Design and Development of a Foldable Motorized Micro-Haulage Vehicle

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MASTER THESIS

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Abstract

This thesis describes the process of designing and developing a foldable motorized micro-haulage vehicle, which follows the user, for urban transportation. The project is made in collaboration with Volvo Car Corporation.

The transportation industry stands as a significant contributor to greenhouse emissions. As a result, many efforts are being made to lower these emissions and reach sustainability goals, hence why many transportation companies are shifting to electric options. At the same time, urban spaces in cities are becoming more congested which have environmental and social consequences. In response to congestion, infrastructural changes are being made, such as limiting personal traffic within certain areas and dedicated pedestrian-bike paths. With these goals and changes in mind, new or alternative modes of transport are required for a more sustainable future.

Through the use of the established product development process by Ulrich and Eppinger, a conceptual vehicle was developed. The goal for the vehicle was to encourage walking and aid users in personal haulage activities. While at the same time keeping the vehicle low weight, foldable, sturdy and within size requirements. Additionally, packaging of an electric powertrain should be incorporated, and additive manufacturing (AM) should be explored to reduce the number of parts in the vehicle.

The final version of the product was made entirely in CAD to visualize the product concept digitally. Topology optimization was performed on the main critical part of the vehicle, the skeleton, which through the use of AM could reduce the number of parts simultaneously. The optimization yielded a weight reduction of 88% while complying with stiffness requirements.

Keywords: Product Development, Additive Manufacturing, Topology Optimization, Walking, Micro-Haulage Vehicle.

Sammanfattning

Den här rapporten beskriver processen att designa och utveckla ett hopfällbart motoriserat mikrotransportfordon, som följer användaren, för urban transport. Projektet görs i samarbete med Volvo Car Corporation.

Transportindustrin står som en betydande bidragsgivare till växthusgasutsläpp. Som ett resultat görs många ansträngningar för att minska dessa utsläpp och möta hållbarhetsmål, varför många transportföretag övergår till elektriska alternativ. Samtidigt blir urbana utrymmen i städer trängre, vilket har miljömässiga och sociala konsekvenser. Som svar på trängsel görs infrastrukturella förändringar, till exempel begränsning av persontrafik inom vissa områden och dedikerade gång- och cykelbanor. Med dessa mål och förändringar i åtanke krävs nya eller alternativa transportmedel för en mer hållbar framtid.

Genom att använda den etablerade produktutvecklingsprocessen av Ulrich och Eppinger utvecklades ett konceptuellt fordon. Målet för fordonet var att uppmuntra gång och hjälpa användare med personliga transportaktiviteter. Samtidigt som fordonet håller låg vikt, hopfällbar, robust och inom storlekskrav. Dessutom ska packningen av en elektrisk drivlina integreras, och additiv tillverkning ska utforskas för att minska antalet delar i fordonet.

Den slutliga versionen av produkten gjordes helt i CAD för att visualisera produktkonceptet digitalt. Topologioptimering utfördes på den viktigaste kritiska delen av fordonet, skelettet, som genom användning av AM, samtidigt kunde minska antalet delar. Optimeringen gav en viktminskning på 88% samtidigt som man uppfyllde styvhetskraven.

Nyckelord: Produktutveckling, Additiv Tillverkning, Topologioptimering, Gång, Mikrotransportfordon.

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Lund, August 2023

Gustaf Andersson and Mårten Lönn

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List of acronyms and abbreviations

3DP	3D printing
AM	additive manufacturing
BLDC	brushless DC electric motor
CAD	computer-aided design
DFAM	design for additive manufacturing
FMP	function means pair
FMT	function means tree
PLA	polylactic acid
TO	topology optimization
TPU	thermoplastic polyurethane
VCC	Volvo Car Corporation

1 Introduction

This section introduces the background and possibility for the project. The host company, Volvo Car Corporation is presented. A problem description as well as the goals and delimitations of the project are also described.

1.1 Background

1.1.1 **European Sustainability Goals**

The transportation industry is today responsible for around 25% of the European Union's total greenhouse emissions. EU´s goal is to become the first climate-neutral continent by the year 2050 which should be achieved partly by a 90% reduction in transport-related greenhouse gas emissions [1]. The European Commission has adopted a set of proposals, called the European Green Deal, to achieve this goal. One proposal is to lower transport related emissions by at least 55% by 2030 compared to the levels of 1990 [2]. This puts a lot of responsibility on transport related businesses and industries for them to adapt and conform to the European Green Deal. Volvo Car Corporation strive to become a climate neutral company and a circular business by 2040. Electrification is a big part of Volvo Car Corporation's sustainability goals, and they aim for their global sales to be 100% electric 2030 [3].

1.1.2 **Change in Cities**

The transportation industry does not only require large changes in going electric but also because of the development in cities and urban areas. Urban spaces have become congested due to the wide use of combustion engine vehicles throughout cities, which has negatively impacted the environment, human health, personal safety, reduced livability, and social inclusion. To address these issues, cities have implemented different strategies such as better public transport, vehicle restrictions for certain areas or dedicated pedestrian-bike paths. This has changed the transport behavior and lifestyles of city inhabitants which opens new possibilities in urban mobility and requires new modes of transport [4].

1.1.2.1 C40 cities

C40 is a global network who works to confront the ongoing climate crisis. One of their visions is to implement the 15-minute city strategy which aims to have the inhabitants of a city meet most of their daily needs with either a short walk or bike ride. For longer trips, quality public transport and cycling infrastructure should be available to cover individuals' needs. There are many benefits to a 15-minute city approach, such as a more inclusive city with a stronger sense of community due to easier access and more public areas. By reducing the personal traffic within cities, health and wellbeing gets better, both because of the increase in physical activities and transportation but also because of lowered emissions and better air quality [5].

One city where influence of the 15-minute city strategy can be found, is Barcelona, where the approach was to implement Superblocks. The city itself is built very dense and lacks green spaces in urban parts. The Superblocks approach are not a rebuild of the city, instead the approach is to limit the traffic within certain neighborhoods. By clustering traditional blocks in to one larger block and only allowing traffic around the perimeters of the Superblock, the area within the Superblock becomes reserved for cyclists and pedestrians. The people can enjoy the benefits such as, a higher number of green spaces, more social interaction, improved air quality and reduced noise pollution levels. Some necessary traffic such as transportation of goods and to an individual´s home is still allowed on the streets of the Superblock [6].

1.1.2.2 Gothenburg

This change in urban environments and city planning is also something which is seen in Gothenburg, the home of Volvo Car Corporation headquarters. Pedestrians, cyclists, public transport, and freight transport are all higher in priority then passenger cars when the city rebuilds and evolves [7]. The ongoing and future changes in the city of Gothenburg is represented by several strategies implemented to improve and develop within areas such as traffic and environmental impact. In the "Trafikstrategin" given out by Gothenburg city, one of the goals is to have at least 35% of all trips be either walking or cycling by the year of 2035 [8, p. 41]. The importance of ecological development and preservation of current parks and greenery in the Gothenburg area is also one of the areas where strategies have been implemented. By having attractive local parks located within a kilometer of an individual's home, walking will be incentivized and thus promote health and wellbeing for the city´s inhabitants [9, pp. 42-47].

1.2 Volvo Car Corporation

Volvo Car Corporation is a multination car company that produces cars in the premium segment. Volvo was founded in 1927 in Gothenburg, Sweden. Since

2010 the company is owned by Geely Automobile and sells vehicles in over 100 countries and has over 40,000 employees worldwide. The company aims to sell 1,2 million cars annually by 2025 where 50% will be fully electric vehicles. The company also aims to reduce total lifecycle CO2 emissions per car by 40% by 2025 compared to 2018 [10].

1.2.1 Future Mobility Lab

The project has been carried out in collaboration with Future Mobility Lab (FML), which is a group at VCC. FML focuses on new mobility solutions in accordance with sustainability goals and changing cities/infrastructure to prepare VCC for different futures.

1.3 Problem description

1.3.1 Problem Description

To reach a more sustainable future where sustainability goals can be met and where people can adapt to the changes in cities, new alternative modes of transport are required.

VCC’s ambition is to help people achieve personal, sustainable, and safe mobility across modalities in the context of urban environments. Based on a given design brief, the scope for this project was to develop a conceptual micro-haulage vehicle, where micro-haulage corresponds to low volume transportation of goods such as a grocery bag. The main goal was to develop a vehicle which could encourage walking and aid users in their personal haulage activities. The vehicle should be motorized and foldable to align with the goals of VCC.

The project was performed in collaboration with VCC where their preceding research and prerequisites were used for pre-defined constraints and requirements, such as footprint, foldability, and functional aspects.

Aesthetics of the vehicle should be taken into consideration, but the focus was on the mechanical design, material choices, packaging and selection of electronic components, and feasibility of the vehicle. Additionally, user-facing aspects, such as basic usability, ergonomics, weight, size, and practicality would also have to be taken into consideration in development of the vehicle, due to these aspects having a large impact on the final design.

1.3.2 **Problem/Research Questions**

The main challenges regarding the project is presented below.

1. How can the vehicle meet the size requirements and be sturdy enough while at the same time be lightweight and foldable?
2. Is it possible to achieve fewer number of parts by using specific material properties to enable functionality? Is additive manufacturing (AM) a solution to achieve this?
3. While complying with other requirements such as size, foldability and functionality, how can the vehicle enable and ensure optimal usability?
4. Due to being motorized, how can electronic components be included and packaged to still meet space requirements and achieve optimal performance?

1.4 Objectives

To meet the main goal of a conceptual micro-haulage vehicle and to find answers to the main challenges presented in 1.3.2, objectives for the project was established.

The main objective was to generate a concept vehicle through a dedicated product development process. Ulrich & Eppinger´s product development process was chosen due to the authors familiarity with the process and the possibility to adapt the process depending on the required project outcome. The product development process was limited in some areas such as detail design, where some sub-systems would have a higher relative importance and thus require more focus from the team. Some parts of the product development process would be disregarded almost fully, e.g., production development and cost analysis. These areas were not excluded entirely but a reasonable argument and information should be utilized in the concept generation stage.

The chosen concept should be modeled in CAD to be able to validate its functions, physical properties, and design. If AM would be seen as a reasonable solution for the chosen concept relevant work such as topology optimization would be utilized to minimize the mass of the concept vehicle.

Prototyping was used in a limited regard due to complexity of the product. Initial small scale physical models were utilized throughout the concept generation stage to easy test and verify the generated ideas. For the final concept, prototypes were only made for subsystems of the vehicle to visualize or verify functionality. Final prototypes were not intended for testing purposes and could be made in a smaller scale than the intended size of the product.

1.5 Delimitations

Delimitations was set together with VCC to utilize the time for the project optimally and receive a result that can aid them in their future work.

- Fully incorporating all electronics and their wiring as well as how they function is outside of the scope of the project. The packaging of these components is still required to be thought of and assumptive calculations for components affecting the requirements such as batteries and motors are performed.
- The developed concept vehicle is only exploratory. The vehicle is not intended to go into production at this stage and therefore there is not a focus on cost or manufacturing. Assumptions/ideas regarding these topics should still be feasible and reasonable.
- Due to the time limit, all parts of the vehicle couldn't be fully optimized or analyzed. The most critical/important parts were chosen in discussion with VCC and project supervisor.
- VCC is the main stakeholder for the project. This affected decisions in testing, requirements, and specifications.

1.6 Overarching Method

The thesis project was performed at VCC headquarters in Gothenburg. The thesis workers worked closely with VCC by having weekly meetings. These weekly meetings were held both as design reviews to check if the design complied with VCC's requirements and to provide the students with the possibility to receive supervision of the project. The meetings were usually one hour or longer. Since the students were working on site, small questions could be handled quickly by asking the supervisors at lunch or at other times of day when the supervisors didn't have meetings. The students had contact with the supervisor at LTH, Axel Nordin, roughly once a month where the progress of the project was followed.

2 Theory

This section explains the theory used throughout the project to establish specifications and grounds for design decisions.

2.1 Walking & Gradient

2.1.1 **Walking**

A study performed in Sweden showed that the main reason why people avoid walking, was because of the transportation of heavy shopping bags [11, p. 18]. With cities changing and walking becoming more favorable, new solutions are required to aid people so walking can be prioritized.

The walking speed of pedestrians is dependent on several aspects such as physical ability and if the pedestrian is carrying goods. The mean speed of pedestrians walking is between 4.2-5.7 km/h. The start time of walking is defined as the time from which the pedestrian receives a signal and starts to walk. For younger pedestrians the mean start time was 1.9 s and 2.5 s for older pedestrians [12, p. 19].

2.1.2 **Gradient**

The slope towards the horizontal plane in the roads longitudinal direction is defined as the gradient. The size of the slope is measured in % or with the relation Y:X where Y is the height difference and X is the horizontal distance. If the slope is given in % with a negative sign, it represents a descent [13, p. 41].

In Sweden, walkways should have a gradient that is either equal or less than 2%. The largest gradient acceptable for walkways is 5%, which can be increased to 8% in some cases. A gradient of 8% must be approved and can only be implemented if there is an alternative pathway for individuals with a movement impairment [14, p. 174].

There are streets where pedestrians travel which are not defined as walkways. These streets can have a higher gradient than the recommendations for walkways. One example of this is Kvarnbergsatan in Gothenburg which has a gradient of 13% [15].

2.1.3 **Traffic Laws**

This project has followed the requirements from the Swedish Transportstyrelsen [16] regarding the law for traveling in traffic by bike and by electric scooter. The Swedish Transportstyrelsen states that a bike should have the following:

- A light at the back that is visible up to 300m away. Can be pulsating if the pulses are less than 200/minute.
- Light at the front with white or yellow light so that the vehicle can be maneuvered in the dark.
- Red reflector in the back
- White reflector in the front
- White or orangeyellow on the sides.
- Electric bikes without pedals can use a maximum of 250W of electrical power and at maximum 20 km/h.

Since September 1st, 2022, you can't legally drive on the sidewalk with an electric scooter in Sweden [17]. The legislation regarding electric scooters is the following [18]:

- Electric scooters shall be ridden in the same way as bikes.
- They shall have brakes and bell.
- When driving in the dark the scooter shall have front and rear light as well as reflectors.

The concept this project is aiming to define doesn't define as neither a bike nor a scooter, but with these Swedish laws in mind the project can use these to define their own specifications to follow the rules enforced in Sweden. The market for this product is the whole world which is another point of not defining it as neither a bike nor electric scooter.

2.2 Additive Manufacturing

2.2.1 **AM benefits/opportunities**

In this project all the final parts were made with additive manufacturing in mind. Using additive manufacturing in the beginning of a concept is highly beneficial since the cost compared to regular manufacturing can be much lower when doing concepts with complex parts or shapes. There are also opportunities to do instant assemblies where for example a hinge can be 3DP in the part and therefore no need for assembly of the hinge. 3DP also enables complexity of parts in a way to reduce weight, by removing unnecessary material in components and can be driven by doing Topology optimization on the part which may make it impossible to manufacture without 3DP. Reduced number of parts in a product is also a big opportunity in 3DP which can lower cost per part and assembly cost [19].

2.2.2 Design for Additive Manufacturing

Following the guidelines from "A practical guide to design for Additive Manufacturing" [19] there are different ways to design parts depending on what material will be used when 3DP the part. The main idea with DFAM is to ensure good print quality, robust parts and to make sure the print is up to standard with what is required by the manufacturer of the part.

There are also differences in the design depending on what type of 3DP method that will be used. When designing the part, it can also be hard to know what the best ways of printing, or design of a part may be, and therefore iterations might be necessary. For example, the orientation of the print affect how stresses in the part behave and to find the best possible print orientation may be to print in different orientations and test them against each other.

When designing, consideration should be made if the part needs isotropy or not which may affect the printing orientation that is doable for the specific part. Anisotropy is when the properties of a part in different orientations are not the same. This might be needed when for example 3DP a clip for easy assembly of parts.

When designing the part one should also take into consideration that when using some 3DP there will need to be support material to be able to 3DP. This should be thought of so that it won't affect the performance or desired quality of the part.

2.3 Materials

Using the right material for the right part is crucial to meet the requirements set by Volvo Cars regarding weight. The team also added criteria's regarding stiffness and strength to be able to have more parameters to find the best solution for different parts. The main materials used was Nylon plastic and aluminum grade T6. In later chapters there will be clarification of all the forces that act upon the vehicle and what maximum stresses occur and where.

2.3.1 **Aluminum**

Aluminum grade T6 is a material with high strength and low density which was required to keep the weight down. The high tensile strength of >290MPa and yield strength of >240MPa is suitable for the needs of the vehicle [20].

2.3.2 **3D-printed plastics**

The 3DP of the plastic reduces the kinds of plastic that can be used compared to normal manufacturing using mills, injection molding etc. In this project a plastic called Nylon 12 GF and a polylactic acid (PLA) plastic is used for different parts that require different material properties.

Nylon 12 GF is a glass-filled nylon. The glass in the material helps with enhanced stiffness and heat resistance for a more durable construction. The structural rigidity is of great importance in some of the parts [21].

Printable PLA is a bio-plastic material with great printing properties that is cheap and easy to print. The material doesn't shrink or deform much after cooling down which makes it perfect for printing high resolution parts [22].

2.3.3 **3D-printed TPU**

A thermoplastic polyurethane (TPU) material was chosen for the rubber on the wheels. A TPU is a soft rubber-like material with great flexibility and durability. It is also abrasion resistant and is resistant to many chemicals which will be a great property since the vehicle will move in many different environments [23].

2.4 Powertrain Calculations

2.4.1 **Vehicle dynamics**

The tractive force acting on the wheels of the vehicle is given in equation 2.1 and is the sum of the aerodynamic force F_d, the rolling resistance of the tires F_{rr}, the acceleration force F_a and the road grade force F_{rg} [24].

$$F_{wheel} = F_D + F_{rr} + F_a + F_{rg} \tag{2.1}$$

Each constituent force is presented in equation 2.2 through equation 2.5 with each parameter presented in table 2.X.

$$F_D = \frac{\rho}{2} \cdot C_D \cdot A \cdot v^2 \tag{2.2}$$

$$F_{rr} = C_r \cdot m \cdot g \cdot \cos\alpha \tag{2.3}$$

$$F_a = m \cdot \frac{dv}{dt} \tag{2.4}$$

$$F_{rg} = m \cdot g \cdot \sin\alpha \tag{2.5}$$

Table 2.1 Parameters for Force Calculation

Parameter	***Description***	***Unit***
ρ	Air density	[kg/m^3]
C_D	Aerodynamic drag coefficient	-
A	Effective cross-sectional area	[m^2]
v	Vehicle speed	[m/s]
C_r	Rolling resistance coefficient	-
m	Vehicle mass	[kg]
g	Gravitational constant (9.81)	[m/s^2]
α	Road gradient	Degrees

With each separate equation established for the vehicle dynamics, equation 2.1 can be rewritten as:

$$F_{wheel} = \frac{\rho}{2} \cdot C_D \cdot A \cdot v^2 + C_r \cdot m \cdot g \cdot \cos\alpha + m \cdot \frac{dv}{dt} + m \cdot g \cdot \sin\alpha \tag{2.6}$$

2.4.2 **Energy Consumption**

When calculating the mechanical energy required for propulsion of the vehicle, the power is first calculated as the product of the established wheel force and the speed of the vehicle. The total energy is found with the time integral of the calculated power [24] Respective equations for power and total energy consumed are presented in equation 2.7 and 2.8

$$P_{wheel} = v \cdot F_{wheel} \tag{2.7}$$

$$E_{wheel} = \int P_{wheel}\, dt \tag{2.8}$$

2.4.3 **Motor Specifications**

To find a motor with certain specifications that can deliver on the wheel force necessary for propulsion, the electric-machine torque and speed required, need to be calculated. The wheel radius r, transmission gear ratio k_{gear}, and transmission efficiency η_{gear} is used to establish the electrich-machine torque and speed [24]. The torque is calculated with equation 2.9 and the speed with equation 2.10.

$$T_{EM} = \frac{r \cdot F_{wheel}}{\eta_{gear} \cdot k_{gear}} \tag{2.9}$$

$$\eta_{EM} = k_{gear} \cdot \frac{v}{r} \cdot \frac{60}{2 \cdot \pi} \tag{2.10}$$

3 Process and Methods

In this section the process and methods used for the master thesis is described.

3.1 Time Planning

The master thesis project is intended to be finished during a timeframe of 20 weeks. To establish the work, deliverables and tasks that needs to be done to complete the project a Gantt-chart was made early in the project with estimations on how long each of the different parts of the project would take. This initial time planning can be seen in Appendix A.2. Due to the process itself being dynamic and of uncertainties of how the project would develop, an actual time plan was made at the end of the project to show how much time each task had required. The actual time plan can be seen in Appendix A.2.

A description of how the work was divided between the authors can also be found in Appendix A.1.

3.2 Product development process, U&E

The product development process used for this project is a modified version of the generic product development process developed by Karl T. Ulrich and Steven D. Eppinger. The generic process includes different activities or tasks which are allocated to different parts of the process to transform inputs into outputs using structured methods. The generic product development process consists of six phases which takes a product from planning all the way to production ramp-up. These phases can be seen in figure 3.1 [25, p. 12-13].

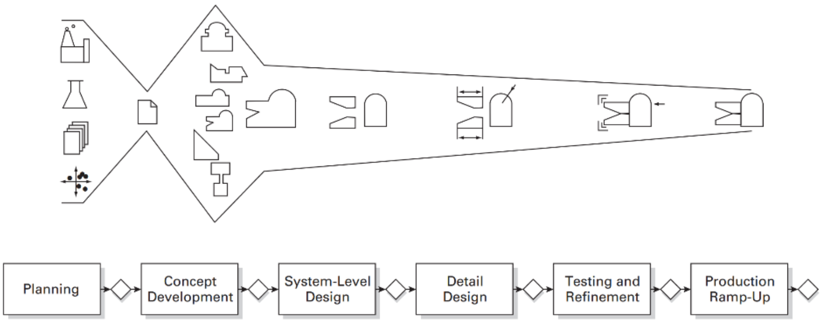

Figure 3.1 Generic Product Development Process [25, p. 14]

Many of the development methods U&E describes are placed within the phase of concept development because of an often-higher coordination among functions. The concept development phase is therefore expanded into another process which U&E call the front-end process. The front-end process is shown in figure 3.2 but is rarely followed in its sequential order. This is because of the interrelated nature of the activities performed during these stages of the process. Some activities may overlap others in time and other activities might have to be remade due to new information or results. The dashed lines in figure 3.2 represent the uncertainty of the process and the possibility to iteratively move between different activities within the process [25, p. 16].

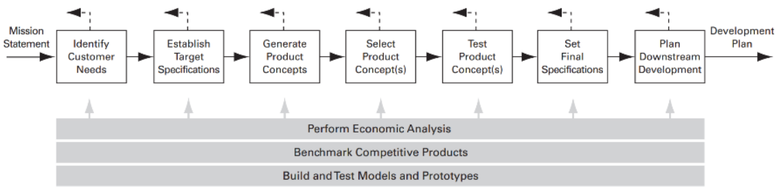

Figure 3.2 Front-End Process [25, p. 16]

3.2.1 **Modified approach**

The choice of product development process is chosen because of the authors knowledge with the process as well as the possibility to move from idea to a finished concept with clear structural steps. The modified version of Ulrich & Eppinger's generic product development process used for this master thesis skips some of the earlier and later stages due to information, limitations and prerequisites provided by VCC. The project focuses mainly of the activities within the front-end process with some work in the phases of system-level design and detail design. Due to the complexity of the product, not all sub-systems can move on to detail design and the authors will choose a “critical part” from the selected product concept which shows most important to focus on and go into detail design on that part. The detail design will be used to approve design decisions and confirm feasibility. System-level design will be used in conjunction/parallel with the concept development to define the sub-systems and architecture of the product.

Phases or activities excluded because of VCC’s previous work:

- Planning
- Concept Development – Identify Customer Needs (Partly)
- Concept Development – Establish Target Specifications (Partly)

Phases or activities excluded because of timeframe and scope of the project:

- Concept Development – Set Final Specifications
- Testing and Refinement
- Production Ramp-Up

Some of the activities performed within the front-end process will be altered because of limitations within VCC and quicker decision-making to move forward with the project.

Some of the following subchapters within this chapter will further explain the activities and methods used within each phase. Due to some phases being excluded for the modified process, only an overview will be presented for these activities while methods included in the project will be presented in detail. This is to better provide the reader with a good understanding of how the entire product development process is carried out and why the authors have chosen to skip some of the phases.

3.2.2 **Planning**

The planning phase is performed before the actual product development process is launched and identifies one or several product development opportunities to pursue. Ulrich and Eppinger [25, p. 70] describe a five-step process for the planning phase which follows the order:

1. *Identify opportunities.*
2. *Evaluate and prioritize projects.*
3. *Allocate resources and plan timing,*
4. *Complete pre-project planning.*
5. *Reflect on the results and the process.*

During the fourth step of the planning process a “Mission Statement” should be created to provide the product development team with better guidance when starting and working with the project. The mission statement should provide a basic description of the product and its functions. A benefit proposition, key business goals and the target market for the product should also be included to make the development and corporate alignment easier. Finally, assumptions and constraints about the product as well as stakeholders should be added to the mission statement for better understanding of the limitations and needs of the product [25, p. 67-68].

3.2.3 **Concept Development**

The activities to be performed in the concept development process or the front-end process is presented in the following subchapters.

3.2.3.1 Identify Customer Needs

Ulrich and Eppinger describes the start of the concept development process with identifying the customer needs. The process of finding the customer needs can be vital to the success of the product and gives information on how the product should behave and what characteristics it should have [25, p. 88]. The steps a development team should follow to identify these needs are:

1. *Gather raw data from customers.*
2. *Interpret the raw data in terms of customer needs.*
3. *Organize the needs into a hierarchy.*
4. *Establish the relative importance of the needs.*
5. *Reflect on the results and the process.*

3.2.3.2 Establish Target Specifications

The specification of the product is the next step that needs to be established. This is important to establish early in the process to delimit the product and make sure that the final product will have the required specifications found to meet customer needs [25, p. 111]. The process for deciding the specifications is:

1. *Prepare the list of metrics.*
2. *Collect competitive benchmarking information.*
3. *Set ideal and marginally acceptable target values.*
4. *Reflect on the results and the process.*

3.2.3.3 Generate Product Concept(s)

The third step in the concept development process according to Ulrich and Eppinger [25, p. 119] is to develop different product concepts. This means, looking widely at different possibilities and ideas to find solutions to the problems, customer needs and specifications generated previously in the process. The ideas or concepts are presented as sketches or models and often with keywords to describe it. The steps U&E recommend following to generate the product concepts are:

1. *Clarify the problem.*
2. *Search externally.*
3. *Search internally.*
4. *Explore systematically.*
5. *Reflect on the solutions and the process.*

The five steps presented does not have to be followed in a linear fashion. An iterative approach is possible, the steps should be done in the way which most effectively helps the development team solve their problems.

3.2.3.3.1 Clarify the Problem

The product intended to be developed have through previous steps in the process acquired several requirements, assumptions, and limitations. To be able to figure out which problem to solve a general understanding and description of the product within the development team is important.

For technological or complex products, a single solution might be difficult to generate due to the intricate nature of these systems. The main problem can therefore be decomposed into sub-problems so further development can be done in a simpler way. The problem decomposition can be performed in many ways, a functional decomposition is preferred when working with technological products. The functional decomposition starts with the main function of the system and is broken down into subfunctions to understand which part of the product that performs the subfunction. Every subfunction can be further broken down into subsequent subfunctions and this should be performed until the development team feels confident in finding a solution to that function [25, p. 121-123].

3.2.3.3.2 Search Externally

After the problem or main function is broken down, finding a solution to these problems is the next step. By gathering information through external search of already existing solutions or similar products, the development team gets a better understanding of which problems that can be implemented with current solutions and which problems that require greater development efforts. Current solutions do not have to be implemented from directly competitive products, solutions to subfunctions can be found in other markets where the products share similar subfunctions. U&E lists five ways to gather this information: interview lead users, consult experts, search patents, search published literature and benchmark related products [25, p. 124].

3.2.3.3.3 Search Internally

Internal search or brainstorming which it is commonly called is the collective efforts of the team and the individual developer to creatively generate product concepts. Ideas generated during this step comes from already known personal or team knowledge and the activity can be carried out either individually or with a collaborating team [25, p. 128]. Ulrich and Eppinger provide five guidelines to improve the outcome of the internal search:

1. *Suspend judgement.*
2. *Generate a lot of ideas.*
3. *Welcome ideas that may seem infeasible.*
4. *Make plenty of sketches.*
5. *Build sketch models.*

3.2.3.3.4 Explore Systematically

Many different solutions to the subproblems will be generated from the search activities performed. Ulrich and Eppinger [25] explain a systematic approach called the concept combination table to consider the combination of different solutions to subproblems into a complete product concept. The table is set up with the subproblem as the heading for each column and the generated solutions as inputs. Combining one solution from each column will yield one potential complete concept which can be used for comparisons with other combinations.

3.2.3.4 Select Product Concept(s)

The fourth step in Ulrich and Eppinger's concept development process is to evaluate the concepts from the concept generation stage and choose a concept to go forward with and develop. The concept selection Ulrich and Eppinger propose [25, p. 161] is done in two stages where the first method is called concept screening and the second is called concept scoring. The difference between the methods is that concept screening aims to reduce the number of concepts quickly and broadly while concept screening is carried out with a finer evaluation. Both methods follow the same six-step process, which is:

1. *Prepare the selection matrix.*
2. *Rate the concepts.*
3. *Rank the concepts.*
4. *Combine and improve the concepts.*

5. *Select one or more concepts.*
6. *Reflect and improve the concepts.*

3.2.3.4.1 Concept Screening

For concept screening, the matrix should be set up with simple concepts and criteria. The criteria should be generated by the development team, based on the customer needs and requirements from other stakeholders. Around five to ten criteria which differentiate the concepts should be included, these criteria are often at a fairly high level of abstraction. A concept or available product is then chosen as a benchmark, a reference concept, which the other concepts should be rated against. For concept screening, a relative scoring method is used with a plus (+) if the concept performs better than the benchmark, a zero (0) if the concept performs equal to the benchmark and a minus (-) if the concept performs worse than the benchmark. After rating the concepts, the net score is calculated for each concept based on the difference in pluses and minuses and ranked according to the score. The ranked result of the concepts should be controlled so it is reasonable and if there are any concepts which ranked low, an improvement or combination of concepts should be considered. If new concepts arose from this stage, these are added to the matrix and compared to the benchmark. When the development team reaches a satisfactory ranked result of the different concepts, one or several concepts can be chosen to move into the next step of concept selection [25, p. 153-155]. An example of the concept screening matrix can be seen in table 3.1.

Table 3.1 Example of Concept Screening Matrix

	Concepts		
Selection Criteria	***A (Reference)***	***B***	***C***
Criteria 1	0	+	0
Criteria 2	0	+	-
Criteria 3	0	-	-
Sum +´s	0	2	0
Sum 0´s	3	0	1
Sum -´s	0	1	2
Net Score	0	1	0
Rank	2	1	3
Continue?	No	Yes	No

3.2.3.4.2 Concept Scoring

The concept scoring follows the same principles as the concept screening apart from some modifications. The concepts are usually more refined in this stage and the criteria may be broken down in more detail. Instead of using a relative scoring method, the concept screening instead uses a scale from one (1) to five (5) where three (3) is equal performance to the reference and lower is gradually worse and higher is gradually better. The benchmark is changed from a reference concept to different reference points at certain criteria throughout all the concepts, to avoid scale compression. Each criterion is also weighed with a percentage of relative importance, summarizing 100%. When rating the concepts, a numerical score is given to each criteria of the concept. The score is multiplied with the corresponding weight of the criteria and summarized to give the ranking of the concepts. As for concept screening, improvements and combination possibilities should be explored and potentially ranked. When all concepts have been considered and depending on the project limitations, either one or several concepts are brought to the next step of the development process [25, p. 156-159]. A concept scoring matrix is shown in table 3.2 to better illustrate the differences between the screening and scoring methods.

Table 3.2 Example of Concept Scoring Matrix

		Concepts					
		A (Reference)		***B***		***C***	
Selection Criteria	***Weight***	***Rating***	***Weighted Score***	***Rating***	***Weighted Score***	***Rating***	***Weighted Score***
Criteria 1	10%	***3***	0.3	2	0.2	3	0.3
Criteria 2	20%	***3***	0.6	4	0.8	4	0.8
Criteria 3	30%	2	0.6	***3***	0.9	3	0.9
Criteria 4	10%	***3***	0.3	5	0.5	2	0.2
Criteria 5	30%	4	1.2	1	0.3	***3***	0.9
	Total score	3.0		2.7		3.1	
	Rank	2		3		1	
	Continue?	No		No		Develop	

3.2.3.5 Test Product Concept(s)

After a concept has been chosen the next step according to Ulrich and Eppinger [25, p. 181] is to test the concept. This is an experimental phase done with potential customers to verify customer related questions such as satisfaction with customer needs or potential improvements to make the product concept more appealing. The steps below are the ones U&E recommend when performing the tests:

1. *Defining the purpose of the concept test.*
2. *Choose a survey population.*
3. *Choose a survey format.*
4. *Communicate the concept.*
5. *Measure customer response.*

6. *Interpret the results.*
7. *Reflect on the results and the process.*

3.2.3.6 Plan Downstream Development

After the final concept has been chosen, the remaining development required to finalize the project is planned out. This planning activity is made to minimize cost and time consumption while also looking at the amount of resources required for remaining activities. This step is also commonly used to establish an agreement between the development team and management within the company, by providing the results from the previous steps of the front-end process [25, p. 17]

3.2.4 **System-Level Design**

In this phase the focus is on the product architecture, subsystems, components, and preliminary design of key parts. Planning of detail design, assembly sequence and manufacturing of the product are started in this phase of the process [25, p. 15].

When establishing the product architecture, Ulrich and Eppinger describes [25, p. 193] the result to be an approximative geometrical layout of the product based on required subsystems or parts which U&E call chunks. The result should also include a description of these chunks and key interactions between them. U&E recommend four steps to follow when establishing the product architecture which are:

1. *Create a schematic of the product.*
2. *Cluster the elements of the schematic.*
3. *Create a rough geometric layout.*
4. *Identify the fundamental and incidental interactions.*

3.2.5 **Detail Design**

During the detail design phase, all product parts, and their properties such as dimensions and material is specified. Tooling, processes, and production is chosen, which enables the possibility to perform and evaluate a cost analysis, manufacturing methods and part performance for the intended product concept [25, p. 15]

3.2.6 **Testing and Refinement**

During the testing and refinement phase, several prototypes are usually built in order to evaluate customer satisfaction, performance and production processes. These prototypes are typically called alpha and beta prototypes where the alpha prototype is an early prototype which is geometrically correct and with similar material properties but possibly manufactured with an alternative method. The beta prototype is produced in a later stage with intended manufacturing methods but could be assembled according to an alternative assembly sequence than intended for production [25, p. 15].

3.2.7 **Production Ramp-Up**

The final phase before the product is launched is called production ramp-up. The main focus in this phase lies in evaluating and finalizing the intended production processes so there are no hidden problems. Training of the workforce producing the product is also performed during this stage [25, p. 15].

3.3 FMT

Functions Means Tree (FMT) is a method which is used to understand and separate the functions within a system. The tree is built up of several functions-means pairs (FMP) where the function describes the individual operation which is needed to contribute to the performance of the system. The mean describes the solution which delivers the function. The initial FMP is the main function of the system or product, and subsequent FMP’s branch out from the initial pair [26]. An example of a FMT and a single FMP can be seen in figure 3.3 below.

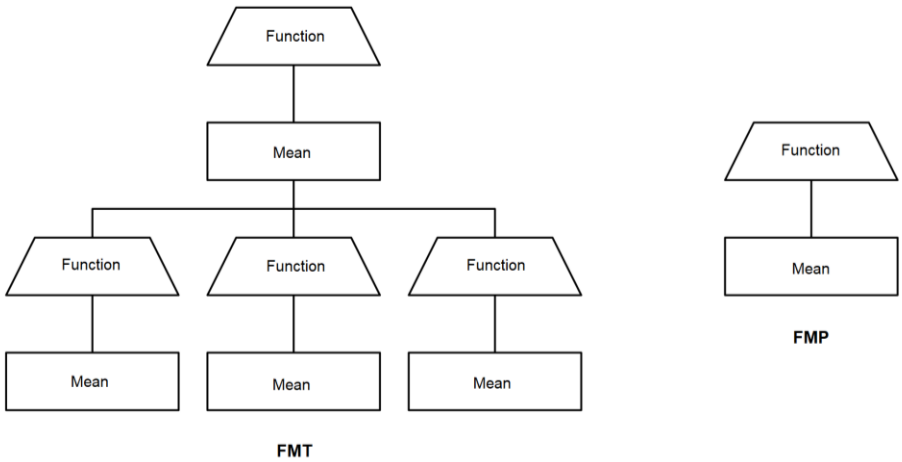

Figure 3.3 FMT and FMP

The FMT can be used to derive the entire system into modules or sub-systems by enclosing certain FMPs into groups. This can be utilized to understand the interfaces within the system and which components/parts that are required to be able to deliver a fully working system.

3.4 Topology Optimization Process

With AM being explored as a potential manufacturing method for the vehicle, topology optimization was chosen as an optimization tool to minimize the weight of the vehicle. A. Nordin et al. [27, p. 128] presents an eight-step process to perform the TO, the eight steps are:

1. *Define design space*
2. *Define non-design space*
3. *Define boundary conditions*
4. *Define constraints and objectives*
5. *Define optimization settings*
6. *Solve*
7. *Interpret the results*
8. *Validate*

The design space should be made as large and simple as possible. Unnecessary details should be removed before the TO is performed. Surfaces which are necessary for the design or where the design have interfaces with other parts should not be affected by the TO. These should be marked as non-design spaces and one such example is fasteners [27, p. 128-129].

When interpreting the results, performing a manual re-design of the TO result is the preferred method if the design should be adapted for future development. This is because of the high parametric controllability and design intent gained by a manual parametric model. Other methods with smoothing-operations of the TO result are generally quicker but lack the parametric controllability compared to the manual re-design [27, p. 131-132].

3.5 Analytical/Computer tools

3.5.1 **CAD**

During this project the CAD software used was CATIA V5 which was licensed to the team by VCC. CAD was be used to create 3D models for digital prototypes, renders and files for 3DP.

3.5.2 **Topology Optimization & CAE**

Altair Inspire was used to perform the topology optimization (TO) and structural analysis for the project. Altair Inspire was licensed to team by VCC.

3.6 Prototyping

The prototyping stages of this project were made in different time stages of the project. This chapter will generally talk about prototyping and in later chapters the different types of prototypes made will be shown.

3.6.1 **Prototyping**

A prototype in a project can be a way of understanding the product further instead of just understanding it from 3D-files on a computer screen or a drawing on a paper. A physical protype is a tangible artifact that is made as an approximation of the product. The protype is then used to understand the product further in terms of size, design or if it can withstand the forces it is designed for. It can then show what needs to be updated on the part or if the part is sufficient in its design.

The physical prototype can also be used as communication to show the management or stakeholders what the product would look like. If the prototype is a part in a system, the prototype can be used to find out more about the integration of all the parts in the system. For example, if the wheel can be screwed in properly in the frame or if the design can be improved for better integration.

The prototype is also a great way of reducing the cost for the project since doing prototypes can find errors in manufacturing or errors in how the part will integrate in the system. By doing a prototype the need of starting the real manufacturing of a part is put on hold until you know that the prototype meets the requirements that are needed for the specific part.

A way of prototyping physical prototypes is by using a 3DP. This gives fast and accurate results of the product with a cheap price compared to doing the product in for example a workshop.

Another way of prototyping is using 3D Cad softwares and testing the parts for strength and fitness inside the software. This is the cheapest way of testing the part for strength and analytical purposes. [25, p. 291-311]

4 Initial Concept Development

This chapter includes system-design and the preceding activities in the product development process performed before concepts were generated and selected.

4.1 Planning

The planning phase was performed by VCC prior to the project beginning and the opportunity they identified is the project itself. To have a clear goal and a framework to fall back on if problems were to arise further on in the project, a mission statement, based on the problem description in section 1.3.1 was created. The mission statement can be seen in table 4.1.

Table 4.1 Mission statement

	Mission statement: Design and Development of a Foldable Motorized Micro-Haulage Vehicle
Product Description	• A lightweight foldable micro-haulage vehicle designed for personal haulage.
Benefit Proposition	• Accelerate the transition to walk more and use the car less. • Help users carry personal goods.
Key Business Goals	• Develop and design a concept.
Primary Market	• Consumer sector.
Assumptions & Constraints	• Fit most ages. • Frees its master from haulage. • High useability. • Use AM for lightweight.
Stakeholders	• VCC • Users

4.2 Identify Customer Needs

Prior to the project starting, VCC had performed the activity of market research and identification of customer needs. Due to this work being confidential and owned by VCC, a thorough presentation of the identification of customer needs will not be presented in the report.

As presented in section 3.2.3.1, customer needs are vital to the success of the product and to provide some information and understanding for the reader of how future work was carried out and what certain decisions and ideas was dependent on, some of the more overarching requirements/needs will be presented. These requirements/needs were given by VCC and the teams interpreted versions can be found in table 4.2. The requirements/needs are not presented in any specific order regarding importance.

Table 4.2 Overarching Requirements/Needs

Requirement/Need no.	***Requirement/Need Description.***
A.1.	The vehicle follows the user
A.2.	The vehicle can be folded
A.3.	The vehicle is lightweight
A.4.	The vehicle can transport goods
A.5.	The vehicle can travel on different terrain
A.6.	The vehicle can carry different goods
A.7.	A user can control the vehicle manually
A.8.	The vehicle is low maintenance
A.9.	The vehicle is sustainable
A.10.	The vehicle can be used by different users
A.11.	The vehicle should fit in Volvo cars
A.12.	The vehicle can handle different weather and temperatures
A.13.	The vehicle uses an electric powertrain.
A.14.	The vehicle is easy to use
A.15.	The vehicle can travel safely in traffic
A.16.	The vehicle can promote walking
A.17.	The vehicle can be lifted easily
A.18	The vehicle can traverse stairs with help from user

During initial meetings with the supervisors at VCC, traffic conditions were discussed. Since the intended product is not commonly found in Sweden and there are no current Swedish laws or regulations affecting requirements on the product, the decision was made to look at other micro mobility products and their regulations. Especially electric scooters which are of a similar size compared to the vehicle being developed. Electric scooters follow the same regulations as electric bicycles without pedals and as presented in the theory section 2.1.3 there are some requirements which were added as additional requirements to the micro-haulage vehicle. These requirements are presented in table 4.3. The reasoning behind looking at the Swedish electric scooter requirements was to identify requirements for the micro-haulage vehicle with potential regulations arising from future implementation of similar products in cities. Complying with these regulations prior to potential implementation would prevent future adaptations to the concept vehicle being developed.

Table 4.3 Electric Vehicle Requirements

Requirement/Need no.	***Requirement/Need Description.***
B.1.	A light at the back that is visible up to 300m away. Can be pulsating if the pulses are less than 200/minute.
B.2.	Light at the front with white or yellow light so that the vehicle can be maneuvered in the dark
B.3.	Red reflector in the back
B.4.	White reflector in the front
B.5.	White or orangeyellow on the sides.
B.6.	Electric bikes without pedals can use a maximum of 250W of electrical power and at maximum 20 km/h.
B.7.	Electric scooters shall be ridden in the same way as bikes.
B.8.	When driving in the dark the scooter shall have front and rear light as well as reflectors.

4.3 Establish Target Specifications

Similarly, to the customer needs, many of the requirements given by VCC at the start of the project came with corresponding specifications. To respect the confidentiality and ownership of this information, specifications will not be displayed. The most critical specifications, which further on are needed for structural analysis and topology optimization will however be given in the report and can be found in table 4.4.

Table 4.4 Critical Specifications

Metric no.	***Metric***	***Units***	***Marginal Value***	***Ideal Value***
1	Maximum vehicle weight	kg	< 10	6-8
2	Maximum load	kg	> 15	20

4.4 Problem Clarification & External Search

4.4.1 **Clarify the problem**

The problem or main function for the project was a foldable motorized micro-haulage vehicle, supporting personal haulage activities in urban environments. This together with the requirements/needs and specifications presented in previous subchapters concluded in a very complex product description.

To better understand the complexity and generate a well performing concept, the approach presented in 3.3.3.3.1 was followed. With a functional decomposition, the main problem could be broken down in to subproblems which would be easier to find solutions to further on. Some of the sub-functions could be derived based on the requirements/needs and due to the importance of the architecture of the product and the packaging of needed components, some sub-solutions were already predefined. E.g., electric powertrain which required a battery and electric motor as a solution for the propulsion of the vehicle. A FMT was used to derive the breakdown of functions, due to its dual possibility of understanding and planning the architecture of components as well as the visualization of functions. The FMT generated at this stage can be seen in figure 4.1.

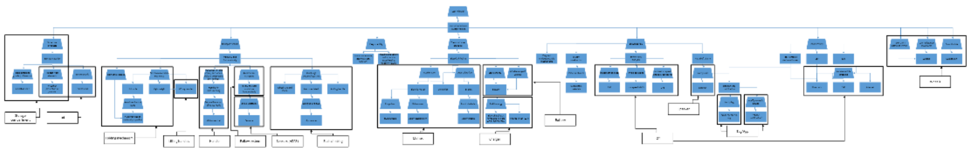

Figure 4.1 FMT of Main Function

The boxes in figure 4.1 represent several functions and means which could be grouped together as a solution for the subproblems with a potential single sub-system or part. The groups of sub-systems were later used as names for the subproblems they were intended to solve when defining mechanical concepts during internal search. The groups of mechanical, electronic, function and other are listed in table 4.5.

Table 4.5 Groups from FMT

Mechanical	*Electronic*	*Function*	*Other*
Folding Mechanism	Speaker	Stair Climbing	Tag or App
Handle	IOT		
Lid	Motor		
Lifting Handles	Battery		
Storage Capacity	Charger		
Wheels	Follow System		
	Sensors (ADAS)		

The electronic components/systems required to solve some of the sub-problems are not defined as groups/sub-systems since their implementation solves the subproblem directly. Focus is instead put on choosing these systems or components how to package them within the mechanical parts of the design.

The function of stair climbing is only related to the possibility for the user to traverse stairs with the vehicle when its being driven manually. No system should be implemented which lets the vehicle climb stairs on its own.

A tag or app should be used for the user to connect to the vehicle and enable the vehicle to follow the user. The project was focused on the vehicle design and development so further development of one of these systems was not performed.

4.4.2 **Product architecture**

The four steps presented in 3.3.4 were recommended to establish the product architecture. In the previous subchapter, the FMT was used to group different functions together. This corresponds to both the step of creating a schematic of the product as well as to cluster the elements into chunks. The remaining steps for the activity are to create a rough geometric layout and to identify the fundamental and incidental interactions. A decision was made, to perform the rough geometric layout when generating the concepts to have more freedom in how potential concepts should look and function. Understanding the interactions between sub-systems and components is however important for concept generation, due to the packaging of these and because of the overall complexity of the product. The team researched the electronic groups presented in table 4.5 to get a better understanding of how these sub-systems and components function, potential interactions, their sizes, and their limitations.

4.4.3 **Search externally**

To get a better understanding of current solutions to the problem and it´s subproblems the method presented in 3.2.3.3.2 was used. Due to personal micro-haulage vehicles not being a widespread technology with many users and many products, finding key users and experts regarding the subject would be difficult. The team decided to search published literature and look at related products to find useful information for the concept development.

4.4.3.1 Competitive Products

There are not many products within the same product segment and those available do not deliver all functions which the team tried to find solutions to. The main contender on the market is a two-wheeled micro-haulage vehicle that follow its user using sensors and lidar.

4.4.3.2 Similar Products

Other products which the team reviewed where food-delivering robots which have the capability to store and deliver goods. These are however fully automatic which adds more electronics and thus have an increased weight compared to the goal of the team's vehicle. Another similar product is golf-carts which follow the user. These are usually foldable but lack the storage capabilities in the product itself.

4.4.3.3 Solutions to Subproblems

When trying to solve other separate sub-problems, the team mostly looked at other micromobility vehicles and regular shopping carts. This was to better understand functions and dimensions of details such as wheels and handles.

5 Iterative Concept Development

This section includes the remaining steps of the concept development process. These activities were performed iteratively, to effectively move from subproblem solutions to a complete product.

5.1 Structure of Cycles

Generating and selection of concepts were performed iteratively in three cycles.

In the first cycle, solutions to the different subproblems were generated and evaluated with the concept screening method. For those subproblems where a lot of concepts were generated, an initial comparison was made and concepts which underperformed were not taken into consideration for the concept screening. This was done to quickly narrow down the possible subproblem solutions which could be used for complete concepts.

The solutions to the subproblems which ranked higher in the concept screening from the first iteration were used to systematically explore and generate potential complete concepts in the second cycle. These were also evaluated with the concept screening method due to the need of quickly reducing the number of concepts.

For the third iteration, only a few concepts from the previous iteration were left for evaluation. The concept scoring method was used to get a more accurate result of the relative performance of each concept.

5.2 First Iteration – Subproblem Solutions

5.2.1 **Folding Mechanism**

5.2.1.1 Internal Search – Folding Mechanism

The concepts generated for the folding mechanism can be seen in figure 5.1 and figure 5.2. To avoid interference of mechanical parts folding, several of the concepts include parts labeled with origami. Origami refers to either a softer material with compliant folding capabilities or a textile of some sort.

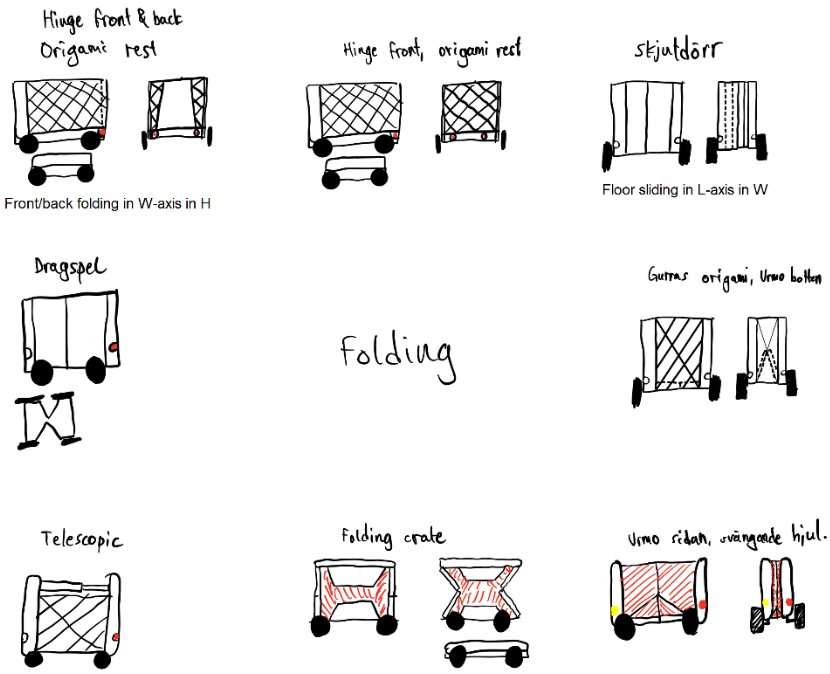

Figure 5.1 Folding Sketches 1

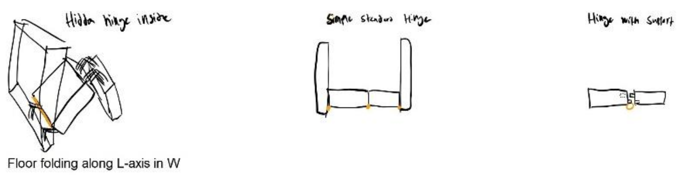

Figure 5.2 Folding Sketches 2

When evaluating the concepts for the folding mechanism it was clear that several of the concepts were folding in a similar manner. For better clarity regarding the concepts, some of them were renamed based on their motion. The folding motion of “hidden hinge inside” in figure 5.2 was renamed to “Floor folding along L-axis in W” where the reduction in size was in the width (W) of the vehicle- and the folding along the length (L). The same principle was applied to the “hinge front & back, origami rest" and "skjutdörr" in figure 5.1. "Hinge front & back, origami rest" was renamed to "Front/back folding in W-axis in H" and "skjutdörr" was renamed to "Floor sliding in L-axis in W".

The "folding crate" concept in figure 5.1 could be broken down in to two different folding motions, one where the sides folded to the base of the vehicle and one where the sides were collapsible. The two concepts were renamed to "foldable tophat" and "collapsible tophat" for future work within the concept development phase.

5.2.1.2 Selection – Folding Mechanism

The renamed concepts were the concepts which the team believed would show the most promise to continue working with. To get a better understanding of how these concepts performed against each other, the concept screening method was used. The result from the screening can be seen in table 5.1. The selection criteria were chosen in a way that would meet the customers need in the best possible way.

Table 5.1 Concept Screening of Folding Mechanism

	Concepts				
Selection Criteria	***Floor folding along L-axis in W***	***Front/back folding in W-axis in H***	***Floor sliding in L-axis in W***	***Foldable tophat***	***Collapsible tophat***
Useability	0	+	0	+	0
Integration of electronics	0	0	0	0	-
Footprint folded	0	-	-	-	-
Safety	0	+	0	0	+
Ergonomics	0	0	0	-	-
Durability	0	0	0	0	-
Capacity	0	0	-	0	-
Number of parts	0	+	-	+	+
Stability	0	0	0	-	-
Part complexity	0	+	-	-	-
Sum +´s	0	4	0	2	2
Sum 0´s	10	5	6	4	1
Sum -´s	0	1	4	4	7
Net Score	0	3	-4	-2	-5
Rank	2	1	4	3	5
Continue?	Yes	Yes	No	No	No

The two concepts which ranked the highest in the screening matrix were to be used in the next cycle of concept development. The next stage would integrate several sub-problems in to one complete concept, which would require better understanding of how the folding mechanism would function practically. For this reason, two simple cardboard prototypes were made. The "floor folding along L-axis in W" concept is shown in figure 5.3 and the "front/back folding in W-axis in H" is shown in figure 5.4. Both figures show the folding motion, open to closed, from left to right.

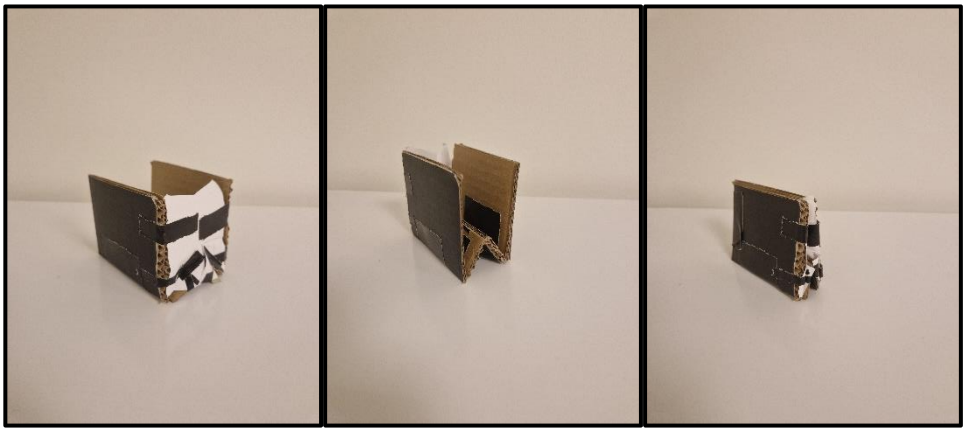

Figure 5.3 Folding Motion of "Floor Folding in L-Axis in W", also called EKA

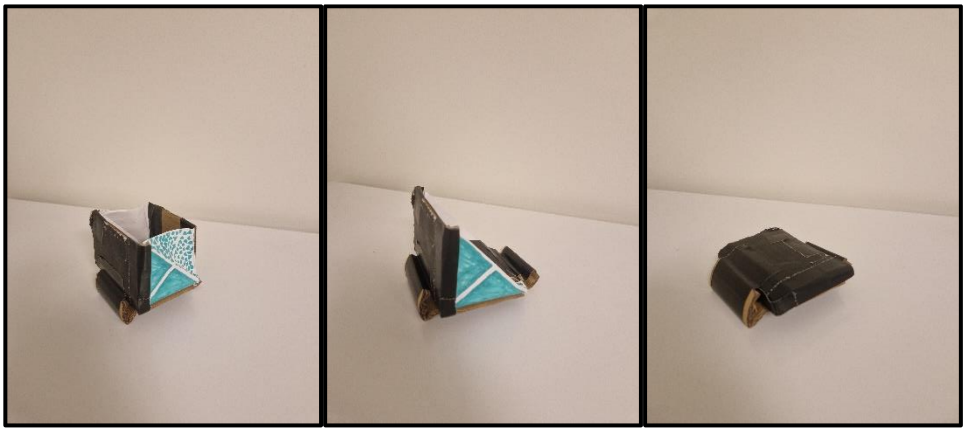

Figure 5.4 Folding Motion of "Front/Back Folding in W-Axis in H"

5.2.2 **Handle**

5.2.2.1 Internal Search – Handle

Internal search for the handles generated a lot of different concepts which are shown in figure 5.5 and figure 5.6.

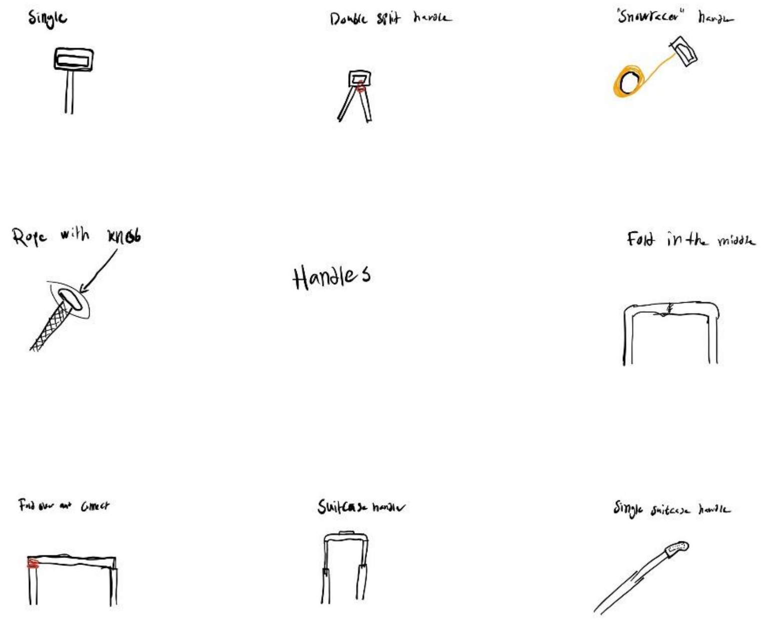

Figure 5.5 Handle Sketches 1

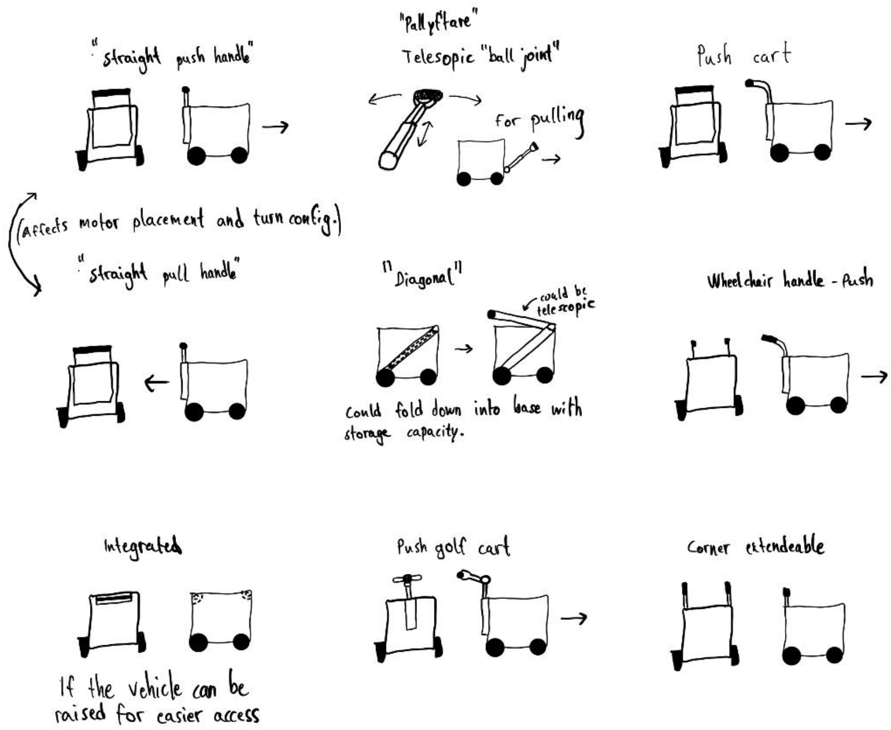

Figure 5.6 Handle Sketches 2

To decrease the number of concepts for the screening of the handles an initial evaluation was made. Manual control of the vehicle was the main topic of discussion when figuring out which concepts should be excluded from future development. The “snowracer handle” and “rope with knob” were removed because they included a rope as a connection to the vehicle. There would be no easy way to control a motorized vehicle manually if the handle lacks rigidity.

5.2.2.2 Selection – Handle

The screening of the handle concepts is presented in figure 5.7.

	Handles																	
Selection Criteria	Single telecsopic handle	Double split handle	Fold in the middle	Fold in the middle (Seperate completely)	Fold and connect	Suitcase handle	Single suitcase handle	Straight push handle	Pallyftare	Push cart	Straight pull handle	Suitcase handtag som öppnas	Suitcase handtag som fälls ut som pallyft	Integrated	Push golf cart	Corner Extendable	Fold from edge	Diagonal
Foldability	0	-	+	+	+	0	0	0	0	-	0	0	-	+	-	+	-	0
Functionality (push/pull)	0	0	+	+	+	0	-	0	0	0	0	+	+	-	0	-	0	0
Useability	0		0			0		0		0					0			0
Ergonomics	0	0	0	+	0	0	-	+	+	+	-	+	+	-	+	-	-	0
Electronic controls	0	0	-	-	0	0	-	+	0	+	-	-	-	+	+	-	+	+
Durability	0	-	-	-	-	0	0	+	-	+	0	-	-	+	+	0	-	-
Integration in tophat	0	-	-	-	-	-	-	-	-	-	-	0	-	+	-	-	-	-
Part count	0	-	-	-	-	0	0	0	-	0	0	-	-	+	-	0	-	-
Stable position	0	0	0	-	0	0	0	+	-	+	-	-	-	+	+	0	+	-
Looks	0	+	+	+	-	0	-	0	-	0	0	+	-	0	+	-	0	+
Sum +'s	0	1	3	4	2	0	0	4	1	4	0	3	2	6	5	1	2	2
Sum 0's	10	4	3	0	3	9	4	5	3	4	5	2	0	1	2	3	2	4
Sum -'s	0	5	4	6	5	1	6	1	6	2	5	5	6	3	3	6	6	4
Net Score	0	-4	-1	-2	-3	-1	-6	3	-5	2	-5	-2	-6	3	2	-5	-4	-2
Rank	5	12	6	8	11	6	17	1	14	3	14	8	17	1	3	14	12	8
Continue?	MAYBE		MAYBE			MAYBE		YES		YES				YES	YES			

Figure 5.7 Concept Screening of Handle

5.2.3 **Lid**

5.2.3.1 Internal Search – Lid

The lids were searched internally and can be seen in Figure 5.8 to 5.9 below. The ideas were brainstormed with the idea of trying to find as many different ideas as possible for a lid that is easy to use and can be stored easily.

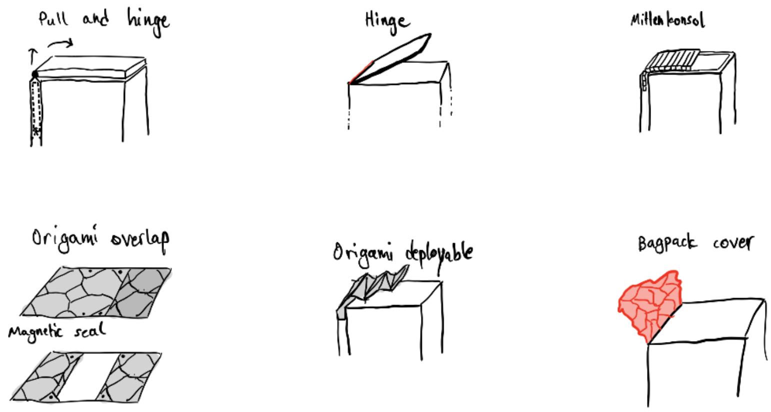

Figure 5.8 Lid Sketches 1

Figure 5.9 Lid Sketches 2

When reflecting upon the lids that had been sketched, the lids which were solid, were not a great idea in terms of space efficiency and feasibility. The “cup holder lid” was a great idea since it could be stored efficiently and be able to show the user that the lid was not for sitting since it had a softer fabric. The “hinge” was also found to be unsuitable since the vehicle needs to be foldable. The “origami” versions would look futuristic and could be a smart way to do the lid, but since the development of such a lid is greater than many others it might not be suitable.

5.2.3.2 Selection – Lid

The screening of the lid concepts is presented in table 5.3.

Table 5.3 Concept Screening of Lid

	Concepts				
Selection Criteria	***Piaggio Gita (Reference)***	***Roll up lid***	***Store in the side***	***Cup holder lid***	***Origami deployable***
Ease of use	0	-	-	0	-
Securing goods	0	-	0	0	-
Possibility to lock	0	0	0	0	-
Looks	0	-	0	+	+
Size/weight	0	+	0	0	+
Weather protection	0	-	0	0	-
Part count	0	+	-	0	+
Durability	0	-	0	-	-
Hot/Cold	0	-	0	-	-
Integration with foldability	0	+	+	+	+
Sum +´s	0	3	1	2	4
Sum 0´s	10	1	7	6	0
Sum -´s	0	6	2	2	6
Net Score	0	-3	-1	0	-2
Rank	1	5	3	1	4
Continue?	No	No	Yes	Yes	No

5.2.4 **Lifting Handles**

5.2.4.1 Internal Search – Lifting Handles

When brainstorming concepts for lifting handles, few ideas were generated regarding the choice of handle solution. Ideas regarding the potential placement of lifting handles and how the vehicle would be lifted were added to have more ideas when creating complete concepts. The lifting handle concepts are shown in figure 5.10 and the lifting placements can be seen in figure 5.11.

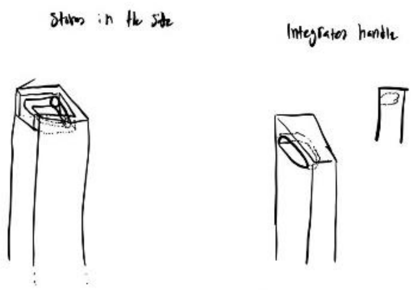

Figure 5.10 Lifting Handle Sketches

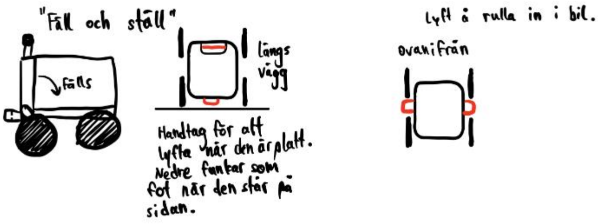

Figure 5.11 Lifting Placements Sketches

Lifting handles should be discrete and communicate that this is where the vehicle can be lifted. A few different lifting handles was investigated, but at first glance considering the space constraint on the vehicle, an efficient lifting handle without moving parts should be optimal.

5.2.4.2 Selection – Lifting Handles

Since there only were two concepts for the lifting handle construction, no concept screening method was performed. The team thought that both concepts were potential candidates for future complete concepts.

5.2.5 **Storage Capacity**

5.2.5.1 Internal Search – Storage Capacity

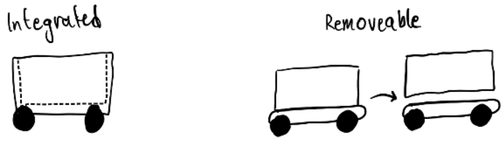

Figure 5.12 Storage Capacity Sketches

5.2.5.2 Selection – Storage Capacity

The storage capacity of the vehicle is of great importance since the vehicle is intended to be used as a transportation aid for the user. A removable storage capacity is an option that requires more engineering to work since all different parts of the vehicle needs to meet the requirements of foldability, lifting handles, driving handles, lights etc. Because of this an integrated storage is the way to go. An integrated storage with ability to have paper bags inside is a better and more versatile option. Another concern with a removable storage capacity would be that all electronics would have to be implemented in the bottom of the vehicle, limiting functionality due to packaging of the electronics.

5.2.6 **Wheels**

5.2.6.1 Internal Search – Wheels

Concepts of the wheels are shown in figure 5.13. A brainstorming session was held where the idea was to take inspiration from all different kinds of vehicles and to find the best possible candidate for our product.

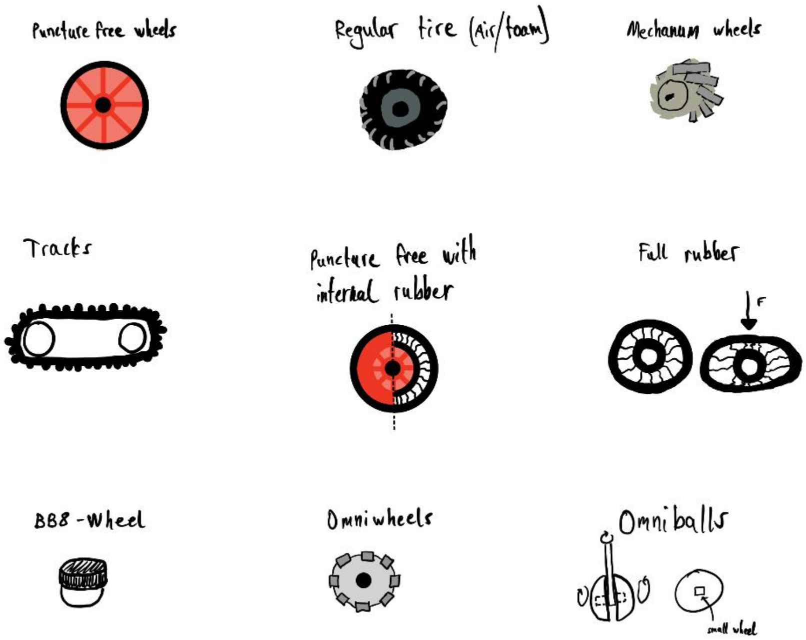

Figure 5.13 Wheel Sketches

The different wheels offer different properties, but as conclusion the wheels need to offer stability, some sort of dampening and enough traction to work on different surfaces such as low friction stone tiles inside grocery stores, asphalt, wood floor and gravel. Low maintenance is also a priority for the wheels so that the vehicle can be in operation as much time as possible.

Since the vehicle should be able to travel on different kinds of terrain, dirt would play a significant role in how the wheels would function. The “BB8-wheel”, “omniballs” and “mechanum wheels” all required more parts than the other concepts which would both add costs and the collection of dirt between moving parts. For this reason, the team decided that these concepts should be excluded from the concept screening of the wheels.

5.2.6.2 Selection – Wheels

One concept not presented in figure 5.13 which the team decided to add for evaluation was a regular swivel wheel. The screening of the wheel concepts is presented in table 5.4.

Table 5.4 Concept Screening of Wheels

	Concepts						
Selection Criteria	***Regular tire (air/foam)***	***Puncture free***	***Swivel***	***Tracks***	***Full rubber***	***Omniwheels***	***Puncture free + rubber***
Weight	0	+	-	-	0	-	-
Turnability	0	0	+	+	0	+	0
Suspension	0	-	-	-	+	-	0
Looks	0	-	-	-	+	-	0
Maintenance	0	+	-	-	0	-	0
Part count	0	+	-	-	+	-	0
Repairability	0	-	0	0	-	-	-
Durability	0	+	-	+	0	-	+
Readily available	0	0	0	-	-	-	-
Grip	0	-	-	+	+	+	+
Motor Integration	0	0	-	+	-	0	0
Sum +´s	0	4	1	4	4	2	2
Sum 0´s	11	3	2	1	4	1	6
Sum -´s	0	4	8	6	3	8	3
Net Score	0	0	-7	-2	1	-6	-1
Rank	2	2	7	5	1	6	4
Continue?	Yes	Yes	Maybe	Yes	Yes	Maybe	Maybe

A realization made during the concept screening of the wheels was that the vehicle would be very dependent on how the wheels were configured. Some of the questions regarding the configuration were:

- How many wheels would be needed to ensure stability?
- Which wheels would provide propulsion power?
- How would the motors be connected to the wheels?

To answer these questions the team decided to create another sub-problem group called “wheel configuration” where concepts could be explored. Some of the concepts in table 5.4 are labeled maybe. Since most of the wheels share the same geometry, the concepts labeled “maybe”, could be potential candidates if they would increase the overall performance of driving and steering, both manually and automatic.

5.2.7 **Wheel Configuration**

5.2.7.1 Internal search – Wheel Configuration

For the wheel configuration various setups were found from doing a brainstorming session. Different setups also meant different tophat’s of the vehicle which was not taken into consideration until doing the scoring of different completed concepts. The result from the internal search of the wheel configuration can be seen in figure 5.14 through figure 5.18.

Figure 5.14 Wheel Configuration Sketches 1

Figure 5.15 Wheel Configuration Sketches 2

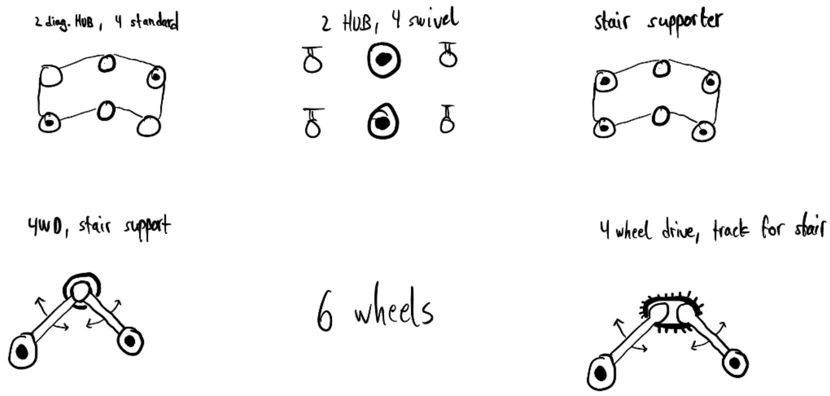

Figure 5.16 Wheel Configuration Sketches 3

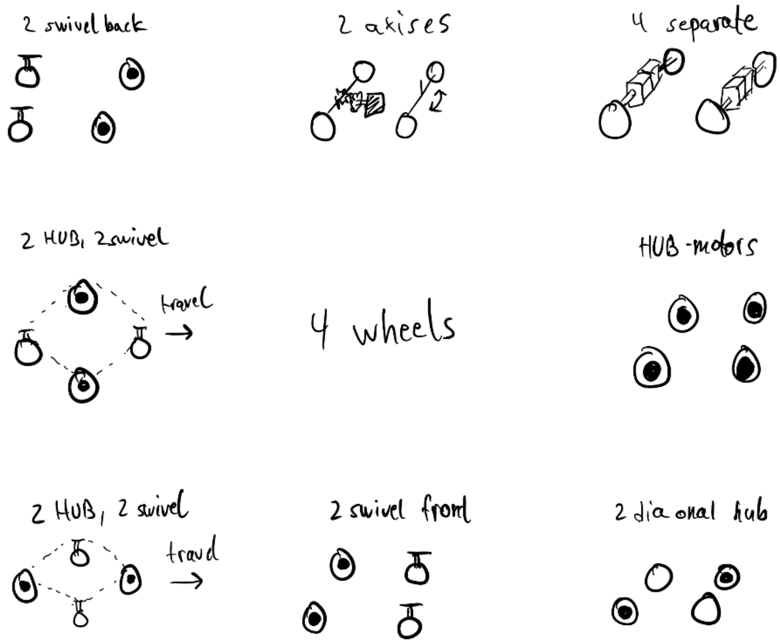

Figure 5.17 Wheel Configuration Sketches 4

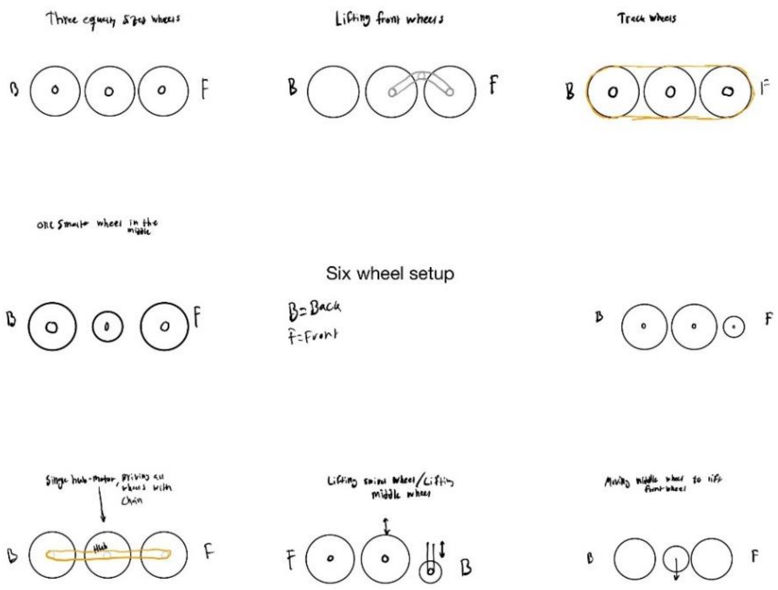

Figure 5.18 Wheel Configuration Sketches 5

The wheels are of particular interest for the vehicle since the setup of the wheels will affect how many motors can be used, how it handles on different terrain, how it can be manufactured/assembled and how it handles in stairs.

Due to stability concerns, the “hoverboard” and three-wheel concepts were removed from future development and either a four-wheel, six-wheel or tracks vehicle was preferred.

5.2.7.2 Selection – Wheel Configuration

The concept screening matrix for the wheel configuration concepts is presented in figure 5.18.

	Wheel Configuration																		
Selection Criteria	Small in middle	2 swivel back	4 separate	Hub-motors(4)	2 Swivel front	2 diagonal HUB	2 diagonal HUB, 2 swivel (SAKNAR BILD)	2 HUB, 4 Swivel	Stair supporter (6)	4WD, stair support	4WD, track for stairs	Track: Straight	Track: Configurable	3 equal sized wheels	Lifting front wheels	Turning front wheels	Single hub motor with chain	Lifting swivel wheel	Middle wheel which moves down to lift front
Weight	0	+	-	-	+	+	+	-	-	-	-	-	-	-	-	0	-	-	-
Looks	0	-	+	+	-	-	-	-	0	0	-	-	-	0	-	0	-	-	0
Maintenance	0	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-
Road safety	0		+	+					+	+	+	+	+	+	+	+	+	0	+
Suspension	0	-	0	0	0	0	0	-	0	+	+	+	+	+	+	0	0	0	+
Turnability	0	+	+	+	+	0	+	+	0	0	0	+	+	-	+	+	-	+	0
No. Of parts	0	+	-	-	+	+	+	-	-	-	-	-	-	0	-	-	-	-	-
Obstacle handling	0	-	-	-	-	-	-	-	+	+	+	+	+	+	+	0	0	+	+
Durability	0	-	-	-	-	-	-	-	0	0	0	+	+	0	+	0	-	+	+
Propulsion	0	-	+	+	0	0	0	-	+	+	+	+	+	+	+	0	+	0	0
Sum +'s	0	3	4	4	3	2	3	1	3	4	4	6	6	4	6	2	2	3	4
Sum 0's	10	0	1	1	2	3	2	0	4	3	2	0	0	4	0	6	2	3	3
Sum -'s	0	7	5	5	5	5	5	9	3	3	4	4	4	2	4	2	6	4	3
Net Score	0	-4	-1	-1	-2	-3	-2	-8	0	1	0	2	2	2	2	0	-4	-1	1
Rank	7	17	11	11	11	16	11	19	7	5	7	1	1	1	1	7	17	11	5
Continue?	MAYBE	OMNI							MAYBE	YES	MAYBE	YES	YES	YES	YES	MAYBE			YES

Figure 5.18 Concept Screening of Wheel Configuration

The concepts labeled maybe were ideas which could potentially be included or adapted depending on future detail design of completed concepts.

5.3 Second Iteration – Complete Concepts

5.3.1 **Explore Systematically & Internal Search**

When starting the second cycle of concept generation, the best performing concepts from the individual sub-problems were placed in a concept combination table, which can be seen in table 5.6, according to the description given in 3.2.3.3.4.

Table 5.6 Concept Combination Table

Folding Mechanism	***Handle***	***Lid***	***Lifting Handles***	***Wheels***	***Wheel Configuration***
Floor folding along L-axis in W	Straight push handle	Store in the side	Integrated	Regular tire (air/foam)	4WD stair support
Front/back folding in W-axis in H	Push cart	Cup holder lid	Stored in the side	Puncture free	Track straight
	Integrated			Full rubber	Track configurable
	Push golf cart				3 equal sized wheels
					Lifting front wheels
					Middle wheel which lifts front

With the concept combination table set up a new internal search was made. The individual solutions were combined into complete concept vehicles at random except the ones that were not feasible that were disregarded, which can be seen in figure 5.19 through figure 5.26.

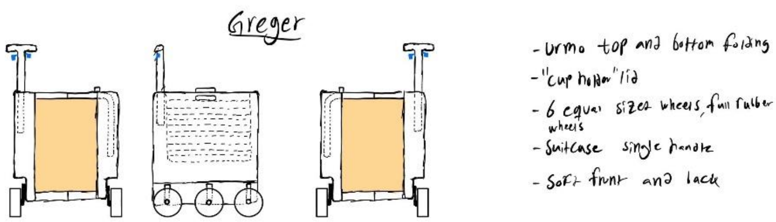

Figure 5.19 Concept “Greger”

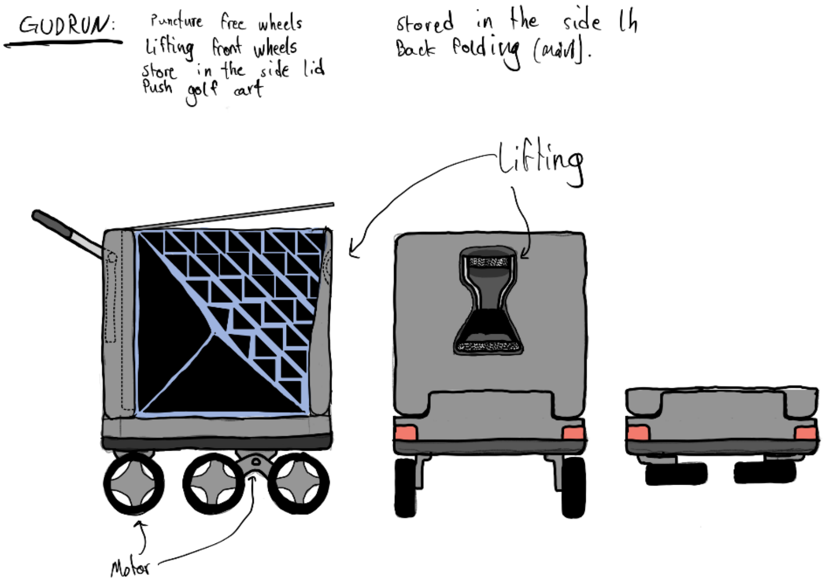

Figure 5.20 Concept "Gudrun"

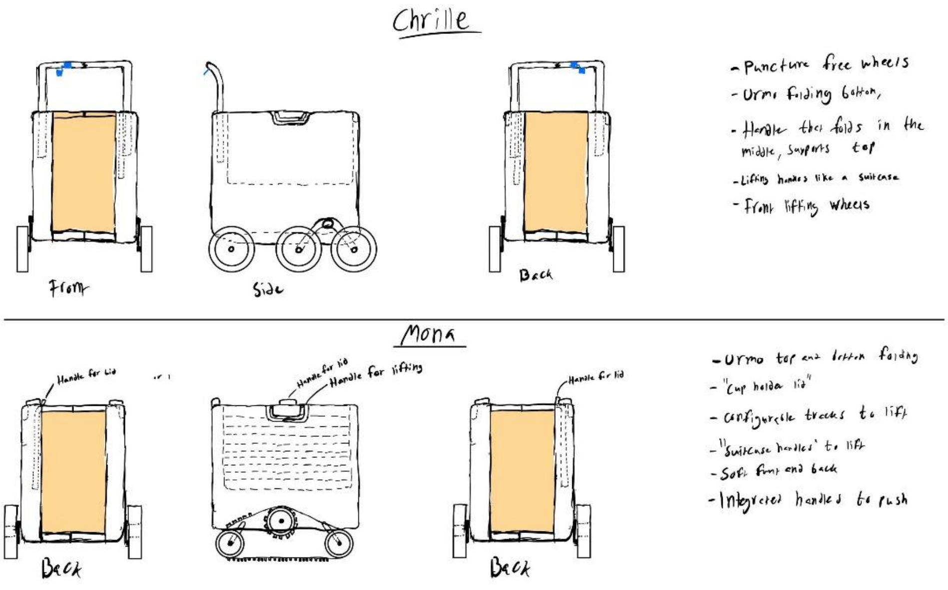

Figure 5.21 Concept "Chrille" and "Mona"

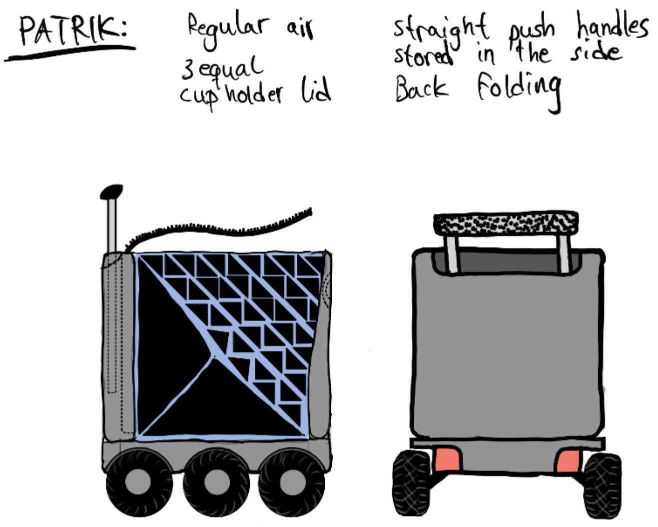

Figure 5.22 Concept “Patrik”

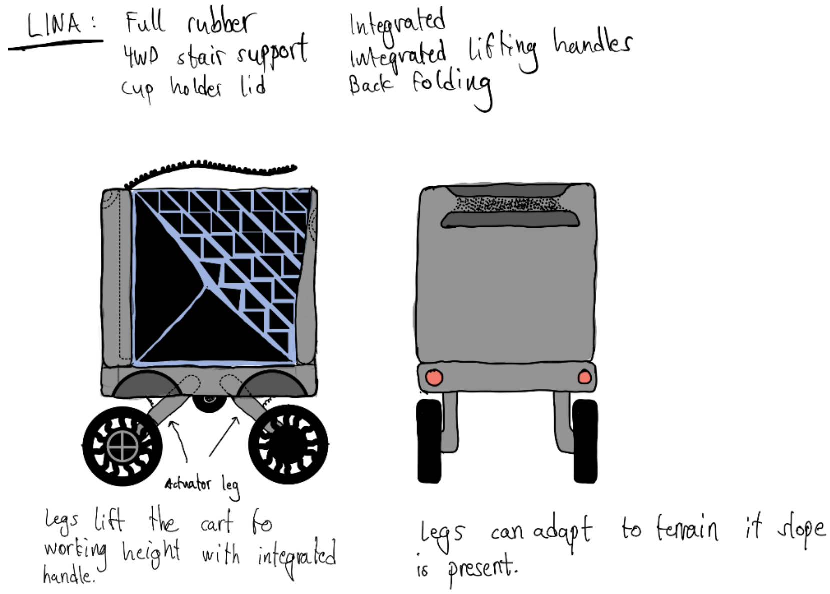

Figure 5.23 Concept “Lina”

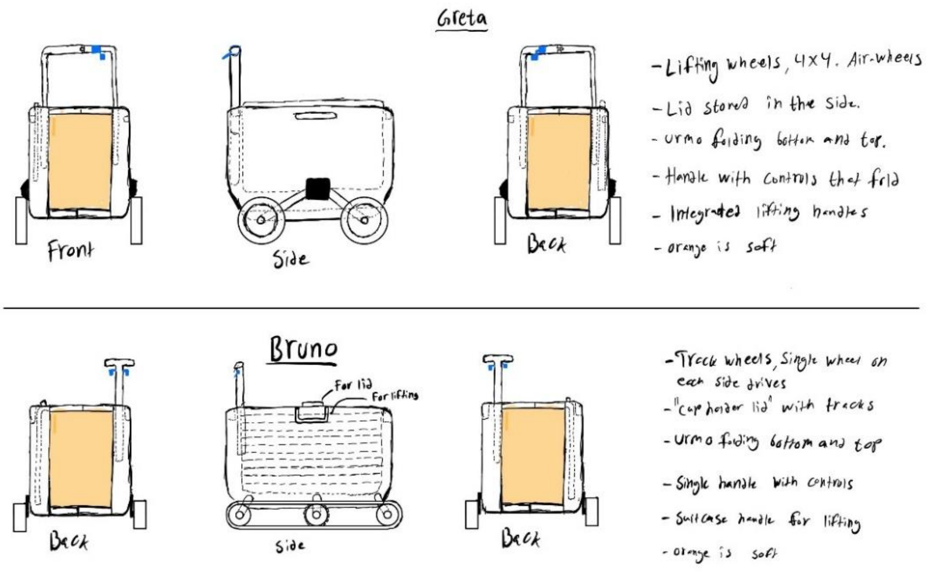

Figure 5.24 Concept “Greta” and “Bruno”

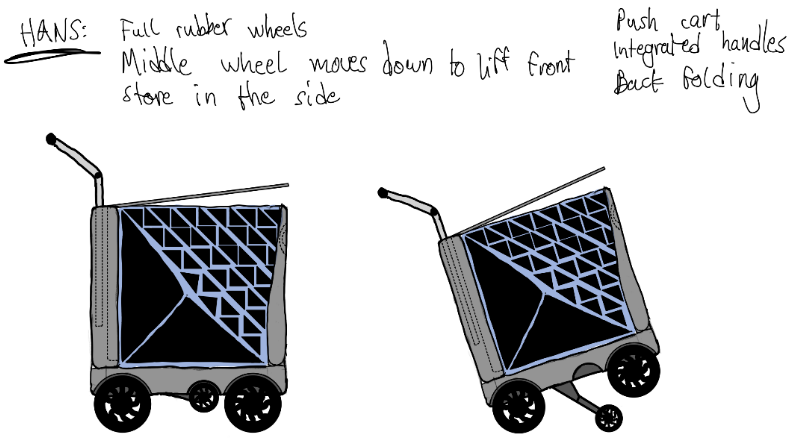

Figure 5.25 Concept “Hans”

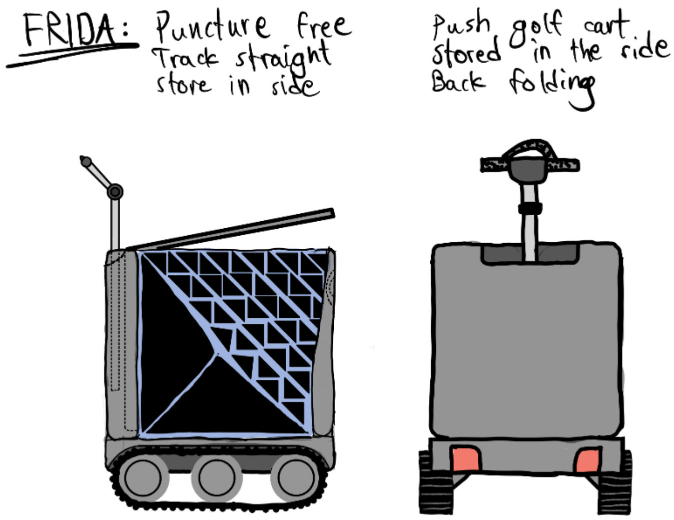

Figure 5.26 Concept “Frida”

5.3.2 **Selection**

The generated concepts were evaluated with the concept screening method, with its results in table 5.7. The selection criteria named “other” includes, manufacturing, looks and cost.

Table 5.7 Concept Screening of Combined Concepts V.1

	Concepts									
Selection Criteria	***Greta***	***Bruno***	***Chrille***	***Mona***	***Greger***	***Frida***	***Patrik***	***Hans***	***Lina***	***Gudrun***
Foldability	0	+	0	0	0	0	0	0	0	0
Functionality	0	0	-	-	0	-	-	-	-	-
Useability	0	-	+	-	-	-	-	0	-	-
Safety	0	0	0	0	0	0	0	0	0	0
Ergonomics	0	-	+	-	-	+	-	+	-	0
Electronics placement	0	0	-	-	0	+	+	+	-	-
Mobility	0	+	+	+	-	+	-	-	0	+
Durability	0	0	0	-	+	+	+	0	+	-
Capacity	0	+	0	0	+	+	+	0	-	-
Other	0	+	0	-	+	-	+	0	-	-
Sum +´s	0	4	3	1	3	5	4	2	1	1
Sum 0´s	10	4	5	3	4	2	2	6	3	3
Sum -´s	0	2	2	6	3	3	4	2	6	6
Net Score	0	2	1	-5	0	2	0	0	-5	-5
Rank	4	1	3	6	4	1	4	4	6	6
Continue?	No	Yes	No	No	No	Yes	No	No	No	No

The track wheels are great for handling on different type of terrain and give great traction but aesthetically they are not what fit into the Volvo lineup of products. A lifting wheel in the front might be good for getting over curbs but by adding a lifting wheel a motor is needed to lift the wheel which adds cost, complexity and weight which might not be suitable for this type of vehicle.

The team felt that it was possible to rethink and combine some of the concepts and explore options even further, outside of the concept combination table. One of the main concerns apart from the tracks was the useability and ergonomics with concepts that folded flat towards the ground, this would increase the amount of bending a user would have to do, either to deploy, fold or lift the vehicle. The new explored concepts, which included ideas from the already ranked concepts, can be seen in figure 5.27 through figure 5.36.

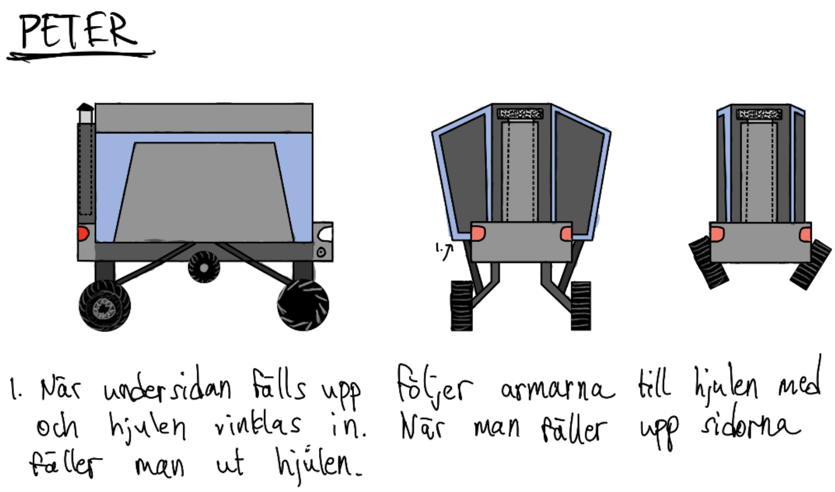

Figure 5.27 Concept “Peter”

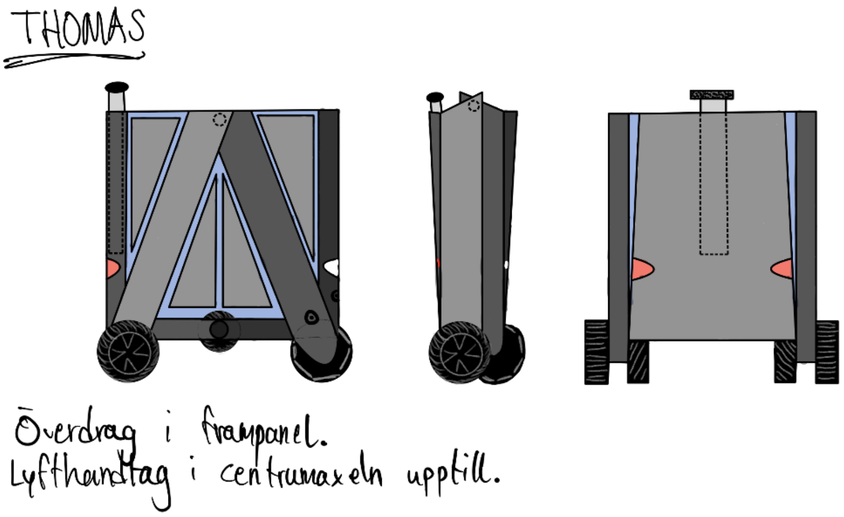

Figure 5.28 Concept “Thomas”

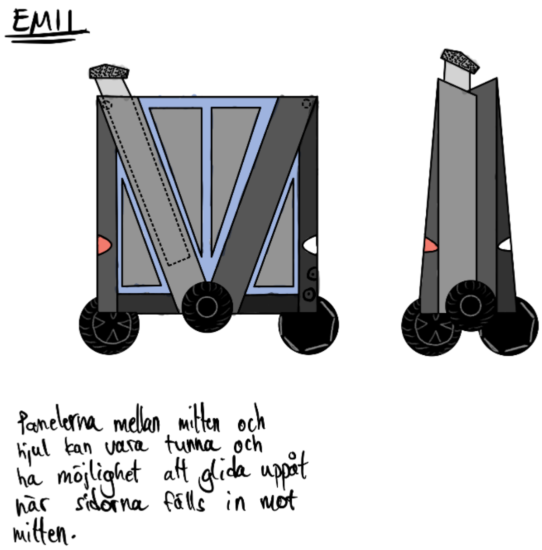

Figure 5.29 Concept "Emil"

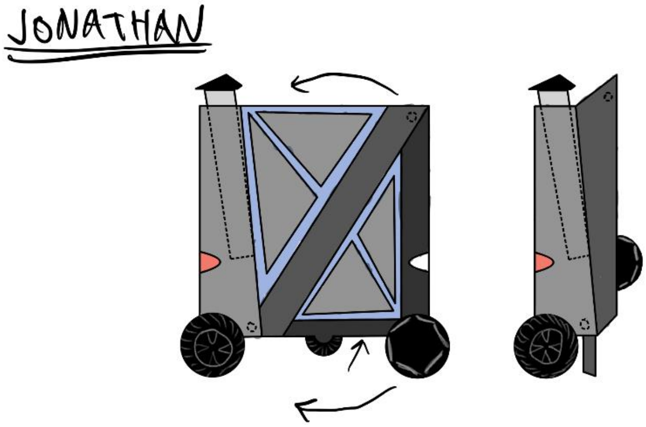

Figure 5.30 Concept "Jonathan"

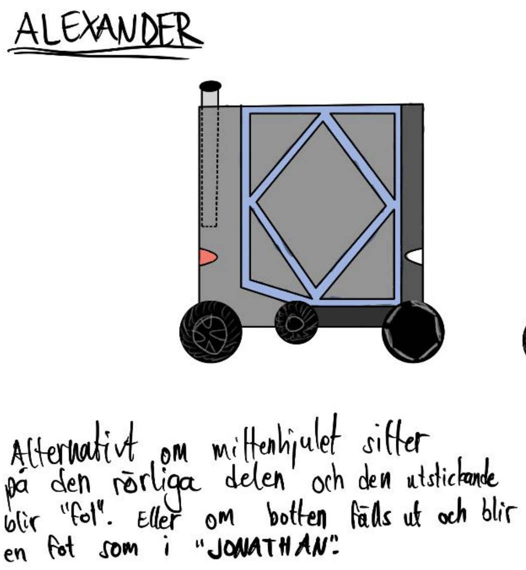

Figure 5.31 Concept "Alexander"

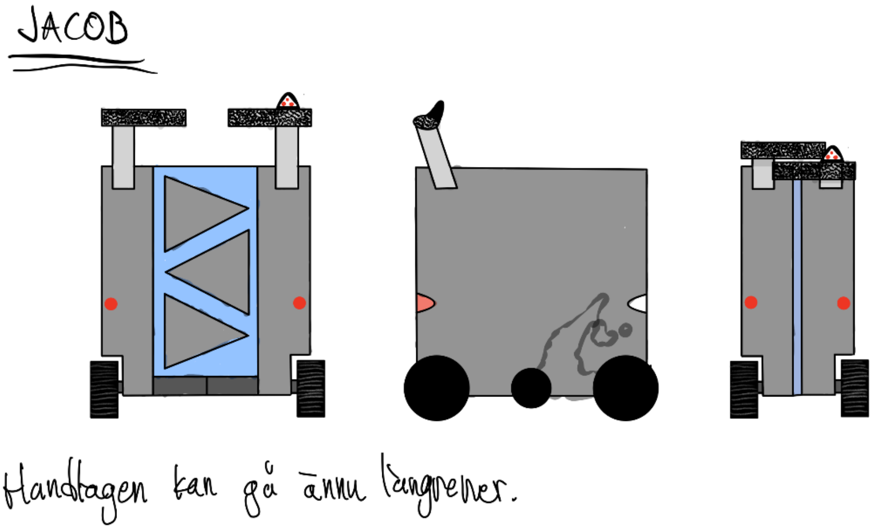

Figure 5.32 Concept "Jacob"

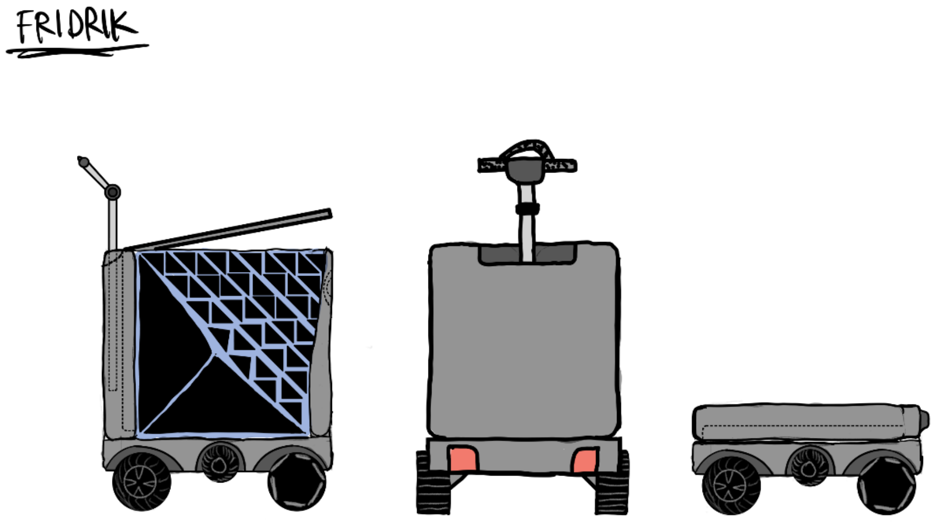

Figure 5.33 Concept "Fridrik"

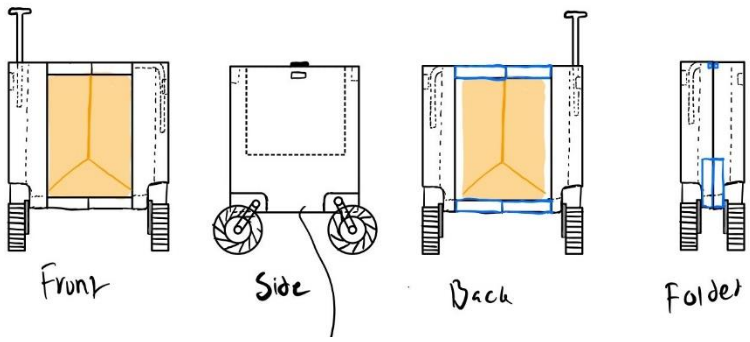

Figure 5.34 Concept "Eka"

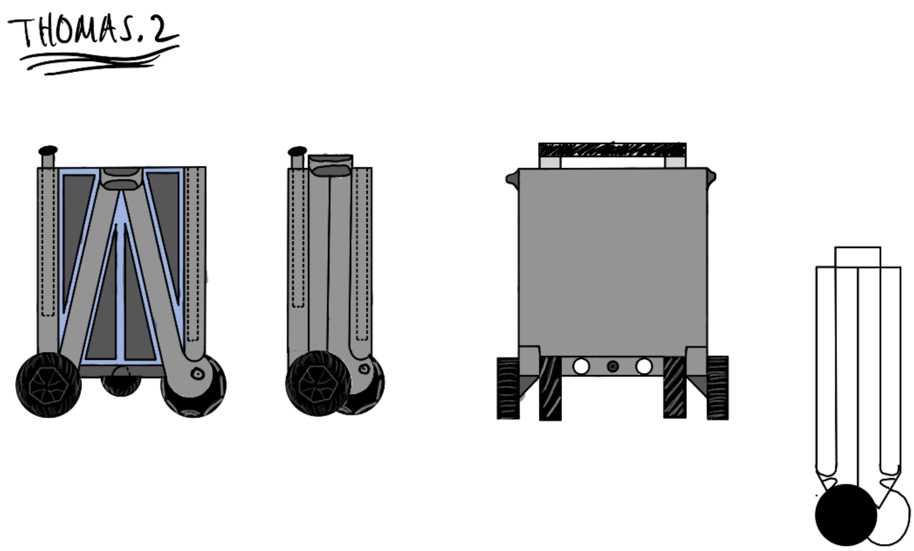

Figure 5.36 Concept "Thomas 2"

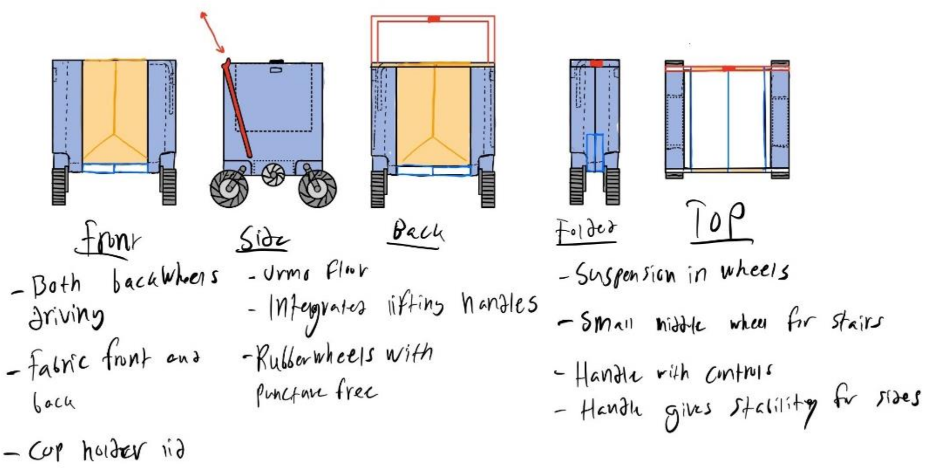

Figure 5.36 Concept "Eka 2"

The new concepts were added to the original screening matrix in table 5.7 and evaluated with the already ranked concepts. The new evaluation is presented in figure 5.37.

V2. Concept name	GRETA	BRUNO	CHRILLE	MONA	GREGER	FRIDA	PATRIK	HANS	LINA	GUDRUN	EKA	PETER	THOMAS	EMIL	JONATHAN	ALEXANDER	JACOB	THOMAS2	EKA2
Foldability	0	+	0	0	0	0	0	0	0	0	0	-	+	-	+	0	0	0	+
Functionality	0	0	-	-	0	-	-	-	-	-	+	-	+	-	-	-	0	0	+
Useability	0	-	+	-	-	-	-	0	-	-	-	-	-	+	-	-	+	+	+
Safety	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0
Ergonomics	0	-	+	-	-	+	-	+	-	0	-	-	+	0	0	-	+	+	+
Electronics placement	0	0	-	-	0	+	+	+	-	-	+	+	-	-	0	0	+	-	+
Mobility	0	+	+	+	-	+	-	-	0	+	-	-	-	-	-	-	-	+	+
Durability	0	0	0	-	+	+	+	0	+	-	+	-	0	0	-	-	+	+	+
Capacity	0	+	0	0	+	+	+	0	-	-	+	-	-	-	-	+	+	0	+
Other	0	+	0	-	+	-	+	0	-	-	+	-	+	+	-	+	+	+	+
Sum +'s	0	4	3	1	3	5	4	2	1	1	5	1	4	2	1	2	6	5	9
Sum 0's	10	4	5	3	4	2	2	6	3	3	2	0	2	3	3	3	3	4	1
Sum -'s	0	2	2	6	3	3	4	2	6	6	3	9	4	5	6	5	1	1	0
Net Score	0	2	1	-5	0	2	0	0	-5	-5	2	-8	0	-3	-5	-3	5	4	9
Rank	8	4	7	15	8	4	8	8	15	15	4	19	8	13	15	13	2	3	1
Continue?	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES

Figure 5.37 Concept Screening of Combined Concepts V.2

Fridrik was not added to the evaluation since it was a combination of Frida and Patrik, the better performing concepts from V.1, which folded flat. The team wanted to keep one idea which folded flat for the concept scoring matrix to see how it would compare with the other concepts which performed best in the V.2 screening.

5.4 Third Iteration – Final Selection

5.4.1 **Selection**

The final selection of the generated concepts can be seen in figure 5.38.

		Concept							
		A		B		C		D	
		Jacob		Eka II		Thomas 2		Fridrik	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Foldability	13,0%								
Size when folded	4,0%	3	0,12	4	0,16	2	0,08	1	0,04
Time to fold	3,0%	3	0,09	3	0,09	2	0,06	2	0,06
Time to unfold	3,0%	3	0,09	3	0,09	2	0,06	2	0,06
Number of moving parts	3,0%	3	0,09	3	0,09	1	0,03	2	0,06
Functionality	17,0%								
Lightweight	5,0%	3	0,15	3	0,15	2	0,1	3	0,15
Stability	2,0%	3	0,06	3	0,06	2	0,04	4	0,08
Sustainable (material use, amount of electronics etc)	3,0%	3	0,09	3	0,09	3	0,09	4	0,12
Placement and orientation in car	2,0%	3	0,06	3	0,06	3	0,06	1	0,02
Visible lights and reflexes	2,0%	3	0,06	3	0,06	2	0,04	3	0,06
Amount of maintenance	1,0%	3	0,03	3	0,03	2	0,02	3	0,03
Sturdiness(Construction)	1,0%	3	0,03	3	0,03	2	0,02	2	0,02
Reasonable wheel size	1,0%	3	0,03	3	0,03	2	0,02	2	0,02
Useability	21,0%								
(Un)folding	4,0%	2	0,08	2	0,08	3	0,12	1	0,04
Lifting	2,0%	3	0,06	3	0,06	2	0,04	1	0,02
(Un)packing goods	3,0%	3	0,09	3	0,09	3	0,09	3	0,09
Transportable folded	3,0%	4	0,12	4	0,12	3	0,09	1	0,03
Flexible enough to be used by everyone	2,0%	3	0,06	3	0,06	4	0,08	1	0,02
Easy to clean/wipe off	1,0%	3	0,03	3	0,03	2	0,02	4	0,04
Enable/disable "Drivläge"	1,0%	2	0,02	2	0,02	3	0,03	3	0,03
Easy to enable assistance in stairs (Forwards/Backwards in "Drivläge")	1,0%	2	0,02	2	0,02	3	0,03	3	0,03
Function triggers/mechanisms are easy located and initiated (no bending over etc.)	2,0%	4	0,08	3	0,06	3	0,06	1	0,02
Easy tiltable to enable stair transportation	1,0%	4	0,04	4	0,04	3	0,03	4	0,04
One hand operation, driving, folding, operating	1,0%	3	0,03	3	0,03	3	0,03	3	0,03
Safety	3,0%								
Protects from weather	2,0%	3	0,06	3	0,06	3	0,06	4	0,08
Protects from theft	1,0%	3	0,03	3	0,03	3	0,03	3	0,03
Ergonomics	13,0%								
Handle shape	2,0%	2	0,04	2	0,04	3	0,06	2	0,04
Handle length	3,0%	3	0,09	3	0,09	3	0,09	3	0,09
Handle placements	2,0%	4	0,08	4	0,08	3	0,06	1	0,02
Liftability (folded/unfolded)	2,0%	3	0,06	3	0,06	2	0,04	1	0,02
Controls placements	2,0%	2	0,04	3	0,06	3	0,06	3	0,06
Reachability (Handles, controls...)	2,0%	2	0,04	3	0,06	2	0,04	2	0,04
Electronics placement	6,0%								
Battery placement	2,0%	3	0,06	3	0,06	2	0,04	4	0,08
Cabling (folds, length)	1,0%	3	0,03	2	0,02	2	0,02	4	0,04
Sensors directivity	2,0%	4	0,08	4	0,08	3	0,06	4	0,08
Speaker directivety	1,0%	3	0,03	3	0,03	3	0,03	3	0,03
Mobility	10,0%								
Curbs up/down	2,0%	3	0,06	3	0,06	2	0,04	2	0,04
Indoors	2,0%	3	0,06	3	0,06	3	0,06	3	0,06
Outdoors	2,0%	3	0,06	3	0,06	2	0,04	2	0,04
Turning radius	1,0%	3	0,03	3	0,03	3	0,03	3	0,03
Stair assistance	3,0%	2	0,06	3	0,09	3	0,09	2	0,06
Durability	3,0%								
Longevity	3,0%	3	0,09	2	0,06	2	0,06	3	0,09
Capacity	8,0%								
Storage size	4,0%	3	0,12	3	0,12	2	0,08	3	0,12
Hot/Cold	1,0%	3	0,03	3	0,03	3	0,03	3	0,03
Storage relative to maximum dimensions	1,0%	3	0,03	3	0,03	2	0,02	3	0,03
Two grocery bags side by side	2,0%	3	0,06	3	0,06	2	0,04	3	0,06
Other	6,0%								
Manufacturability	3,0%	3	0,09	2	0,06	1	0,03	2	0,06
Appealing design	2,0%	4	0,08	4	0,08	3	0,06	3	0,06
Cost	1,0%	3	0,03	3	0,03	3	0,03	3	0,03
Sum %:	100%								
Sum %:	Total Score	2,97		2,99		2,44		2,43	
	Rank	2		1		3		4	
	Continue?	Yes		Yes		Yes		No	

Figure 5.38 Scoring selection of different concepts

As seen above in figure 5.38 Jacob and Eka II resulted with almost equal scores and since both concepts were built on similar ideas with some differences in details and sub-problem solutions. The team decided to move forward with them as one single concept where the differences could be applied as options when working with the detail design of the vehicle.

Fridrik ranked the lowest from the scoring method, with Thomas 2 having a total score which was very close to Fridrik. The discussion regarding ergonomics and usability was brought up again and since the vehicle is a user-centered product the team felt that Fridirik should be omitted due to the vehicle folding towards the ground and being more difficult to lift.

There were still uncertainties in how the concepts would perform when the vehicle would be realized as a physical product and not as a sketch. Therefore, new refined cardboard prototypes were built, without the middle wheel. The Thomas 2 concept can be seen in figure 5.39 and the Jacob and Eka II combined concept can be seen in figure 5.40.

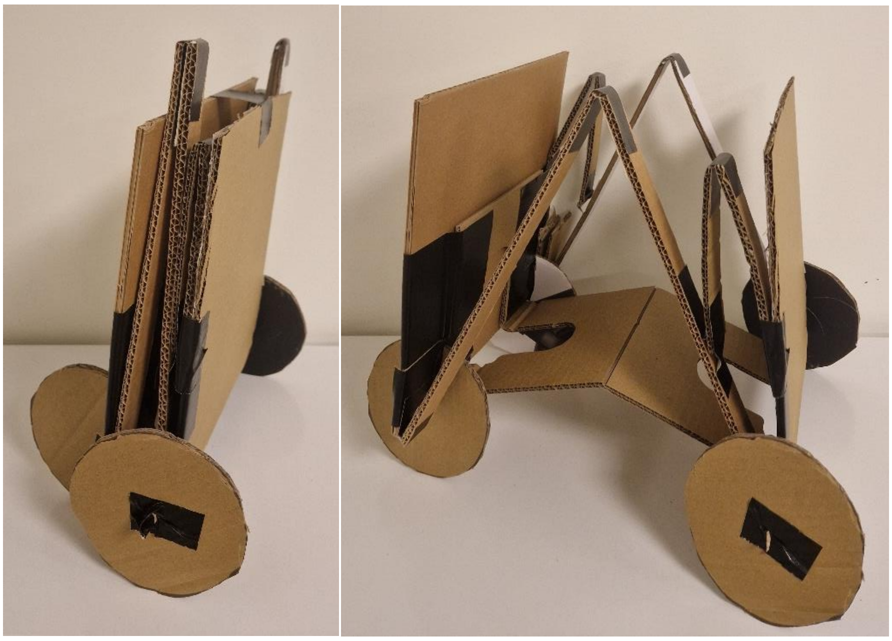

Figure 5.39 "Thomas 2" concept cardboard model

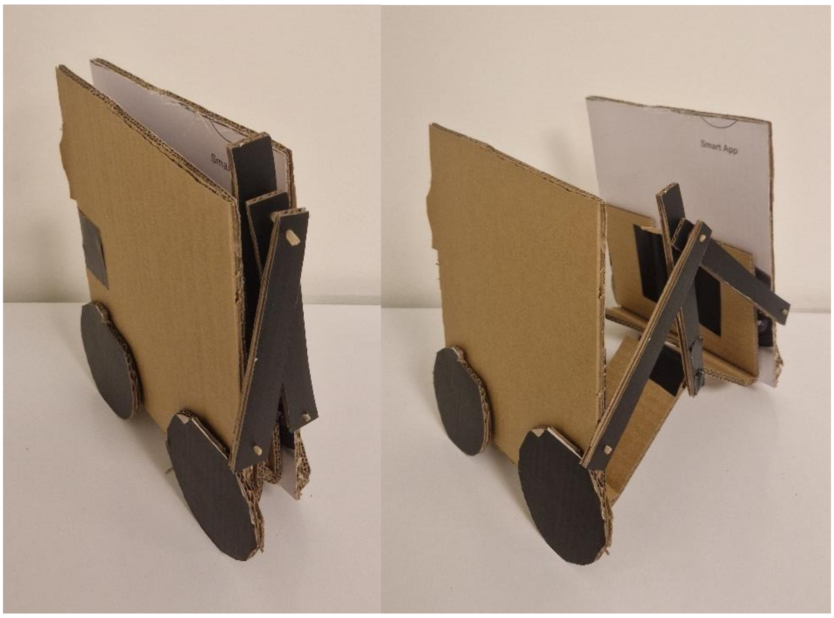

Figure 5.40 "Eka II" concept cardboard model

When constructing and evaluating the refined cardboard prototypes, it was obvious that the Thomas 2 concept required more supporting mechanical elements to keep the vehicle stable, both folded and unfolded. The combined concept folded completely flat with no protruding wheels which meant that the vehicle could be stored efficiently, both in homes and in other vehicles. The folding mechanism also felt more intuitive with fewer actions for the combined concept compared to the Thomas 2 concept.

The decision was made to continue development with the combined concept.

5.5 Concept Testing

The concept testing presented in 3.2.3.5 was not performed according to the presented method. A discussion was continually held with the supervisors at VCC about the different concepts generated during each cycle, to make sure that the requirements were met. Since VCC was the main stakeholder and the project had goals which were more related to performance and properties, focus was put on optimization and analysis in the detail design phase.

5.6 Plan Downstream Development

With the final concept chosen, future activities were planned out. The main activities required for the completion of the project:

- Selection of electronic components and packaging of these.
- 3D-CAD model of the vehicle
- Identification of critical part.
- Detail design and analysis of critical part.

Based on specifications and assumptive estimations on performance, calculations should be made to find the performance required for the vehicle. With these results, electronic components which performed according to the calculations could be found and implemented in the design of the vehicle.

A 3D-model of the vehicle needed to be developed to evaluate the size and functionality of mechanical parts.

Since the vehicle is a complex product with many different sub-systems and the project is limited, there would not be enough time to explore and focus on every part or sub-system during the detail design. The idea was to develop the final concept to the geometry specifications given by VCC and package the electronic components. When this would be finished, enough knowledge about the vehicle and it´s requirements would have been gained to decide on which part where additional development would be beneficial.

Production of the vehicle was not a focus for the project. An assumption was made that many of the parts could be produced with AM since the only production of vehicles would probably be prototypes or small-scale production for future work. This put less limitations on the detail design of parts due to the possibility to create complex geometry with 3DP.

6 Detail Design

In this section the detail design is presented. The detail design includes specification of geometry, material choices, electronic components selection and design regarding manufacturing processes.

6.1 Powertrain Selection

6.1.1 **Powertrain Calculations**

When setting up the powertrain calculations according to the theory presented in chapter 2.5, several assumptions were made to validate the choice of parameters.

- No wind speed, the aerodynamic force would only be affected by the speed of the vehicle.
- The density of air is taken at standard atmospheric pressure with a temperature of 20°C.
- The maximum weight of the vehicle is 30kg and the minimum weight is 10kg.
- Range calculations only consider set gradients and velocities. No consideration of acceleration is made.
- For range calculations, auxiliary electronics are assumed to have a combined power of 40 W.
- Wheels with a diameter of 200mm were chosen.
- The motors should be hub motors and there would be no need for a transmission. The transmission gear ratio k_{gear}, and transmission efficiency η_{gear} is set to 1.
- Top speed of 8 km/h.

6.1.1.1 Wheel Force & Motor Specifications

To find the tractive force of the wheels and the motor specifications the equations in chapter 2.5 were used. The tractive force could be found with equation 2.6 and the motor specifications with equation 2.9 and 2.10.

The density of air at the assumed conditions is equal to 1.204 kg/m^3 [28, p. 3]. Since the selected concept is shaped as a cube, the aerodynamic drag coefficient C_D is 1.05 [28, p. 32], with an effective frontal area A of 0.2773 m^2. The rolling resistance coefficient C_r is dependent on wheel specifications, an assumption was made that the wheels would perform more like a bicycle tire then a car tire due to the dimensions of the tire. The rolling resistance coefficient C_r was set to 0.008 based on the typical value of bicycle tires on a rough paved road [29]. These parameters are final for all calculations and are presented together with already set parameters in table 6.1.

Table 6.1 Set Parameters

Parameter	***Description***	***Value***	***Unit***
ρ	Air density	1.204	[kg/m^3]
C_D	Aerodynamic drag coefficient	1.05	-
A	Effective cross-sectional area	0.2773	[m^2]
C_r	Rolling resistance coefficient	0.008	-
g	Gravitational constant	9.81	[m/s^2]
r	Wheel radius	0.1	[m]
k_{gear}	Transmission gear ratio	1	-
η_{gear}	Transmission efficiency	1	-

The other parameters not presented in table 6.1 would be dependent on different scenarios. A fully loaded vehicle with a total weight of 30 kg was chosen since it would affect the torque required the most. The team chose three different scenarios to evaluate motor specifications:

1. Vehicle starting from standstill in a hill with a 15% gradient, with an acceleration of 3 m/s^2.
2. Consistent speed of 8 km/h (2.22 m/s), travelling on flat ground.
3. Travelling up a hill with a 15% gradient, with a constant speed of 5 km/h (1.39 m/s).

The gradient of 15% was chosen based on the steep walkable street in Gothenburg presented in 2.1.2, with a slight increase for even steeper conditions. The acceleration is based on reaching the top speed in one second which equals 2.22 m/s^2. This was increased to 3 m/s^2 to allow for even swifter changes in speed. The constant speed of 5 km/h in scenario 3 was set according to the mean value presented in 2.1.1 with an assumption that it would be slightly lower in incline. The varying parameters of each scenario and the results to equation 2.6, 2.9 and 2.10 are presented in table 6.2. The gradient of 15% is equivalent to an incline of 8.53°.

Table 6.2 Motor Specifications Calculation

Scenario		***1***	***2***	***3***
m	[kg]	30	30	30
v	[m/s]	0	2.78	1.39
$\frac{dv}{dt}$	[m/s^2]	3	0	0
α	Degrees	8.53	0	8.53
Result				
F_{wheel}	[N]	135.98	3.22	46.32
T_{EM}	[Nm]	13.60	0.32	4.63
η_{EM}	RPM	0	212.2	132.63

6.1.1.2 Energy Consumption

An approximative drive-cycle was set up to evaluate the mechanical energy consumed by the vehicle, to perform the sizing of the battery. The drive-cycle should show a potential scenario where a user walked with an empty vehicle to a location where the vehicle was loaded and then walking the same distance again. The drive-cycle can be divided into 4 steps, which are:

1. Weight of 10 kg travelling 5 km at a constant speed of 6 km/h (1.67 m/s) on flat ground.
2. Weight of 10 kg travelling 5 km at a constant speed of 5 km/h (1.39 m/s) up a hill with a 5% gradient.
3. Weight of 30 kg travelling 5 km at a constant speed of 6 km/h (1.67 m/s) on flat ground.
4. Weight of 30 kg travelling 5 km at a constant speed of 5 km/h (1.39 m/s) up a hill with a 5% gradient.

The set parameters from table 6.1 were used together with the parameters established in each step of the drive-cycle. The time of each step is derived from the distance of travel and the gradient of 5% is equivalent to an incline of 2.86°. Auxiliary electronics are assumed to be on all the time throughout the drive-cycle. The parameters and results to equation 2.6, 2.7 and 2.8 are presented in table 6.3.

Table 6.3 Energy Consumption

Step		*1*	*2*	*3*	*4*
m	[kg]	10	10	30	30
v	[m/s]	1.67	1.39	1.67	1.39
$\frac{dv}{dt}$	[m/s^2]	0	0	0	0
α	Degrees	0	2.86	0	2.86
t	[s]	3000	3600	3000	3600
Result					
F_{wheel}	[N]	1.27	6.02	2.84	17.39
P_{wheel}	[W]	2.12	8.36	4.74	24.15
E_{wheel}	[kJ]	6.36	30.1	14.21	86.93
P_{aux}	[W]	40	40	40	40
E_{aux}	[kJ]	120	144	120	144
E_{tot}	[kJ]	665.6			

The total energy consumed for the entire vehicle during the drive-cycle is calculated to be 665.6 kJ which is equivalent to 184.89 Wh. The calculation is assumed to be ideal, and no regard is taken to energy losses within the system.

6.1.2 **Powertrain Selection**

6.1.2.1 Motors

The motor found for the vehicle had a rated torque of 3 Nm, a peak torque of 9 Nm and a rated speed of 233 rpm. By utilizing two of these motors, the result in table 6.2 can be met since the results are total torque required. Two motors would give a rated torque of 6 Nm and a peak torque of 18 Nm. The rated speed is higher than the requirement, this can however be lowered by introducing a controller for speed control since the motor is a brushless DC electric motor (BLDC). The rated voltage for the motor is 24 V.

Additional benefits of the motors are a low weight of 368 g per motor and a small form factor, 79 mm in diameter and a thickness of 39.5 mm.

6.1.2.2 Battery

Selection of batteries was done by benchmarking different Li-ion cells. Since low weight was preferred, cells of the 21700 type was chosen due to having a higher energy density compared to the commonly used 18650 type. Specifications of the chosen battery is presented in table 6.4.

Table 6.4 Battery Specifications

Type	*Chemistry*	*Voltage*	*Capacity*	*Height*	*Diameter*	*Weight*
21700	Li-ion	3.6 V	4000 mAh	70.10 mm	21.00 mm	67 g

For the battery to match the rated voltage of the motor, seven batteries would have to be connected in series which would yield a battery voltage of 25.2 V.

The capacity of one series of batteries is 4000 mAh or 100.8 Wh, based on the voltage of 25.2 V. From the calculation of energy consumption in table 6.3, the required energy was calculated to 184.89 Wh. To meet this requirement, two series of seven cells would have to be connected in parallel, resulting in a total capacity of 201.6 Wh.

A total amount of 14 cells in a 7S2P configuration is required to meet the requirements of the powertrain. The total weight of the batteries would be 938 g.

6.2 Design of Vehicle

The final combined concept was refined with an additional prototype made of LEGO. By constructing the protype, which can be seen in figure 6.1, out of LEGO, the team got a better understanding of the mechanical interactions within the vehicle and how the folding mechanism would be initiated by a user.

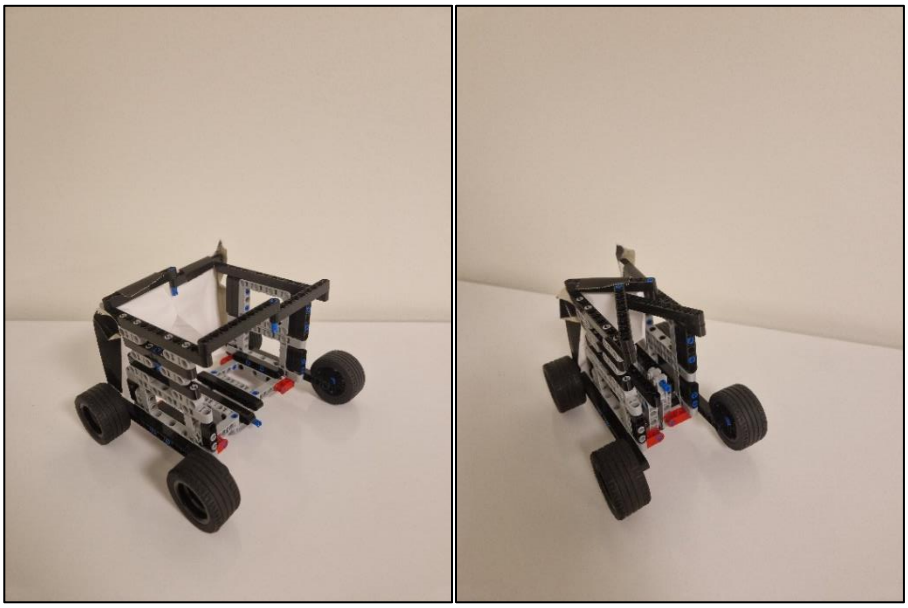

Figure 6.1 LEGO Prototype

6.2.1 **Wheels**

The wheels were chosen to be of two different kinds. For the front wheels regular air-less tires manufactured from TPU were chosen with a rim manufactured out of PLA. The back wheels were chosen to be omnidirectional wheels and are made from PLA rims with PLA small plastic wheels with a TPU outer layer for better traction and performance. The use of airless tires in the front will reduce maintenance of the vehicle, and the back omni-directional will also require less maintenance than using air-filled wheels. The omni-directional wheels were necessary to incorporate to enable a smooth driving experience when the vehicle is driven manually. The user will not have to tilt the vehicle to be able to turn it.

6.2.2 **Handle**

The handle was chosen to be split into two parts where one was a bit longer than the other. This was done to make the handle fit on each of the sides when the vehicle is in its folded state. When the vehicle is unfolded and in manual mode the handles can fold up and into each other for a continuous handle along the width of the vehicle. The handle also accommodates the controls for moving the vehicle both forwards and backwards.

6.2.3 **Folding mechanism**

The folding mechanism splits the vehicle in two on the width and therefore runs along the whole length of the vehicle. Therefore, it affects many different parts such as the handle, front and back wall, and bottom of the vehicle.

6.2.4 **Storage capacity**

The storage capacity is surrounded. The bottom and the sides are made from PLA. The front and back are made from a mix of both PLA on the upper half and textile on the bottom half to make the vehicle to be able to fold.

6.2.5 **Lid**

The lid is made from PLA in the outer edges to create stability when closing or opening the lid, and the rest is made from textile which is waterproof to make the storage weather protected.

6.2.6 Lifting handles

The lifting handles are integrated in the sides of the vehicle and is supported by the skeleton to be able to support the forces being generated when lifting the vehicle.

6.2.7 Speaker

The speakers are mounted in the skeleton and face outwards on the right and left side of the vehicle. The outer shell of the sides has holes that the sound can go through to make the speakers being able to sound without any obstruction.

6.2.8 Follow System

The following system of the vehicle will follow the user based on their phone. The user will have their phone in their pocket and the vehicle will follow the user with triangulation with the help of high frequency senders. This was found to be a cheap reliable solution with high precision.

6.2.9 Sensors (ADAS)

The sensors will be used as guidance for the vehicle together with the following system mentioned in 6.2.8. The sensors will determine distance to objects and the vehicle can try to maneuver around obstacles when it is in automatic following mode.

6.2.10 Motor Placement

The motors are placed on the skeleton which will be further explained in chapter 6.3 and connected to the front wheels. This is the best option due to that the vehicle will be in contact with the front wheels when lifting/driving it up the stairs. Since the motors are small, they will fit inside the wheels and almost act like hub-motors and will also be air-cooled due to being on the outside of the vehicle but with protection from the rims on the wheels.

6.2.11 Battery Placement

The batteries are placed in the bottom of the vehicle due to their weight; a lower center of gravity would improve the stability of the vehicle. Two groups of seven cells are connected in parallel, each group is placed diagonally relative to each other on respective side of the folding bottom parts. The placement is chosen because of a better weight distribution and heat dissipation.

6.3 Critical part

6.3.1 Identification of Critical Part

When the final concept was fully designed according to given specifications, with implementation of functions and electronics, an evaluation was made to find a part of the vehicle where additional development would improve the overall performance.

The most critical part found was the sides of the vehicles. Many of the electronic components were mounted to this part, which included the motor, lights, speaker, and sensors. There were also many interactions and interfaces with mechanical parts, such as the handle, lifting handle, folding panels, lid, wheels, and folding base. The critical part is illustrated as the transparent volume along the sides of the vehicle in figure 6.2 and figure 6.3. The critical part would be the main structural element of the vehicle and hence, stiffness was of great importance. The critical part was named skeleton due to structural importance and the many interactions with other parts. Reducing the weight of the skeleton and maximizing its stiffness would increase its performance, which TO would be an ideal candidate for. Together with reducing the number of parts by 3DP the part.

Figure 6.2 Transparent version of the vehicle when folded

Figure 6.3 Transparent version of the vehicle when semi-folded and with semi-raised handles

6.3.2 Topology optimization of Skeleton

The following steps are made to perform the topology optimization.

- *Define design space*
- *Define non-design space*
- *Define boundary conditions*
- *Define constraints and objectives*
- *Define optimization settings*
- *Solve*
- *Interpret the results*
- *Validate*

The project had a clear statement of doing a structural analysis on critical parts or part. The most critical part that would affect weight, stiffness, cargo space, manufacturability and assemblability was found to be the skeleton. The outer dimensions of the micro-haulage vehicle were already set from the beginning with availability to some adjustment. The goal from of putting two regular sized paper bags inside the cargo space set a base measurement for the measurements needed. This led to a design space between the outer walls and the inner walls that the skeleton should fit into. In this space there should also be the lights, sensors, speaker, handle placement and all the wires between for example the motors up to the control unit and battery in the bottom of the vehicle. From this information a design space was found and with this design space a 3D-model in Catia V5 was made.

The next step in designing the skeleton was setting up the forces that acted on the skeleton in different scenarios. This can be seen in table 6.1 below. During all the scenarios the boundary condition are fixed in all directions on the wheels. The bearing forces are based on a cargo weight plus the vehicle weight of 30KG.

Table 6.4 Forces and their direction in the XYZ-plane

Force's location	***Lift in lift handle (N)***	***Push on handle (N)***	***Lift in handle (N)***	***Side load (N)***	***Reaction force middle wheel stairs (N)***	***Weight on folding wall front (N)***	***Weight on folding wall back (N)***
Bottom mounting hole	-62.5 in Z-direction bearing load for each hole	-62.5 in Z-direction bearing load for each hole	-62.5 in Z-direction bearing load for each hole	-62.5 in Z-direction bearing load for each hole	-62.5 in Z-direction bearing load for each hole	-62.5 in Z-direction bearing load for each hole	-62.5 in Z-direction bearing load for each hole
Driving handle		100 in aluminum pipe X-direction	200 in X-direction and 350 in Z-direction	300 in 45-degree angle between X- and Y-direction			
Front and back jalousie mounting point						-100 in Z-direction for each hole	-100 in Z-direction for each hole
Side handle	-200 in Z-direction						
Reaction force middle wheel in stairs					200 in 70-degree angle from X-plane		

There were also requirements of how much deflection could be allowed before the skeleton and the whole vehicle would move to much during load so that it would feel unsafe or cheap even though it didn't break during these loads. These deflections will be mentioned in chapter 7. The limits are set in such a way that the mountings of the different parts don't release and become loose after sustaining the different load cases.

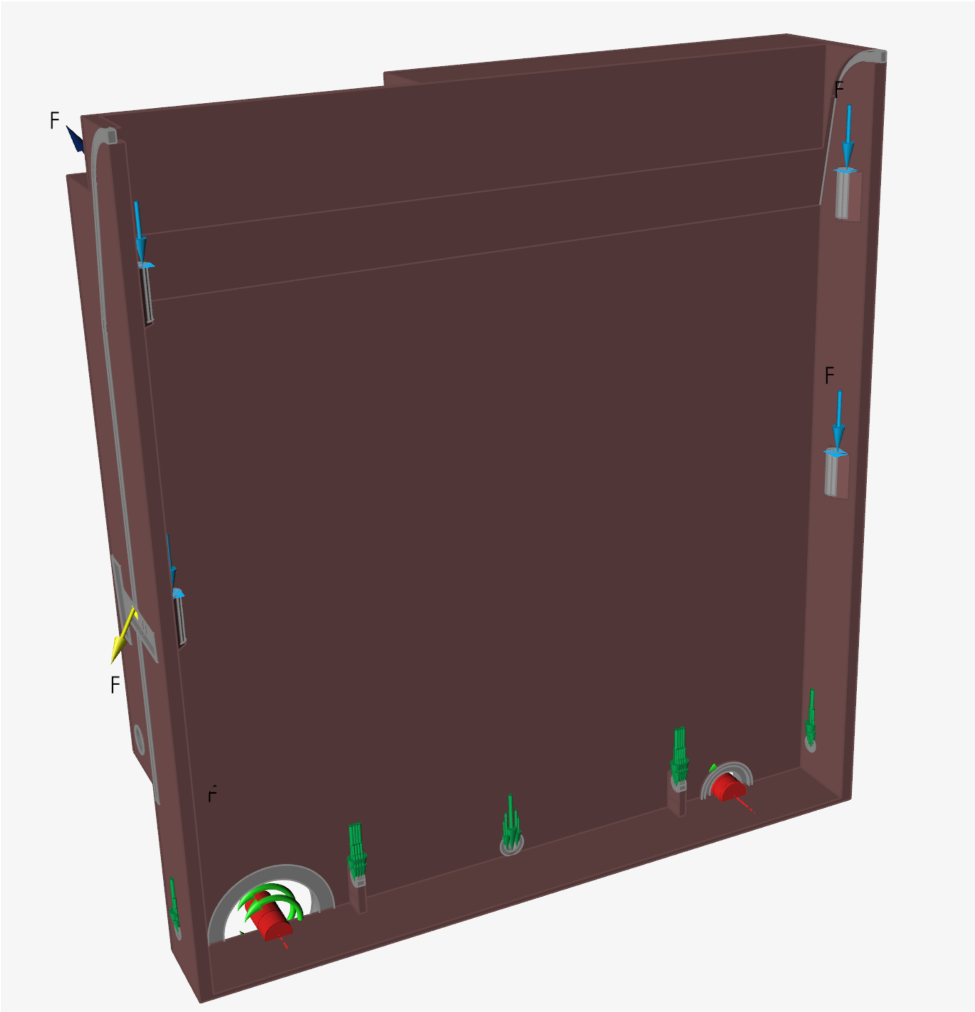

Figure 6.4 Inside View of Boundary Conditions

In figure 6.4 above the blue arrows correspond to the weight on the folding walls, green arrows to the bearing loads, yellow arrows to the forces implied by gravity from the accessories such as the lights and ultrasonic sensors. Where the wheels are mounted the supports are in most cases rigid, but for the load case when moving the vehicle up a staircase the front support can rotate around the Z-axis.

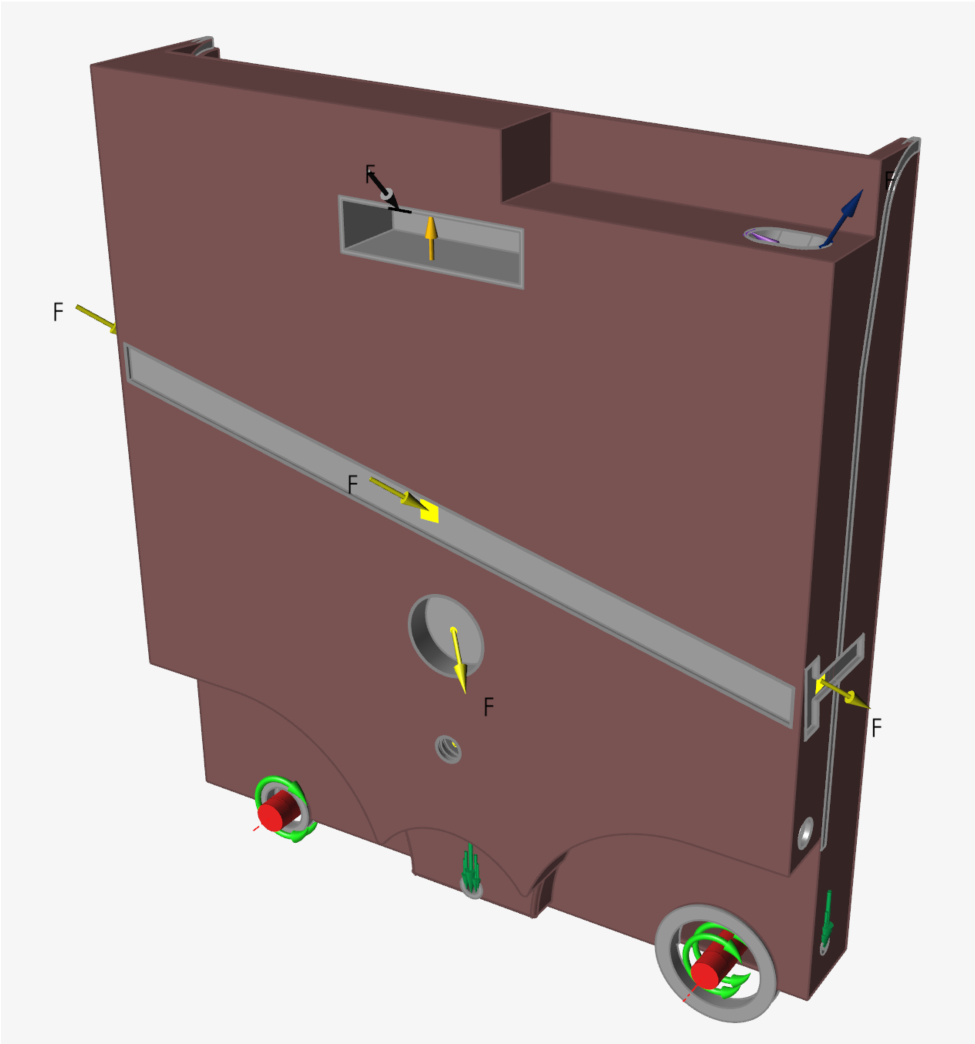

Figure 6.5 Outside View of Boundary Conditions

In figure 6.5 the black arrow on the side handle corresponds with the side forces, the orange arrow with the lifting force on the lift handle, the yellow arrows to the forces implied by gravity from the accessories such as the lights and ultrasonic sensors, the purple arrow to the push on handle force, and the dark blue arrow to the lift in handle force.

Table 6.5 Maximum deflection on different parts on the final version

Deflection's location	*All load cases (mm)*
Top of skeleton at jalousie	<8
Mounting point for front light	<1
Mounting point for back light	<1
Mounting points for side lightbar	<1
Mounting point for sensors	<1

With the help of Altair Inspire a design space with all the different forces acting on the skeleton was made. By using topology-optimization and iterating and improving different parameters inside the program a final design was found. The materials in the topology optimization were T6 Aluminum for the pipe and the Nylon 12 GF for the rest of the part. The objective was to maximize stiffness and find the best possible solution at 10% weight of the original design space.

The design was then exported as an .STL file into Catia V5 where the work of doing a parametric skeleton with the .STL file as a baseline was made.

When the parametric version was finalized, it was again put into Altair Inspire and a structural analysis was run to verify that the structure had the right stiffness and met the requirements set from the beginning. The weight of the final version compared to the design space was decreased by 88%.

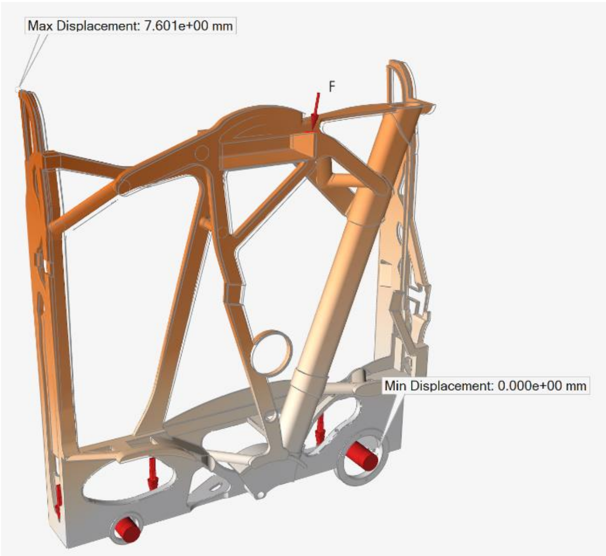

Figure 6.6 Maximum displacement of side load

As seen in figure 6.6 above the side load induces 7.6mm of displacement and is therefore the worst-case scenario for the skeleton and vehicle.

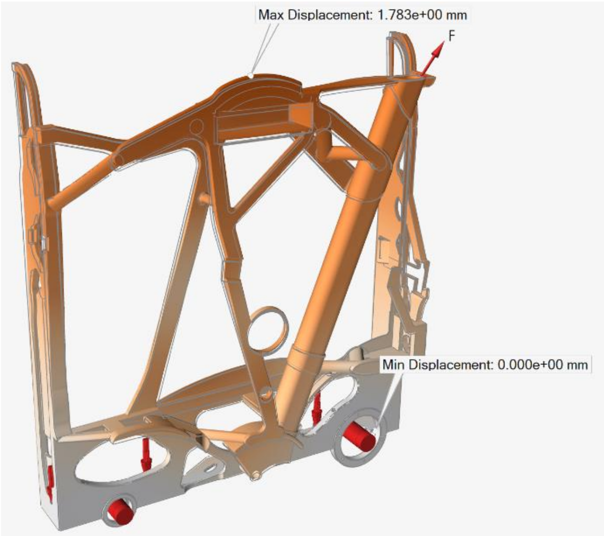

Figure 6.7 Maximum displacement of pulling on handle

As seen in figure 6.7 above pulling on the handle only induces a displacement of 1.8mm.

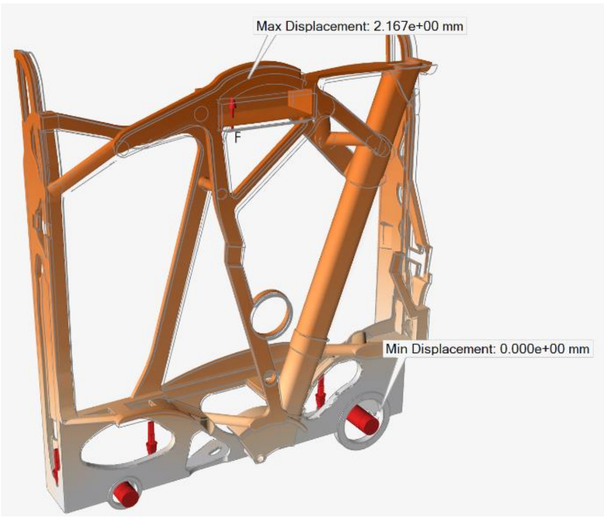

Figure 6.7 Maximum displacement of lifting on lift handle

As seen in figure 6.7 above lifting on the lift handle only induces a displacement of 2.2mm.

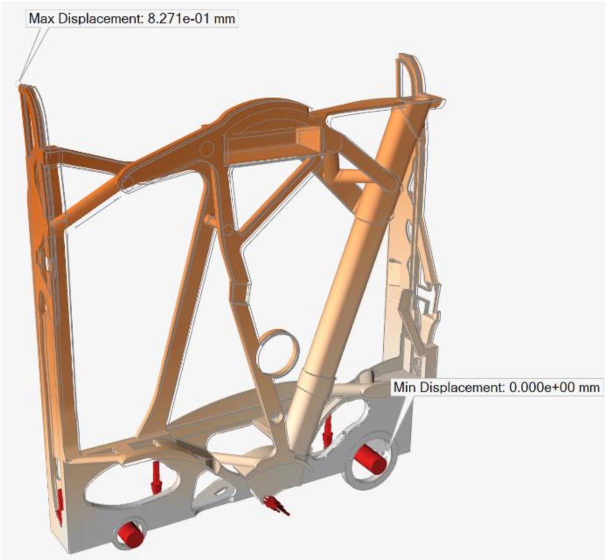

Figure 6.8 Maximum displacement of Reaction force middle wheel stairs

As seen in figure 6.8 above, moving the vehicle over stairs on in a staircase only induces a maximum displacement of 0.8mm.

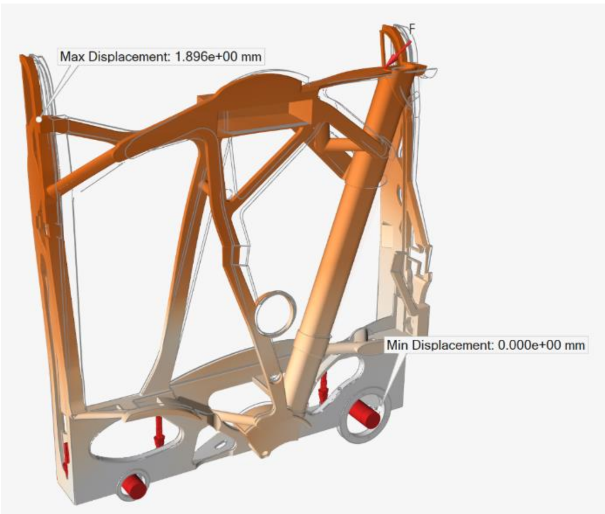

Figure 6.9 Maximum displacement of pushing on handle

As seen above in figure 6.9 a maximum displacement of 1.9mm occurs at the back of the skeleton.

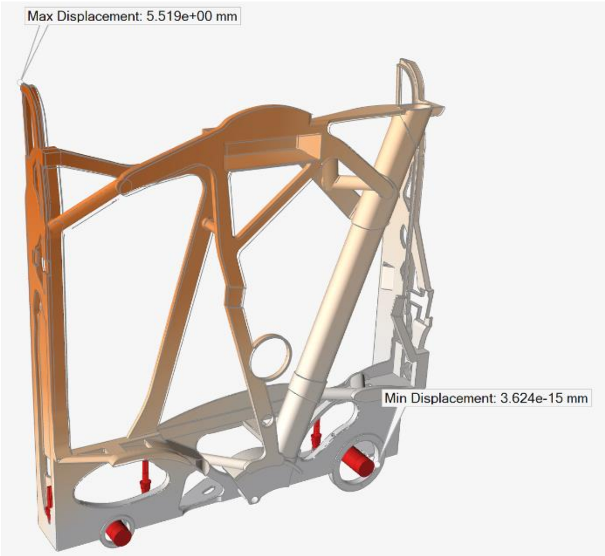

Figure 6.10 Maximum displacement of weight on the back folding wall

As seen above in figure 6.10 the maximum displacement is 5.5mm when putting the weight on the back folding wall.

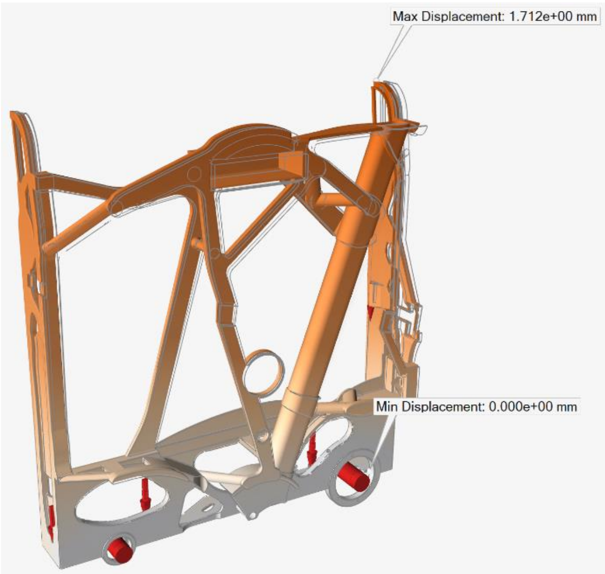

Figure 6.10 Maximum displacement of weight on folding wall front

As seen above in figure 6.10 a maximum displacement of 1.7mm occurs at the front top of the skeleton.

7 Results

7.1 Final design

The final version of the micro-haulage vehicle can be seen in Figure 7.1-7.4 below.

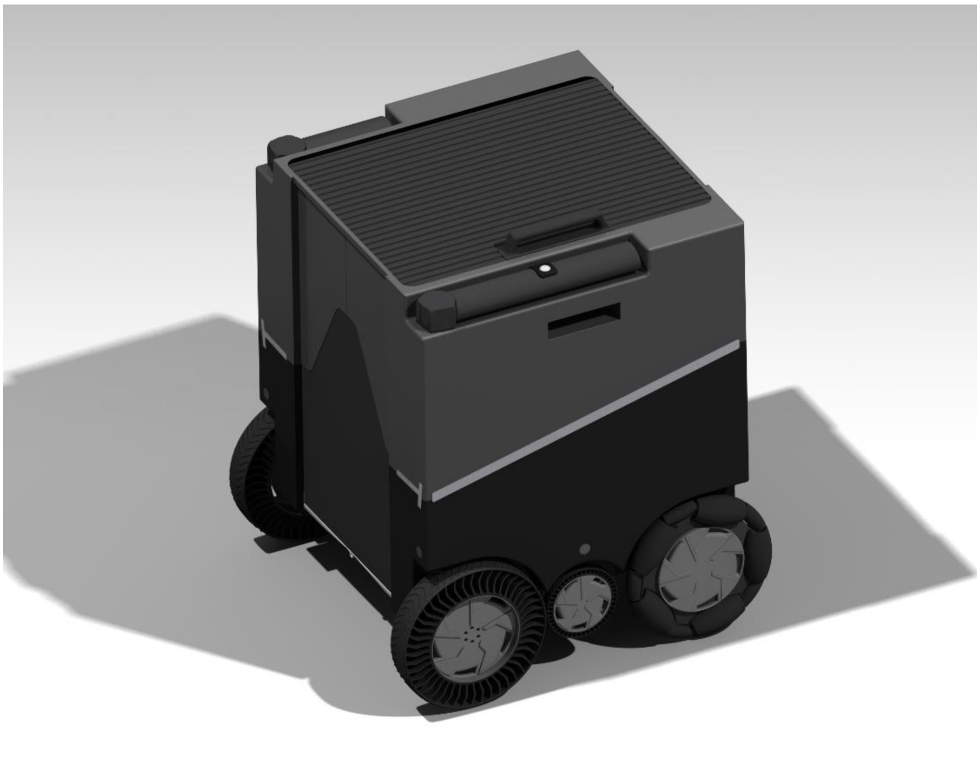

Figure 7.1 Final version of the micro haulage vehicle

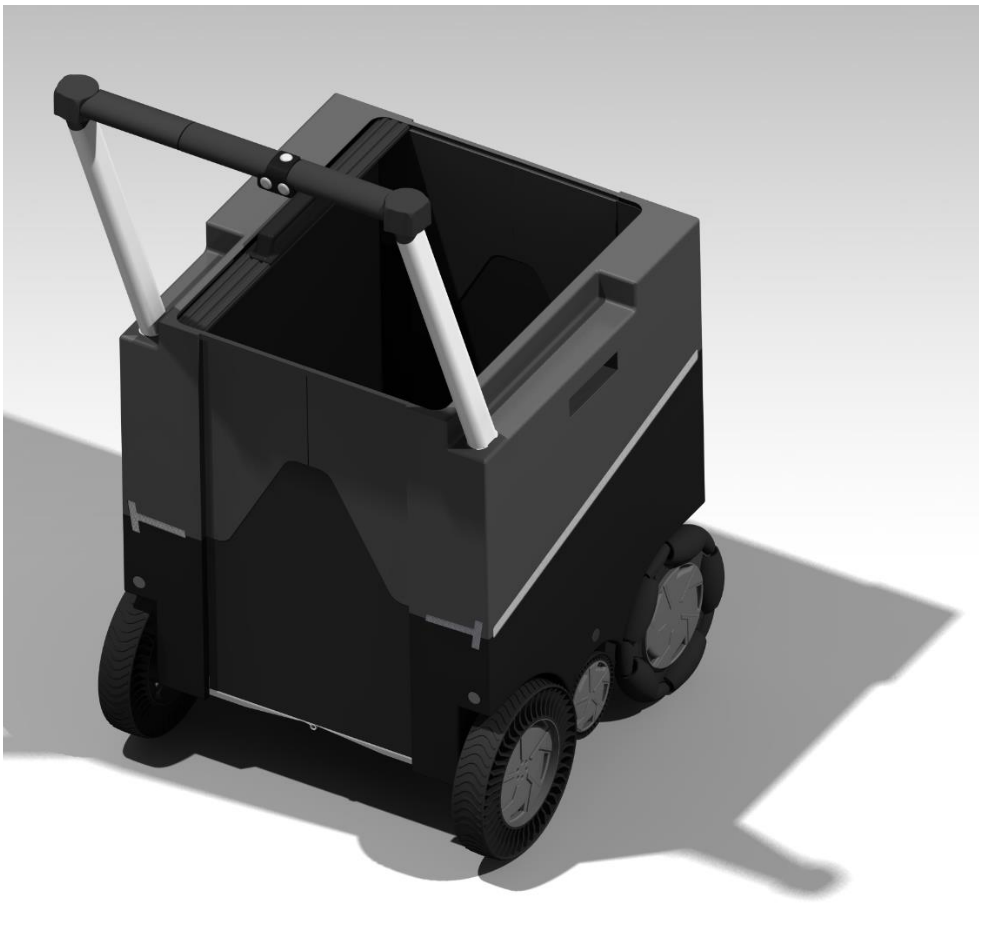

Figure 7.2 Final version of the micro-haulage vehicle

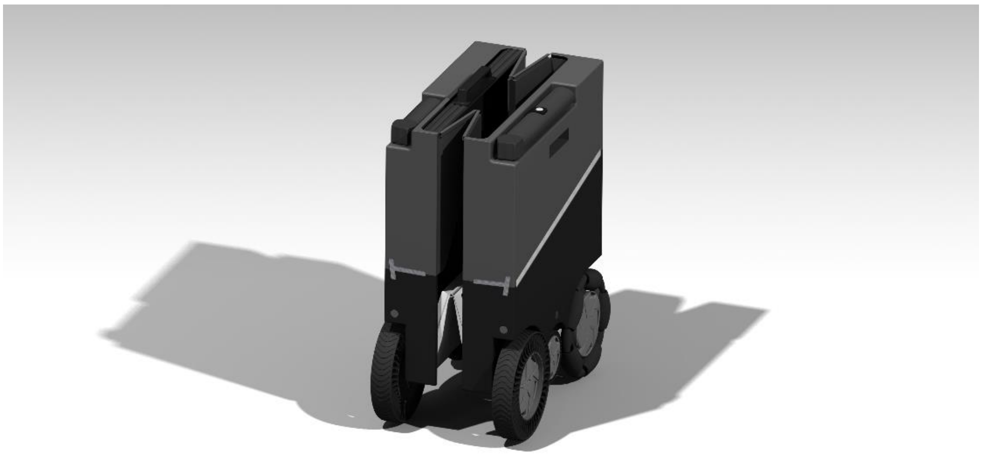

Figure 7.3 Final version of the micro haulage vehicle

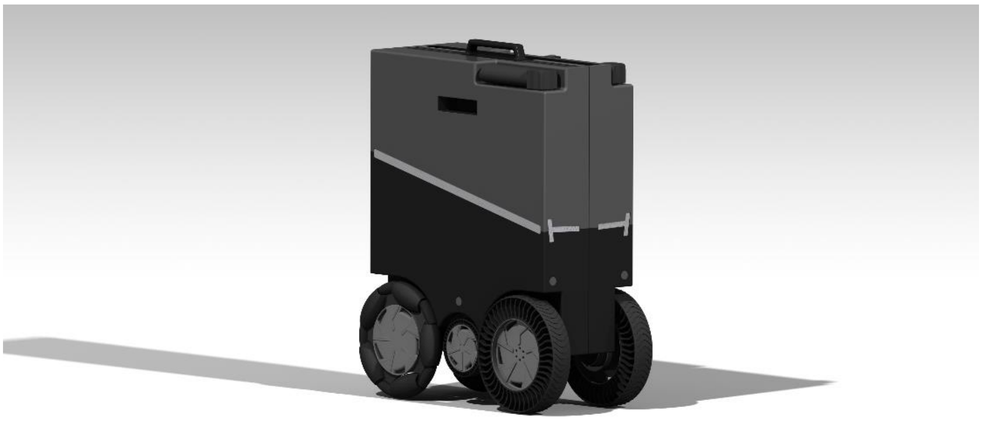

Figure 7.4 Final version of the micro haulage vehicle

A final prototype for the folding mechanism was made to clearly illustrate the main structural parts and their relative motion. The prototype can be seen unfolded in figure 7.5 and folded in figure 7.6.

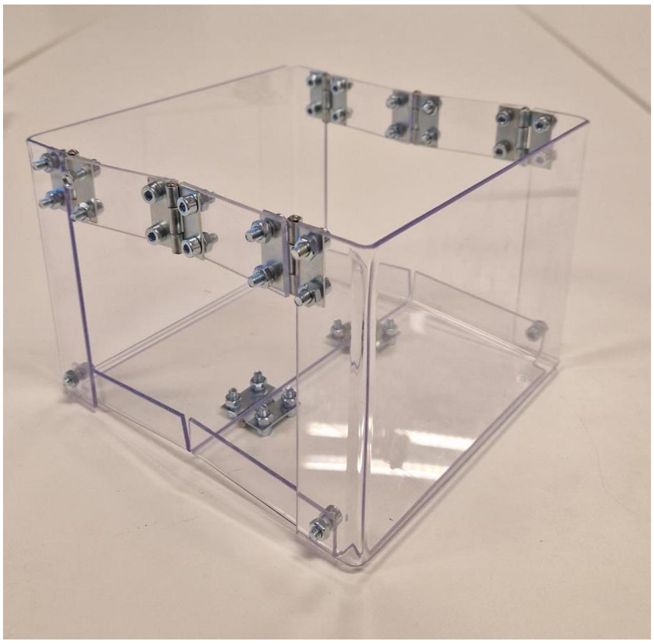

Figure 7.5 Unfolded Prototype

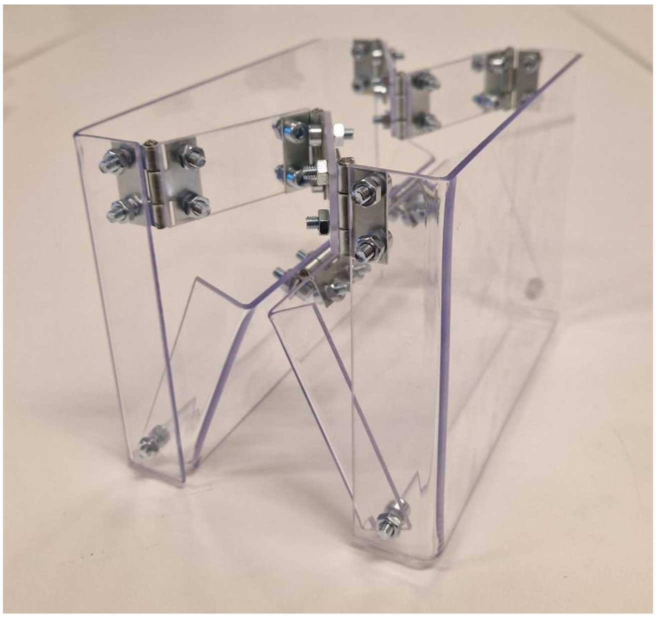

Figure 7.6 Folded Prototype

7.2 Final Specifications

The vehicle's final specifications are of great importance for the success of the project and therefore they have been finetuned all throughout the project.

7.2.1 **Range**

The total energy consumed, both mechanical and auxiliary, for the vehicle during the presented drive-cycle was 184.89 Wh. The total range for the drive-cycle was 20 km with some variations in terrain and weight. To achieve the energy requirement, 21700 Li-ion cells in a 7S2P configuration is used with a total capacity of 201.6 Wh.

7.2.2 **Electrical motors**

The electrical motors were chosen early in the project when the specifications of the maximum weight and speed of the vehicle was set. This was made to know what design space was left to work with and where to place the motors so that all the other parts could fit in the vehicle. The solution was chosen to be two electrical motors from with a weight of 368g each. The motors are planetary gear motors with a rated torque of 3 Nm with a peak torque of 9 Nm for each motor. The calculations shown in chapter 6.1.1 shows that the maximum torque needed is 14 Nm.

7.2.3 **Ultrasonic sensors**

The sensors were chosen to maintain a safe distance to objects and should be able to detect objects on many various distances. These sensors can detect objects from 15cm to 5.5m with a horizontal angle detection zone of +-70 degrees and vertical detection zone of +-35 degrees. Four of these sensors are located around the vehicle to detect objects around the vehicle both when stationary, so it knows what to avoid when initiating movement, and when moving.

7.2.4 **Ultra-wide band**

To follow the user, two ultra-wide band receivers are installed on the vehicle. These are connected to the user's mobile phone which take this information and sends back information about the position the user is at compared to the two devices on the vehicle to triangulate the user's position. This makes the vehicle know what direction the user is and makes it possible that the vehicle can follow the person at a specified distance, for example 50cm.

7.2.5 **Size and weight of Micro-Haulage Vehicle**

The final size of the vehicle was chosen from the beginning but with some room for either decreasing or increasing the size. The final size of the outer dimensions of the vehicle came out to be 585mm in height, 475mm in width and 520mm in length. The inner dimensions of the compartment that can be filled with luggage, groceries etc. came out to be 450mm in height, 350mm in width and 430 in length. This adds up to a total packing volume of 67.7 Liters. The outer volume adds up to 144.4 Liters which gives give the packable volume in reference to the total outer volume to be 46%. The total weight of the vehicle adds up to be 9.2 kilograms with a maximum packing weight of 20.8 kilograms.

7.2.6 **Lights**

To ensure safety while maneuvering the vehicle on the sidewalks, the vehicle must be equipped with appropriate lighting. This means the vehicle has a comprehensive lighting setup, featuring front-lights, back-lights, and a subtle light-bar on the side. The front and back-lights serve a dual purpose, with both red and white lights that change depending on if the vehicle is in automatic or manual mode. The side light-bar emits a soft white glow, effectively warning and cautioning pedestrians and others in the vicinity.

7.2.7 **Speaker**

A speaker was chosen to be put on two of the sides of the vehicle. The speaker can be used to inform the user of the product in case the vehicle gets stuck, and the user doesn’t notice. The speaker is also a good function to locate the vehicle in case of losing sight of it when parked. The final use case of the speaker is as a theft-alarm. If the vehicle is lifted or moved when put in “park”, the speakers will emit a loud alarm-sound so that either the owner or someone around will notice it and therefore scare away the thief.

7.2.8 **Lid**

A lid was used to make the cargo compartment closable. It is used as a lid that will help with stiffness of the whole vehicle when in closed position, as weather protection and theft protection. The lid is made with plastic HDPE in the hinges and a soft cloth that is water resistant in the middle to ensure a lightweight construction and to also inform the users that it can’t be sat on since it is only a thin cloth.

7.2.9 Manufacturing techniques

Most of the parts in the low-production run in the beginning will be printed using a 3DP. This is to allow for future development after the first working prototypes have been made. The printing process is also a quick way to verify if the product works, looks ecstatically pleasing and to see that the vehicle can be put together in a manufacturing line.

In the future an investment in tools for injection-molding can be made on parts that are possible to manufacture in such a way. The parts that could be injection molded are the wheels, bottom, all the outer shells, handles and the front and back of the vehicle.

7.2.10 Material choices

The materials chosen, have been different on various parts to meet requirements in weight, stiffness, and manufacturability. The outer shell will be printed in PLA the low-production run but can be injection molded in the future when an investment in tools for the specific part can be feasible. The HDPE meets the requirement for finish, weight and stiffness which makes it a perfect choice for the outer parts. The battery casing/bottom of the vehicle have also been chosen to be in plastic. The skeleton of the vehicle needs to be printed and therefore a special printing material called Nylon 12 GF was chosen. This material has great properties for printing and meets the requirements for both strength and stiffness. The wheel-rims will be 3DP in PLA for the low production run but can be manufactured using injection molding in the future. The handle-pole that is inside of the sides will be in aluminum with a T6 grading. The reason for going with aluminum is because of its strength to weight ratio and to give strength to the skeleton to increase the stiffness and durability of the skeleton. The wheels will be made using a TPU material since it need to be printed in the low-production run. The TPU material is a softer rubber-like material that will flex under pressure and therefore work great as wheels and dampening of the vehicle. In the future this can be made in some sort of rubber material to use injection molding.

7.2.11 Controller unit

Because of the different systems in the vehicle a control unit is needed. This unit will interconnect the motors, ultrasonic sensors, high frequency sensors and battery management system. This will ensure all the different electrical components have the right data from the right source to take decisions when for example the vehicle is moving or when to activate the theft system.

7.3 Topology Optimization Result

The final version of the skeleton was found after using Altair Inspire by doing a topology optimization. The final version was then put into Catia V5 where the final design was made and parametrized. The final version can be seen down below in figure 7.5.

In chapter 6 the deformation results from the final version of the skeleton can be seen. The worst-case scenario is the load case where there is a load on the side of the vehicle. This induces a maximum deflection of 7.6mm. The other load cases have maximum deformation less than 2.3mm except the back folding wall load which generates 5.5mm of maximum displacement. The reason the back folding wall has more deflection than when pushing with the same force on the front folding wall is because the front of the skeleton is more stable since it has the aluminum extrusion in the front. The total weight reduction of the skeleton, accomplished with the TO was 88%.

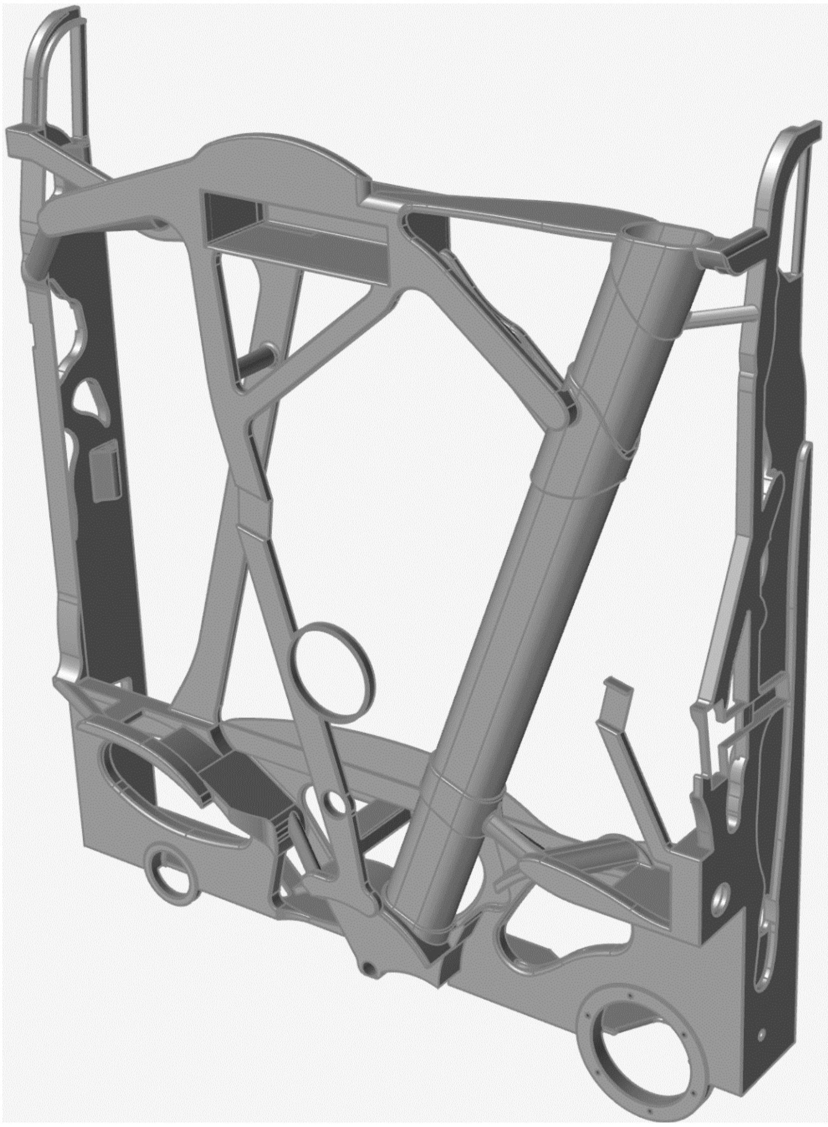

Figure 7.5 Final version of skeleton with aluminum extrusion for the handle

A 3DP small scale protype used for visualization of the final version of the skeleton and some of the components was printed in PLA. The PLA prototype can be seen in figure 7.6 and 7.7.

Figure 7.6 PLA Prototype of Skeleton – Front View

Figure 7.7 PLA Prototype of Skeleton – Back View

8 Discussion

In this section a discussion is made on the final design and its performance relative to the specifications and requirements set by VCC. The overall product development process is also discussed and the possibilities of future work.

8.1 Final Design

The final design of the vehicle is in some ways a little bit bulky and boxy. This doesn't go with other Volvo products and can therefore be a lot more refined to fit into the portfolio of Volvo products. Although, because the design is boxy it has a great cargo volume to total volume which is what was sought for. The reason for not developing the design further was a lack of time in the end of the project and because the projects description didn't have a pleasing design in the requirements.

A further investigation into making all the different parts more modular can also be done. The rims for the back wheels and front wheels can be the same with a bit of work. The inner plastic parts on the right and left side of the vehicle should also be possible to make the same with some clever engineering and investigation. These two ideas save at least two injection molding tools which means a saving in manufacturing cost and eventually higher margin or lower price for the consumer.

8.2 Project Goals

The problem questions presented in 1.3.2 are:

1. How can the vehicle meet the size requirements and be sturdy enough while at the same time be lightweight and foldable?
2. Is it possible to achieve fewer number of parts by using specific material properties to enable functionality? Is additive manufacturing (AM) a solution to achieve this?
3. While complying with other requirements such as size, foldability, and functionality, how can the vehicle enable and ensure optimal usability?

4. Due to being motorized, how can electronic components be included and packaged to still meet space requirements and achieve optimal performance?

8.2.1 Problem Question 1

Based on the delimitations of the project and how the team decided to proceed with detail design which focused mainly on the skeleton, a lightweight and foldable solution was found. The order in which the team decided to work, was very beneficial, where a concept which focused on functions was established first. This meant that the team could comply with size and foldability requirements first and then focus on optimization. Using TO and structural analysis the result received indicates that stiffness requirements were met and at the same time a substantial reduction in weight was received.

These results are very dependent on the boundary conditions when performing the optimization and analysis. At this time the team is satisfied with the result based on how the boundary conditions was set up. With additional work or if established standards for these kinds of vehicles were available, alterative boundary conditions could be evaluated and an even stiffer solution could be found. The parametric re-model of the skeleton also affects the result and since the skeleton part is very complex, a lot of time was required to generate a parametric model. If there would be more time, alternatives to the model could also be evaluated better, for a part with a higher performance.

The low weight of the vehicle is mainly because of the material choices, which primarily are polymers. Since AM was chosen and the skeleton part was very complex and large, polymers were the best alternative regarding support structures during manufacturing. If there was more time, alternative materials could also be evaluated which in turn would affect performance and properties.

The team is satisfied with their result within the time frame they had and since they had a very extensive generation and selection phase, they believe that the result they have found is the best they could accomplish within the scope of the project.

8.2.2 Problem Question 2

The team is happy with the construction of the skeleton since it became the main part of the vehicle, where several components could be mounted directly to the part. This would not be possible with another manufacturing method besides AM if the optimized and low weight skeleton should be used.

Regarding functionality, AM could be used to print the entire structure in its folded state which would eliminate hinges or similar parts which enable the folding mechanism currently. This would require more time, to be able to test the precision and tolerances of each folding axis. More structural analysis would also be necessary to evaluate dimensions of the folding axes. Since the project was limited and the team did not go into detail design of these areas, they are recommended as potential future work if the project would continue.

8.2.3 **Problem Question 3**

Overall, the vehicle complies with the requirements and constraints set by VCC and the team is happy with the generated result. It would however be of interest to build a complete fully functioning prototype so the vehicle could be physically tested, both in performance aspects such as motor strength and range of the vehicle and in how well the product performs in the hands of a user. Right now, only small-scale prototypes of the vehicle are made, and the testing can only be applied on these. Even though the prototypes illustrate the folding motion well, a full-scale model would better show how a user would interact with the product and if the presented concept could ensure optimal usability. Decisions made throughout the project are all made with the user in mind and the team have tried to be very thorough when evaluating prototypes and ideas. There could still be a bias from the team regarding how the product should or could be used based on their own experiences but with a complex product and limited time, questions like these are difficult to evaluate before a fully working prototype can be tested.

8.2.4 **Problem Question 4**

Smaller electronic components are all placed on the outside perimeter of the skeleton which enables the storage capacity to be as large as possible. The same thing is applied to the motor and battery, where in-wheel motors was the best choice to not take up space from the rest of the design. The battery is placed in the bottom compartment where other electronic components such as controller and charging unit also can be placed. All these decisions enable the storage capacity to be as large as possible and avoid any hindrances when the user is packing or unpacking.

Based on the calculations performed, optimal performance is achieved. Calculations regarding the specifications of the motors have less uncertainties than those made for the energy consumption, based on the assumptions made. The motors chosen performs better than what was required from the calculations which gives an area of safety if there are any losses within the system. The energy consumption calculations are only assumptive and are highly dependent on auxiliary electronics and the real drive-cycle. Since acceleration consumes the most energy, the calculated drive-cycle might not be enough and there is no regard in how the real terrain would affect the performance of the vehicle. To get a better understanding of the auxiliary components, additional development of the electronics would have to be made. A test environment could be set up to simulate the motors and auxiliary electronics which would lead to a better estimation of energy consumption before a complete prototype is made and tested. Since this was outside of the scope of the project, the team is satisfied with the results they received. For future work, if there would be a need for a larger battery, the bottom compartment could be made a little bit bigger to allow additional batteries in parallel, in each quadrant of the bottom compartment while keeping the storage space the same size.

8.3 Choice of Method

Choosing to follow U&E product development method worked well for the project. The authors knowledge of the method from previous courses deemed to be very useful and helped the team to follow the process instead of trying to understand the process that was used.

8.4 Future Work

For the vehicle to be successful a more cost-effective manufacturing will need to be done. The parts that are 3DP in the first-production run will have a high manufacturing cost and many of them could be done using injection molding instead. A thorough cost breakdown on what parts is cheaper and more cost effective to do in other ways than 3DP is therefore necessary.

8.5 Thermal Analysis

A thermal analysis should have been great to have since both the motors, batteries and the controller of the vehicle will generate heat. Since they are in a closed compartment this will generate heat that can only be extracted from the compartments via thin plastic. The battery will generate heat both when under load and during charging, the motors will generate heat when under movement and especially if it’s going slow in an uphill in a warm climate. If there was more time to do so, a thermal analysis could have been done to show whether an active cooling solution was needed such as s fan.

8.6 Structural Analysis

The structural analysis made in Altair Inspire is the best the writers could do. The setup of the forces and reaction forces were made after discussion with the supervisor where the conclusion was that 100% realism could not be met with the optimization we had chosen. For example, the reaction forces will spread throughout the entire vehicle but the writer's setup in Altair Inspire is done in such a way to simplify the reaction forces to reassemble a rigid structure for some forces. This is a delimitation due to the complexity of making the whole vehicle in Altair inspire and instead just doing it on the skeleton itself. The deformation is also not 100% realistic since only the skeleton is tested and not the whole vehicle. Testing the whole vehicle would take too much time and therefore the tests are simplified with the best possible knowledge from the authors.

The rubber wheels could also have been structurally tested since the dimensions of the ribs inside the air free wheels are of great importance of how the vehicle will behave during use. Too small dimension on the ribs will make the wheels compress too much and therefore lose energy when moving due to the force it takes to compress the wheels. Too big dimensions will result in that the vehicle doesn't have any dampening which can make the vehicle bumpy when traveling over a surface that's not flat, for example cobblestones.

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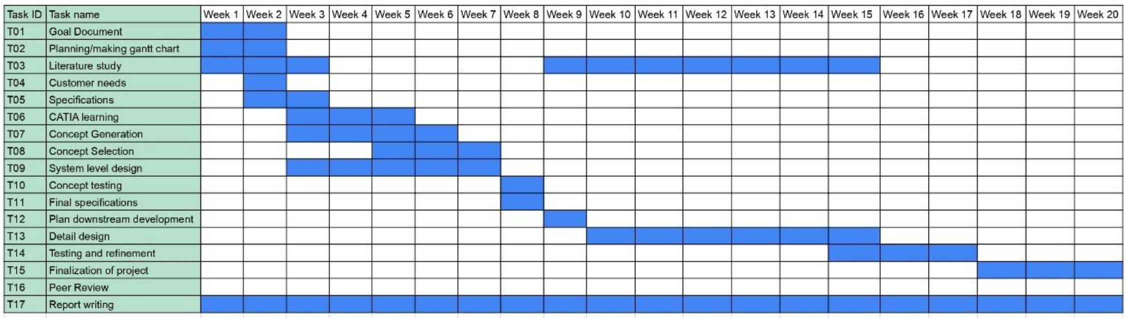
Appendix A

A.1 Work Distribution

During this project the authors have performed all activities together. The only part of the project which was divided between the students were the modelling of different parts in CAD. Decisions and evaluations have been performed together as a team and writing of the report was divided equally between the authors.

A.2 Time Planning

Initial plan:



Actual plan: