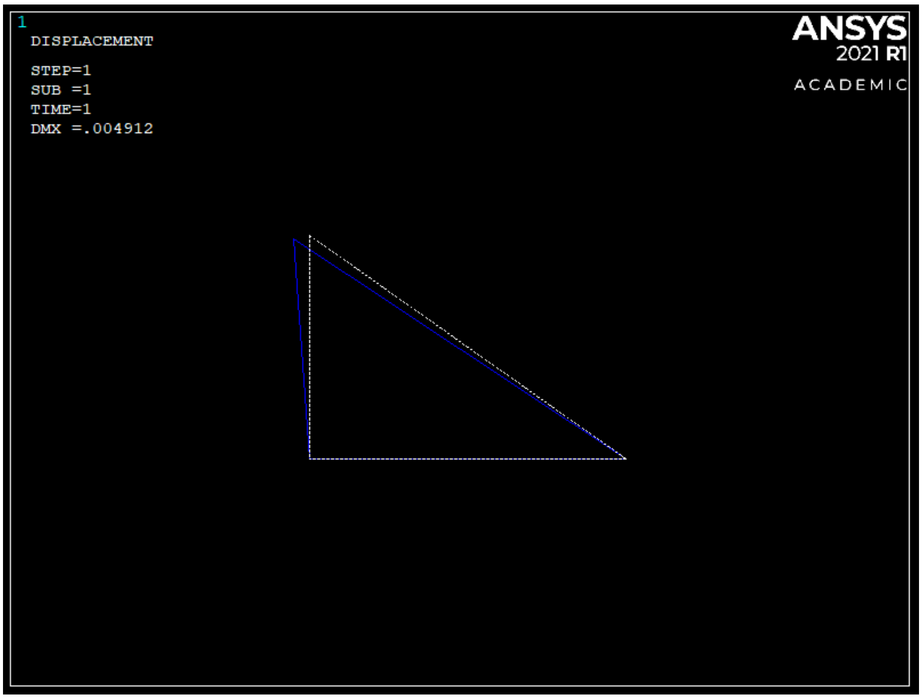
Figure 29: Braces in the frame represented as truss members.

The braces are analysed as simple truss members since they are symmetric. Points A and C are roller and pinned support, and a force is applied at point B of 10kN. The deflection of the z-brace at point B is noted as 6 mm and for spine brace the deflection at point B is 5 mm. The supporting calculations are attached in **Appendix H.** The theoretical results are verified with analysis results which gives a comparable deflection of 5 mm for both the braces (figure 30,31).



```
1
DISPLACEMENT
STEP=1
SUB =1
TIME=1
DMX =.004923
```

Figure 30: Deflection of Z-brace truss member in Ansys APDL.



```
1
DISPLACEMENT
STEP=1
SUB =1
TIME=1
DMX =.004912
```

Figure 31: Deflection of spine brace truss member in Ansys APDL.

Material Selection:

For material selection, the methods described in Material Selection in Mechanical Design by Ashby was referred to determine the material indices[23].

1. Design requirements for a light stiff tray

Function: tray

Constraints: bending stiffness S specified

Objective: minimize mass

Free variables: Tray thickness, choice of material

$M_{tray} = E^{1/3}/\rho$ is the material index that needs to be maximized.

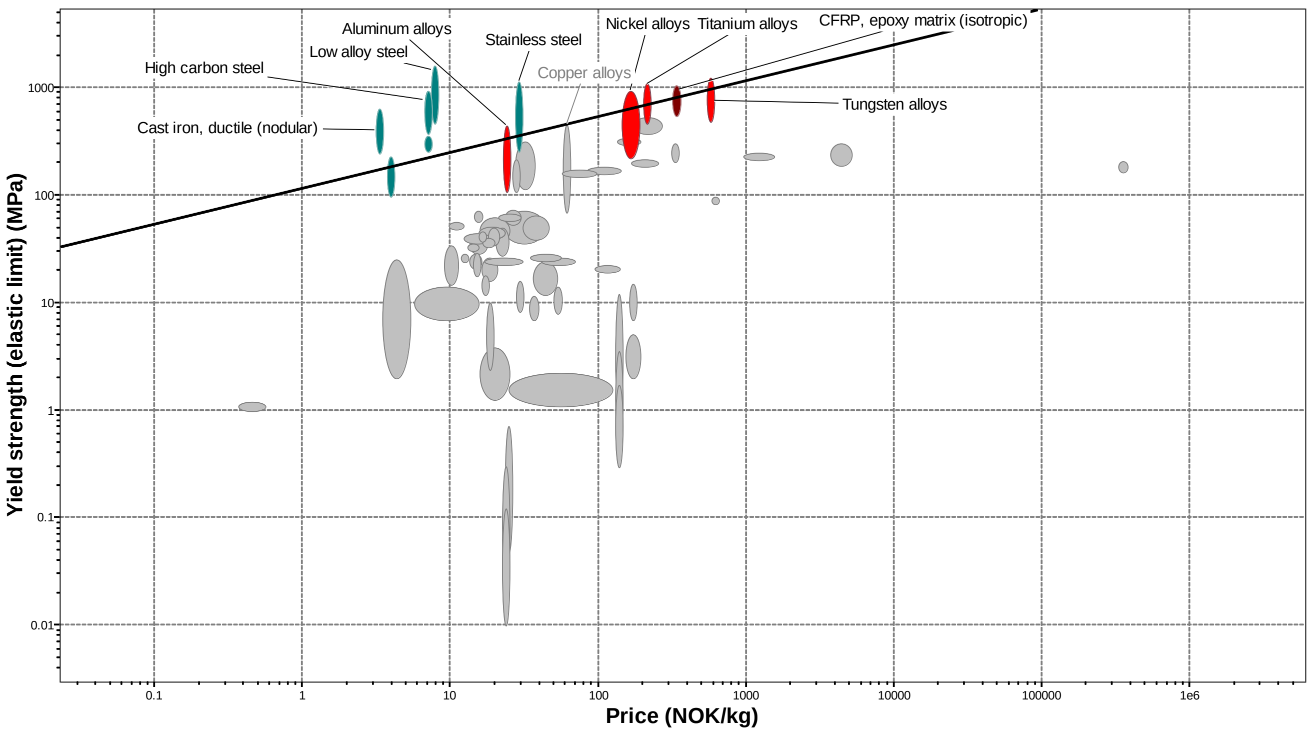


Figure 32: Yield strength vs price for material selection of tray.

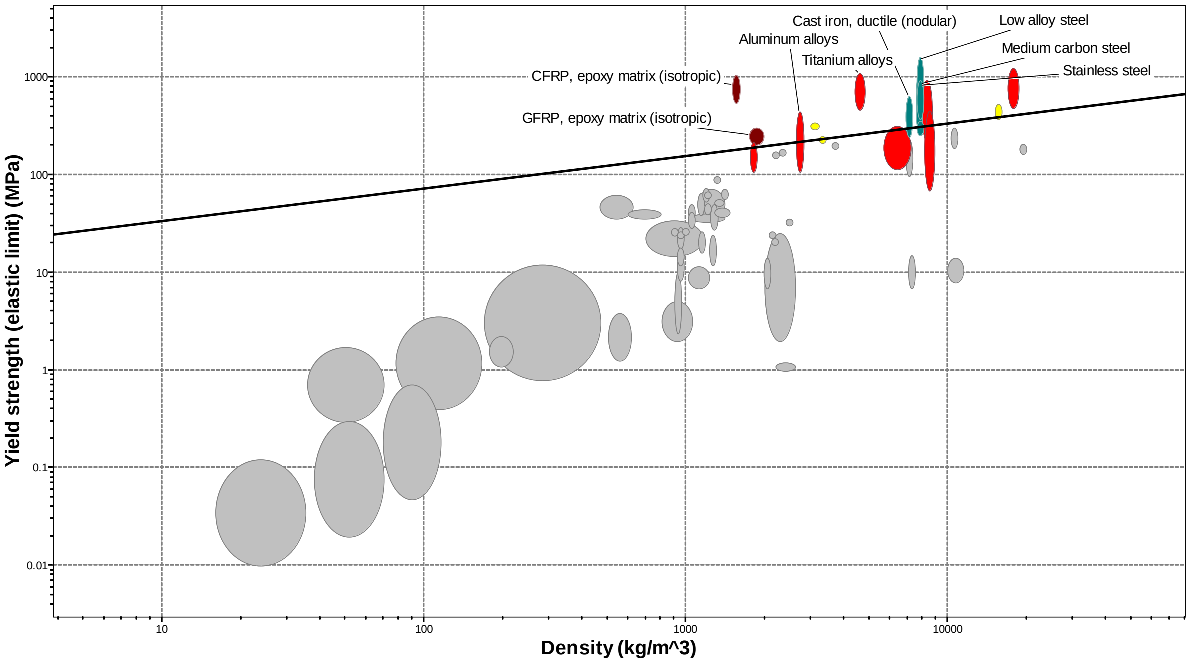


Figure 33: Yield strength vs density for material selection of tray.

From the above material selection charts, it is observed that Aluminium alloys are the best suitable material for this section due to its low weight, on the contrary Aluminium alloys are more expensive as compared to the next best options which are high,low, medium carbon steel and stainless steel. Since this part is a large member, it would be best to select Aluminium alloy to manufacture this part as there can be significant weight reduction.

2. Design requirements for a light stiff beam/horizontal support

Function: beam/ horizontal support

Constraints: Length L specified, bending stiffness S specified

Objective: minimize mass

Free variables: Beam thickness, choice of material

$M_{beam} = E^{1/2}/\rho$ is the material index that needs to be maximized.

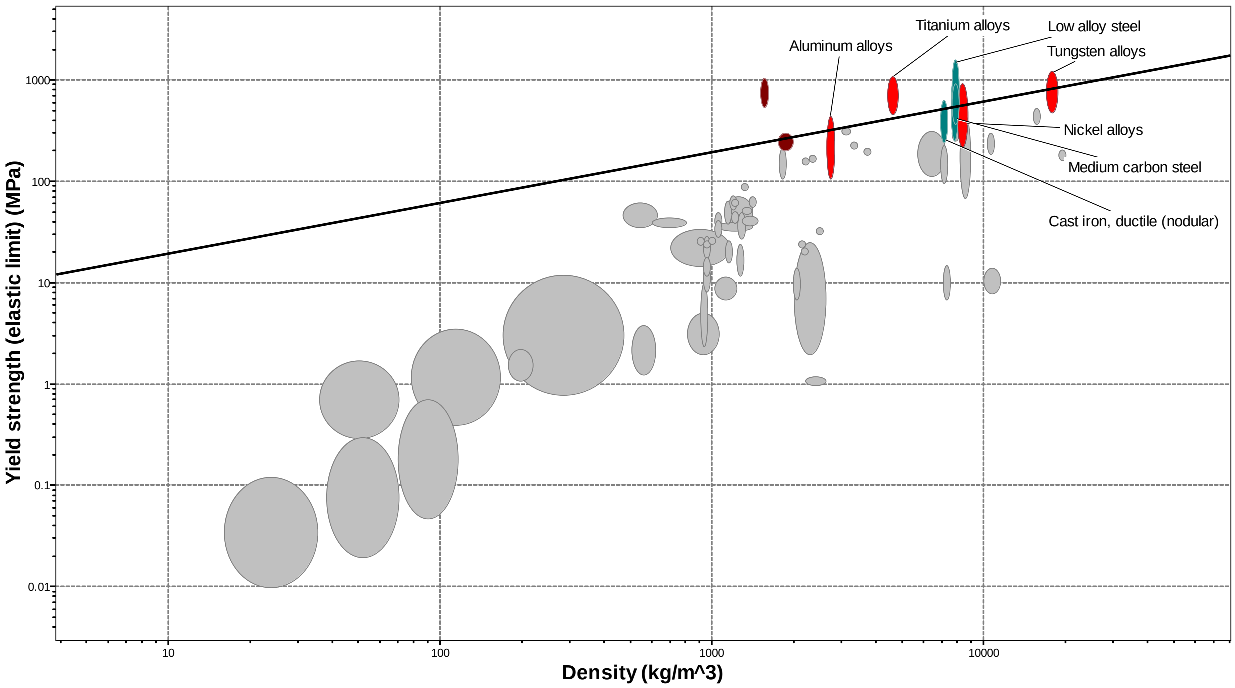


Figure 34: Yield strength vs density ofr material selection of beam.

As in the previous case, the ideal choice of material would be Aluminium alloys. Since this beam is a small member, stainless steel or high carbon steel can be utilized to make this part. There will be also a reduced cost advantage.

3. Design requirements for a light stiff column

Function: column [supporting compressive loads]

Constraints: Length L specified, must not buckle under design loads, must not fracture

Objective: minimize mass

Free variables: Column thickness, choice of material

$M_{column} = E^{1/2}/\rho$ is the material index that needs to be maximized.

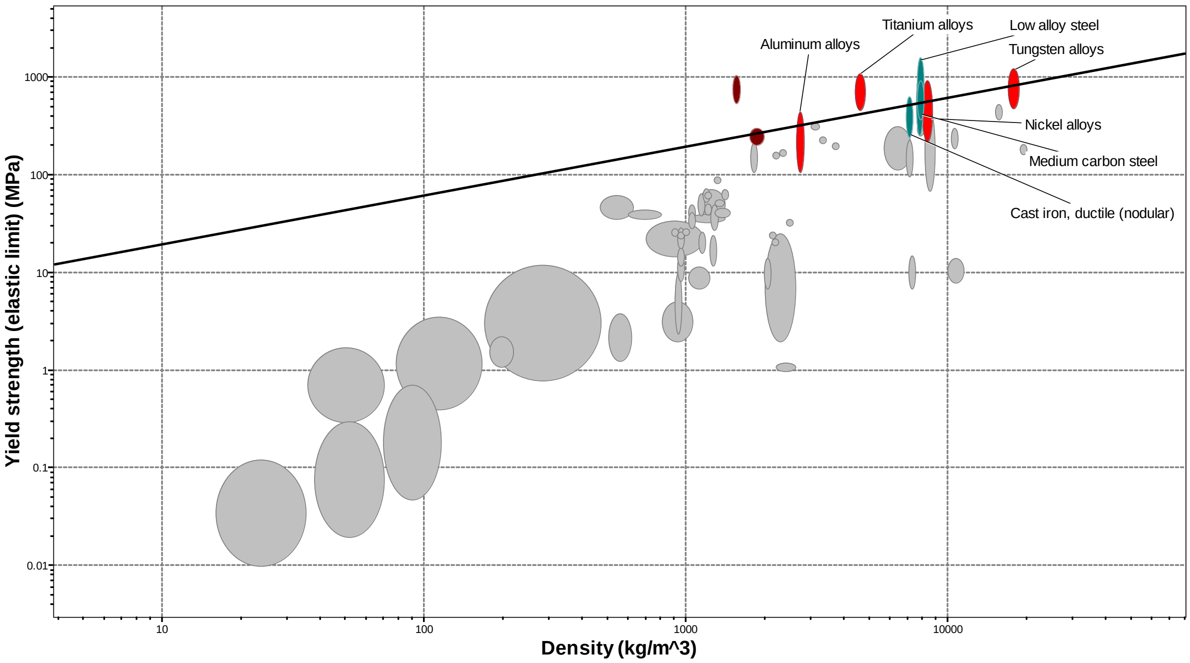


Figure 35: Yield strength vs density for material selection of column.

The optimal choice of material here is Aluminium alloys, solely for the reduction of weight purpose.

9. Casing design

Few preleminary outer casing design concepts were explored (**Appendix F**). The following casing design was selected based on ease of manufacture using sheet metal, ease of assembly(figure 36) and for the aesthetic value .

Figure 36: Casing design with RePack logo.

10. Generating alternatives - Category 3

Concepts generated in **category 3** were influenced by the locally available materials and manufacturing methods for quick and easy prototyping. This was done solely for the pupose of rapid prototyping, which is carried out to asses the design flaws at an early stage of design. This concept has the frame and the casing integrated into one. On exploring designs for similar applications, few simple alternatives were generated :

1. A handheld portable battery module unit made from PLA (figure 37) [which is close to polycarbonate and ABS plastic used in making suitcases] . Advantages include: This design is easy to make using a 3D printer, the design can have complex curves for visual appeal. Disadvantages include: Long time to 3d print [10 days], uses a lot of PLA , cost, thick and heavy [4 Kg+].

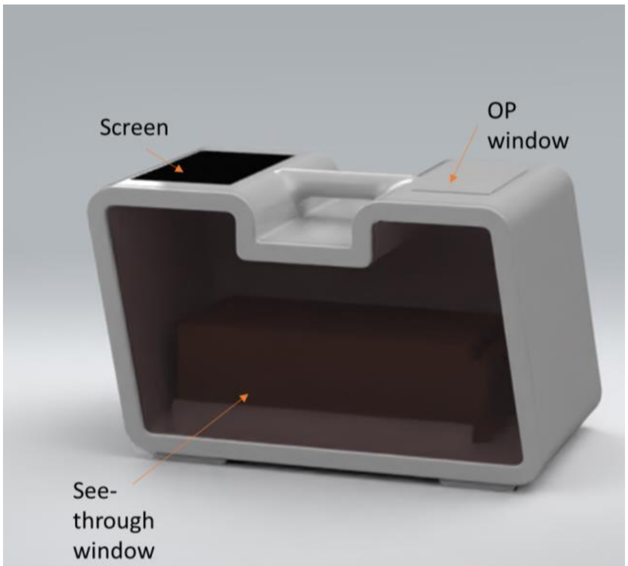


Figure 37:Category 3, handheld BESS concept 1.

<u>2. Handheld portable battery module unit made purely from sheet metal (figure 38).</u> Advantages include : thin, lightweight [<2Kg] and sleek design, can be manufactured faster than 3d printing. Disadvantages: an expert intervention is required to carry out sheet metal works such as cutting, bending and welding, cannot make complex curves, rough surfaces and edges, design must undergo further finishing processes to have a smooth surface finish.

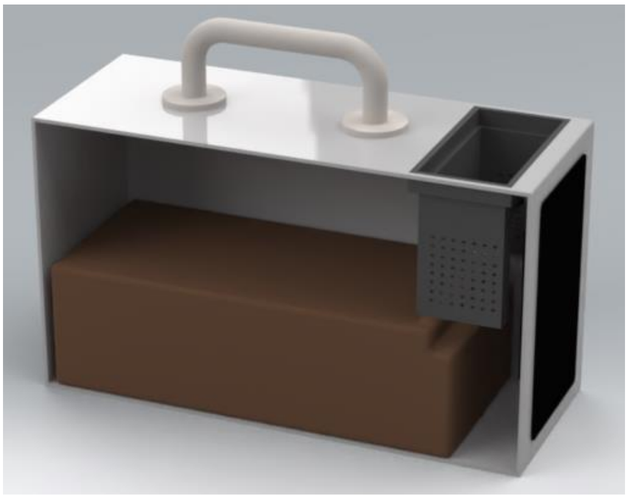


Figure 38: Casing made with sheet metal, handheld BESS concept 2.

<u>3. A case made with combination of sheetmetal and 3D printing (figure 39)</u>. It is primarily from sheet metal and rough edges and surfaces covered with 3d printed parts. Advantages: Less cost, less manufacturing time, curved edges. Disadvantages: finishing process and

assembly.

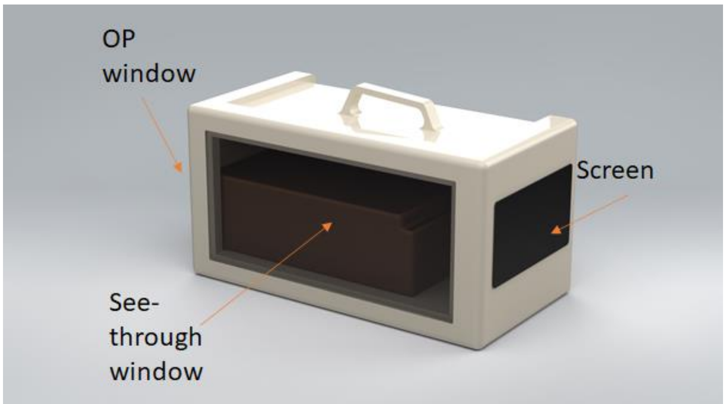


Figure 39: Sheetmetal+ 3D printed casing

4. Other case concepts explored w.r.t materials and manufacturing were case made of wood and case made of thermoforming polymers. These concepts were rejected for rapid prototyping due to difficult manufacturing process or requirement of expensive craftmanship.

10.1. Selecting an alternative - Category 3

Selection of a concept in category 3 was done considering rapid protoyping. Hence quick and easy to manufacture was priortised. The sheetmetal + 3d print design was considered to be the best solution satisfying the design objectives and requirements.

11. Detailing the alternative - Category 3

The selected alternative was detailed with the following components:

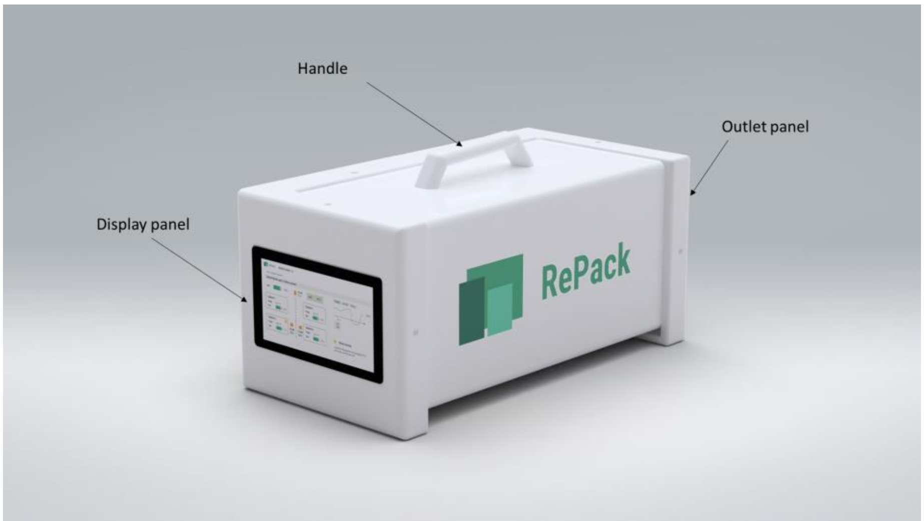


Figure 40: Detailing the alternative, category 3 solution

Display panel: This section houses the raspberry pi display to show-case battery data. The display is fit using 4 M3 screws.

Handle: An ergonomic handle to carry the casing with battery module.

Outlet panel: This section houses the power button, usb outlets and a charging port. It is removable and is secured using 4 M3 screws. It is covered with a hinged door with magnetic ends to lock it in place (figure 41).

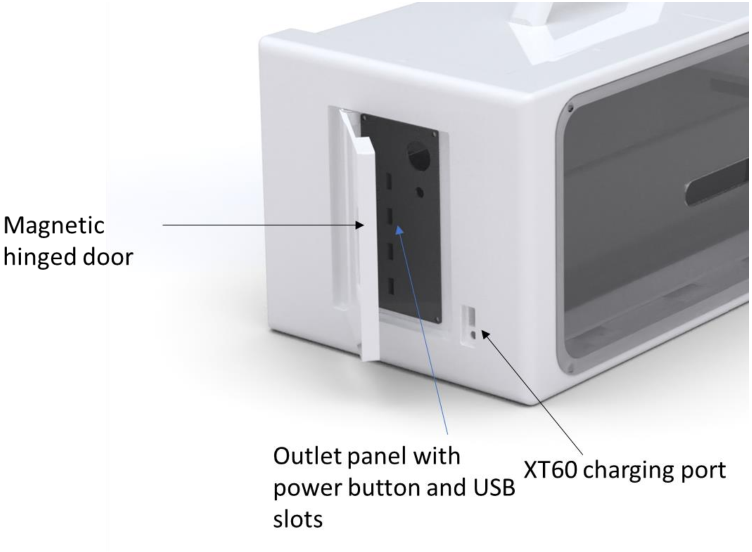


Figure 41: Outlet side

Securing battery module: The battery module is mounted on to the floor of the casing . The battery module is secured with 2 M8 nut-bolts going through the mounting points in the battery module.

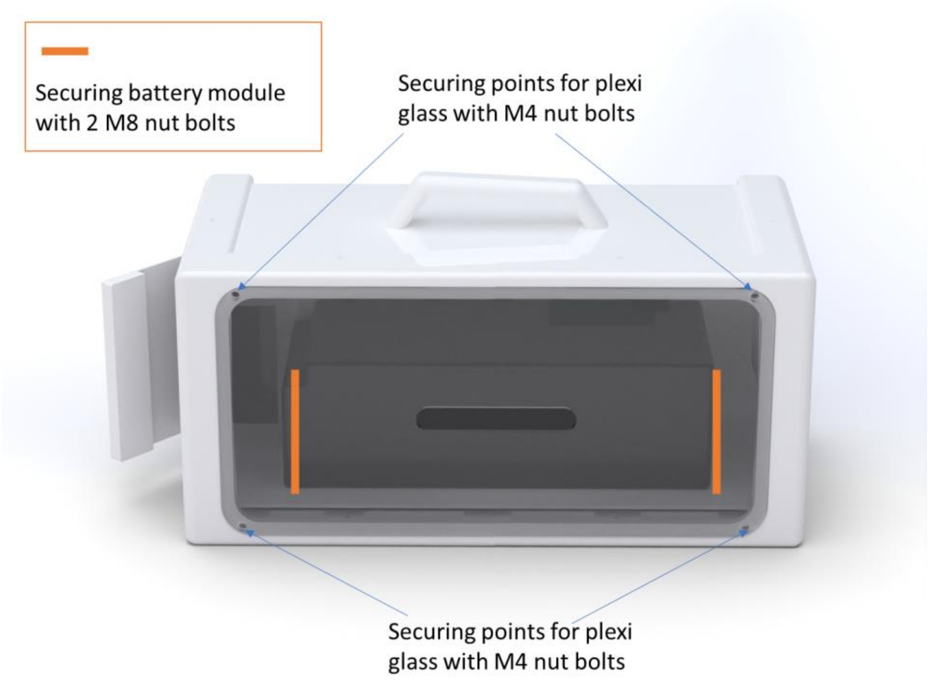


Figure 42: Front view, securing battery module and plexi glass

Plexi glass: The plexi glass in the front is to showcase the tech inside. It is secured using 4 M4 nut bolts in the four corners (figure 42). More information on the parts, manufacturing and assembly of category 3 solution is presented in **Appendix A,B,C,D.**

12. Discussion

The frame design for **category 2** solution has been detailed with bill of materials and cost (**Appendix G**). The iproperties function in inventor was used to derive the masses of the components. The overall weight of the design is around 30 Kg. Various casing designs were explored and the next steps regarding the production has been added in further work.

The final prototype was manufactured for **category 3** solution (**Appendix A**). The prototype was sent to students at NTNU Trondheim for assembly of electronics. The feedback form related to the solution has been filled and appended(**Appendix C**). This feedback will be used in further work for the next iteration of design. The overall weight of the prototype is 14.5 Kg including the battery module and 3.5 Kg exculding the battery module.

13. Conclusion

The primary task objectives were clarified. The product requirements were investigated with the company RePack. The main functions of the product were established, and few concepts were explored in both categories of solution space. The concept generation process was expanded. Two detailed design concepts were generated for both the categories of solution mentioned. One rapid prototype was manufactured.

14. Further work

- Further work in **category 2** solution are:
  -Experimenting with K-braces to improve stiffness,
  -Simplifying manufacturing, and assembly by reducing the design into fewer parts,
  -Thermal analysis and design of ventilation for the casing,
  -Production planning.
- Further work in **category 3** solution are:
  - Reducing the part complexity for manufacturing using molding process,
  - Introducing an option for cable management.

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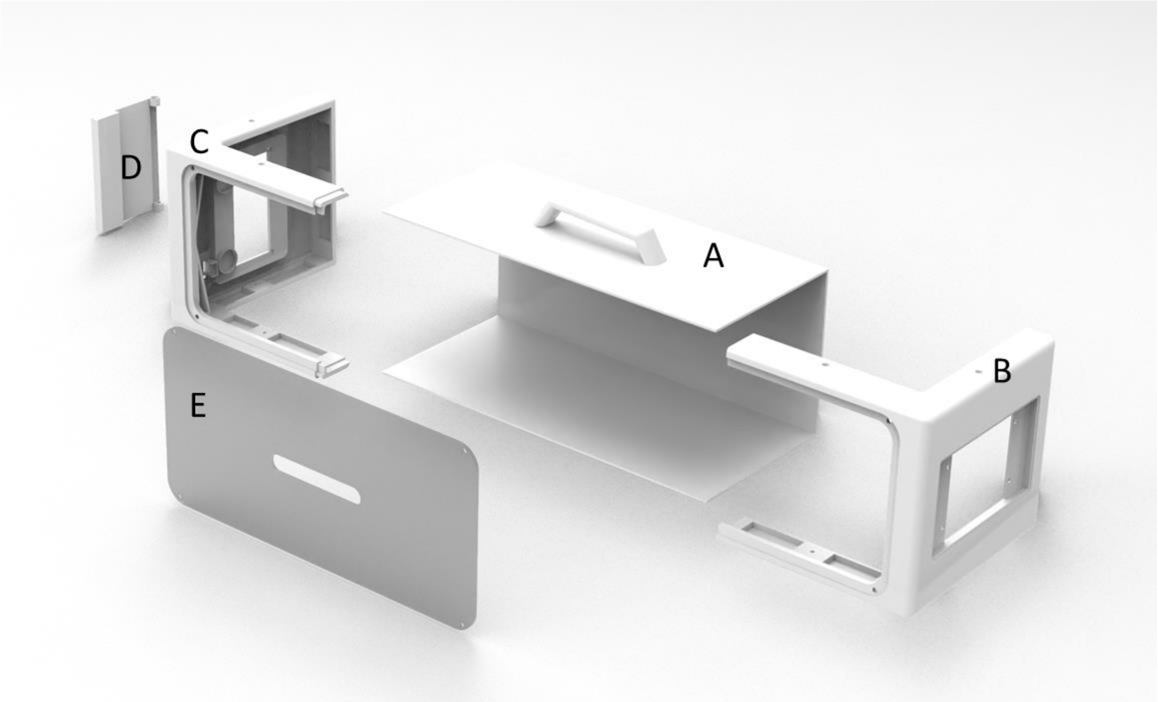
[25] 3D modelling and rendering was carried out using: Solid Works, Solid Work visualize (startup license), Auto Desk Inventor (student license)

Appendix A – Catgory 3 - Manufacturing

Manufacturing the prototype – Category 3:

The prototype had the following major types of parts:



A – Sheet metal casing and frame to mount and support the weight of the battery module. This part was designed considering sheet metal properties.

B – Screen side part for mounting the raspberry pi screen and to cover the sharp edges of the sheet metal part. This part was designed to be 3D printed from PLA.

C – Output side part for housing the output panel containing charging port and USB ports. This part also covers the sharp edges of the sheet metal. This part was designed to be 3D printed from PLA.

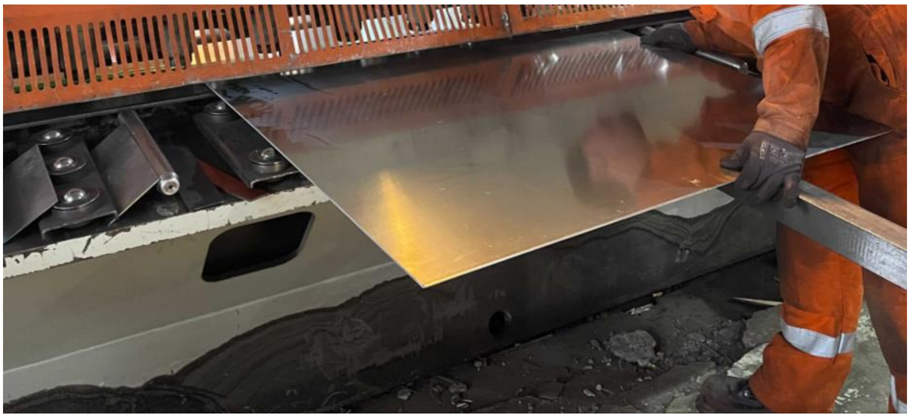
D – Lid to protect the output panel from external atmosphere. This part was designed to be 3D printed from PLA.

E – Plexi glass to showcase the tech during technical demonstrations. This part was designed to be laser cut.

The manufacturing of the parts mentioned above are made in the following manner:

The sheet metal work of part A was done at Ofoten Mek Narvik. The following process was carried out:

1. Sheet metal cutting: Aluminum alloy of 3mm thickness was cut the desired dimensions.

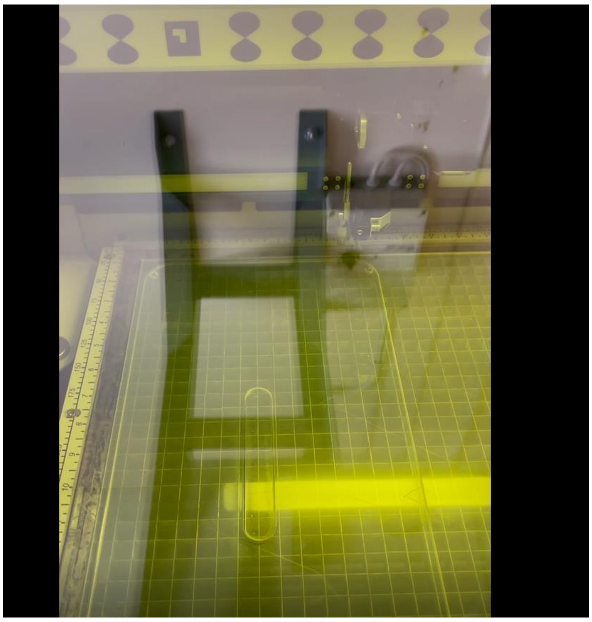


2. Sheet metal bending: The cut piece was then bend in a “U” shape.

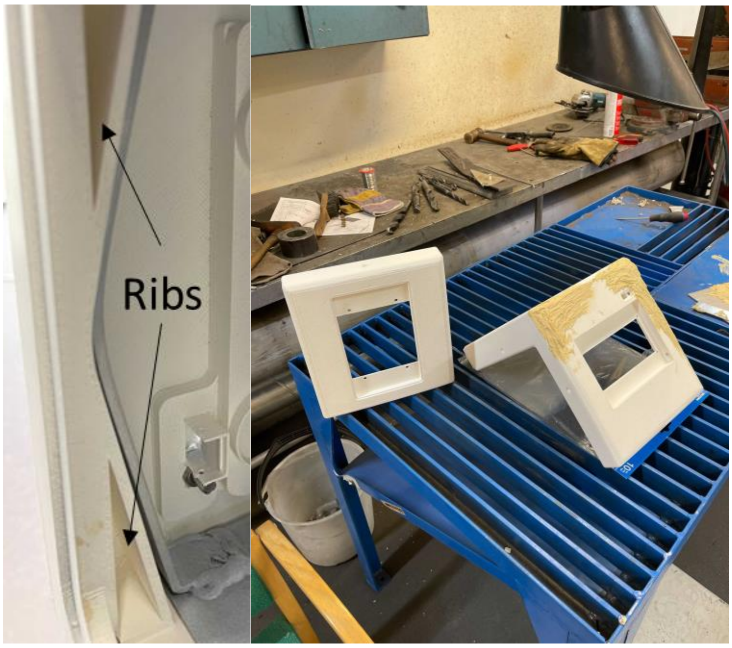
3. Welding: The bend part was then welded with support structures.

4. Drilling: A drilling setup was used to drill holes of various dia viz used to attach the 3d printed parts and to mount the battery module. From here the manufacturing was done at various labs at UiT, Narvik.

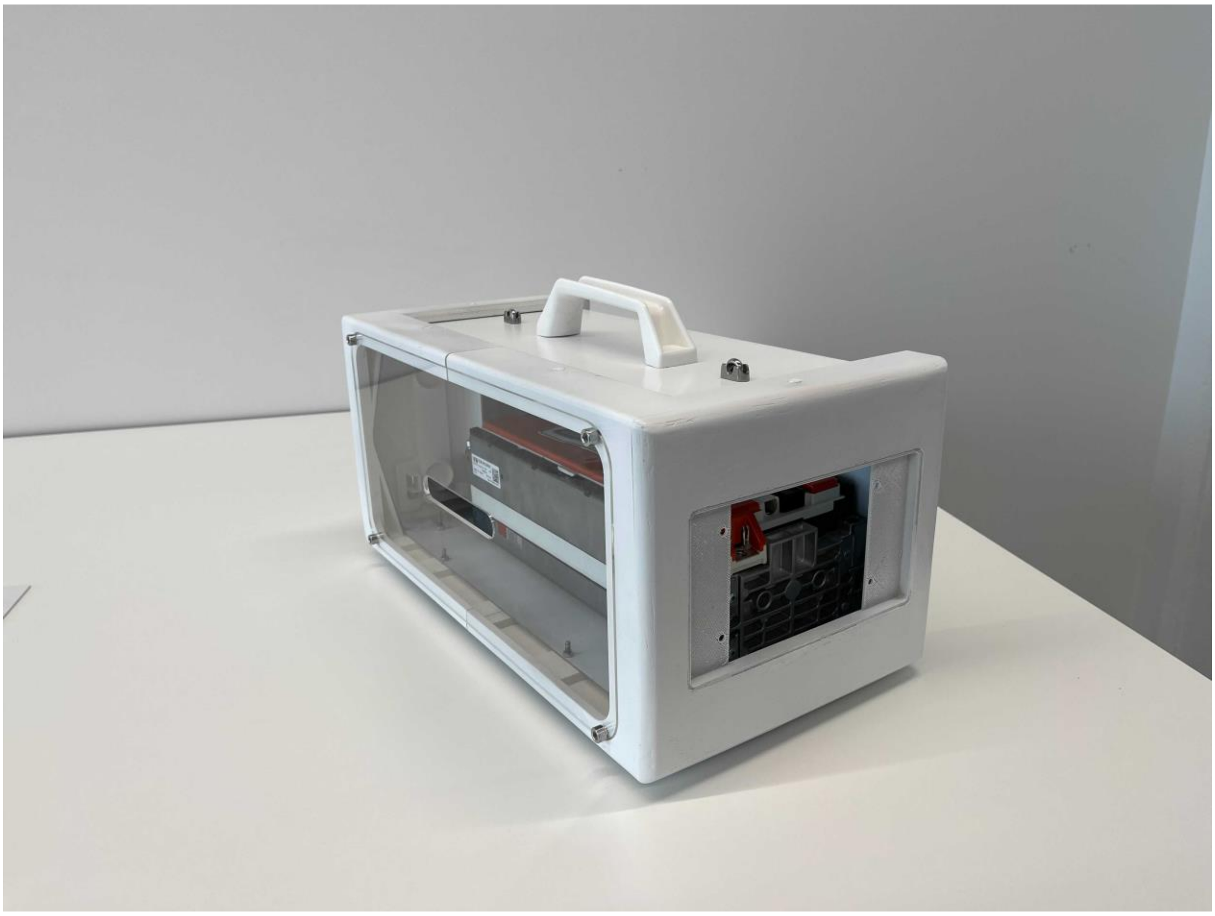
5. Laser cutting: The plexi glass (Part E) was cut using a laser cutting tool. A slot is cut in the middle of the plexi glass for ease of placing and removing it from the case.



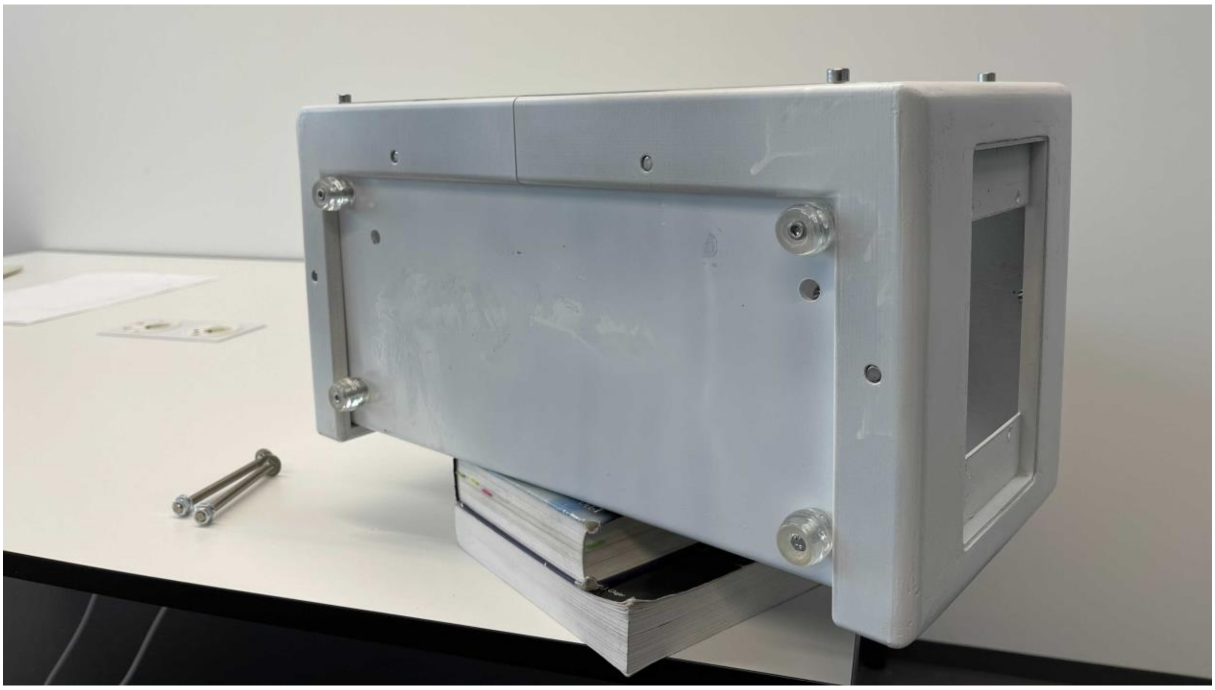
6. 3D Printing: Part B,C and D were 3d printed. Ribs were introduced in the 3d printed parts to reduce weight and print material. Minor defects were corrected using Spackel and then sanded.



7. The finished parts were assembled, and then spray painted. A caravan door handle was used for the handle.



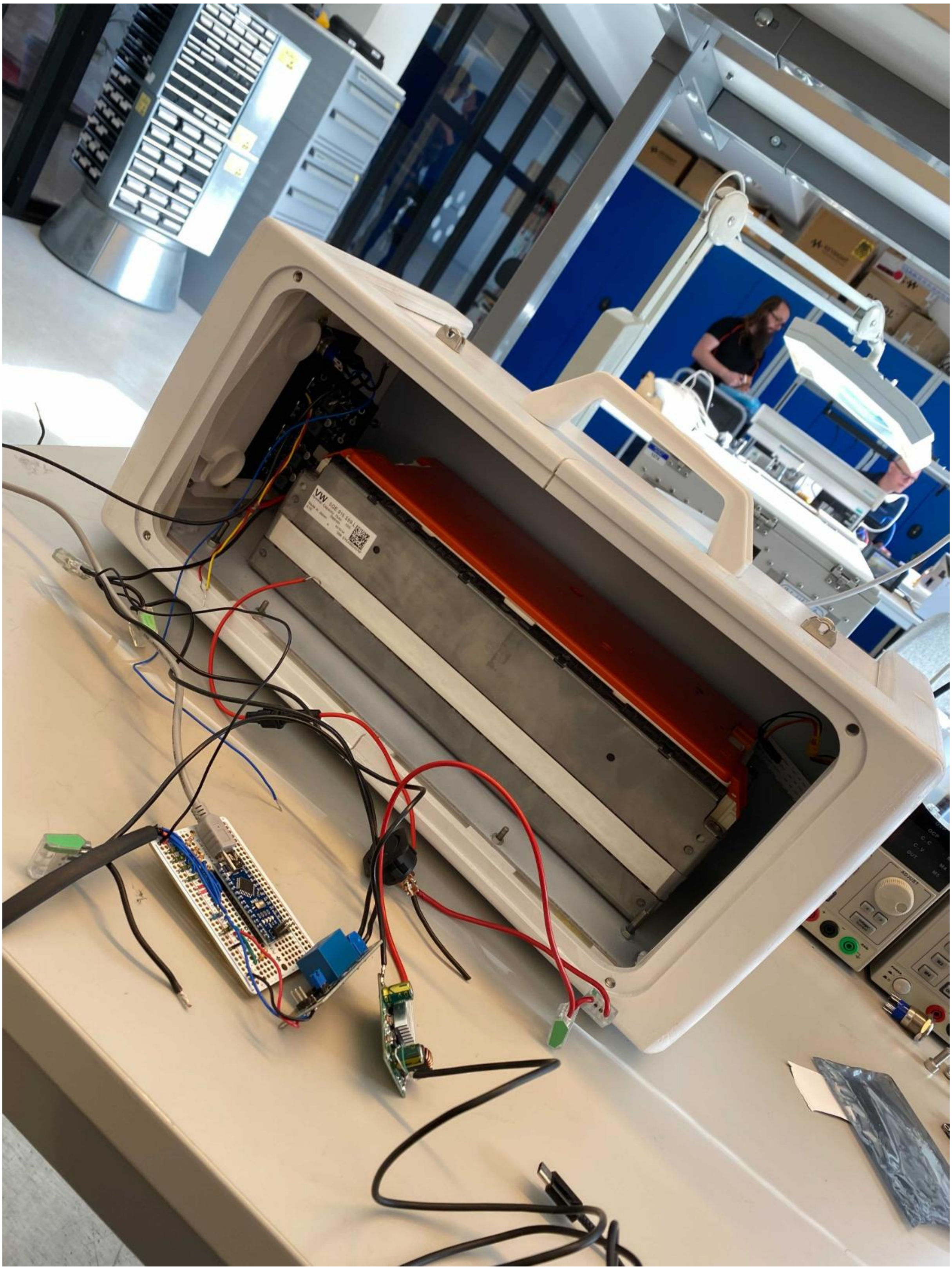
8. Rubber feet was added at the bottom for shock absorption.

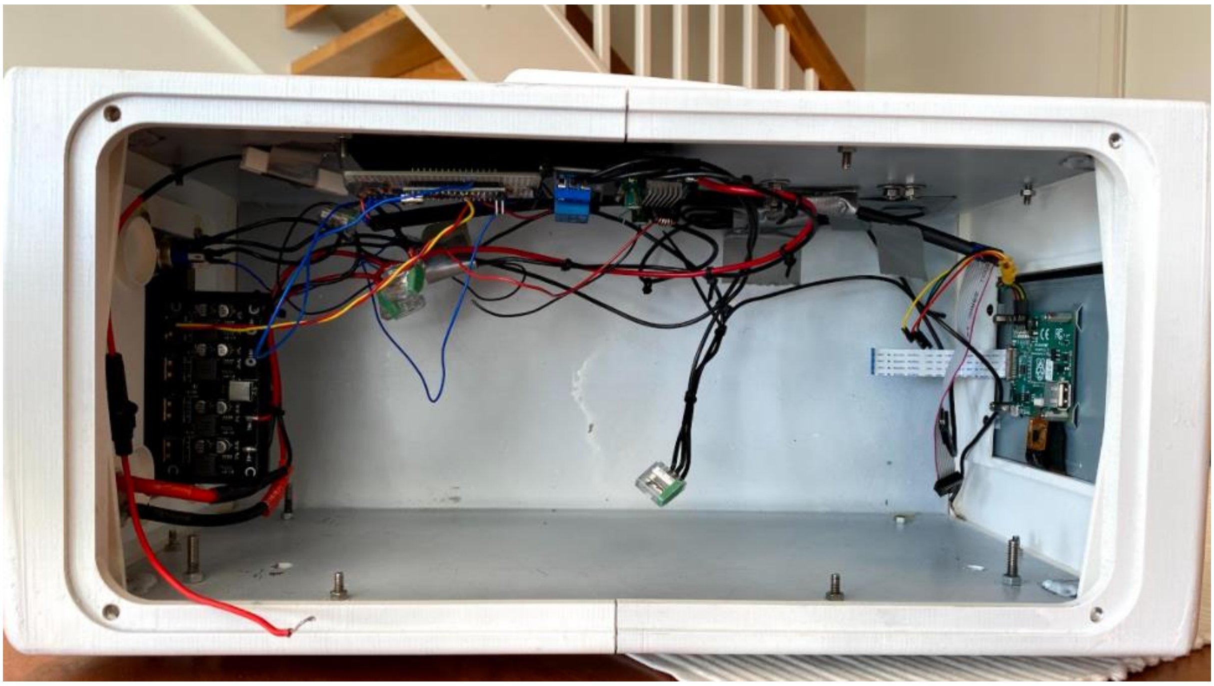


Appendix B - Category 3 – Installation of electronics

Installation of electronics at FAKTRY, NTNU Trondheim:

The following images show the installation of the electrical components, outlet panel, charging xt60 connector, raspberry pi display.





Appendix C – Category 3 – Feedback form

FEEDBACK FORM CASE DESIGN REPACK MINI

Filled by Herbert Wikheim [sensors and communication intern @ RePack, engineering student @ NTNU]

Please score the following from the perspective of ease of installation and assembly of the RePack Mini

1. Mounting and removing the battery module [1-5] with 5 being easiest.

Remarks: It boils down to the electronics and their placement. Mounting the battery without it is perhaps a 4, but as there is little room/mounting for the electronics the score sits around 2.5. The USB PCB sticks out a bit and is a little close to the battery.

2. Installing the output panel [1-5] with 5 being easiest.

Remarks: Very easy and intuitive, 5

3. Installing the screen [1-5]

Remarks: The mounting holes were a bit off, but otherwise around 4 after putting the screen down towards the table

4. Installing the xt60 charging connector [1-5]

Remarks: Not very easy to do to be honest, but i found an easy solution, epoxy haha. The mounting didn’t fit, had just a little deformation and perhaps too little clearance. So I just sanded it down and used way too much epoxy and voila. So I guess a 2?

5. Fixing the plexi glass [1-5]

Remarks: Quite easy, 4.5. Only thing to pick on was that the one side lacked a millimeter or so clearance to be a 5, requiring just a bit of strain to screw.

6. Ease of installation of wiring and other electronic components [1-5]

Remarks: Well this was the hardest part, as it usually is in an assembly, i guess. We thought there was to be some clearance behind the battery, which could’ve made the process a bit easier and cleaner. We instead opted to use the roof and tape the electronics (not the best solution, but there were time constraints). This worked for a bit, but after a while it fell down on its own and got in the way again. So as there was no designated mounting i guess the score should be around 2? There was room in there for it, not much, but enough. There were just no wire holders or mounting for zip ties or such to make it easier.

7. Overall shape and design of the case [1-5]

Remarks: Very nice!!! I look at it constantly as I walk by it multiple times a day. A 5 from me

8. Carrying the case fully assembled and ergonomics of the handle [1-5]

Remarks: Guess a 4 as it could’ve included some padding on the handle to

9. Any parts that had come off like [nuts, screws, any broken components etc]

Remarks: Think a nut from the upper left plexi fitting fell out once, plugged it in and never had an issue after haha.

Appendix D – Category 3 – Assembly instructions

The following assembly instructions were provided to the students of NTNU for easy of assembly.

1. Install the screen first

2. Mounting the battery module:
Mount the battery module by aligning the mounting points on the battery module with the 10mm holes on the base of the casing. You may place the casing on the corner of a table as shown in pic for ease of mounting.

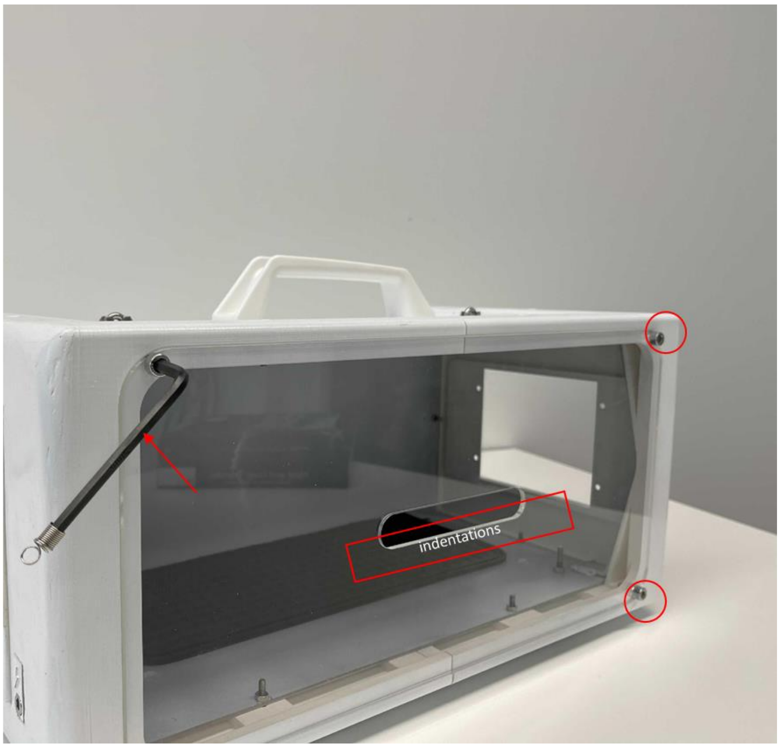
Make sure the battery module does not impact the PLA 3d print as the printed part can be quite fragile/brittle. The battery module can be easily placed or removed from the casing by placing one hand underneath the battery module for support. Lifting and placing the battery module by holding the sides are not recommended.

2. Mounting the battery module:
Send the 8mm bolts through the 2 holes and secure it with the nut.

If the bolts are not going through, slight adjustments of the module always work.

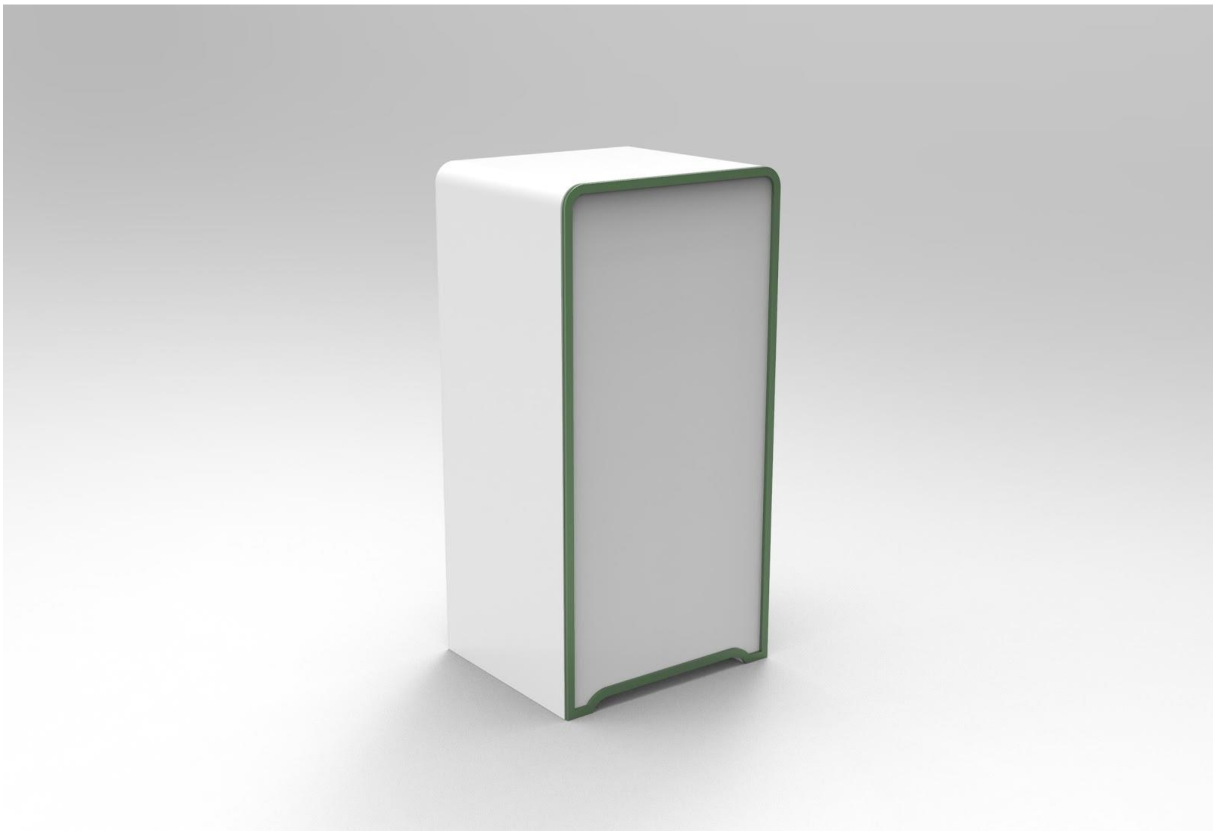
3. Charging connector:
The charging xt60 connector can be tightly fit in the space shown in the picture.

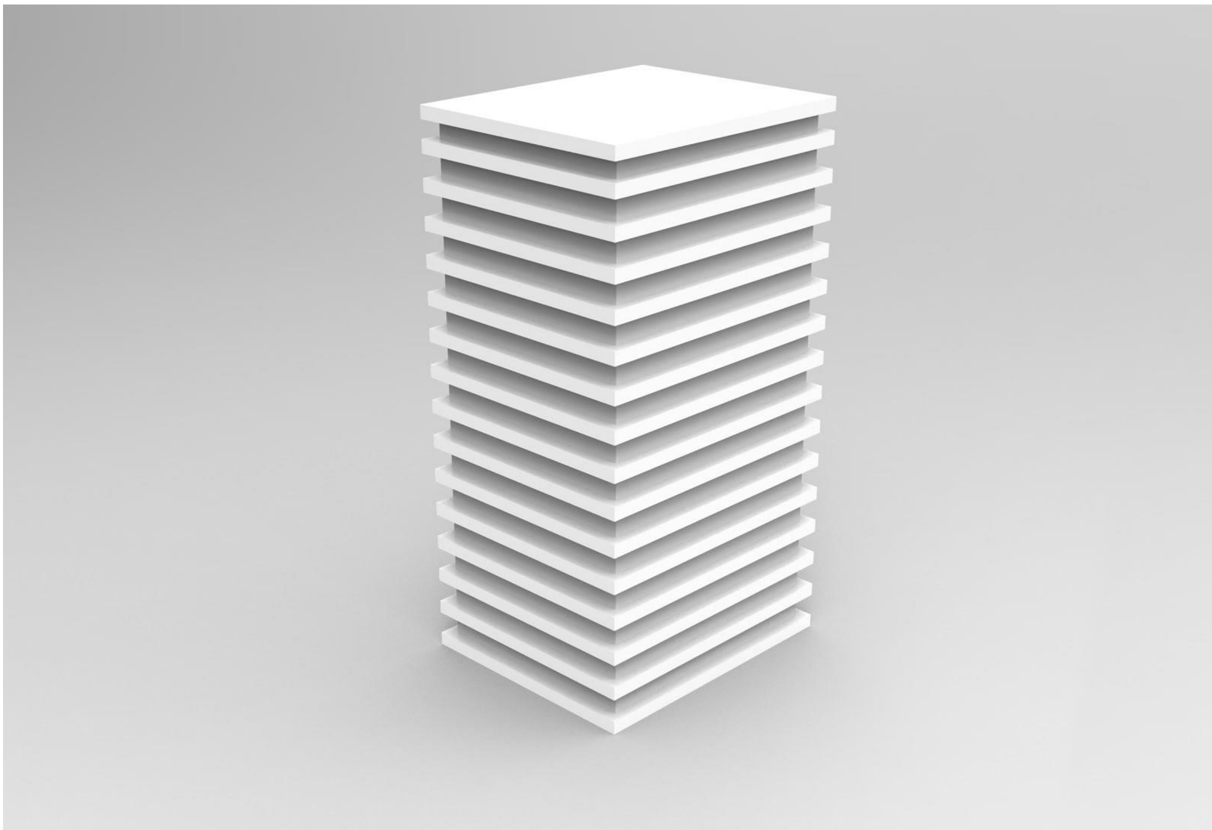
3. Plexi fitting:
There are subtle indentations marked on the outer edge of the plexi handle for accurate fitting as shown in pic. Please note the location of these indentations for accurate fitting of the plexi glass, also use the “umbrakonøkkel” provided for fastening the bolts. The ones on the right are easy to fasten.

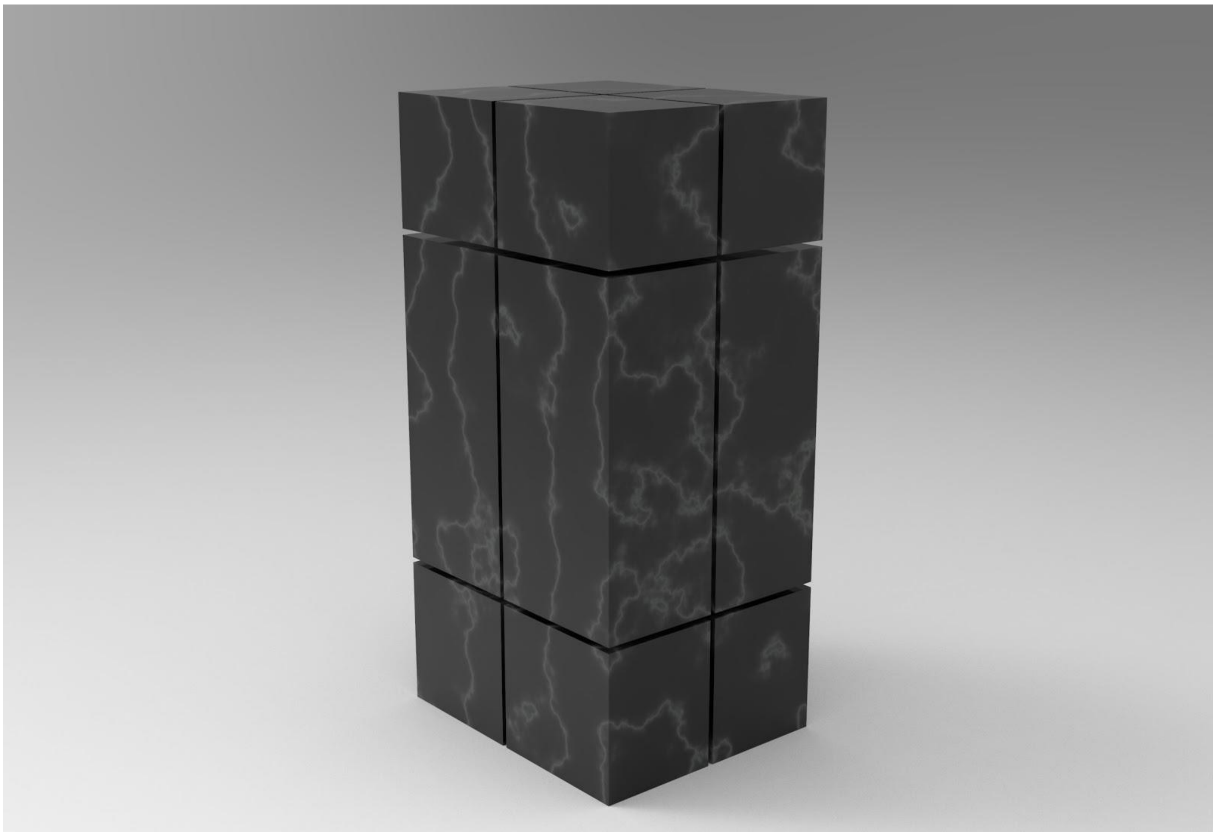


Appendix E – Category 3 – Renderings

Appendix F – Category 2 – Case Designs







Appendix G – Category 2 – BOM

Parts	Qty	Weight (Kg)	Material	Cost (NOK) Material cost only
1.Column	4	0.9X4 = 3.6	Al alloy	82
2. Beams [top and bottom cover]	2	3 X2 = 6	Al alloy	138
3. Rails	6	0.189X6 = 1.13	Stainless steel	31.64
4. Z braces	4	0.072X4 = 0.288	SS	8
5. Spine brace	2	0.156X2 = 0.312	SS	8.7
6. Rubber bushing	4	0.5		100
7. Battery module tray	2	4.2X2 = 8	Al alloy	184
8. Power electronics tray	1	0.366X2 =0.73	Al alloy	16.8
9. Wireway	1	1.2	Al alloy	4.6
10. Plexi glass	2	2.5		~100
11. M8 nut-bolts	24	1.1		~300
12. M4 nut-bolts	8	0.2		~100

13. Other misc. components	-	5 Kg		~300

Appendix H – Category 2 – Stress analysis

Stress analysis of the M8 nut was carried out w.r.t shear forces acting on it.

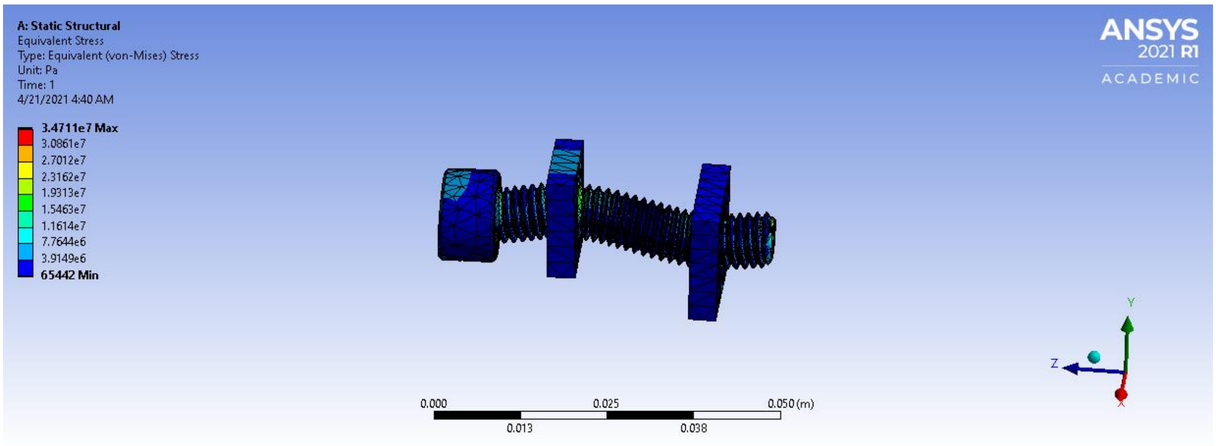
Material chosen: Stainless Steel

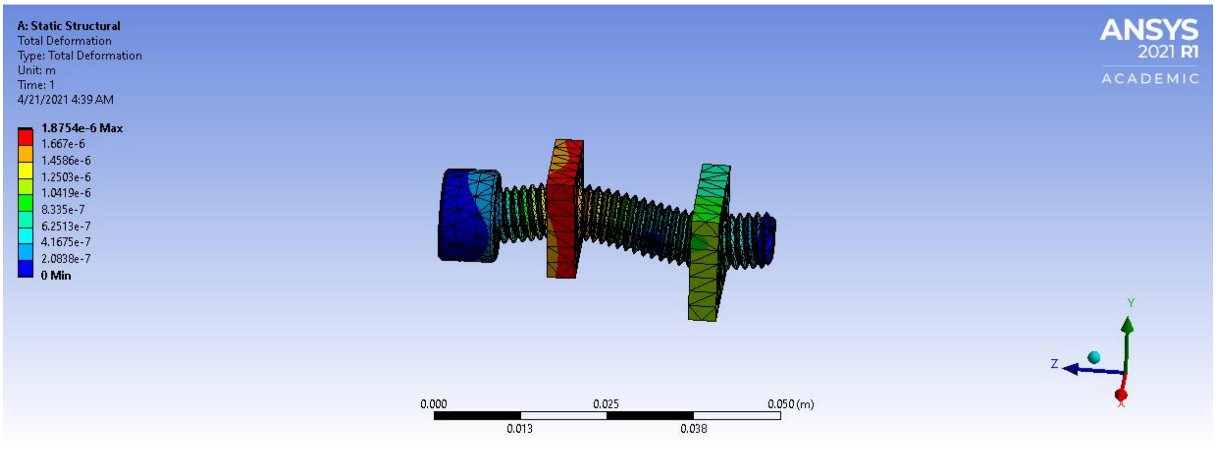
Nodes: 6896, Elements = 5117

Fixed support: surfaces on both ends are fixed such that it is similar to a simply supported beam

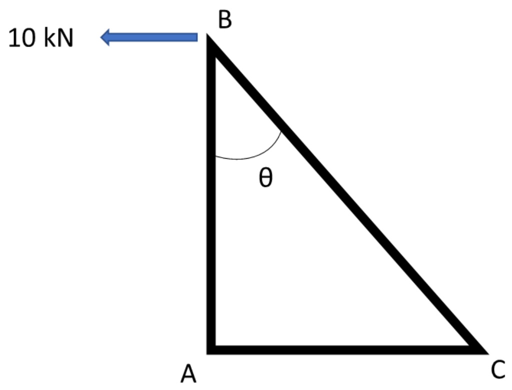
Opposing forces of 1200 N is applied onto the middle blocks as uniformly distributed load.

Almost negligible deflection observed for the design loads.

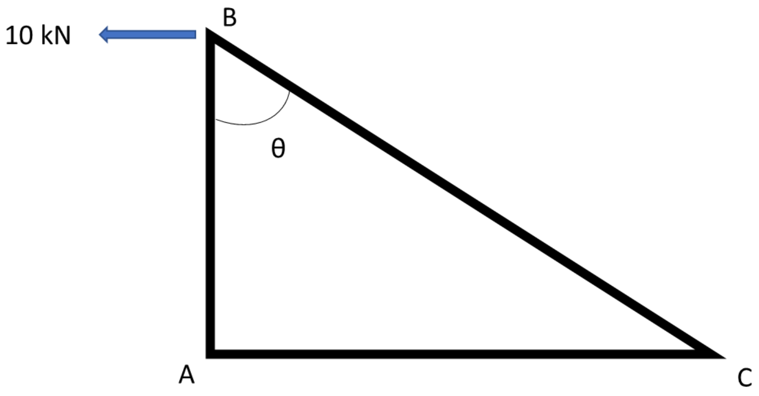




Braces deflection estimation:



Z-braces



Spine -braces

Calculation of deflection for Z- braces:

Point A is a roller support while point B is a pinned support.
10 kN load is applied at point B.

AB = 449.25 mm
BC = 310.121 mm
CA = 326.307 mm
$\theta = 46.58^{\circ}$

Elastic strain energy is given as

U = $\frac{P^2L}{2AE}$ -(1)

U = $\int_0^{x_i} P\, dx$ -(2)

From (2) we get

U = $\frac{Py_B}{2}$ or y_B = 2U/P -(3)

Resolving forces along y direction, we get F_{AB} = 13.76 kN (tension)
Resolving forces along x direction, we get F_{BC} = - 9.4 kN (compression)

Substituting the values in equation (1), we get elastic strain energy U = 30532 N/mm
Using equation (3) we get deflection at B, y_B = **6.1 mm**

Calculation of deflection of spine braces:

Point A is a roller support while point B is a pinned support.
10 kN load is applied at point B.

AB = 692.79 mm
BC = 401.129 mm
CA = 565.113 mm
$\theta = 54.65^{o}$

Elastic strain energy is given as

U = $\frac{P^2L}{2AE}$ -(1)

U = $\int_0^{x_i} P\, dx$ -(2)

From (2) we get

U = $\frac{Py_B}{2}$ or y_B = 2U/P -(3)

Resolving forces along y direction, we get F_{AB} = 12.26 kN (tension)
Resolving forces along x direction, we get F_{BC} = - 7.09 kN (compression)

Substituting the values in equation (1), we get elastic strain energy U = 26612 N/mm
Using equation (3) we get deflection at B, y_B = **5.3 mm**

Appendix I – Battery modules

From left to right: VW- E-golf battery module, source: own; Nissan leaf battery module, source: www.nissan-global.com

Appendix J – Category 2 - Determining characteristics

Determining Characteristics

The characteristics of this concept are listed. Each characteristic is to be scored on a scale of 0-10 with 10 being the highest. This can help avoid unnecessary components/parts, reduce cost and time taken to manufacture. Also increase the overall product quality.

Characteristics	Relative importance [0-10 with 10 being highest]	Remarks and values
1.Structural integrity	9	**This has been given a high priority to avoid wobbling, swaying , increase structural rigidity**
2.Ease of access to power electronics	6	*If this is given low priority then we need not have a separate tray on top to mount these, they can be mounted on the bottom cover or top cover.*
3.Fixing the electronic components	7	*Fixing the power electronics may require further parts, slots to be provided on the tray. If this has*

		low priority then the power electronics can just be loosely placed on the tray
4.Neat cable management	9	*If this is low priority then an extra part to mount the cables neatly may not be required. They can be attached to one of the columns instead.*
5.Lightweight frame	7	*If this is low priority then the weight may be increased to contribute to structural integrity and reduce cost*
6.Standardised parts	10	*If this is low priority then there could be more parts which need to be custom made.*
7.Ease of assembly	8	*This is related to the overall time taken to assemble the frame*
8.Appealing surface finish of the frame	6	*This is related to the surface finish of the frame, does it have to be good looking on the inside too? The frame+ nuts and bolts will be painted/ polished as in the rendered model*
9.Provision for attaching the casing	10	*Mounting points might be needed on the frame for attaching the casing*
10. Cost	9	
11. Sustain loads upto 300 Kg including factor of safety	1	
12. Standard manufacturing	9)	*No complex manufacturing process involved such as CNC machining or selective laser sintering or welding, ex: instead of welding tubes together for bottom and top support, 5-10mm thick sheetmetal can be bent and used for bottom and top support [cover]*
13. Rubber bushing on the bottom	7	
14. Provision for lifting the frame fully assembled with battery modules	10	I don’t think we need lifting points, more allowance for alternative lifting methods (flat lower section, etc)

Appendix K – Category 2 - Renderings

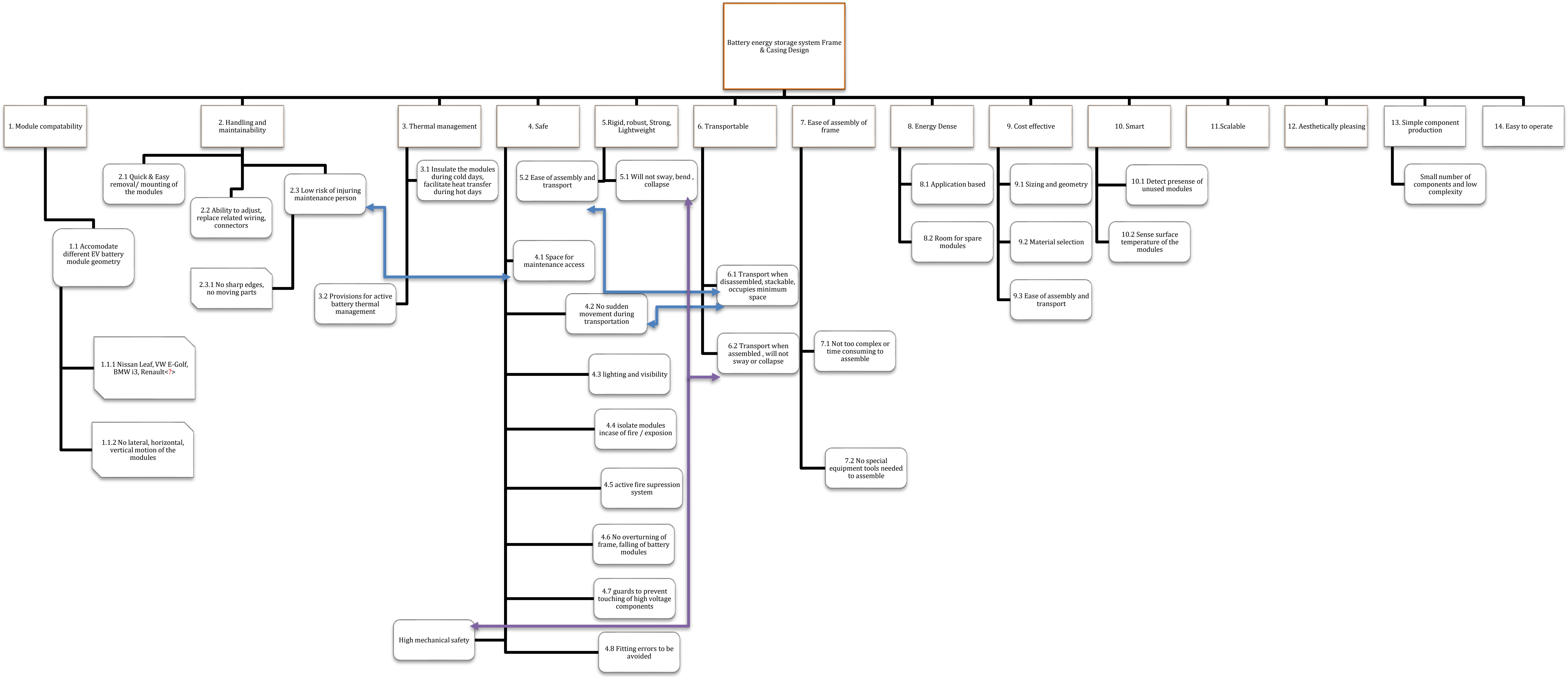


Figure 43 Appendix L, Design objectives - Category 2 solution.

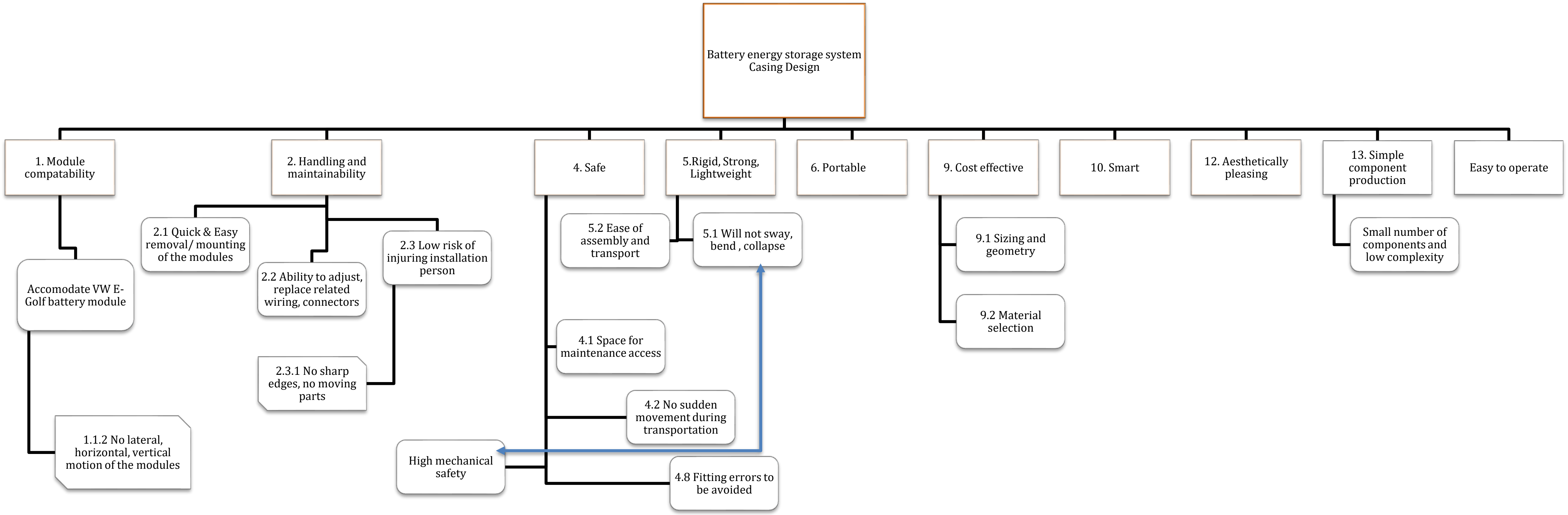
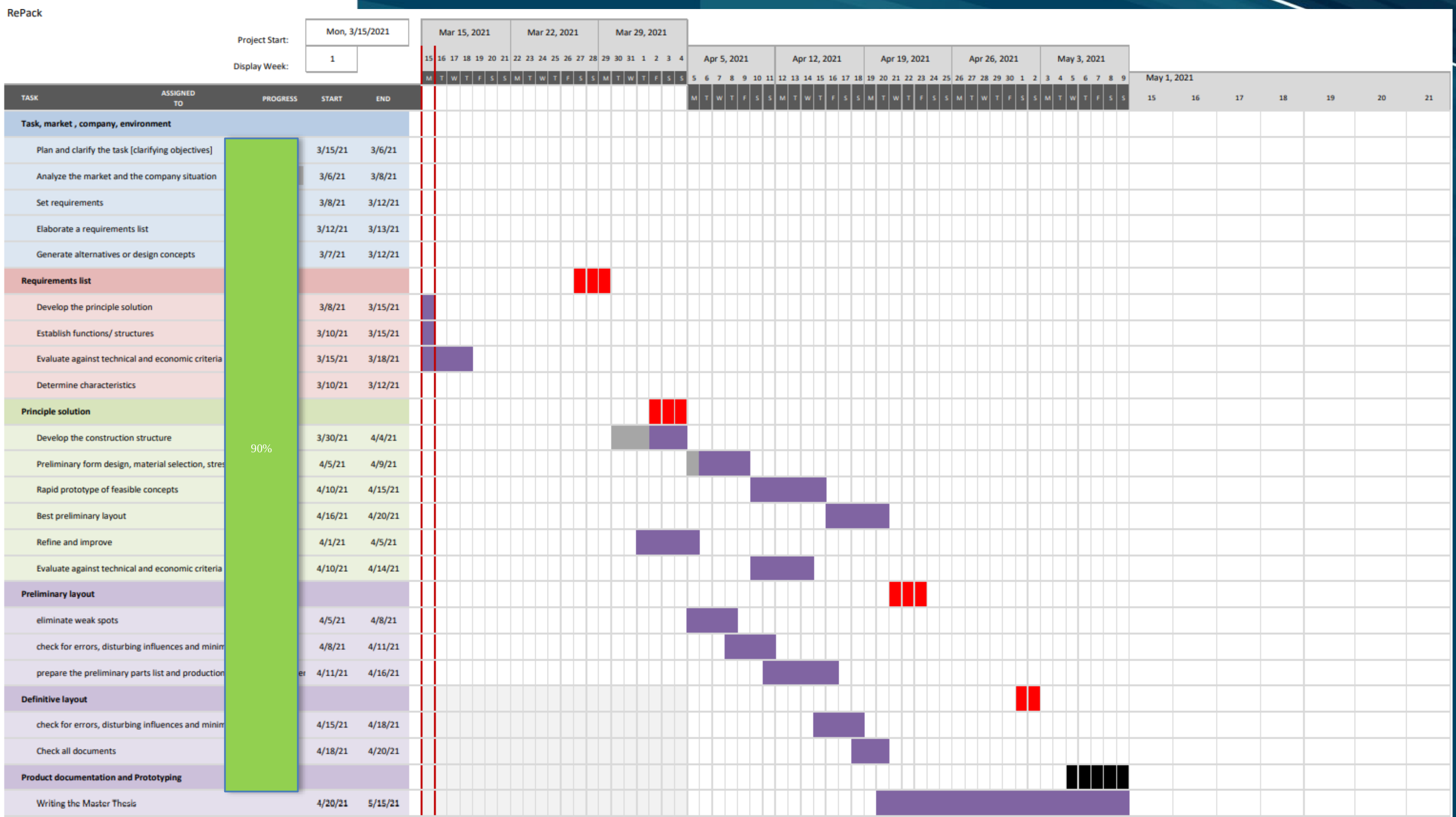


Figure 44: Appendix M, Design objectives – Category 3 solution.

Appendix N – Time plan

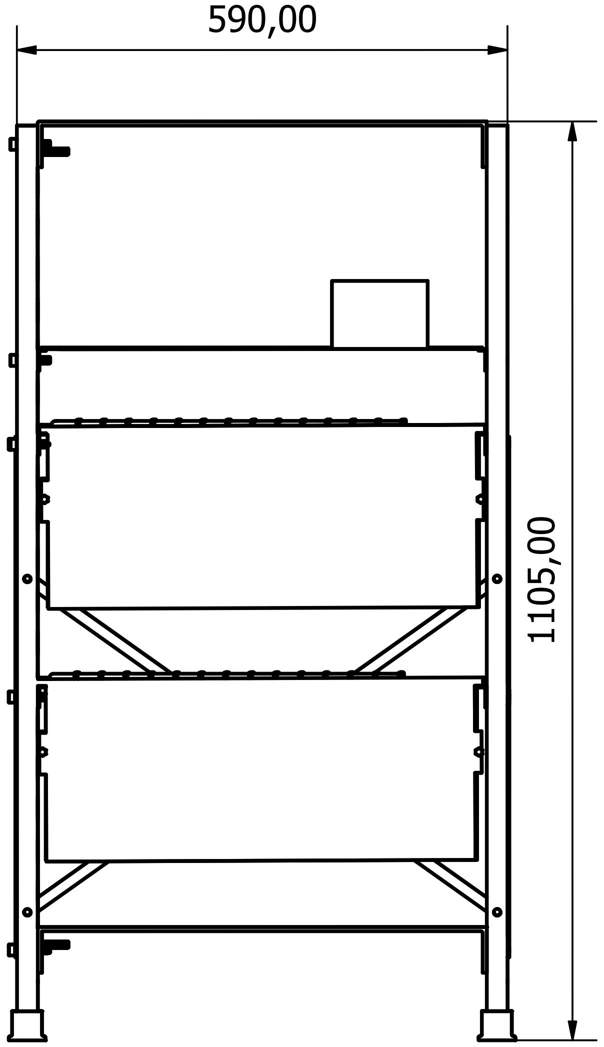


RePack

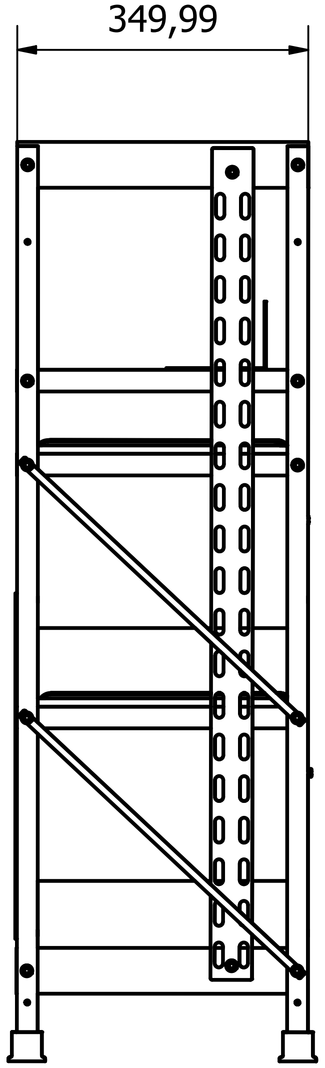
Project Start: Mon, 3/15/2021

Display Week: 1

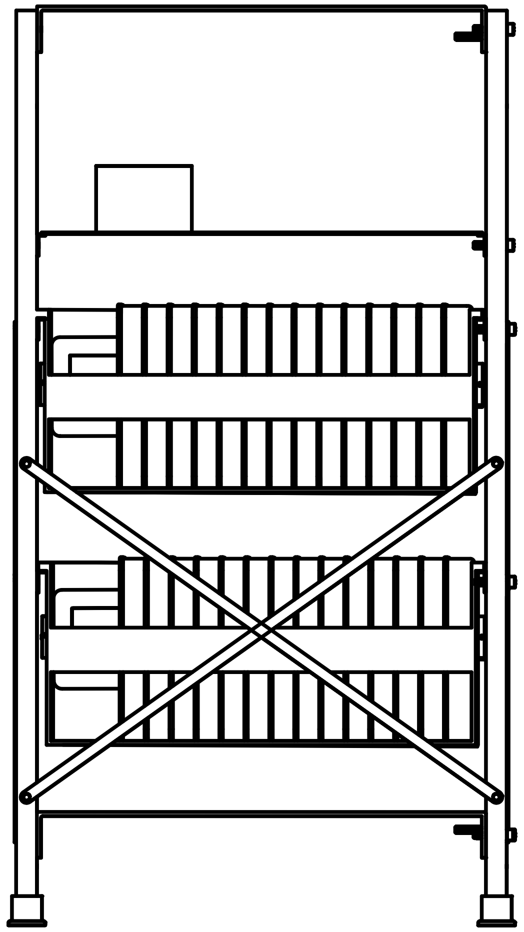
TASK	ASSIGNED TO	PROGRESS	START	END
Task, market , company, environment				
Plan and clarify the task [clarifying objectives]		90%	3/15/21	3/6/21
Analyze the market and the company situation			3/6/21	3/8/21
Set requirements			3/8/21	3/12/21
Elaborate a requirements list			3/12/21	3/13/21
Generate alternatives or design concepts			3/7/21	3/12/21
Requirements list				
Develop the principle solution			3/8/21	3/15/21
Establish functions/ structures			3/10/21	3/15/21
Evaluate against technical and economic criteria			3/15/21	3/18/21
Determine characteristics			3/10/21	3/12/21
Principle solution				
Develop the construction structure			3/30/21	4/4/21
Preliminary form design, material selection, stres			4/5/21	4/9/21
Rapid prototype of feasible concepts			4/10/21	4/15/21
Best preliminary layout			4/16/21	4/20/21
Refine and improve			4/1/21	4/5/21
Evaluate against technical and economic criteria			4/10/21	4/14/21
Preliminary layout				
eliminate weak spots			4/5/21	4/8/21
check for errors, disturbing influences and minim			4/8/21	4/11/21
prepare the preliminary parts list and production			4/11/21	4/16/21
Definitive layout				
check for errors, disturbing influences and minim			4/15/21	4/18/21
Check all documents			4/18/21	4/20/21
Product documentation and Prototyping				
Writing the Master Thesis			4/20/21	5/15/21



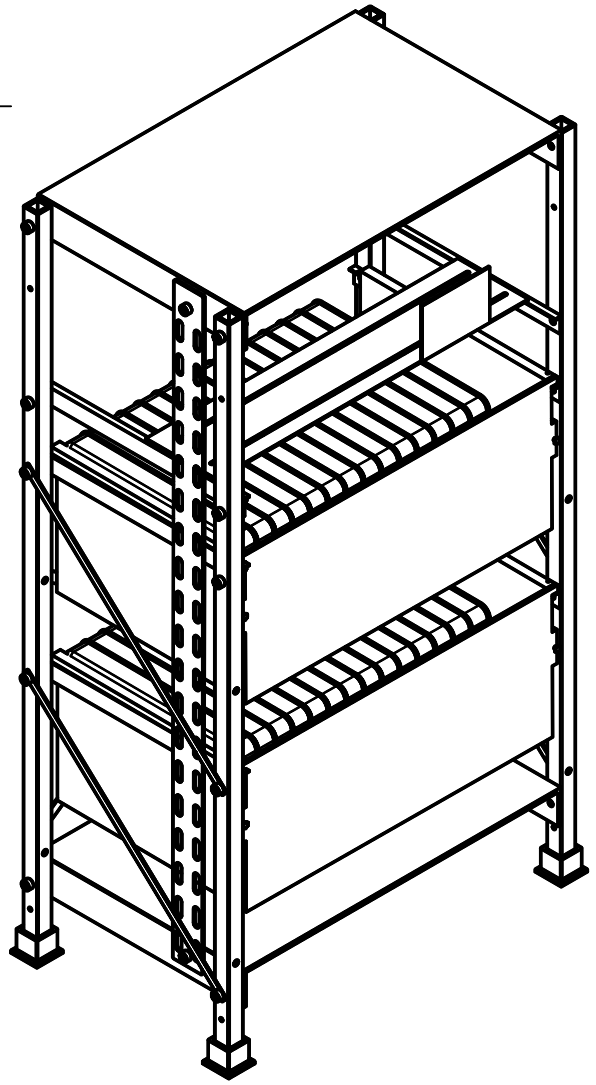
Front view



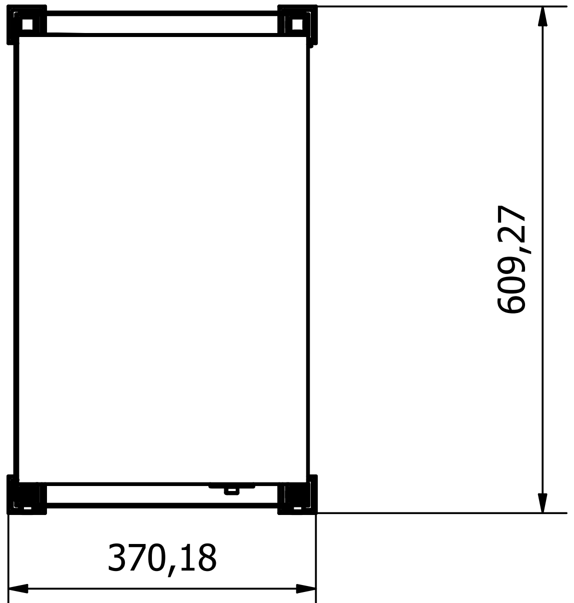
Side view



Rear view



Isometric view



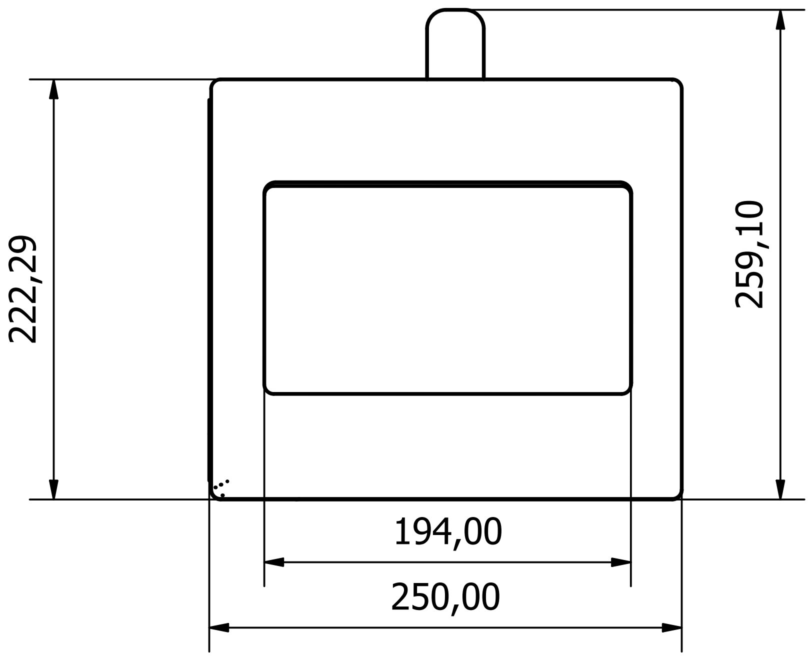
Top view

Appendix O

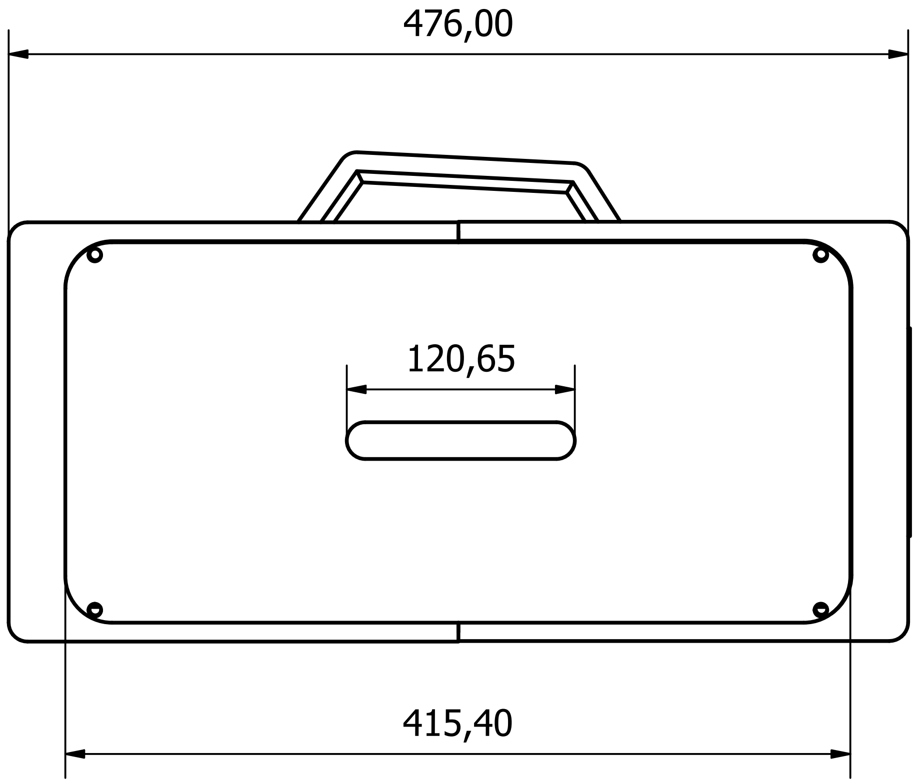
Designed by Anirudh	Checked by	Approved by	Date 5/1/2021	Date 5/15/2021

All measurements in millimeters

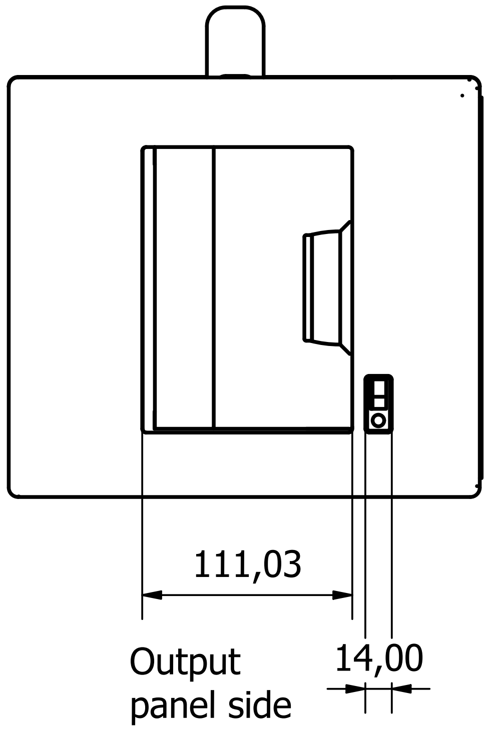
Edition	Sheet 1 / 1



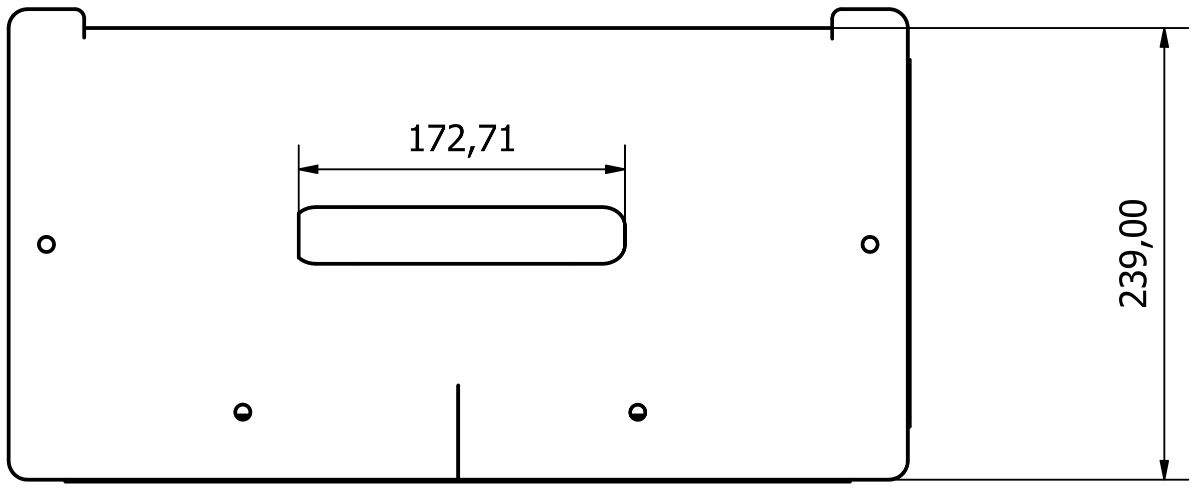
Screen side



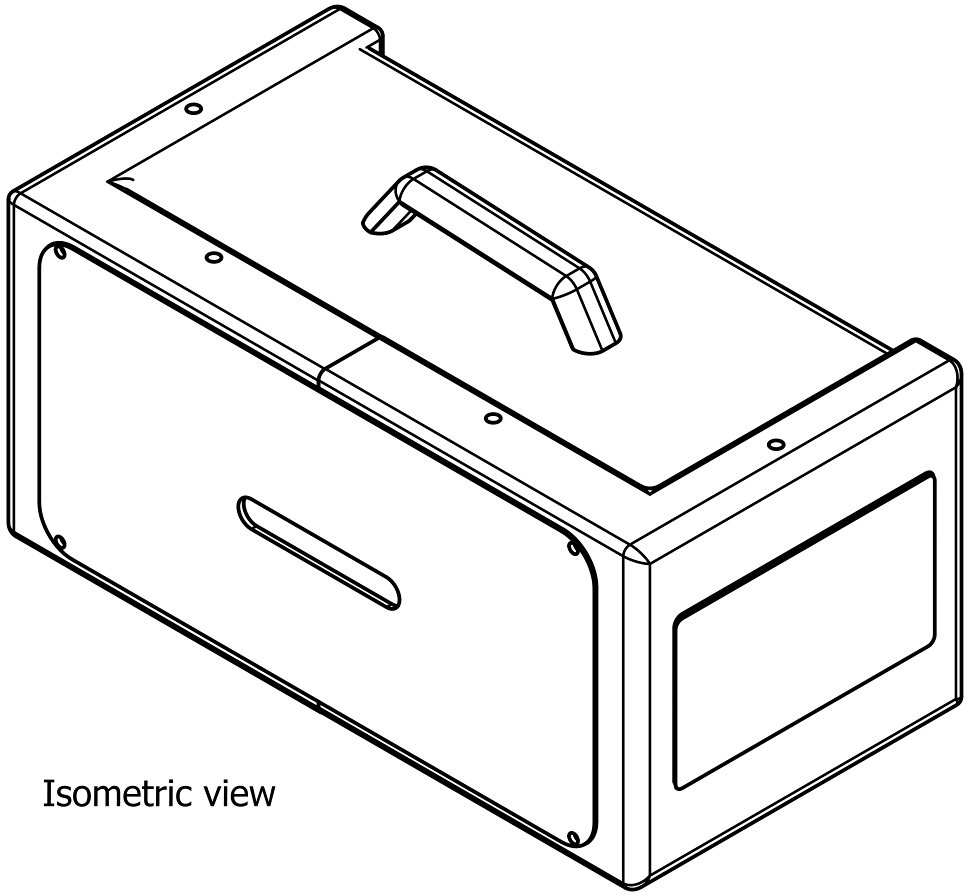
Front view



Output panel side



Top view



Isometric view

Appendix P

Designed by Anirudh	Checked by	Approved by	Date		Date 5/1/2021
All measurements in millimeters				Edition	Sheet 1 / 1