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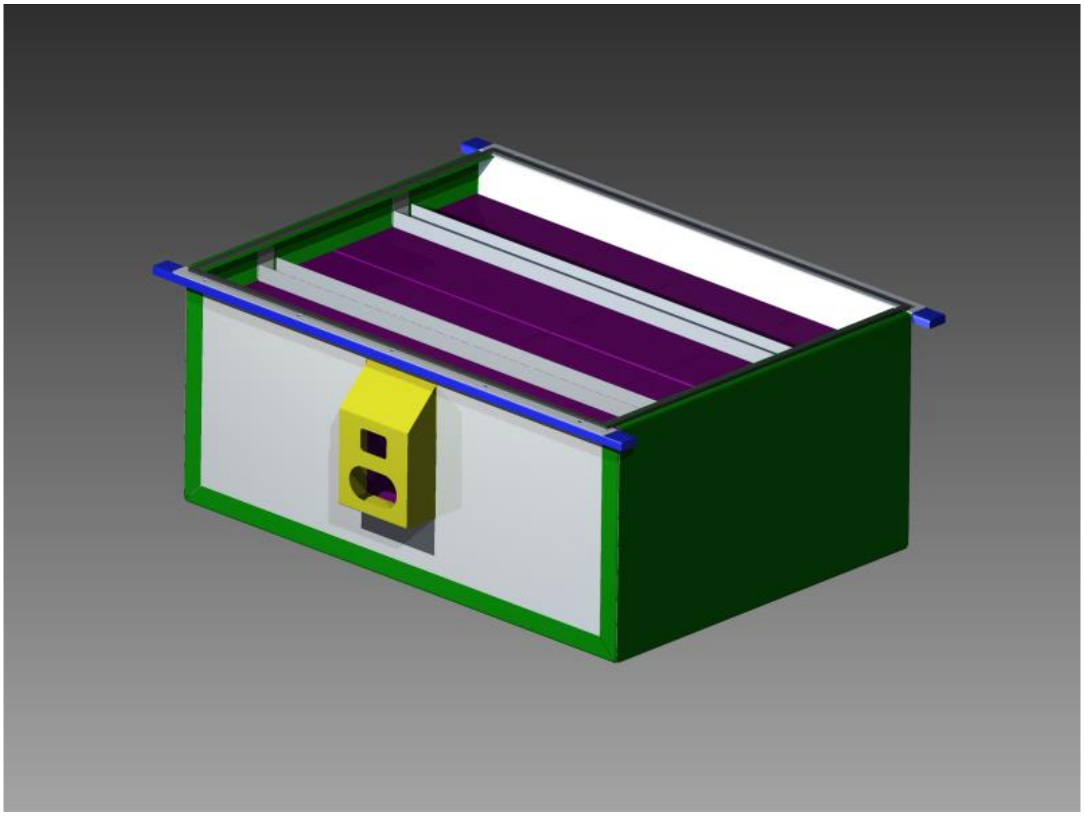

Development of a Battery Pack Container for an Electrical Vehicle

Master's thesis in Product Development

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“Wisdom comes from experience.
Experience is often a result of lack of wisdom”

- Sir Terry Pratchett

i. ABSTRACT

This report describes an incremental product development process of a Battery Pack Container (BPC) for an electrically converted vehicle. The current BPC is made in aluminium and has a structure of lathes in steel for extra protection. The total weight of this assembly, batteries and other structures included, is around 114 kg. The aim is to lower that weight by using Hybrix instead of aluminium. Hybrix is a metallic sheet sandwich material that is very stiff in relation to its weight, and also has thermally insulating properties. When machining Hybrix, the conventional methods are all possible to use, but if a weld is needed special and difficult configurations of the material are needed.

The project started off with a feasibility study to gather needs of the product as well as learning more about the battery pack. Here it was found that a battery's life is dependent on the temperature and a better insulated BPC might help keeping the temperatures more stable. A lot of demands here were found in European Union directives for vehicles in general but also about electrical vehicles in particular. The next step was to derive concepts from the assembled needs, which had been arranged in a specification of needs and requirements. This was done in two steps: brainstorming to fabricate some possible solutions and; morphological matrix to synthesise full concepts by combining parts and sub-solutions. After this was done 14 concepts were derived, and in need of some evaluation to prove themselves worthy for proceeding in the project. The first evaluation was a Pugh matrix where the concepts are evaluated against some criteria and then compared to a datum concept; in this case the current BPC was used as datum. Six concepts passed the matrix at this point; 5 by the score achieved and one by choice of the project team. Before going into the Kesselring matrix, the 6 concepts were developed further and some additional parameters were unveiled for each concept. Then they were ready for the weighted Kesselring matrix, with weights derived via comparison between the criteria. The yield was that a final concept could be presented and put forth for continuous development. When developed further and looking into details of the BPC, it was found that some problems might arise. Some liquids that may come in contact with the BPC causing it to delaminate, tests showed, however, that this was not the case. Another issue was the deflection at the bottom of the container. This was planned to be solved by having imprinted ribs in the bottom, to increase stiffness, but the cost for such ribs in production would be high. Instead a foam board with a thickness of 6 mm was added at the bottom, increasing the stiffness and insulation as well as being an off-the-shelf item that would lower the cost of production.

All in all the new BPC has reduced the weight by about 10 kg, most of which is due to the fact that the external structure was greatly reduced. The new BPC also increases the thermal insulation and facilitates a better micro climate, thus potentially prolonging the battery life.

ii. SAMMANFATTNING

Denna rapport beskriver produktutvecklingsarbetet med en inkapsling för ett batteripack till en bil som konverterats att drivas med el-kraft. Den nuvarande inkapslingen är gjord i aluminium och har en skyddsbur av stål runt om. Den totala vikten av alla ingående delar är 114 kg och målet är att minska denna vikt genom att använda Hybrix istället för aluminium. Hybrix är ett metalliskt sandwichmaterial som har hög böjstyvhet i relation till dess vikt, men har även termiskt isolerande egenskaper. För att bearbeta Hybrix kan tillverkningsmetoder för vanlig plåtbearbetning tillämpas, t.ex. stansning, borrning, bockning m.m. Däremot kan svetsning I Hybrix vara komplicerat och det kräver speciella konfigurationer i materialsammansättningen.

Projektet startade med en förstudie för att lära mer om produkten och för att samla information om krav och egenskaper som var nödvändiga för produkten. Bland annat uppkom information om hur batteriernas livslängd påverkades av omgivningens temperatur vid drift. En slutsats från det var att en bättre isolerande behållare kunde gagna hållbarheten på batterierna då temperaturen skulle kunna vara jämnare och högre. Flera andra krav och information återfanns I direktiv angående fordon, samanställda av EU. Efter att ha samlat information sammanställdes delar av denna i en kravspecifikation vilken sedan, tillsammans med funktionsanalys, låg som grund då konceptuella lösningar togs fram. Dessa genererades i två steg; först brainstorming och sedan med en morfologisk matris.

De olika metoderna resulterade i totalt 14 olika koncept som skulle utvärderas och analyseras för att visa vilka som kunde prestera tillräckligt bra för att föras vidare I projektet. Den första utvärderingsmetoden som användes var Pughs matris där koncepten utvärderas mot en referens; i detta fall användes den ursprungliga inkapslingen som referens. Totalt passerade 6 olika koncept den första evalueringen. Innan det var dags för nästa utvärderingsmetod, Kesselringmatrisen, arbetades det lite mer på de olika koncepten och ytterligare parametrar hittades. Därefter användes Kesselringmatrisen med vikter på utvärderingskriterierna för att se vilka koncept som presterade bra på viktiga punkter. Resultatet av detta var att ett slutgiltigt koncept kunde väljas för vidare utveckling. Under detta utvecklingsarbetet framkom ytterligare faktorer som kunde påverka produkten. Specifikt var det två vätskor som potentiellt kunde lösa ut sandwich-strukturen men materialet testades i båda vätskorna och det visade sig att det inte var någon fara. Ett annat område som behövde beröras var bottens utböjning på grund av batteriernas vikt och som var tänkt att motverka med en korrugerad botten för ökad styvhet. Men istället valdes en 6 mm tjock polymerskiva som användes som kärna I botten vilket ökade styvheten och termisk isolering.

Projektet ledde fram till en ny inkapsling av batteripacket med en reducerad vikt av ungefär 10 kg. Den största viktbesparingen skedde i och med att stålburen kunde elimineras. Ytterligare anses den nya inkapslingen öka termisk isolering och ge bättre mikroklimat, vilket ökar batteriernas livslängd.

iii. PROLOGUE AND ACKNOWLEDGEMENT

This project has been very much similar to the other projects undertaken at my time at Chalmers University of Technology. That is to say the form and steps taken during the project has followed were similar. The preconditions for the project, however, were very different indeed. In the last project before this, I was a part of a project team consisting of eight students. This time I was part of a team consisting of only me, myself and I. Because of this, and although the overall steps were basically the same, the details of each step was varied to better suit when conducted by a group of one. Being alone and conducting a project has made me realise how much easier it is to be a team, working together, despite possible differences between team members. Especially when writing this report a team of eight would have been appreciated. It has also revealed some flaws in the methods used in the project, but the methods were regarded more as guidelines and not as something to follow blindly.

The project was originally meant to be run in a slightly different fashion, but circumstances unable to effect made it go in another direction. At the time for the divide of the project, it was uncertain on how to proceed with the project and maintaining the scope in mind; Lamera AB and ECar made it possible however. The two companies have supported me with input, in the form of knowledge and advice, but also listened to what I have had to say. For this I owe them many thanks. Bengt Nilsson and Jon Wingborg at Lamera AB have helped me throughout the project and sharing their knowledge, expertise, and experience in industrial projects. As well, thanks go to Ben van der Geer who has been my main contact at ECar, but also to Jan Hedegaard who I spoke to several times during the project start-up. Finally I would like to address a thanks to my supervisor, who have supported me throughout the project, sometimes by demolish my arguments and nit-pick on details, but has ultimately strengthen the project and has had a great effect on my learning and understanding.

Before continue reading notice that the report is written in a way that it can be used as a reference in other projects, explaining the theory and the use of them in a way that may sometimes seem redundant. Some very basic knowledge might be needed still.

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1. INTRODUCTION

To set the reader into context and understanding of the prerequisites of this project, a brief introduction regarding these matters is hereby given. The introduction also aims at make the continued reading to be more understandable, since some aspects affects the thought processes and outcomes at some points.

1.1. Context of project

In the automotive industry today there is a large focus on minimising the fuel consumption and reducing the emissions, and the car companies spend vast amounts of money on R&D each year [1]. One way of achieving this is to switch from cars based on a combustion engine to electrical propulsion. But when you do this swap you get a new set of problems that have to be solved in order to adequately replace a fossil fuelled vehicle. One such dilemma is that the range of electrical cars relies on heavy batteries to store energy, and the batteries are heavy whether they are fully charged or depleted. So in order to extend the range you need to make the rest of the car lighter, minimize losses in energy transfer, make the batteries more efficient per unit weight etc. If you manage to reduce even a gram on each part in a car, the end result would be a significantly lower weight.

Another aspect of cars in general is that there is a high material usage in order to produce a car. This material is needed to be extracted and processed before you can put it into a press and make car parts out of it; a process that demands much energy put into it. So if there was another material that could be used that lowered the overall material need the entirety of the car would be more sustainable. Add the electric propulsion to that and you get a car that is reducing the negative effects on the environment in a great way.

1.2. Description of participating companies

The reason the project is defined the way it is, is largely because of the participating companies. So to increase the understanding of the context of the project further, some description of these companies is of necessity.

1.2.1. Lamera AB

The company Lamera AB, the main cooperating company during this project, is primarily a material manufacturer who produces a material called Hybrix. The company is based in Göteborg and it was founded after a project from Chalmers School of Entrepreneurship in 2005. The reason for why that project started was since AB Volvo, who originally came up with the idea of the material, wanted to reduce the cost of producing the material but did not have the time and resources themselves. The result of the Chalmers project was Hybrix; a sheet metal material which has a beneficial ratio between the weight of the material and its stiffness, especially when loaded in bending. Since then both the company and the material have evolved further since; the company now takes bigger part in development projects and the constitution of the material has changed.

1.2.2. Ecar

The customer as well as another cooperating party in this project was the company ECar. ECar is a retailer and producer of electrically converted cars, where they have stripped the car from all fossil fuel related parts and exchanged them for electrical driven instead. The company started in 2011 as Jotech Design bought the company EV Adapt and changed the name. At this time EV Adapt was converting Fiat 500 to electrically propulsion, and newly founded ECar continued on the same course. But as Fiat now makes the 500 model with electric propulsion from factory, the need of conversion was no longer practically sound. Another conversion was regarded instead, namely that of the van Fiat Fiorino (fig 1.2.) This time around the aim was to get the car as a transport and service vehicle at sites such as airports and harbours.

Figure 1.2. Fiat Fiorino

1.3. Description of the type of material used

The material produced by Lamera AB is called Hybrix. It is a sheet sandwich material that consists of two thin metal sheets who are bound together with polymer fibers and a glue, as seen in fig 1.3 a). This configuration makes the material stiff in relation to the weight.

Figure 1.3 a). A cut-through of Hybrix where the different layers are visible.

To work in the material you can use ordinary sheet metal processes, with some limits regarding the welding possibilities (see fig 1.3 b).). This ability of the material makes it have a competitive edge against several other composite materials, which often need some special tooling in order to be processed. The reason ordinary processes work is because the fibers in Hybrix are individually bound to respective surface, thus a gap between the two plates are created. This gap of air then can take almost any shape and you do not need to pre-shape the internal structure or add a special tool to acquire the desired shape. The gap also adds some additional properties to the material such as: increased thermal insulation compared to solid metal; better structural damping; and the possibility to have two different surface materials on either face of the sheet.

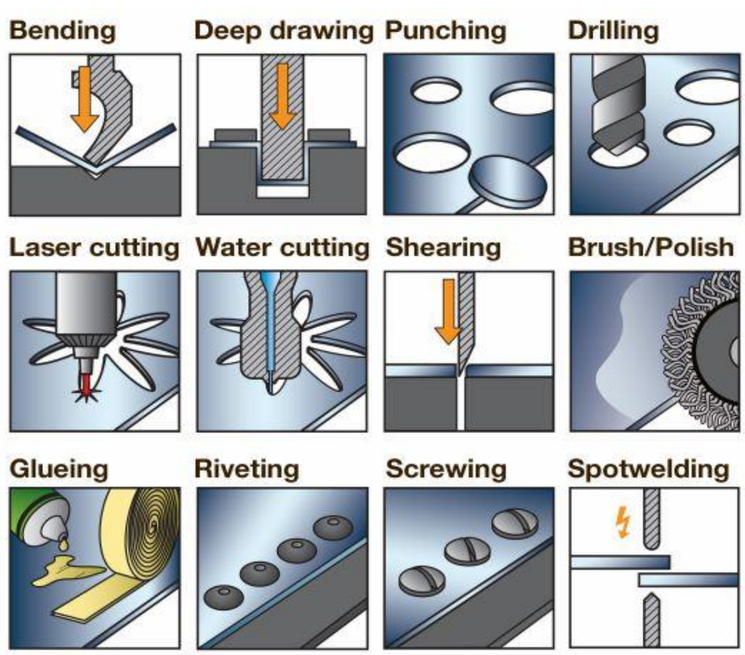


Figure 1.3 b). Machining operations available to use with Hybrix.

1.4. Description of the vehicle and its use

The recipient of the project is the company ECar, which converts the combustion engine car Fiat Fiorino into an electrically propelled vehicle. At the moment they have only a prototype of the electric Fiorino and in need of a better Battery Pack Container (BPC) since the current one can be improved. Although, the traveling distance is not as important as the battery life is, since the idea with the car is to operate in confined spaces with a speed limit of 50 km/h. Another aspect is that it is more starts and stops when driving such small distances and a lighter car requires less energy to get up to speed. The placement of the battery pack on the vehicle is at the area where the petrol tank used to be when the car was running on fossil fuels (see figure 1.4.1). Thus it hangs from the undercarriage of the car and has to be in order for related products to work as intended. Additional information regarding the vehicle and its' performance, is available in "Appendix 1".

1.5. Description of the current battery pack

The Battery Pack Container (BPC) that was produced for the Fiorino was more or less made up as they went along. Few calculations regarding strength or endurance have been made, nor have any development work been done. To put it crude it was just a square box with a lid mounted under the car. It is made of aluminium which is folded lengthwise and the sides are welded on to that folded model. There was also a need of moving the power outlet down on the side since there is a beam on the car that hindered the power cord to be plugged in. A "cage" of steel was put around the battery pack in order to make sure it would not come off. All of this can be seen in the figure below and in "Appendix 2" there are measurements and information regarding the weights.

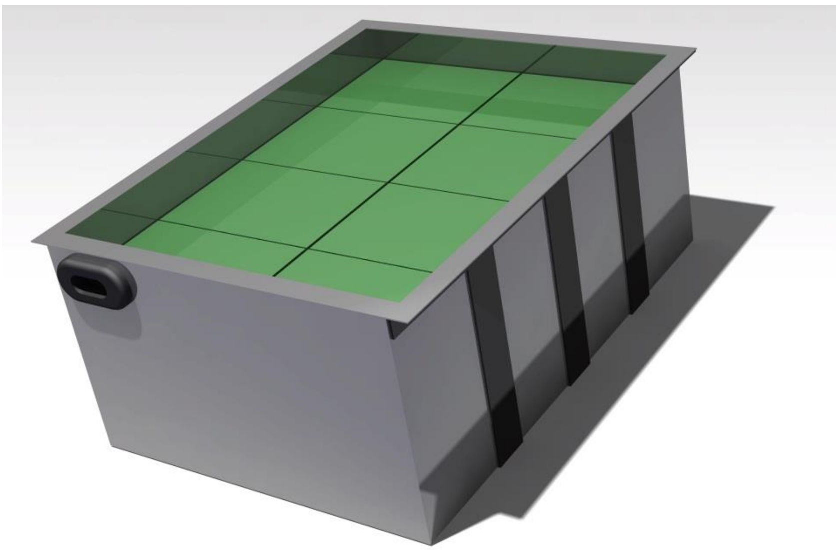


Figure 1.5. Current BPC as made by ECar

1.6. Purpose

The Company ECar ís planning on market a new type of a vehicle converted to electric propulsion. In order for this conversion to be optimised regarding performance, ECar saw the need of a new BPC. Thus the purpose of this project is to develop a new BPC that is more suitable for mounting on the car as well as enhancing performance.

A secondary purpose is to provide Lamera with a process that can be referenced to in future product development projects.

1.7. Objectives

In order to fulfil the purpose some objectives are set out to be met.

- Make the BPC lighter
- Ensure that the BPC has the possibility to maintain better working temperatures.
- Minimize energy losses.
- Facilitate increased performance.

1.8. Delimitations

Setting some boundaries on the project helps keeping the focus on the task at hand and also hinder additional areas to be added to the project over time. For this project the following delimitations have been made and will be respected:

Design

- Some parts might not be able to produce in Hybrix and in such case additional materials will be used as a compliment.
- No changes in design of the electronic components; rearrangement might occur.
- If automated system for battery replacement is considered it will limit the measurements of the BPC.

- *Analysis*
- Some basic FEM analysis will be considered, e.g., static loads.

- *Economical*
- Costs will only be estimated and a full scale analysis will not be part of the project.

- *Outcome*
- Only one concept will be presented in the end.

- *Time*
- The time for the project is 20 weeks.

1.9. General approach of the Project

When conducting a development project there are some different ways of working, for this project though, the approach is as follows:

1. Feasibility study, where the product is explored and literature studied. Also included here is to look for information for a specification of requirements. Often this study includes methods such as SWOT and PEST, but they are disregarded in this project since there has been a request of development; thus a need for the product is already established.
2. Needs and requirements specification assembly, and function analysis of the product.
3. Development of concepts; via some methods for deriving concepts.
4. Evaluation and screening of concepts; a somewhat iterative process often including decision making matrices.
5. Refinement and verification of concept where the chosen concept is tuned to perform as to specifications and hopefully exceed them to some extent.
6. Cost estimation; a rough estimation of what the cost of the product would be.
7. Reflection of the project and the processes.

The structure of this report follows the structure of the project undertaken. Although for the report the theory is explained in the second chapter, then the use of methods and result thereof in the third chapter. After this a discussion regarding the project is placed, followed by a conclusion of the project as well as recommendations for future work and adaption of project outcomes. The conclusions of the project and the adaption of the same, are two closely linked chapters but a distinction was regarded to be in place. This is since the adaption of the project is related to a specific area, whereas the conclusion is more general.

1.10. Search terms

In order to find information the following terms have been used to search the internet. The terms have been combined and moved around in different ways in order to find as much information as possible regarding a specific area.

- Automotive battery patent
- Electronic container patent
- Battery container patent
- Automotive battery patent
- Automotive battery housing patent
- Electric vehicle accident
- Electric vehicle failure
- Electric vehicle problems
- Temperature and battery life
- Directives electrical vehicles
- Laws and regulations electrical vehicles

This is not a complete list but variations on the same themes was also used.

2. THEORY FOR PRODUCT DEVELOPMENT PROJECT

In any project it is advisable to follow a series of structured methods in order to systematically derive concepts. Ottoson [2] states that there are two different types of development procedures to go by; static or dynamic. The different types facilitate different methods, but for this project the static development and its methods have been used. The methods available are perhaps not always suitable for the process and one might need to stray from the original intent of a method. If done differently and in a way that can show how it was used, and also point out why it was used differently, this is perfectly fine. The reason for using any method is merely to have the project team look scientifically on the task at hand and not rush into a solution that might not be a good solution. Johannesson et. al. [3] argue that the methods and systematic approaches might inhibit creativity in the development process, and also that the methods are general but the problems unique. On the other hand the processes works well when dealing with incremental change, since nothing radically new is meant to be a result but rather a stepwise improvement. Further the systematic processes are easy to follow and keeps track of the progress. In this section, some of these methods will be explained in how they work but also how they were applied to this particular project.

A pre-study (also called feasibility study) is vital in order to get a better understanding of a product early in the project when the chance of alter the process is high but the cost, in this case in terms of time, is low (as seen in figure 2.1). The more knowledge being gained in the front end the easier to have a good development process. Such a study can also make the goals more clear and perhaps even alter them in some small way.

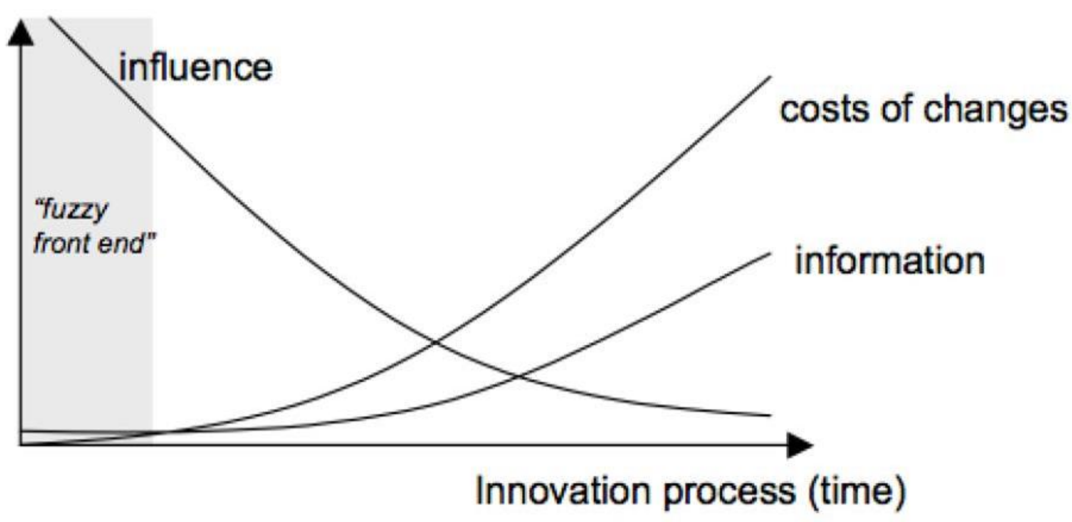


Figure 2.1. The relation between cost of change, information and influence of the design [4]

2.1. Theoretical approach of finding demands of a product

In order for the development process to deliver what the customer needs it is important to know what is expected of a product. To learn about the product and how it is used is therefore of great interest, as well as how users have interacted with similar products. By studying this one creates a foundation for the further development. But not all knowledge gained can be regarded as demands, some knowledge might be inherent and some knowledge found can be regarded as a pointer to where the industry is heading. All of which are relevant to know of, but not all applicable onto the project.

2.1.1. Theory of the Feasibility Study and Gathering of Information

The gathering of information is recommended to commence as soon as the project starts and the limits of the project is set. Because in the beginning of the project the information gathered will greatly influence the design of the concepts, and changing a concept in a late stage is often costly. However, gathering information about the product never stops during the project; you always have to keep an ear to the ground, allowing to adapt if new information arise.

There are plenty of ways of acquiring information and knowledge about a product, each with its own set of pros and cons. Because of this, when gathering information, a variety of methods are often used in order to look at a product from different angles. This helps increase the resolution of the product, thus achieving a better blend of impressions. If only one method would be used the risk is that the information will be highly biased and perhaps influenced by the onlooker, something that should be avoided if possible. The multiple sources is therefore also a way of cross referencing the different information to check for correlation and verification of the collected data. Another aspect of this is to create a problem statement with a neutral mind-set. Keeping a neutral problem statement can help avoid excluding some information because it does not match the statement, thus a wider span of information gathered is probable.

As stated there are several ways of getting to the information. What methods to be used are dependent on the type of project and what limits is set upon it. Other factors that influence this decision is how much that is already known about the product and what type of product it is. The most common ways of gathering information are:

- *Interviews*
- One or more members of the team has a dialogue with a customer about the product. The dialogue aims at finding information regarding the subject.
  - *Structured*: The interview follows a strict protocol of pre-stated questions. It is a rigid way of interviewing and the possibility to follow up on some interesting aspect that may arise is limited. Good if a lot of technical details are needed, such as “How much…?”, “How wide…?”

- *Unstructured:* The interview is relaxed and more a general discussion on the topic with very few or none pre-stated questions. With this type there is a risk of forgetting something important.
- *Semi-structured:* A mix of the two. [5]

- *Focus groups / workshops:* A form of group discussion moderated by a member of the project team or an external professional. Usually the session is recorded in some way for later scrutinising. [5]
- *Observations:* One or more members of the team observe the product in use by a customer. This is a good way of detecting if the product is used as intended and also to discover use of product that might not have been thought of. [5]
- *Literature study:* Study what others have found when they have done research on similar subjects. Literature regarding theories and methods that could be of use is also studied at this time, as well as literature regarding adjacent subjects. [3]
- *Search of patents:* A search of patents is really recommended since it is otherwise a possibility infringing on an existing patent. If no patents exist on this subject there is a freedom to operate. Another benefit of looking at patents is that you might get ideas and inspiration on how to solve a problem in a new way. [3]
- *Internet searches:* There are large numbers of sources possible on the web and the easiest way to find them is to use a search engine. This way, however, results in any text in which the term used for the search exists. So in order to distil good knowledge by use of this tool, a certain amount of scepticism and doubt regarding what is written is in its place. Always look for sources used to refer the texts to. [3]
- *Questionnaire:* A leaflet of questions that are handed out to participants in a survey. The questions are often of a type where the participants are asked to rank or rate a number of statements and/or yes-or-no questions. [5]

From this list one can basically pick and choose what suits best at the time and to what type of project that is underfoot. In this project, which is a derivative product development, it was regarded that unstructured interviews, literature study, search of patents and internet searches, were the methods to go with. The methods used were the ones perceived as yielding answers that could be used. The basis for this decision is that the product has yet to be tried properly by the end customers; hence questionnaires and focus groups were out of the picture. Similarly the possibility to observe the use of the product was not possible since the product at this stage is a prototype and only one, and it was needed to stay on the vehicle for other purposes. Secondly on the observation method is the fact that it is a prototype, and the way to manage it is not entirely decided. The reason for selecting unstructured interview was that the contact with ECar was really good and there was a possibility to contact them at all times for additional questions.

Some time was also spent on finding patents on the subject. This is a vital step to take since there is a possibility that an accidental infringement on someone's patent, which could be a costly mistake. However it also serves as inspiration and idea evoking basis [3].

2.1.2 Theory of the Specification of Requirements and Sorting the Information

After obtaining the information it needs to be sorted and adjusted into a form that could be related to for the development process. This is because of statements and phrasings, as found during feasibility study, not complying with how to write when describing design needs or requirements. The wording has to be in a way that it is easy to follow and expressing a statement in words that have a meaning from a design point of view [5]. An example of this can be that the information found says: "I do not want to burn my hand when holding the cup". Translated into design terms the same statement would perhaps be: "Material of cup to provide adequate thermal insulation" or more simply put "Cup must not burn hand". That is a statement that could be designed for and used as a reference in the continuous work. To get from found information to statements like this there are again a number of tools available to use.

The total ranges of needs are then assembled into a requirements specification in order to get a better overview of the situation and also having the needs structured for continuous work in the project. This is advisable to do in any project since it is really easy to lose track of where you are heading and a specification of needs and requirements can help to keep focused on the work at hand. The specification of requirements is also used when evaluating and comparing different concepts. However, the specifications are not a fixed document but rather a living document, evolving alongside the product. All need gathered might not be applicable on the prototype, nor on the finished product, since a lot of information is regarding cars operating in traffic rather than in a confined space.

2.1.3. Function Decomposition

Describing the product and how it works can be represented in a function decomposition. It is a hierarchical structure, often depicted in a tree structure, providing an overview of the functions of the product. By making a schematic image over the functions it is easier to grasp the entirety of the product and also gives a possibility to see which functions that needs to be solved and how the different functions are related. A function is best described with a verb and a noun, e.g. "dampen impact" or "seal box". Sometimes this two-word-phrasing might not be enough and a more thorough description is needed. The functions of the product are written in tiers where the top tier is the main function(s) that the product realises. The lower tiers are sub-functions, and sub-sub-functions etc., to the previous tier, thus increasing detail level as moving down in the tree [cf, 6].

From the tree structure the correlations between functions can also be seen in this diagram. As a result the solutions to the functions can be adjusted to fit these correlations and trade-offs can be made to best suit opposing functions. Other parameters that might affect the development process can also be found when the functions are studied.

2.2. Development of concepts

When developing new concepts from the gathered data there are several ways of synthesise different versions. The definition of *concept* is different from can vary depending in what context it is used. In a product development process the word means a preliminary product layout and cost. It also includes description of the different technical solution in text, diagrams, sketches, physical models, etc. Further it possesses an explanation and justification on why the solution of parts is chosen as they are, as well as the properties of the solution in relation to the specification of needs and requirements [3]. So in order to develop a concept all those parts are needs to be covered to some extent. The generation of concepts has its base in the specification but the concepts themselves needed to be derived in some way.
Ideas for concepts can be achieved in a number of ways, a couple of which might be: Osborne's idea-spurring checklist, Gordon's method or analysis of the nature [3]. All of which are good under certain conditions, but generally relying on a group of participants. The synthesis of concepts from those ideas can be achieved via one of the common methods function tree modelling or morphological matrix. For this project the ideas for parts were derived by brainstorming, and concepts were synthesised using morphological matrix [7].

2.2.1. Brainstorming

Brainstorming is one way of starting the idea generation, and works by just thinking up all kinds of solutions; seemingly impossible as well as possible solutions. While brainstorming no critique and no judgement is allowed to be put upon the proposed solutions thought of. After the session is closed however one *must* look at the ideas from a critical point of view in order to make progress in the development process. One can however find parts in an impossible solution that could actually work, and perhaps even brilliantly. That is the true use of brainstorming; you can get solutions or part of solutions that would never have sprung if you never thought about the impossible ways of dealing with the product, and that is the point where the developments in products are made.

For this project a sort of brainstorming session were conducted in order to derive some concepts and sub-solutions. The session however was conducted in a different way than the usual, i.e. gathering a group who then thinks up many solutions individually and as a group. In this project only the individual part was conducted and the reason for that was that there were no possibilities to gather a group that could apply input in this matter at the time the brainstorming was held. The "normal" way to do this is to assemble a group of 5 -15 persons

[5], of which one is a session leader, and the group states ideas and build on each other's ideas. According to Johannesson et. al. [3], the session usually passes through five stages:

1. Ordinary ideas.
2. Quietude or a slower pace in the generation of ideas.
3. The "large brain" starts working.
4. Quietude or a lower rate of generation.
5. Unusual ideas surface.

These five stages are representative for a group but might not be present if the session is conducted in a way that do not correspond to the way Johannesson [3] assumed; which is in a group, consisting of 7-10 persons.

2.2.2. Morphological matrix

Another way of creating concepts is to structurally order solutions and sub-solutions in a matrix and then puzzle the pieces together to a whole. This is what the Morphological matrix is helping to achieve, and is done by cross referencing solutions to functions or variables in construction/design or other parameters that affect the outcome. Since the matrix works by having sub-solutions to sub-functions, it often follows after the brainstorming where you can disassemble the complete concepts to parts and include the ideas for only sub-solutions and add to the matrix. Before the brainstorming no, or a very small number of, solutions could be placed in the matrix, thus limiting the usefulness of said matrix. After the brainstorming you assemble the matrix with all solutions to each criterion listed in rows to the right of the criteria; criteria listed in a column to the furthest left in the matrix. When all is set up accordingly you can start by stepwise combining the solutions until one solution per row are marked, thus creating a whole product from the parts. This is then repeated until all possible combinations has been examined and created. By labelling the columns for the solutions you get, when combining the parts, a name for each complete product, e.g. 1f-2c-3a-4a where the numbers are stating the row and the letter the column. By doing this it is easier to refer to a concept as the project continues. For large matrices, however, the names will be very long and perhaps even really similar, thus another way of sorting the concepts might be advisable. A way of doing this is to mark each sub-solution with a figure or code, representing a concept, so when referring to "Concept 1" it contains all the sub-solutions marked with the number one (1) and so on. By doing this confusion can be avoided and the process is more clear for new project participants and peer review.

Used in the morphological matrix are the sub solutions and parts of the full concepts from the brainstorming. The matrix works by stepwise combining the sub-solutions, which are solutions to parts and functions the product needs in order to work as it is supposed to. If a solution is general or non-dependent on other solutions, it can be left out of the matrix since it will apply anyway. By excluding such solutions one might argue that the matrix is erroneous, but as they do not affect their surroundings it is regarded as a valid way of working in this project.

2.3. Theory of Evaluation and Screening of Concepts

The development of concepts often works in a way that is easily depicted as a funnel through which the concepts are flowing. Since the mouth of the funnel is wide, it is possible to fit many concepts in here. The ways of narrowing the funnel is to apply conditions that the concepts needs to pass in order to continue, such conditions is often stated and used in different evaluation matrices. By doing this one can sort out the concept, or concepts, that performs best according to the stated conditions. That said, it is not always that the concept able to pass all the conditions is the best concept, only the best concept for the conditions used.

The task of selecting a concept, or concepts, to continue work on is a task that can be tricky. Several different methods can be used to reach the stage where only one, or a few, concepts is still running. Among those methods are different matrices, voting by a group, by consultant of experts and stepwise elimination from tests. For this project two matrix based methods were used; Pugh matrix and Kesselring matrix. The reason for choosing these methods is because they are highly structured and it is easy to follow the process for an external audit. The two methods are also a self-documenting of how the processes were conducted, since it is clear what the evaluation criteria looked like and how the rankings were made.

2.3.1. Theory of using Pugh evaluation method

When using Pugh matrix, or screening-matrix as it is called in Ulrich and Eppinger's *Product design and development*, as a tool for evaluation of the concepts, the aim is to lower the number of concepts. The Pugh matrix is one way of doing this with its basis in the needs and requirements of the product. It works by creating and prepare a matrix for selection, in which the generated concepts are listed at the top row and the criteria for evaluating against is in the furthest left column, (see figure 2.3.1). By having one "concept" as the original product, this matrix can show if the concepts are better or worse than the already existing solution. Often the current product is used as a datum, which works as a ground to the voltage - something to measure against. The criteria mentioned as an evaluation method has to be selected, and are so from the needs and requirements identified earlier on. At this time the criteria are often more general than it would be later on in the project. When selecting the criteria make sure not to bring several criteria of lesser importance to the matrix, since it may cause a concept that scores good on the important matters still lose out to a concept that scores good in only lesser criteria. One can get around this conundrum by using a weighted Pugh matrix, where each criterion gets a weight assigned to it, thus differentiating between important and less important needs. Other than the weights the matrix itself works the same.

If a concept exceeds the datum, it gets a plus (+) score in the corresponding box, if it subceeds the datum it gets a minus (-), for equal it gets a (0). When scoring the concepts, Ulrich and Eppinger suggests that you score all concepts for one criterion at the time. The reason for this is so that the mind-set is equal for all concepts per criteria. Another way of looking at the evaluation is to use metrics as a reference for the score given. By having criteria relate to a metric, e.g. number of parts as a relation to the cost, the risk of being biased is lowered and the process will be fairer.

When all concepts have undergone this procedure, you add up all the plus, minuses and zeroes, and the total you get represents the total score given to each concept. Ulrich and Eppinger also points out that it at this stage is good to try to combine concepts to create a better one, and try to improve concepts where they have shown to have some weaknesses. When combining this has to be done while still keeping the concepts distinguishable from each other, and, when improving, try to change minor details that could affect the result greatly. After finishing the combining and improvements, you re-introduce the new concepts to the matrix and score them alongside the other concepts.

The next step is to rank the concepts related to its score and comparing the concepts score to each other, where the highest score fetches the best rank and so on. From the rankings and the scores, conclusions can be drawn regarding what concepts to let go and which ones to keep for now. However, concepts can also be brought along by choice, or gut feeling. What needs to be done in those circumstances is to reflect on what made you bring that concept even though it was a lower rank than others left out. Perhaps there is a criterion that needs to be added because of a perceived quality of that certain concept as an example. When you feel that there is no longer anything to improve or adjust to make a better screening, you can safely move to the next step in the process.

	Concepts					
Selection criteria	Datum	A	B	C	D	E
Ease of use	0	+	+	0	-	0
Low weight	0	-	+	+	+	0
Low cost	0	-	0	-	+	+
Ability to bend	0	0	+	+	0	+
Ease of installation	0	0	-	+	0	0
Easy maintainance	0	-	-	+	+	+
Sum +'s	0	1	3	4	3	3
Sum -'s	0	3	2	1	1	0
Sum 0's	6	2	1	1	2	3
Total score	0	-2	1	3	2	3
Rank	5	6	4	1	3	1

Fig 2.3.1 Image of a schematic Pugh matrix

2.3.2. Theory of using Kesselring evaluation method

Generally this step does not follow directly after the Pugh matrix since the yield from this would be very similar to the previous. Some additional development on each concept might be needed beforehand and some more detailed criteria and metrics are advisable. Otherwise the two different matrices looks very much alike, but the use of them are slightly different. In the Pugh matrix you only check if a concept is better, worse or equal to the datum, while in the Kesselring matrix you rate the performance of each concept, a datum is not necessary. That is to say each concept gets a number on how well it performs, thus increasing the differences between the concepts. Often added to this in a Kesselring matrix are weights for each criteria, which can then be multiplied with the rating in order for the most important criteria to have greater effect on the overall score. To get the weights for the criteria you can assign the weight how you think the importance is distributed amongst the criteria.

2.3.2.1 Weights to Kesselring matrix

To get a more scientific process, a matrix for calculation of weights is available (fig 2.3.2 a). The matrix aims at comparing the different criteria to each other and therefore lists the criteria on both axles. By stepwise comparing two different criteria with each other and in the corresponding box assign value for more important (1), less important (0) or equal important (0.5). You do this only for the part of the matrix above the diagonal and then invert the values to the part under the diagonal. The sum for each row is then calculated and written to the right of each row. These sums can be used as weights, but you can also continue by calculating the different sums as a percentage of the total of all sums. Again, the percentages can be used as weights but yet another step is possible. That step is to grade the percentages where the highest percentage receives the highest grade, i.e. the criteria with the highest score is the most important.

	Criteria A	Criteria B	Criteria C	Criteria D	Criteria E	Criteria F	Criteria G	SUM	SUM/Total	Weight
Criteria A		1	0.5	0	0	1	0	2.5	0.119048	2
Criteria B	0		0	0	0.5	1	0.5	2	0.095238	1
Criteria C	0.5	1		0.5	0	0	1	3	0.142857	4
Criteria D	1	1	0.5		0	0	0.5	3	0.142857	4
Criteria E	1	0.5	1	1		0.5	1	5	0.238095	7
Criteria F	0	0	1	1	0.5		0.5	3	0.142857	4
Criteria G	1	0.5	0	0.5	0	0.5		2.5	0.119048	2

Figure 2.3.2 a. The weighting matrix schematic representation

Another column that may also be added to the Kesselring matrix, is a column displaying the performance of each concept related to each criteria. Such a column helps the user(s) to keep the ratings in relation to the performance, thus minimizing user bias.

Criterias			Concept A			Concept B			Concept C		
Evaluation Criteria	Measurement	Weights	Magnitude	Score	Weighted score	Magnitude	Score	Weighted score	Magnitude	Score	Weighted score
Criteria A	kg	2.5	11.3	3	7.5	8	6	15	9.7	5	12.5
Criteria B	SEK/unit	2	189	7	14	260	3	6	207	6	12
Criteria C	W/m^2*K	3	3.2	7	21	3.2	7	21	3.5	8	24
Criteria D	psc.	3	7	5	15	10	3	9	6	6	18
Criteria E	dB	5	45	5	25	40	9	45	41	8	40
Criteria F	l/min	3	9	7	21	7	5	15	9	7	21
Criteria G	rpm	2.5	1200	6	15	1500	9	22.5	1000	4	10
Sum					118.5			133.5			137.5
Rank					3			2			1
Weighted score = Score * Weight											
Magnitude displays predicted performance											

Fig 2.3.2 b. Image of a schematic Kesselring matrix

2.3.3. Selection of criteria for evaluation

The criteria used in the Pugh and Kesselring matrices stem from the specifications of needs and requirements. From this table some criteria can be chosen for which the concepts will be tried against. Thus it is vital that the most important requirements are reflected in the criteria, but not all of the requirements are perhaps suitable for use in this way. In the case of the BPC it is stated that "...parts conducting HV must be coloured orange…". This is an example of a criteria that might be redundant, since all of the parts in this case could be made to be orange. It is a very important requirement still, but it will not be a divider in the concept evaluation process. Were it that a part could not be made orange, it could have been a criteria and the concept might have been eliminated. When selecting criteria it is important not to bring too many of the ones of low significance since they can make an otherwise weak concept to look good, even though it does not fulfil important needs [3]. As seen in figure 2.3.2 a), the criteria can be compared to each other thus giving the relative importance of them. Needs with a low score could be taken out if it is not a need that is necessary to fulfil.

2.4. Theory of refinement and verification of concept

The task is to make a product better than its predecessor and it is then good to know the performance the next generation need to surpass. When it comes to mechanical performance there are many ways to go by: real life tests, computer simulations, and calculations to name a few.

2.4.1. FEM analysis of model

A FEM software is basically a differential equation solver for geometries that would be very time consuming if done by hand. The use of this tool is to see if the product can meet the demands and also that everything will withstand the potential loads. Such software works by dividing a CAD model into small interlinked sections and then calculating the effect when some pieces are subjects to a force. Since the pieces are intertwined, if one piece is moved it influences its neighbours, which in turn influence their neighbours. By checking how the pieces affect each other, the program calculates the total effect. FEM software can be used for static as well as for dynamic simulations, but in this project only static simulations were done.

2.4.2. Conduction of tests and verification of design

Tests can be addressed in a number of ways but often sorted into two different categories; test-to-design and design-to-test. In lean product development test-to-design is the preferred method and works by first do tests, and from those tests do the design [8]. This takes some time to set up and conduct many tests but is generally relying on models and mock-ups. By first testing you can also try for different parameters and in that way optimise the way a product may be designed. Often used in this way of working is another helpful tool called Design of Experiments (DOE), which is a systematic test of parameters specifically aimed at optimisation of part or product [9]. Another aspect of test-to-design is that the tests should proceed until failure, thus learning the limits of the product [8].

The other way to work, deign-to-test, works by first making the total design and then conducting the tests needed. The problem with this is that, if something is not working, you might need to scrap the whole product. If it works though, you have saved some time but generally do not know the limits of the product. But for an uncomplicated product this might be a less costly way of getting a good product to the market in a shorter time. It can also be the procedure if the product has many strong limitations in its design, and only minor parameters are allowed to be altered. In this case the tests more or less aim at confirming and make a basis for refinement of the product.

2.5. Cost estimation

Cost estimation is of great significance in any project and should be done properly. By "properly" means consulting with an expert in manufacturing and not just get an estimate from a producer. An expert might tell you that the selected process is not the best suited nor the cheapest. So the costs of the product might be cut if including production in an early stage and also by keeping continuous communications about design issues and progress. If the production is in-house this will also help the production to start their preparations earlier, thus lower the ramp up time.

A quick and easy estimation of cost is to add up all the expected costs that will be bound to the new product. Here one has to assess the number of unique parts; the number of operations per part; the cost per operation; type-bound tool costs; the labour costs; assembly time; and such cost directly related to the new product. In this assessment you do not need to include the rent of space, degradation of equipment, electricity, etc. since these costs will exist regardless of the product. Another aspect to consider is whether the product has some of-the-shelf parts or if everything has to be manufactured from scratch [10].

3. RESULT OF APPLYING THE PRODUCT DEVELOPMENT APPROACH

When the steps discussed in the theory section were applied on BPC project, each method made the project take another step in the direction towards a complete product. In this section it is shown how the methods were used in this particular case and also the results from these methods are displayed here.

3.1. Result of Feasibility study

In the beginning of this project there was a need of getting to know the product that was going to be developed. And as discussed in the theory section, this familiarisation and knowledge about the product was made by conducting short unstructured interviews, internet and patent searches, and also literature study. These methods were deemed to reach an adequate level of knowledge about the product and still not making the project too rigid at an early stage.

In this project most of the information was gathered online and in dialogue with the customer, ECar. The reason for this was that is that the technology is reasonably new for this type of vehicles and not proven in the field of application where it is intended. Because of this not much information could be drawn from user interviews since the people there had not handled a similar product in that environment and setting before. Also because the basis of development was a prototype, little was known about the situations that might have implications regarding the performance of the BPC.

3.1.1. Interviews

The interviews in this project have been done mainly with Ben van der Geer, R&D at ECar, who was regarded as the most knowledgeable in this matter at the company. The first interview was preceded by a study of the current battery pack as it was mounted on the car. This was done in order to raise question and speculation regarding the design and performance of the product. Afterwards the questions were written down and asked to Ben in a dialogue in proximity to the car the battery pack was mounted on. This was so that Ben could demonstrate certain aspects and not just explaining them, thus getting a better understanding of the product. The order of the questions were random and worked more as a guide to the conversation, some of them were not even posed; partly because some of them were answered before asking and some of them were redundant in other ways. After the session the questions as well as the answers were documented and reflected upon and some information was searched for in other ways as well. By doing that more questions surfaced and another meeting at ECar facilities in Kungälv was booked. Therefore a second brief visit to their establishment was done and the additional questions were asked as well as a second viewing and measuring of the current product. Some of the questions could not be applied since the current BPC is also only a prototype, thus not much experience about working with it exists. That is the reason only ECar was interviewed and not some of their customers. Although a very brief conversation with an employee at a customer workshop was made at a later stage of the project, but he could not answer much that would alter the needs in any way.

The written down questions and answers can be found in "Appendix 3", but most of the information was gathered while talking outside of the questions. From these dialogues some really good information could be drawn, e.g.:

- Not only the weight is of interest.
- A battery exchange system is thought of being used for shifting the BPC (Authors note: thus limiting the freedom of design).
- The temperatures inside the BPC reaches 27*C during operation.
- The BPC must be attached to the vehicle in case of collision/emergency.

3.1.2. Internet searches

In order for the new concept to exceed the performance of the current one, as much information of what a BPC must endure was gathered. Knowledge could be gathered from all kinds of documents regarding the subject such as articles in newspapers and forum threads discussing some aspect of a battery pack. For this project much data were available from online sources, although mostly gathered from directives derived by European Union [11]. There have been several standards for battery packs for propulsion which had to be followed, if an Electrical Vehicle (EV) was to be type approved. These directives were regarded as demands, since they were needed to be fulfilled in order for vehicle to get a type approval. But there were also conditional statements of the sort: "If x is in this way, then y has to be fulfilled".

The directives did not actually address any problems with battery packs, but gives guidelines which the complete car should conform to. So in other information were needed as a counterweight to all strict directives. Forums about electric car conversions and forums for owners of electrical cars were addressing some issues regarding the durability of the battery pack. In a forum a statement was made regarding the waterproofness of the battery pack on his fully electrical car, Tesla Model S ; which was regarded as not being adequate. This is then related to electrical IP-class which is a classification for how well electrical units are sealed from ingress of water and dust. IP67 means it is able to immerse the BPC into water to the depth of one meter, measured from the bottom of the BPC to the surface of the water, without any ingress of water allowed. Other issues were also found when it came to fires and EV:s. Specifically here was that when EV:s were rear ended, there was a risk of the batteries catching fire [12]; and it was not a single case but a series of similar events had taken place.

Same goes for the Tesla again, who has developed a shield in titanium for the battery pack, since they had problems with debris piercing the BPC causing fires to occur. The reason for the fire varies but in some cases it has been that a spark discharge from the battery has ignited flammable parts of the car.

3.1.3. Patent searches

Internet was used as a means of finding patents as well, but focused on patents only. When doing this search, anything even remotely similar of the current solution was of interest. This was so no infringement was done in any field of application and also to gather some ideas. Inspiration on how to solve some issues regarding the BPC were found but not incorporated in this project since it was regarded as non-applicable for a smaller volume of production. For this project there were no risk of interfering with any patents found, that is to say there was a freedom to operate in this project.

3.1.4. Literature study

During the literature study most time were spent on trying to find some information about, or some study of, the BPC. However this was mostly just mentioned in the passing while discussing some other aspect of the battery. Although, when reading up on what affected the battery life, some useful facts could be drawn towards the design of the container. More specific the text was about the relation between operation temperature and the battery life. Also the battery depletion rate was found to correlate to the temperature during operation [13]. The study showed that a temperature at about 27*C during operation was to prefer in order to maximize a battery’s life.

An update regarding the theory of product development and methods was part of the literature study. Although much was known beforehand, it was regarded as a necessity to increase the knowledge in the use of the theories and methods.

3.2. Result of Specifying Needs and Requirements

The information gathered was very unstructured and hard to get a good overview of when first assembled. So a structured approach of sorting the information into needs and requirements was needed to be done. This was done in two ways; by creation of a specification of the needs and requirements, and by making a function decomposition.

3.2.1. Result of specifying the needs and requirements

Ulrich and Eppinger [5] describes in their book "*Product development and design*" a way of listing the needs and requirements. This method in combination with Almefelt [10] was used in this project, resulting in a specification of needs divided into four main topicts:

- Operation
- Safety
- Architecture, Geometry and Shape
- Assembly

By having divided the specifications into different parts the overview of the specification were good and specific needs were easy to find when needed. This helped a lot since the specifications were used as a basis on which the rest of the project rested. But it is not a static document and have been added to during the entire project when something important or new has surfaced. They have also grown more specific over time and include more detailed descriptions of parts and functions. In the figure below (fig. 3.2.1.) part of the specifications can be seen, but the full specifications can be viewed in "Appendix 4" at the end of this report.

	Specification of Requirements for Battery Pack (BP)			
Legend: R = Requirement (must have); D = Desire (wish to have)				
UNECE referres to 'UNECE regulation no. 100'				
Requirement		**Justification**	**Verification**	
1. Operation				
1.1 During normal operation				
D1	The BPC maintains a operational temperature in the range of 15 - 40 ºC	Minimize energy loss	Test	
D2	The BPC must withstand temperatures in range -30 - 70 ºC	Must not fail in extreme weather	Assessment	
Battery modules must not move when the vehicle is operated				
R1	Battery modules must be kept in position when driving on uneven surfaces	Lower risk for accidental shortening or malfunctioning	ISO 12405-3	
R2	Battery modules must be kept in position in case of collision in low speeds	Lower risk for accidental shortening or malfunctioning	ISO 12405-3	
BPC must facilitate safe operations				
R3	Vibrations must not casue: a) Electrolyte leakage, b) Rupture, c) Fire or d) Explosion	Safety during operation referred		
2. Safety				
2.1 Electric safety				
No live parts should be accidenatally in contact with operator or conducting surface				
R1	Parts belonging to voltage class B (30 - 1000 Vac alt. 60 - 1500 Vdc) must be orange	No accidental contact with live parts	Yes/No	Fullfilled by other means
R2	Rechargeable energy storage systems (RESS) must be marked with ISO 7010 warning for high voltage	No accidental contact with live parts	Yes/No	Fullfilled by other means
R3	Live parts must be insulated; voltage class B insulation >500 Ohm/V	No accidental contact with live parts	Assessment	Fullfilled by other means
D1	Barriers for additional insulation can be adopted to fulfill R3	No accidental contact with live parts	Assessment	Fullfilled by other means
No accidental shortening of conducting parts shall be possible				
R4	No ingress of water allowed			
R5	No ingress of dust allowed			

Figure 3.2.1. Part of the specification of needs and requirements

Some of the needs and requirements were not used in the project since they were either outside of the limitations or not applicable in this case. Originally they were brought in to the specifications in order not to discard any demands later showing to be of importance. It was decided to be better to add them and not use them rather than not adding them and then needing them at a later stage.

3.2.2. Result of function decomposition

The function decomposition was made after the interviews at ECar were done and the current BPC was studied. It was found to be a difficult task since the container for the batteries more or less just sits under the car. But when thought about it for some time it was found that it actually performs several functions needed to be fulfilled by the new BPC. The found functions were assembled into a hierarchical table instead of a tree diagram. This was because the size if a tree diagram had been used would not have been as manageable. The main function was regarded as to hold batteries as well as guard them from external harm and maintain operational temperature. The sub-functions are more specific in how this was realised by the product, and each step down in the hierarchy further explains the function. This decomposition can be seen in figure 3.2.2 below.

Main funk	Tier 1	Tier 2	Tier 3	Tier 4
Store energy in a manner that also protects it and informs what is inside	1. Keep batteries safe from harm	1.1. Shield batteries from abuse	1.1.1. Protect fom ground debris	1.1.1.1. Resist piercing of objects from ground
				1.1.1.2. Resist blunt object impacts
			1.1.2. Protect batteries when road is un-even (keep batteries still)	1.1.2.1. Minimise movements inside BPC
		1.2. Shield batteries from envioronmental harm	1.2.1. Resist corrosion	
			1.2.2. Keep water from enter BPC	
			1.2.3. Withstand naturally cold temp. without failing	
			1.2.4. Withstand naturally warm temp. without failing	
			1.2.5. Keep temps. within operating temps.	
		1.3. Guard batteries in case of collision	1.3.1. Keep attachment to vehicle.	
			1.3.2. Keep stuctural integrity	
			1.3.3. Keep BPC adequately sealed	
			1.3.4. Keep electircity from beeing conducted through BPC	
	2. Keep operator safe while handling BPC	2.1. Facilitate easy handling	2.1.1. Geometry fits aoutomatic replacement system	
			2.1.2. Provides room for tool to fasten BPC to car	2.1.2.1. Provides enough clearance between side of BPC and head of screw
			2.1.3. Provides self evident operations	2.1.3.1. Only possible to place in one orientation
		2.2. Facilitate safe handling	2.2.1. Mark live parts	2.2.1.1. Warning Label (ISO 7010)
				2.2.1.2. Bright orange (voltage class B units)
	3. Facilitate fastening on vehicle	3.1. Carry the BPC	3.1.1. Increases stiffness	
			3.1.2. Keeps from buckling at bottom	
			3.1.3. Extra protection in collision	

Figure 3.2.2. The Function decomposition.

3.3. Result of the concept generation

When generating concepts some alterations had to be made in the processes. The discussion parts in connection to the generation processes could not be done in the way it is intended to. This was because the number of participants during these processes were quite limited, thus a discussion would have caused concern regarding the persons mental health.

3.3.1. Result of the brainstorming

As the theory states, a brainstorming session is a great way of introducing many ideas to the problem at hand. In this project the brainstorming session were divided to make ideas for parts and sub-systems of the total solution. A lot of inspiration in this case came from everyday items such as shoe boxes and kitchen drawer. Then the parts, thought up during this time, was sketched and also a short text describing some differences between the concepts was added to the drawings. Some ideas came later and were then added to the concepts already derived, since it was regarded that additional concepts were needed. A brainstorming is more effective if you get inspiration from others, so in this case a meeting with the Lamera supervisors were held to get feedback and another view as input. Some re-work and additions were made here as well. The yield from this session was a number of solutions to parts of the BPC. The parts were divided into groups for easier transfer into the morphological matrix later on. Some full concepts were initially thought of but were soon to be imaginarily disassembled into parts and added to the groups mentioned.

3.3.2. Result of the morphological matrix

While the brainstorming was done differently from its usual way, the morphological matrix could be used the way it should. The functions and other variables for the design were listed in a column to the furthest left of the matrix. To the right of that column were the solutions for each function and variable listed in rows. When all this was set up the task of combining the different solutions, where it was possible, could commence. The result of the morphological matrix at this point was hard to understand and the end concepts seemed very much alike. It was regarded that something in the matrix was not correct, so the first result was scrapped. Instead some more thought went into making a new combination matrix, again according to the theory. And after a second pairing of solutions by colour coding the combinations, the result felt as an improvement in the project rather than not advancing at all, as was the case in the first matrix. By colour coding the concepts it was much easier to follow the progress in the matrix. Another aspect was also that the names of the concepts were easier to remember and keep track of during later stages of the project. Left out in the matrix were parts that needed to be done in a specific way that could not be altered or solution to parts that were ridiculously easy to alter at a later stage such as the gaskets for sealing of the box. Also the gaskets would not make any difference for the concepts since they were regarded to suit any concept derived.

From the matrix, 14 somewhat different concepts were derived; each one corresponding to a colour. Some were limited by the wishes of the customer and could have been taken out of scope straight away. But in order not to inhibit the progress of the concept generation they were kept in the running as to provide stimulation of thoughts and ideas. Most of the other concepts are variants of two different concepts; this was because it was perceived that they were different enough to evaluate them alongside its siblings. The full concepts were sketched and a short description of parts was written in order to clarify the differences and features of the BPC. In the figure below, fig. 3.3.2, it is presented how the combinations were in order to derive the concepts.

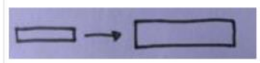
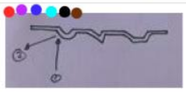
Morphological Matrix	**Possible Solutions**			
Functions to solve for				
Possibel placements of BPC	In loading compartment of the car	Underneath the car		
Possible bottom configurations	Single Layer	Multiple layer	Use car body as floor	
Bottom designs to increase stiffness	 Stiff material	 Deep drawn profile	 Thicker material	 Atleast on layer with profile
Possible placement of fastening system	 Through flange	 External fastening		
Sealing BPC			 Deep Drawn	
Resistance for ground debris	 Deflect debris	 Absorb energy in deformation zone		
Fit battery exchange system	YES	NO		

Figure 3.3.2. The Morphological matrix as performed in this project. The coloured dots lead the way through the matrix where each colour represents one concept.

3.4.1. Decisions from concept generation

Due to the relatively small amount of concepts derived, and with somewhat diverse designs, it was considered as enough to move all of them to the evaluation matrices. An elimination based on the requirements prior to this was regarded as redundant since there were few enough concepts to apply the matrices on and some was kept running in order to show alternative to some more given solutions. The concepts that could have been eliminated directly after the generation also was kept since ideas in those concepts would not be lost. Below (fig 3.4.1.) are some of the concepts generated, the two names for one picture indicates that different type of materials could be used thus being two different concepts while looking alike.

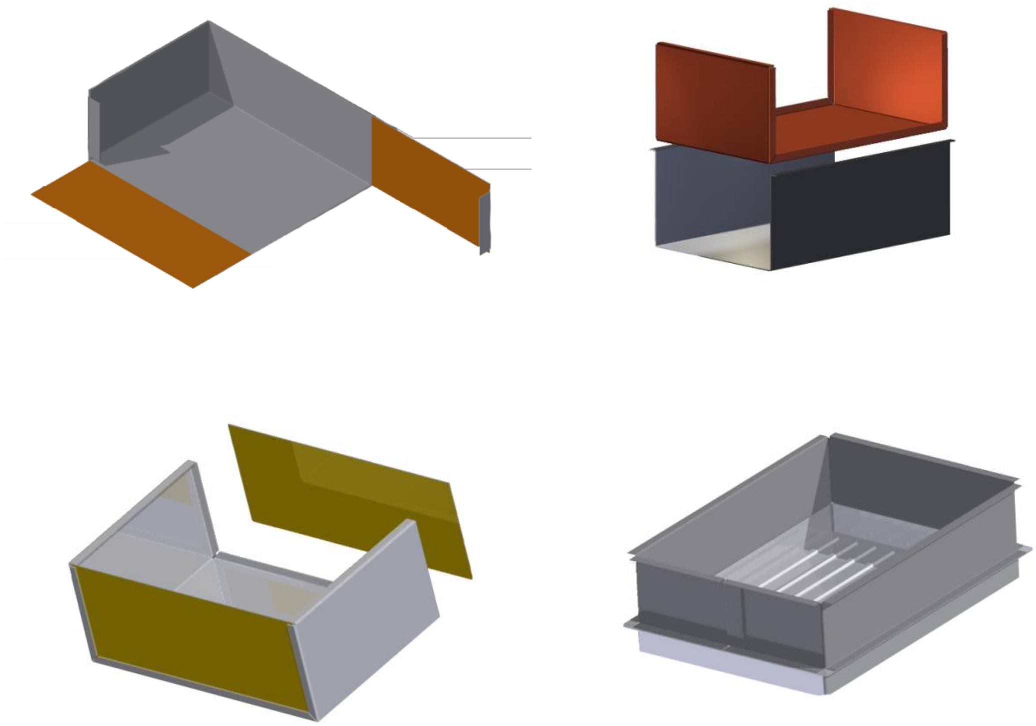


Figure 3.4.1. Some concepts derive: top left Yellow I and II; top right Orange; bottom left Sky I & II; bottom right Pink & Brown.

3.4. Result of the concept evaluation and screening

From the previous stage, generation of concepts, 14 different concepts were found. This was too many concepts to effectively continue working on and therefore needed to be reduced. The Pugh matrix is a useful tool as a first screening when not much is known regarding the performance of each concept. When some more work has gotten into the product concepts a Kesselring matrix is to recommend since it is more differentiates the concepts better than the Pugh.

3.4.1. Result of Pugh evaluation

It was not a feasible task to continue development of all 14 concepts, thus the number of running concepts needed to be reduced. To do this with a systematic approach a Pugh matrix, as discussed in the theory section, was used. The current BPC was used as the datum to which all other concepts were measured. The criteria were assembled from the specifications of needs and requirements available at this point. A slight problem was the risk of biased opinion by the person conducting the screening, so conditional evaluation criteria were added in order to lower the risk. By adding conditions to the criteria, a point of reference is available for the entire evaluation.

A first screening resulted in five concepts being proven worthy of proceeding to the next stage in the development process, as subjects for continuous development. The theory recommends running the matrix a second time with the winner as datum. This was not done since the yield from the first screening was regarded as diverse and the number of concepts was small enough to continue development on each of them. A sixth concept was brought along by choice, which is supported in the theory, since it was regarded as a candidate that could potentially benefit greatly from being developed further. Later endeavours showed this not to be the case, though. When selecting a concept based on gut feeling it is advisable to reconsider what strengths it might inherit that was not displayed in the first screening, and add criteria based upon this for the next stage. One of the downsides of dismissing some concepts early on is that you might disregard a concept that could potentially be really good if it was only developed further. But thinking like this slows the development process and makes it more difficult for the project to progress.

In figure 3.4.1 you can see the Pugh matrix as done in the project. The concepts marked in red means that they were dismissed, the ones marked by green passed this screening, and the one concept marked in yellow was brought on by choice. A total of six concepts remained in development and in further competition. But comparing them against one another straight away would not have deemed any other result than that from the Pugh. Therefore some additional development and further investigations in each concept were done before yet again comparing the concepts to the criteria.

Evaluation Criteria v	Present Solution	Red	Blue	Purple	Green	Yellow I	Yellow II	Orange	Sky I	Sky II	Petroleum	Pink	Black	Brown	Lime
Weight (lower is better)		1	1	1	1	1	1	0	1	0	1	1	0	0	1
Stability	D	1	1	1	1	0	0	1	1	1	1	1	0	0	1
Secure mounting		1	1	1	0	0	0	1	1	1	1	1	1	1	1
Assembly speed	A	-1	0	-1	1	1	1	1	1	0	0	1	0	1	0
No. of Splices		1	1	-1	0	-1	-1	0	0	-1	-1	1	-1	1	-1
No. of Parts	T	1	0	-1	0	1	1	1	0	-1	-1	1	-1	1	-1
No. of Assembly steps		1	1	-1	0	-1	-1	-1	0	-1	-1	1	-1	1	-1
Assembly complexity		-1	-1	1	1	1	1	1	1	1	1	1	1	1	1
Seal	U	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Complexity		-1	-1	0	1	-1	-1	1	0	0	0	1	-1	-1	0
Customizablilty to fit BES	M	-1	-1	-1	1	1	1	1	1	1	1	0	1	0	1
Hazardous if gassing		-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0
N of 1:s		7	6	5	7	6	6	8	7	5	6	10	4	7	6
N of -1:s		5	4	6	0	3	3	1	0	3	3	0	4	1	3
SUMMA		**2**	**2**	**-1**	**7**	**3**	**3**	**7**	**7**	**2**	**3**	**10**	**0**	**6**	**3**
Rank		**10**	**10**	**14**	**2**	**6**	**6**	**2**	**2**	**10**	**6**	**1**	**13**	**5**	**6**
Pass	Green	Orange	Sky I	Pink	Brown										
Pass By Choice	Lime														
Stop	Red	Blue	Purple	Yellow I	Yellow II	Sky II	Petroleum	Black							

Figure 3.4.1. The Pugh matrix as performed in this project.

3.4.2. Decision from Pugh evaluation

The decision from this matrix was to continue development of the five concepts marked in green, but also to bring the concept marked in yellow further in the process. The decision for choosing the first five concepts was easy since they were the ones with the highest score and the difference to the rest of the concepts was high, in relation to the total score for each concept. The “Lime” concept was brought forth based on a gut feeling that a higher degree of diversity was needed as the development continued. Another reason was that the “Lime” concept was perceived as to inherit some aspects that could perhaps benefit from being further developed. Such features were the external structure and that it was constructed using more parts but with a simpler design.

3.4.3. Result of Kesselring evaluation

This matrix was done at a later stage of the project when development of the different concepts had proceeded for some time. By postponing the second evaluation during the time the concepts were developed, additional information, which could be used in the Kesselring, was gathered. This information was partly processed via FEM calculations discussed later in this report, and partly refined information from the Pugh matrix.

The Kesselring matrix needed some alterations in order for it not to be entirely opinion based, which could have been the case otherwise. The alterations that were done were to add a column for the magnitude for the performance of each evaluation criteria. Developing the different concept before the screening made it possible to add the magnitudes, thus minimizing biased opinions. The bias is lowered since the magnitude, or performance index, directly relates the concepts to each other, thus making it visible how to rank them and extremely hard to motivate a high score for a poor magnitude. Also added were weights, calculated according to the theory section of this report. The weights used were represented by the first score derived from the weight matrix, since it was regarded to more accurately reflect the relative importance in this case. The weights helped to further differentiate between the concepts, since a high score on an important criteria could send a concept to the top in the blink of an eye.

The winner at this stage was the concept “Orange” (see figure 3.4.2.) but under other circumstances any other concept might have taken its place. The main reason for this concept to succeed was due to its’ relatively cheap tooling as well as its’ low deflection of the bottom, for the static load of the batteries. A check was also done to see the score for each concept based on the top five most important criteria, and the “Orange” concept had the highest score for those as well; further justifying that as the choice for this project.

No.	Evaluation Criteria	Weight (w)	Parameters	Unit	Green Magnitude (m1)	Green Value (v1)	Green Weighted Value (w*v1)	Orange Magnitude (m2)	Orange Value (v2)	Orange Weighted Value (w*v2)	Sky I Magnitude (m3)	Sky I Value (v3)	Sky I Weighted Value (w*v3)	Pink Magnitude (m4)	Pink Value (v4)	Pink Weighted Value (w*v4)	Brown Magnitude (m4)	Brown Value (v4)	Brown Weighted Value (w*v4)	Lime Magnitude (m4)	Lime Value (v4)	Lime Weighted Value (w*v4)
1	Low Weight	7,5	Weight of box	kg	6,7	5	37,5	7	4	30	9,5	2	15	4,5	7	52,5	9,605	2	15	7,5	3	22,5
2	Simple assembly	9,5	Low number of engagements	#	2	8	76	1	9	85,5	2	8	76	2	8	76	2	8	76	8	2	19
3	Simple production	6,5	Simplicity of parts (1 simple - 5 difficult)	-	4	5	32,5	4	5	32,5	3	6	39	5	2	13	5	2	13	1	8	52
4	No. of parts	6,5	Low number of parts preferred	#	4	6	39	3	7	45,5	4	6	39	3	7	45,5	3	7	45,5	4	1	6,5
5	No. of uniqe parts	10	Low number of parts preferred	#	3	6	60	3	6	60	3	6	60	2	8	80	2	8	80	7	3	30
6	Displacement when loaded	9,5	Deflection of bottom	mm	3	7	66,5	0.9*	9	85,5	1.2**	8	76	4	6	57	5,5	5	47,5	2.7*	7	66,5
7	Insulation properties	4	Thermal conductivity (at bottom)	W/m^2	0,4	5	20	0,2	7	28	1	3	12	0,4	5	20	1	3	12	0,4	5	20
8	Robust attachments	10	Thickness of flanges	mm	4,5	5	50	4,5	5	50	3	3	30	6	7	70	6	7	70	4,5	5	50
9	Simple maintainance	1,5	Easy to keep clean (min corrosion)	-	3	6	9	2	7	10,5	3	6	9	1	8	12	1	8	12	4	4	6
10	Seal from water/dust	11	Total length of joints	m	4,6	7	77	4,2	8	88	4,6	7	77	5,5	6	66	5,5	6	66	8,8	3	33
11	Suitability for Bat.Ex.Syst.	0,5	Suitability	-	5	5	2,5	4	6	3	5	5	2,5	2	2	1	2	2	1	5	5	2,5
12	Tolerance sensitivity	2,5	Assessed sensitivity to tolerances		3	7	17,5	4	6	15	3	7	17,5	4	6	15	4	6	15	2	8	20
13	Cost of type bounded tools	12	Unique tool cost considering 250 psc.	H/M/S***	M	5	60	M	5	60	M	5	60	H	2	24	H	2	24	L	8	96
14	Material need	8,5	Total blank area needed	m^2	2,5	7	59,5	2,9	5	42,5	2,5	7	59,5	2,9	5	42,5	2,9	5	42,5	2,7	6	51
15	Safe evacuation of gasses	5,5	How the box handles pressure		good	5	27,5	good	4	22	good	5	27,5	moderate	2	11	moderate	2	11	good	5	27,5
16							0			0			0			0			0			0
	Sum						**634,5**			**658**			**600**			**585,5**			**530,5**			**502,5**
	Sum of top 5 criterias						389,5			429			379			373			363,5			294,5
	Rank						**2**			**1**			**3**			**4**			**5**			**6**

*Based on a bottom simulation without walls

**Stainless steel bottom

***High/Medium/Small

Figure 3.4.2. Kesselring matrix as done in the project.

3.4.4. Decisions from Kesselring evaluation

After the Kesselring matrix was conducted the decision was to continue development on the "Orange" concept only. This decision was the natural choice since it was the concept with the highest score; both total score and score for the top five most important criteria. It was regarded as a solution that was simple enough yet with high performance, thus the best choice for this project. The "Pink" concept was a strong contender for some time but was surpassed by the "Green" concept in the end. The "Pink" concept is otherwise really good but requires a production of more units in order for it to be cost efficient. So, by choosing the "Orange" concept, development came to a halt for the others. Next step was to tune and tweak the performance of the chosen concept.

3.5. Result of the continued development

Before the second screening, in the Kesselring matrix, and also when one concept had been selected as the one to go with, some further investigations and developments were in order. The development before the second screening aimed at increasing the performance and tweaking the design of the concepts. After the Kesselring matrix had revealed the concept for final development, additional development and verification of design was needed.

3.5.1. FEM analysis of models

One criterion in the Kesselring was the deflection of the bottom measured for the static load of the eight batteries weighing 11 kg apiece. In order to accurately measure the deflection some analyses of the CAD models were made. The FEM analysis software for these test were the one integrated in the CAD software, Inventor. The models were fixed by the flanges, mimicking the fastening on the car, and inside were a distributed force, equal to the weight of the batteries distributed over the bottom surface, applied. In some cases it was not possible to test with the full model, why only the bottom segments were tested for some concepts. This alteration was regarded to have little effect on the overall result. Since no material model for Hybrix is available in CAD and FEM at the moment, the material used for the tests was aluminium; and the thickness of the sheets was set to 2 mm, otherwise the software did not compute. Because of the comparative nature of the process at this stage the difference in result was good enough, since all that was needed was an indication on how each concept performed. The result from these calculations can be found in the Kesselring matrix as magnitude for the criterion for deflection of bottom.

After the Kesselring, when a concept had been selected as the One, when checking the stress and deflection of the “Orange” concept, the 2 mm sheet thickness was used, but then also with an adjusted Young’s modulus in order to get the same stiffness as for 1 mm Hybrix. This time the simulation was made to simulate the actual BPC to as great extent as possible. The result of this simulation is shown in the figure below (fig. 3.5.1). Also in this test a force equal to five times that of the force from the weight of the batteries was applied. This was done in order to simulate what happens if the car runs into a pothole or something similar. According to Ben van der Geer the forces can reach 5g, thus the weight of the batteries in such a case is five times their weight. Each battery weighing 11 kg, eight batteries, force is equal to 5g, and a bottom area on which the force is distributed gives a force of 15kPa. The foam board used in reality was not available as a material in CAD, so a sheet of PET plastic was used for the simulation instead.

Name	Minimum	Maximum
Volume	4361250 mm^3	
Mass	9,74487 kg	
Von Mises Stress	0,000130946 MPa	36,8141 MPa
1st Principal Stress	-9,44316 MPa	40,9803 MPa
3rd Principal Stress	-20,3138 MPa	5,49141 MPa
Displacement	0 mm	3,89154 mm
Safety Factor	3,0174 ul	15 ul
Stress XX	-14,5226 MPa	14,6228 MPa
Stress XY	-8,17426 MPa	8,02275 MPa
Stress XZ	-9,19216 MPa	8,25659 MPa
Stress YY	-20,3132 MPa	20,1873 MPa
Stress YZ	-13,5434 MPa	18,0661 MPa
Stress ZZ	-16,1081 MPa	31,7229 MPa
X Displacement	-0,96896 mm	0,970531 mm
Y Displacement	-1,23603 mm	1,28957 mm
Z Displacement	-3,89154 mm	0,0243784 mm
Equivalent Strain	0,0000000156652 ul	0,00373241 ul
1st Principal Strain	-0,0000317999 ul	0,00424143 ul
3rd Principal Strain	-0,0020068 ul	0,0000107758 ul
Strain XX	-0,00091056 ul	0,000931485 ul
Strain XY	-0,000942402 ul	0,000949234 ul
Strain XZ	-0,0013584 ul	0,00122014 ul
Strain YY	-0,00145857 ul	0,0015765 ul
Strain YZ	-0,00200142 ul	0,00266977 ul
Strain ZZ	-0,0015582 ul	0,00303973 ul
Contact Pressure	0 MPa	7,74775 MPa
Contact Pressure X	-3,24877 MPa	3,13534 MPa
Contact Pressure Y	-4,59762 MPa	4,71613 MPa
Contact Pressure Z	-5,99667 MPa	6,59624 MPa

Figure 3.5.1. Results from the FEM analysis for the Orange concept loaded with a pressure equal to five times the static pressure from the batteries, thus simulating a static force of 5g.

Unfortunately no images of these calculations could be produced due to a lack of memory capacity in the computer used for simulations.

3.5.2. Test of durability of flanges

At this stage in time a test regarding the robustness of the flanges was set up. It was done by making a 90 degree fold in a small sample sheet of Hybrix (150x130 mm) and fixing it, in what could now be regarded as the flange (2,5 mm), to a beam (the blue part in the figure). Then two slats of wood (the green part in the figure) were clamped to it in order to distribute the force uniformly along the free edge (see fig 3.5.2.). The application of a force was the last step and it was done by hanging weights in a rope which hung around the wooden slats. In order to really test the strength the force was gradually increased and when 20 kg were applied the weights were all out and the piece still hanging from the beam. A last test was to lift the weights some 5 cm and then let them go, letting the flange take all the impact. Even this abuse was not enough to separate the piece of Hybrix from the beam. This result was reassuring that the box will be able to carry the weight of the equipment inside, since each battery weighs 11 kg and there are eight batteries. The width of the sample sheet is also by dimensions similar to that of one battery; one battery being approximately 160x224x220 mm, where the width 160 is corresponding to the test width. No calculations regarding the flanges were made at this point. The aim of the test was merely to see if the flanges would withstand some abuse.

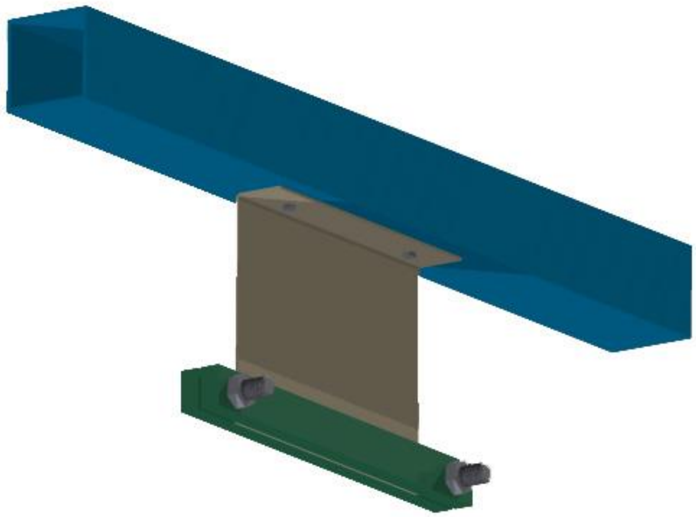


Figure 3.5.2. A CAD model displaying the setup of the flange test.

3.5.3. Test of material when exposed to potentially harmful fluids

At a late stage in the project it was found that the BPC could be exposed to two potentially harmful fluids; propane glycol (used at airports to defrost wings) and alkaline forniat (used at airports to de-ice the runway). The potential hazard was that the fluids might cause the material to delaminate, thus greatly weaken the BPC. To know how the fluids affected the material a test where the material were immersed into binges of the fluids were conducted. Material with two different configurations of the adhesive layer (B and C configurations), were prepared for the test by cutting them to a roughly uniform shape. Then the pieces were weighed individually and also measured the thickness at three points per piece, yielding an average thickness for each piece. After the measurements had been done, one piece from each configuration were submerged into the glycol and the alkaline forniat. One piece from each sample were also just wet really quick and then put in a box to dry. This was done in order to see if it was enough with only a small amount of liquid to have effect of the material. The fully submerged pieces were checked upon every other hour to see what the effects were. After 6 hours and no change in the material, other than an increase in weight by 0.1 g, the pieces were left submerged for 24 hours. After that time had passed the pieces were weighed and measured again and there were still no sign of change of the material. So the pieces stayed in the liquids for another 24 hours, just in order not to draw any hasty conclusions, but the yield was the same as previous. At this stage the material is regarded as to withstand the liquids. A table of the result is available but unnecessary to show since it is two rows of results showing almost the exact same values, since not much changed during the test.

3.5.4. Decisions from the tests

The FEM simulations showed that the displacement of the bottom for the orange concept was the best one. Further the FEM test showed that the displacement was small enough to be tolerated. Thus it was decided to go with the foam board instead of the imprints, a decision that would also have a positive on the total cost of the BPC.

By doing the flange test it was shown that the flanges could really take some abuse and that they would probably withstand the occurring forces. Although, two aluminium slats, running underneath the flanges, was included in order to secure that the BPC would not come off in case of some more serious case were to happen.

Testing the two possible material configurations for the fluids was essential. When this information arose, some concern was raised regarding the possibility to use Hybrix at all for this application. But as the tests showed that no risk was imminent so the decision for which material to use was based on the formability and the ability to withstand corrosion. This was done by consulting Bengt Nilsson and Jon Wingborg at Lamera, who are considered to be experts in the subject. The decision fell on Hybrix SP202. The adhesive of the C-type was chosen since it had the best properties with regards to the formability of the material. Making decisions based on expert opinion has support in the theory [3].

3.6. Presentation of final concept

The Orange concept has been the victor in every evaluation throughout the project, so it was rather natural to continue the development of that concept. The new BPC is made out of Hybrix SP202, which is a sandwich consisting of two layers of 0.2 mm thick stainless steel. The weight of the innards of the BPC is approximately 95 kg and the material is sturdy enough to not deflect more than 0.47 mm, according to FEM calculations. The physical measurements of the BPC are 650 x 458 x 277 mm which is suitable for the planned BES. The BPC is also made in such a way that only small changes to the design will allow the transition to a BES; changes such as a change in placement of socket and bend flanges inwards. Better insulation than the current solution is also achieved by using Hybrix, but is also increased by the double bottom of the BPC. During the development process imprints in the bottom was a strong alternative in order to increase the stiffness and durability of the BPC. Instead in the final version the two shells were separated by 6 mm between the two bottoms, and in this gap a sheet foam material was placed. By adding this foam board the stiffness was increased and at the same time the cost was kept relatively low. The sheet of foam is an off-the-shelf product which makes the solution cheaper since the imprints would need a special tool and the cost of such a tool for a small series production is not financially sound. The foam also adds to the thermal insulation; specifically since the batteries are in contact with the bottom and it will drain the heat from within the BPC. The following figures the new BPC is shown, the Orange concept, a suiting name if thinking about the directive that high voltage parts must be marked in orange (the high voltage wiring is always orange in electrical vehicles).

In the picture below (fig. 3.6 b) an explanation and an overview of the concept is presented. Also provided is a description for each part and how the pieces interact.

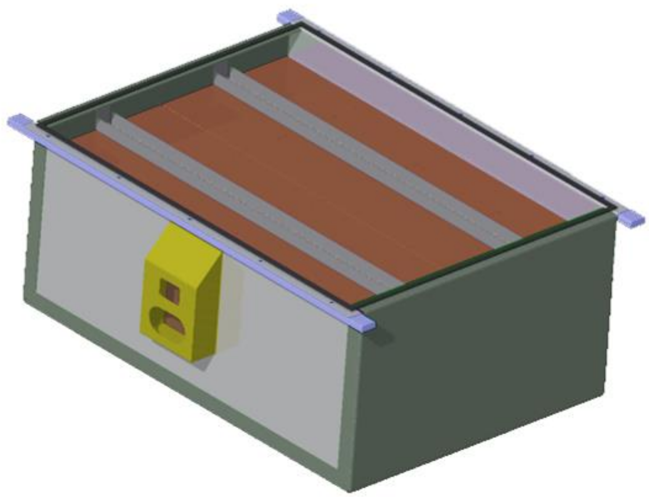


Figure 3.6 a). The new BPC without its lid. The brown parts are the batteries and the light blue parts are two beams for extra securing of the flanges.

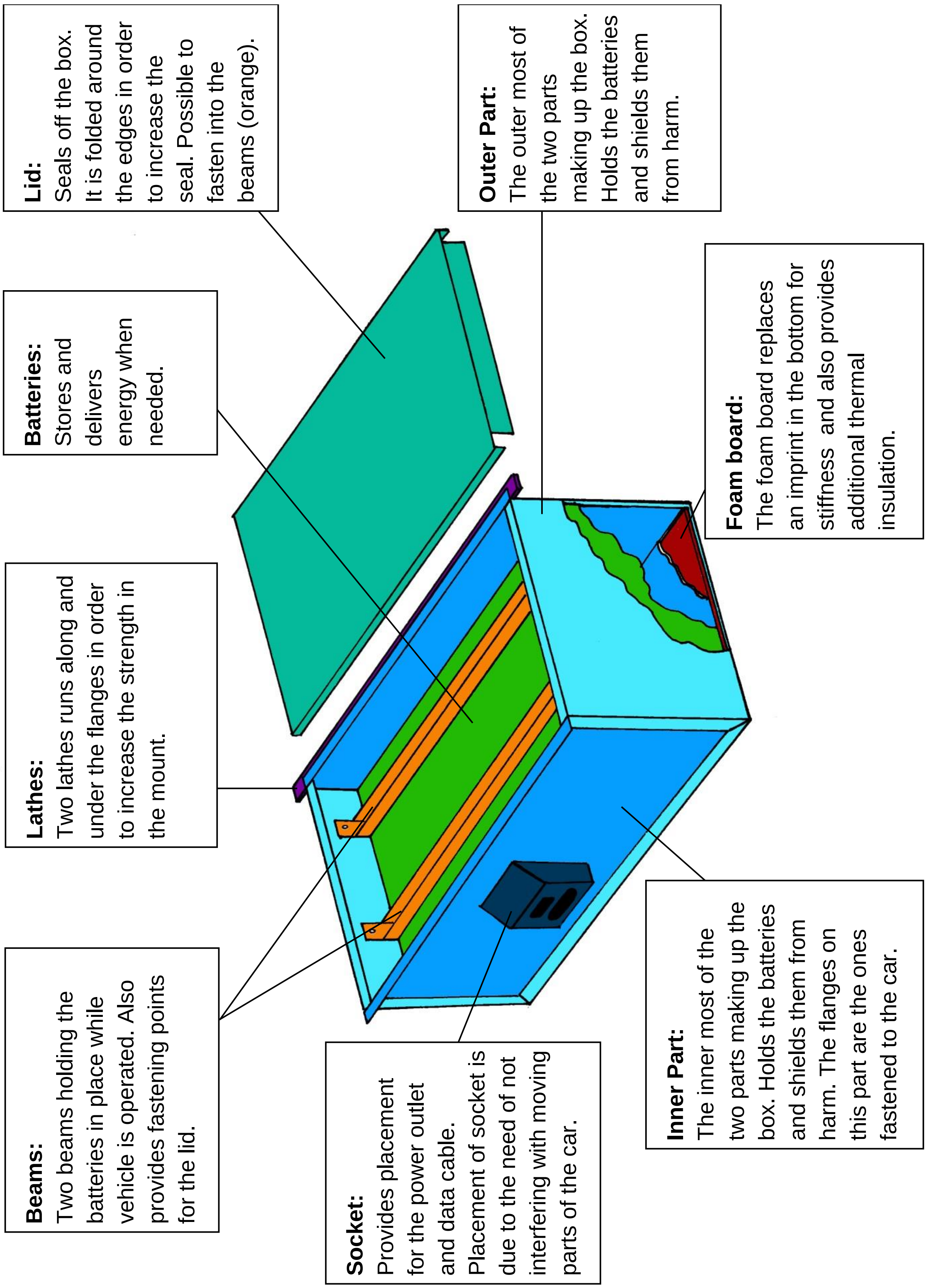


Figure 3.6 b). Overview sketch of the final concept.

In order to justify the new BPC and also describe in what way the performance have changed with this development project, a table (table 3.6) was assembled and is hereby presented to the reader.

Table 3.6. Weight comparison between the current and the new BPC.

Part	Unit	Current	New
Weight of BPC	kg	7,5	6,2
Weight of external structure	kg	10	1
Total weight	**kg**	**17,5**	**7,2**

In percent the total weight saving is about 9% which is mostly due to the elimination of the external structure. Furthermore the new BPC is better when it comes to thermal insulation; this is purely because of the use of Hybrix. Aluminium, as the current PBC is made of, has a thermal conductivity of about 167 W/m*K, while Hybrix has a thermal conductivity of 0.4 W/m*K. The thermal conductivity measures how well heat is transported through a material; the higher the number the higher energy loss. Another part is that the new BPC has a double bottom and with a polymer in between which makes the bottom even more insulated for convection. The extra insulation in the bottom is also good since the batteries are in direct contact with the bottom, thus hinder the loss of heat via conduction.
Because of using a type of Hybrix with stainless steel faces, the corrosion resistance is also improved slightly compared to aluminium, which was used previously.

3.7. Result of cost estimation

The cost per square meter of the Hybrix used is about 2 - 3 times that of aluminium. And in this case the cost of the material is the major difference between the current and the new BPC. The price for an aluminium sheet is 43 SEK/kg. For the current BPC the the price for the amount of aluminium needed is its surface area times its thickness, times its density multiplied with the cost per kilo => 1.2 m^2 * 0.0015 mm * 2700 kg/m^3 * 43 SEK/kg= 208.98 SEK. Assume that Hybrix is 3 times that figure to get the material cost for Hybrix => 208.98 * 3 = 626.94 SEK.

No special tools are needed to produce either of them, and no welds are needed in the new BPC. Although adhesives can be as expensive as welding in aluminium is, and then some. An online calculator [14] for how much material is needed for welding one unit of the current BPC. Assumed was that the seam thickness would be 3mm and that it would penetrate 1 mm into the material. This resulted in a weight of the seams to 0.04 kg and the use of 28 m wire. From *Drift- och underhålls-teknik* [15] it was found that 0.5 kg wire with a diameter of 0.8 mm costs 252 SEK. So if 28 m equals 0.04 kg the price for the weld would be 20.16 SEK/BPC.

In comparison an adhesive found that is used by U.S. military, airplane and car manufacturers costs 832.49 SEK ($112.65 at the time of writing) for twelve units of ~177 ml (6 oz). Assume one unit is enough to glue the parts together that makes the cost of the adhesive 69.3 SEK/BPC; approximately 3.4 times the price for the weld.
To get the overall cost you need to assess the time for assemble the product by a worker and the time it takes to assemble everything. An assumption made here is that the welding takes longer since more preparations are needed and the process is slower, thus the labour cost for the aluminium BPC is higher than that for the Hybrix version. The time for welding the aluminium is set to 1.5 hours and the time for applying glue is set to 50 minutes. With a salary and fees related to the worker that is 500 SEK in both cases, the weld would cost 750 SEK while the gluing would cost 417 SEK.

So in total the costs looks like the following:

Al: 208.98 + 20.16 + 750 = 979.14 SEK/BPC
Hybrix: 626.94 +69.3 + 417 = 1113.24 SEK/BPC
Making the difference between the two >134 SEK/BPC
If a production of 250 units is regarded, the total difference is >33'525 SEK

Although, if considering the effects of the changes done to the BPC and with the assumption made that each kilo of weight corresponds to 50 SEK for a petrol vehicle. This means that if the weight is lowered by 10 kg, as in this case, the reduction is worth 500 SEK/BPC. The effect is even greater for EVs; almost 2.5 times that for petrol vehicles. So the total worth would add up to about 1250 SEK/BPC in added worth. This is valid if the assumptions are correct.

4. DISCUSSION

In this chapter the focus is set upon the project as a whole and argues what could have been done differently and what could have been altered the process in order for the final concept to become as it is. Here a discussion about the adaptability of the methods and results, on other projects, is also taking place.

4.1. Discussion of project approach

The project itself is really suitable for a thesis project, and is so because it includes all the steps needed in a development process. The approach to the project was adequate but some more work could perhaps have been done during the feasibility study to further increase the knowledge of the product. Also, because of the incremental nature of the development project, the processes and methods are really suitable. Had it been a new product development a more creative way could have been chosen. Another thing that should have been done is a dynamic simulation for the loads of the BPC to see if it withstands the use of the car. The reason for this not being conducted was due to a lack of knowledge by the participants in the project. Some methods works better if there is more input from several persons. Brainstorming tends to get stuck in a rut if only one or two persons are conducting it, but if additional persons are included you trigger one another's thoughts. Same argument can be applied to the evaluation matrices where the resolution of the screening is increased with the number of participating individuals. Thus, a sort of workshop could have been arranged in order to get another view of the project and the concepts. Instead this was solved by introducing the weights and the matrix calculating these weights, thus minimizing the bias of the person conducting the evaluations.

4.2. Discussion of project variables

Having a product with a function that is mainly passive made it difficult to break it down into clear sub-functions that could be solved separately. This fact made the following processes somewhat awkward to grasp and had to be redone in order for them to work properly. The fact that the project team consisted of only one person also made the processes slightly uncertain since they are greatly subjects of biased opinions. This was solved by using weights and measures so that it was not just the perception of one person that made the decision but there is still a risk of personal influence over the outcome. During brainstorming a team consisting of several individuals can come up with several different concepts more easily. A team of 5 would only have to think of 3 concepts each in order to surpass the number of concepts in this project. When the number of participants in this activity is very limited, in this case to one, the effectiveness of this method is reduced. Although it is still an important step in order to get some starting points to work from

When conducting FEM calculations a degree of uncertainty in the yield is present. This is since a mathematical model of Hybrix is yet to be derived. So for the FEM calculations a thicker sheet of aluminium 6061 was used as a substitute to Hybrix. This was regarded as good enough for the specific loading cases, but for better simulations and more accurate predictions of products a proper material model is needed.
For an electrically propelled vehicle a selling point is that it is environmentally sound, since the main selling point is to get a “clean” car. And the use of a more sustainable material as the choice for the container makes this claim even more valid.

Alternative placement of the entire BPC could be an issue to discuss since the current placement is situated in a position where the BPC is exposed to a lot of external interaction. Although, a different placement of the BPC would have caused other parts to be redesigned and adjacent solutions would then have to be altered. If making a new conversion from the beginning, this could be something to have in mind in order to minimize the exposure of the BPC to harmful environments.

Discussing why this material, Hybrix, was used rather than plastics or solid metal sheets is a valid point. In the case of plastics or polymers, Hybrix is sturdier and will withstand a higher degree of abuse before fail. This is, however, not the case when you compare it to the solid metal sheets, but in this case you gain the reduction in weight and also the thermal and structural insulation. Also, if regarding the effects in case of a fire would be worse if polymer material had been used, and slightly less severe in case of a solid metal sheet.

5. CONCLUSIONS & FUTURE WORK

The final concept and outcome of this project was a prototype Battery Pack Container (BPC) very similar to the existing one. The similarity is dependent on the exchange system that is planned to work with the BPC, thus limiting the placement and the size of the product. There are a number of differences though, even if not much visible. The new BPC performs better regarding the thermal insulation, because of the insulating properties of the material. It is also lighter and the weight has been reduced by making the lathes structure redundant. The complexity of the product is increased, but the gain from using a sandwich material is greater than the increase of complexity. For an electrically propelled vehicle a selling point is that the car is environmentally sound. And the use of a more sustainable material as the choice for the container makes this claim even more valid.

The overall solution solves what was set out to solve, using methods and theories described in literature. Following and applying the theory was not always easy since the theory is general and the problem specific, but adjustments made it possible to use them as guidelines to the process. Another issue when designing the BPC was whether the flange would be able to withstand the loads during operation. According to tests and fem calculations it will endure, but only real life tests will tell if it really does. Mostly this is dependent on the dynamic forces that will take place when the car is driven, and dynamic simulations were not done in this project because of lack of knowledge.

The prototype is recommended to be part of further tests and validation. These tests and evaluations will not be conducted by the project worker, but is recommended to be done by ECar to verify if the calculations were done correctly and to see if the BPC performs to specifications. Specifically what the temperature range will be for the new BPC, that the flanges endure the abuse and that the deflection of the bottom is conforming to the requirements, will need to be looked in to. A standard drive cycle could perhaps be used in order to simulate the forces in the flange.

Further calculations and investigations regarding the costs of manufacturing are needed in order to get a more accurate number. And the manufacturing might vary because of potential deals made with manufacturers. Also tooling and actual cost of labour are only used as a comparative figure in this case and are not based on any real case.

6. ADAPTION OF RESULT ON OTHER PROJECTS

This project could be viewed as a study in the production of BPCs in greater numbers and other parts in the automotive segment. The methods will be roughly the same but some aspects have to be re-evaluated, such as the weights for the Kesselring. The type bound tools in this project was regarded as something to avoid since the production volume was regarded as low, but in greater numbers this will not be as important. If consider making a BPC in Hybrix for an OEM the BPCs are most likely made in greater numbers, thus a deep drawn construction is probably to prefer since the manual assembly can be lower in such a case. The geometry of the BPC in a car by an OEM is also more complex in details which also points at deep drawing as the method of production. In such a car the BPC seldom hangs from underneath the car, if the profile is not shallow, but rather stands, thus lowering the demands of the fastening points. At the same time, placing a BPC this way might intrude on the available space inside the car and increase the demands on evacuation of gases.

But there is also some knowledge that can be brought forward to the next project and without having to reconsidering anything. This could for example be said about the thermal insulation the material provides. In the BPCs of “normal” cars, the temperatures of the batteries will be higher thus in need of cooling. Although the benefits of having a good insulation in this case will be that the temperature inside the BPC will be easier to control and the generated heat could perhaps be utilised better as well. Another aspect to take into consideration if planned to implement in an OEM car is that the BPCs often need to hold more battery power, therefore it might also be a bigger part of the structure of the car. Thus the BPC could be a part that has to be really sturdy and withstand a collision to a higher degree. Most harmful in this case would possibly be a side collision since there is potentially a small distance from the side of the car to the BPC. Because of this the BPC itself has to include a deformation protection in order to protect passengers inside the car. Hybrix is not very good in this respect but it could be included in the design in order to lower weight where the deformation properties are not as vital, combining it with parts made of more suitable material.

If regarding conversions of vehicles from combustion to electrical engine, the placement of the BPC and the amount of power needed are the most important factors to the design. In turn the placement is limited by the available space left after the combustion related parts are disassembled, and the power relates to the size of the car and under what circumstances the car will be used. If the vehicle is meant to be driven in normal traffic you probably need to use every nook and cranny to stuff with batteries. This is since you do not want to alter the original chassis of the car because then you might have to redo crash tests.

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Appendix 1 – Information about the Vehicle

Some additional information of the vehicle in this project and some data regarding its performance.

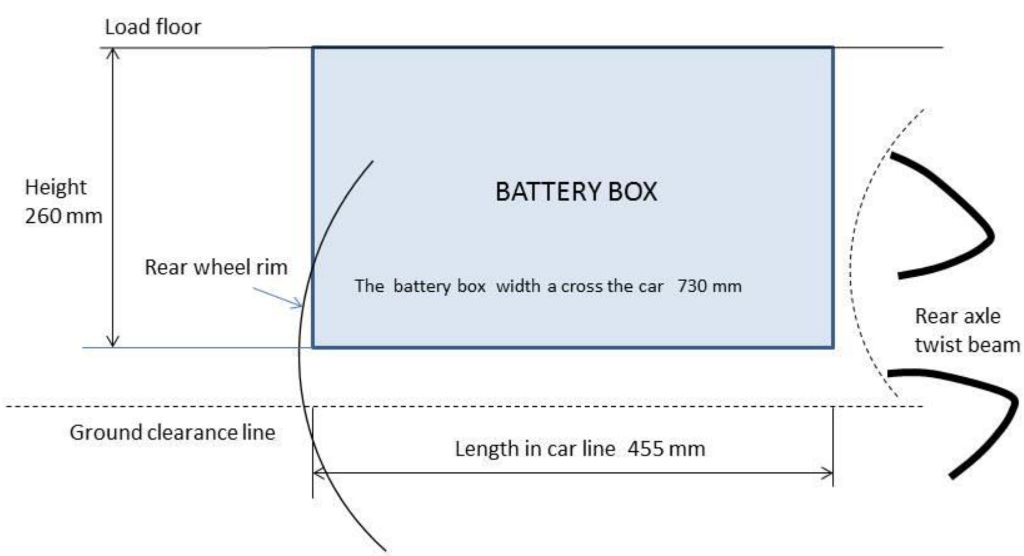
Appendix 2 – BPC info

Additional information regarding the current BPC, its measurements and the space available.

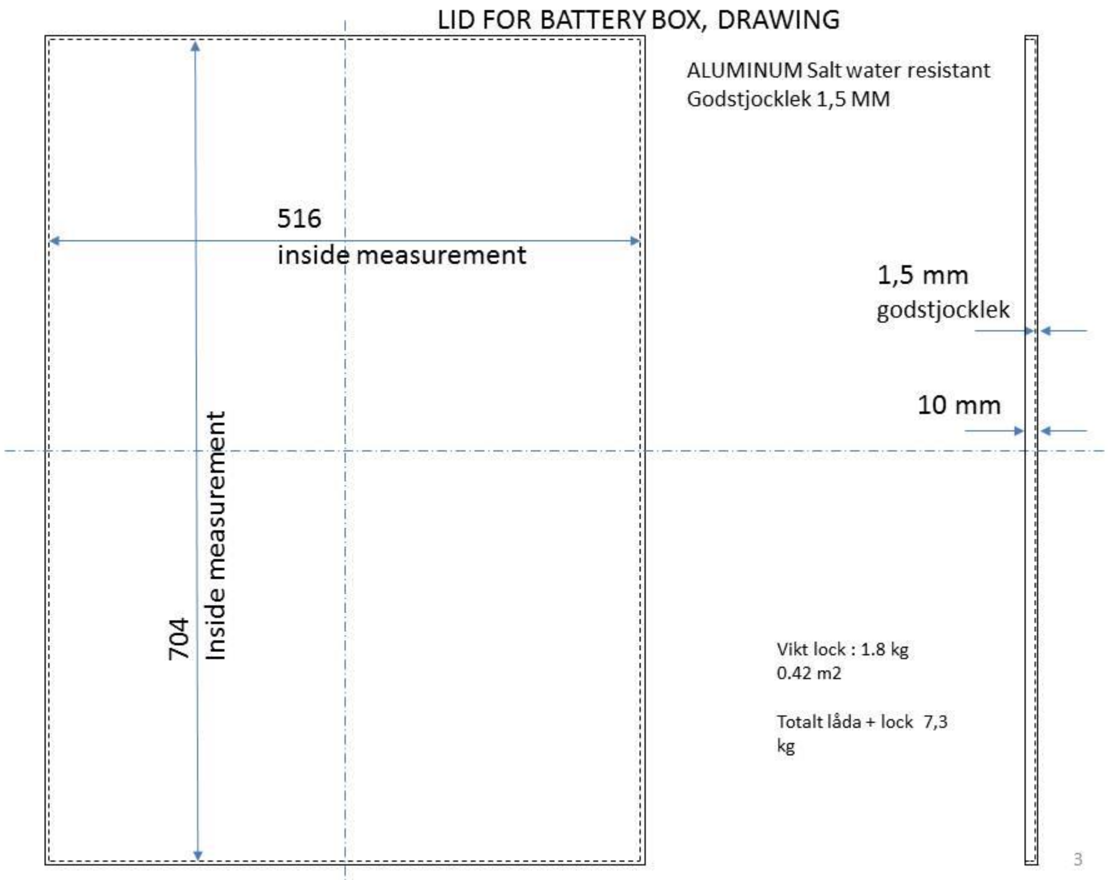
Batteri vikt IR

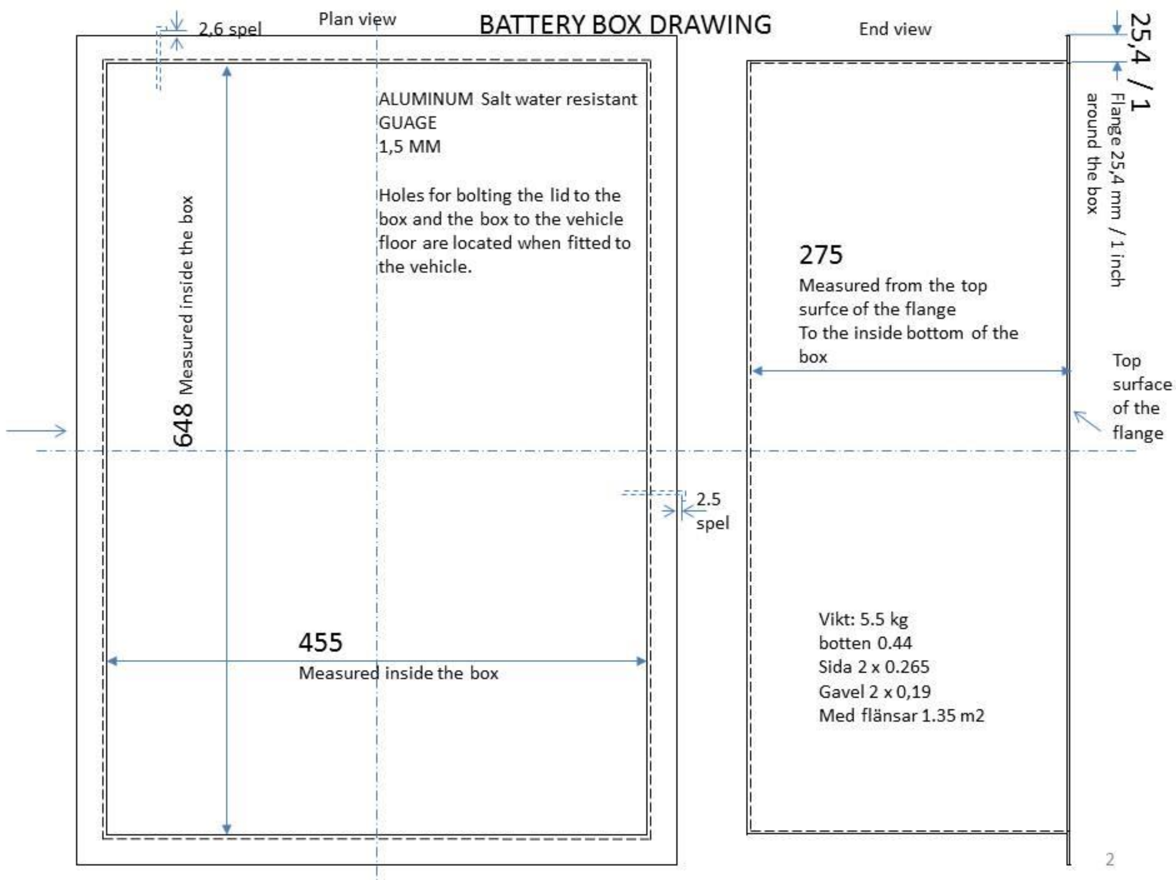
Modul 11 kg st / 8 st	88 kg	
Vinkeljärn 3 st mellan moduler i låda	2,5 kg	
Al - Låda med lock	7, 5 kg	
Hållare	10,0	
Kablage och front end	5 kg	grov bedömning
Fästelement	1	
Totalt per 12 kWh batteri-låda	114 kg	

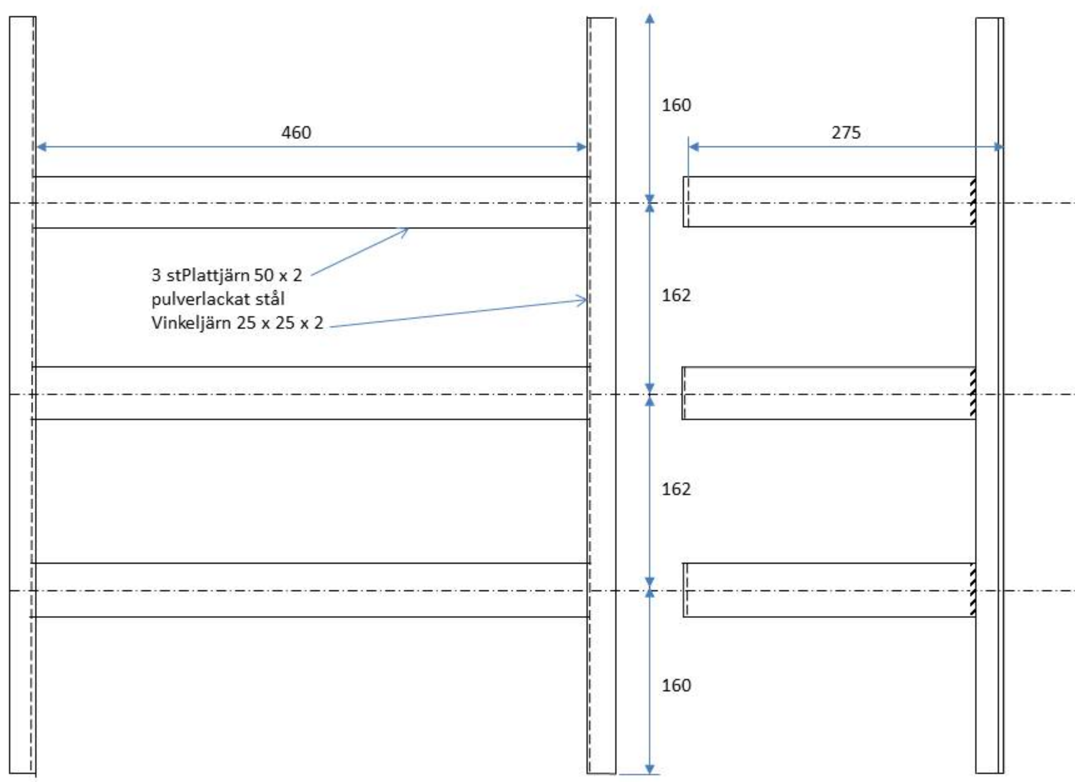
Fiat Fiorino, side view of battery space **behind rear axle**
objective 10 -12 kWh

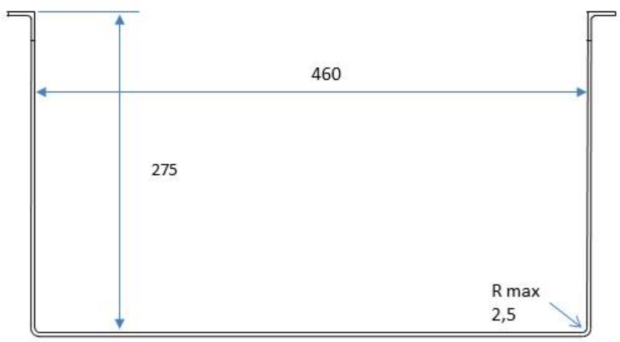


Distance in Y (side ways) between rear axle spring seats 760 mm
Distance in Y (side ways) between rear body spring seats junction w load floor 640 mm


LID FOR BATTERY BOX, DRAWING
ALUMINUM Salt water resistant
Godstjocklek 1,5 MM
516
inside measurement
704
Inside measurement
1,5 mm
godstjocklek
10 mm
Vikt lock : 1.8 kg
0.42 m2
Totalt låda + lock 7,3
kg
3


BATTERY BOX DRAWING
Plan view
End view
2,6 spel
ALUMINUM Salt water resistant
GUAGE
1,5 MM
Holes for bolting the lid to the box and the box to the vehicle floor are located when fitted to the vehicle.
648 Measured inside the box
455
Measured inside the box
2.5
spel
275
Measured from the top surfce of the flange
To the inside bottom of the box
Top surface of the flange
25,4 / 1
Flange 25,4 mm / 1 inch around the box
Vikt: 5.5 kg
botten 0.44
Sida 2 x 0.265
Gavel 2 x 0,19
Med flänsar 1.35 m2
2


460
275
160
162
162
160
3 stPlattjärn 50 x 2
pulverlackat stål
Vinkeljärn 25 x 25 x 2
4


460
275
R max
2,5

Appendix 3 – Interview notes

In this appendix some notes taken during an interview with Ben van der Geer at ECar is assembled, unfortunately it is transcribed in Swedish. The questions and answers are written in a compact form and are somewhat summarised. A lot of the information gathered was not based on questions but small notes taken during conversation with van der Geer.

Markfrigång? Som det är idag, inte lägre än lägsta balken.
Avstånd till fjäderben? Minimum 25 mm
Avstånd till bakaxel? Minimum 15 mm
Vilket material är den gjord i nu? Aluminium, men helst skulle jag använda en komposit som är bättre isolerande (termiskt isolerande. reds anm) och som är mer styvt än alu.
Varför? Bara för att det är lätt.
Kan området framför bakaxeln användas? Ja, men batteriväxlingssystemet fungerar inte om lådan är placerad där.*
Är strömuttagets placering fix? Nej, den går att flytta, men vid batteriväxling så sitter kontakten integrerad i systemet för växling.
Varför är lådan placerad där den är? För att batteriväxling ska vara möjlig.
Vilka dimensioner klarar batteriväxlingssystemet? Den lådan som är monterad är den storleken det behöver vara om det ska fungera med växlingssystemet.*
Varför används en stålbur runt lådan? Det är bara för att kunna testa prototypen.
Vilken temperatur blir det inne i lådan som mest? Det kan bli ca 27*C
Hur hålls batterimodulerna på plats? De bygger på ett system där de kopplar i varandra i långsgående riktning och sedan läggs en u-profil på ovansidan som skruvas fast i ett vinkeljärn på innsidan och på så sätt håller modulerna på plats.
Vilken IP-klass håller lådan? IP67
Hur stor batterikraft behövs? 12kWh för flygplatser och dyl., och 18-20 kWh för stadstrafik. 105 V i nominell spänning.
Är leverantör till batterierna fast? Nej, och vi ska eventuellt byta leveratör snart.
Kommer det påverka den fysiska storleken? Väldigt lite tror jag, men hör med Jan.
Är lådan helt full? Nästan, det är ca 25 mm luft över batterierna.

*Måtten och placeringen idag är anpassade efter batteriväxlingssystemet.

Appendix 4 - Specification of Requirements

	Specification of Requirements for Battery Pack (BP)			
Legend: R = Requirement (must have); D = Desire (wish to have)				
UNECE referres to 'UNECE regulation no. 100'				
Requirement		**Justification**	**Verification**	
1. Operation				
1.1 During normal operation				
D1	The BPC maintains a operational temperature in the range of 15 - 40 ºC	Minimize energy loss	Test	
D2	The BPC must withstand temperatures in range -30 - 70 ºC	Must not fail in extreme weather	Assessment	
Battery modules must not move when the vehicle is operated				
R1	Battery modules must be kept in position when driving on uneven surfaces	Lower risk for accidental shortening or malfunctioning	ISO 12405-3	
R2	Battery modules must be kept in position in case of collision in low speeds	Lower risk for accidental shortening or malfunctioning	ISO 12405-3	
BPC must facilitate safe operations				
R3	Vibrations must not casue: a) Electrolyte leakage, b) Rupture, c) Fire or d) Explosion	Safety during operation referred		
2. Safety				
2.1 Electric safety				
No live parts should be accidenatally in contact with operator or conducting surface				
R1	Parts belonging to voltage class B (30 - 1000 Vac alt. 60 - 1500 Vdc) must be orange	No accidental contact with live parts	Yes/No	Fullfilled by other means
R2	Rechargeable energy storage systems (RESS) must be marked with ISO 7010 warning for high voltage	No accidental contact with live parts	Yes/No	Fullfilled by other means
R3	Live parts must be insulated; voltage class B insulation >500 Ohm/V	No accidental contact with live parts	Assessment	Fullfilled by other means
D1	Barriers for additional insulation can be adopted to fulfill R3	No accidental contact with live parts	Assessment	Fullfilled by other means
No accidental shortening of conducting parts shall be possible				
R4	No ingress of water allowed	Water is not allowed inside BPC due to risk of shortening	Immersion into water	
R5	No ingress of dust allowed	Dust is not allowed inside BPC due to risk of sparks	Immersion into water	
~~D2~~	~~Safety switch to hinder current to flow through live parts~~	~~Safety of operations referred~~	~~Assessment~~	~~Not applicable~~
~~R6~~	~~In case of collision, no current is allowed to pass to parts not meant to conduct electricity~~	~~No accidental contact with live parts~~	~~Assessment~~	~~Not applicable~~
2.2 Crash Safety				
Emergency personnel should not be endagered in case of accident				
R7	Provide information on how to manage the BPC in case of emergency	Safetey of first responders referred	Yes/No	
D3	Construction of BPC makes it self evident how to handle it in case of emergency	Design wish	CAD model	
BPC must guard the innards from external harm				
R8	BPC must not be separated from the vehicle in case of crash.	Guard batteries and systems inside the BPC	FEM	
R9	Battery modules must be kept inside BPC in case of crash.	Guard batteries and systems inside the BPC	Assesment	
D4	BPC must not fracture if hit by blunt objects (e.g. stone the size of a fist) in low speeds (15 km/h)	Hindrance of accident	FEM	