The re-design of an electrical three-wheeler vehicle

Development of an exterior body for a three-wheeler

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

This report presents a master's thesis project from January 2024 to September 2024. The thesis focuses on developing a new exterior body design for an electric 3-wheeler. OMotion AB is an innovative startup focused on sustainable mobility solutions through electric vehicles (EVs). The company aims to develop a more efficient version of its EVs to capture the growing market demand for environmentally friendly transportation. The primary objective of this project is to create an efficient and aesthetically appealing exterior body design that aligns with the company's vision and production capabilities.

The exterior body design of an electric vehicle plays an important role in reducing drag, improving range, and ensuring user appeal. This project considered several factors such as aerodynamics, manufacturability, structural integrity, and visual appeal. Additionally, the company is a startup with limited capital, so the design process was constrained to minimize changes to the core components, ensuring compatibility within existing manufacturing setups and cost efficiency.

The product development process for the new exterior body concept began with market, legal requirements and customer research, both internally and externally. Ideas were generated based on the research findings, followed by iterative concept development using advanced 3D modeling tools such as NX and Alias. The concepts were then refined and evaluated. Aerodynamic simulations were conducted using STAR-CCM+ to assess design efficiency, and high-quality visualizations were produced using VRED to evaluate the aesthetic appeal of the final concepts.

Throughout the detailed design phase, legal requirements and manufacturing guidelines were followed to ensure feasibility and alignment with the company's production capabilities. Despite the challenges of working within specific constraints, the final exterior body concepts developed through this thesis serve as a valuable foundation for future development.

Although this project provides a comprehensive design solution for the exterior body of the new electric vehicle, further research and development are required to fully optimize the design for large-scale production. However, the outcomes of this thesis will serve as a critical reference for OMotion's Research & Development team as they work to bring this innovative vehicle to market.

Keywords CAD, Surfacing modelling, Exterior body design, concept design and development, DFMA, CAE.

Acknowledgements

Working this thesis on a redesign car's exterior has been very enlightening. We delved into the intricacies of design and consumer preference in cars. We are grateful for the opportunity to have learnt so much about this exciting area of study.

We would like to extend our heartfelt gratitude to Ola Svesson, our supervisor at OMotion AB. With his knowledge and encouragement, we were able to steer our project in the right direction. Lars Lindkvist, our academic supervisor and examiner also deserves a mention here as well. His suggestions helped us with ideas which polished our work.

Finally, we would like to say thank you all who willingly participated in our research interviews with us. Their insights based on their personal experiences alone have been invaluable; it was priceless information that could not be found anywhere else. All these people contributed towards this thesis; without them it wouldn't have been possible. They have really bridged us through making this project a success and we appreciate them from the bottom of our hearts for that.

Ateeth Shetty & Vivek Doiphode, Gothenburg, 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order

ABS	Acrylonitrile Butadiene Styrene
BEV	Battery Electric Vehicle
CE marking	Conformité Européenne marking
EU	European Union
FCEV	Fuel Cell Electric Vehicle
PET	Polyethylene terephthalate
PHEV	Plug-in Hybrid Electric Vehicle
PLA	Polylactic Acid
PVC	Poly Vinyl Chloride
UNECE	United Nations Economic Commission for Europe
WVTA	Whole Vehicle Type Approval

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Introduction

1.1 Background

OMotion AB is an engineering company with a background in embedded development, programming and renewable energy projects that started in 2013 in Lund, southern Sweden. Their company mainly focusses on coming up with new solutions to increase performance and have lower environmental consequences for electric drivelines in a new category of vehicle.This thesis is appointed by OMotion AB and focuses on the creation of a new exterior body design for the newly upgraded model of the previous OMotion 2 model.

The OMotion 2 is a three-wheel electric car featuring a unique configuration with two wheels in the front and one in the rear. The product's present state is a functioning chassis and a brief concept vehicle body.

1.2 Purpose

This master thesis aims to design and develop a suitable exterior body for the electric 3-wheeler, considering the challenges from the previous model.During the selection process, the objectives include innovative solutions to improve design aspects and overall efficiency.

A detailed 3D model of the proposed design will be crafted as part of the project, accompanied by surface renderings to provide a comprehensive visualization of the innovation.

1.3 Research Questions

The research questions are formulated at the beginning of the project in order to set a direction for the path of the project and ensure that the project achieves its aim:

- How should the exterior body of the car be designed to meet the stakeholder's requirement?
- How can the attachment of the exterior body to the chassis be designed to decrease the visibility of the attachment?

- How can the utilization of the vehicle be improved for the new three-wheeler exterior body design?

1.4 Project Focus

In the initial phase of the project together with OMotion, project focus was discussed to give more importance to the same to have an efficient outcome.
The list of prime focus is listed below:

- **Aesthetics**
  Creating an appealing exterior that resonates with the target customers.

- **Functionality**
  Ensuring the redesigned body enhances the overall functionality of the car model.

- **Manufacturability**
  Developing a design that is not only innovative but also feasible for practical manufacturing. .

1.5 Delimitation

While OMotion is transitioning to a new version, numerous elements remain consistent with the previous iteration. These shared aspects introduce several design constraints for the new version. Additionally, the scope of this thesis imposes further limitations on the design process. The list of delimitations has been listed below:

- **Redesign Focus** The main focus of the thesis is on the redesigning of the vehicle body. However, it does not include changes to key parts such as the batteries, motor, seats, and tires, despite their concurrent upgrading for better performance. The research shrinks its focus to external body design problems.

- **Aerodynamic Analysis Limitation** While basic aerodynamic knowledge is beneficial, the scope of aerodynamic analysis may be limited. The study's emphasis on the vehicle's body design restricts its research of intricate aerodynamic problems, favoring external aesthetics.

- **Manufacturability Challenges** The thesis aims to build an innovative body design that is easily manufactured. However, the thesis does not address any issues that may arise throughout the manufacturing process. The research focuses on ideas rather than going into manufacturing details.

- **Geographical Limitation** The European Union is the main subject of interest hence all research and surveys will be limited to it.

- **Design Integration** All concepts should be based on the existing OMotion wheel configuration and include minimum changes on the chassis.

The thesis does not involve the technical specifications of the vehicle such as performance, handling and functional frame.

1.6 Organisation

The development of the upgraded model encompasses numerous segments beyond the exterior body design. These segments operate in parallel and are highly interrelated with other projects within OMotion. The company is responsible for managing the design, financial, and production constraints, necessitating the consideration of various factors throughout the exterior body design process.
The development team at OMotion is engaged in advancing battery technology, electrical motors, and embedded applications. Their comprehensive involvement, from the conceptual phase through to project completion, has been instrumental in refining design concepts and achieving an optimal design. This collaboration has significantly contributed to the project's success by eliminating less feasible concepts early in the process.

1.7 Method

The general method that will be used during the thesis is described below
Information gathering

- Review of existing literature, patents, and industry standards on electric vehicles body design .
- Requirements for performance, functional safety, and relevant safety standards.
- Market analysis, benchmarking, surveys, and competitor analysis.

Idea generation This phase involves conducting brainstorming sessions and developing a function-means tree with the help of meetings and an inspiration board, which will later guide us in finalizing the design for the product.
Concept generation and elimination A concept generation phase will be conducted, including innovative ideas for the development phase's needs and requirements. The following methods will be implemented:

- Morphological Matrix
- Elimination Matrix
- Pugh Matrix
- Choosing the most feasible options from the design alternatives.

Final solution In this phase, final design solutions will be developed from the result of the previous stage, whereby the best feasible option is chosen. Detailed sketches of the concept will be perfected; correct CAD models will be generated in the company with high-quality renderings. Also, it ensures a proper assessment and testing that

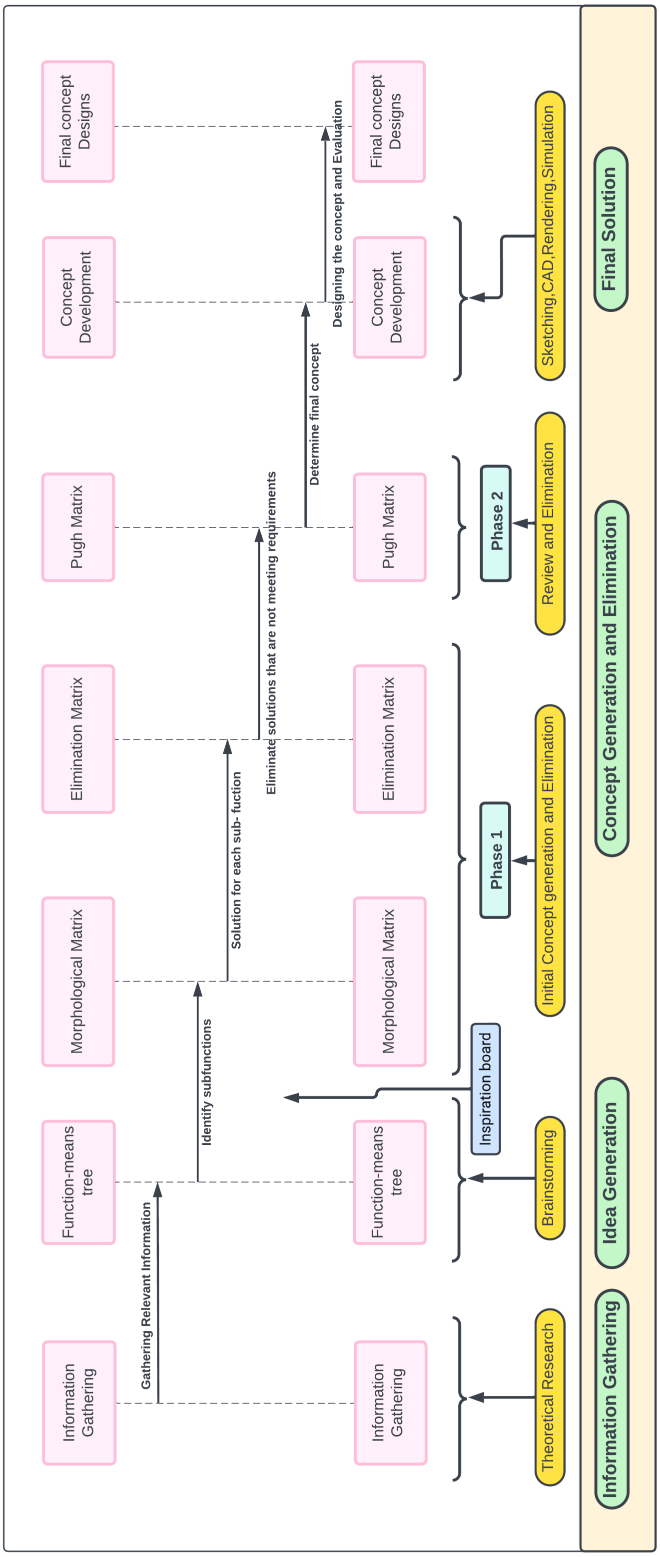


Figure 1.1: Method

the design satisfies all the functional, aesthetic, and technical requirements before it's forwarded for final implementation.

2
Product Background

2.1 Introduction

OMotion AB is a new startup company founded in 2013 by Ola Svensson. The primary focus of the company is to build sustainable solutions for the regular commute. The company develops and manufactures fully electric three-wheelers to overcome the gap between motorcycles and cars.
OMotion's electric vehicles feature a unique configuration with two wheels at the front and one wheel in the back. The company is committed to continuous improvement, actively addressing challenges to develop better new versions of its vehicles.
EU regulations categorize vehicles into various types based on their body type and shape, such as mopeds, mini cars, and motorcycles. These categories are named L, M, N, and T. The OMotion's tricycle vehicles comes under the L category of vehicle with a specific body type known as L5eA. L5 refers to a class of vehicle, and A refers to the type of driving license required to drive it.

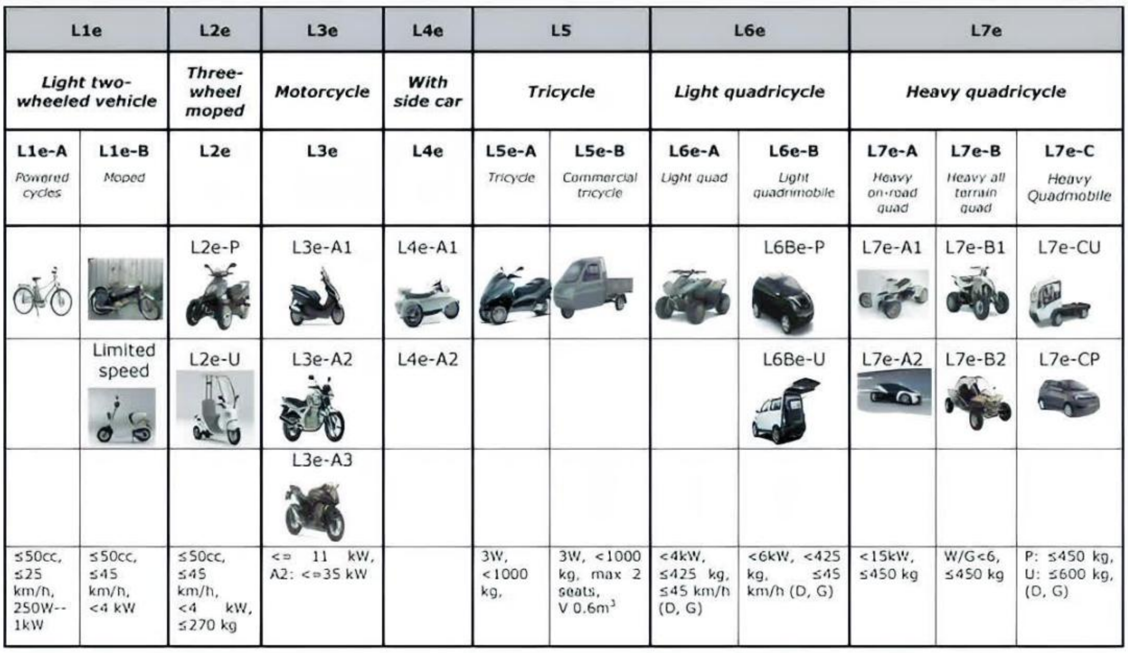


Figure 2.1: EU Vehicle Categories [1]

2.2 Context and User

In order to understand customers' needs and requirements for this product segment. It is important to understand the vehicle category and establish an overview of potential customers and stakeholders. In addition, conducting market research and gathering feedback from targeted audiences will give a more effective understanding of product-specific needs and preferences.

Under typical circumstances, the electric vehicle market includes various users and stakeholders. Those who directly purchase a vehicle and use it for everyday transportation are considered primary user. Their purchasing decision is primarily dependent on factors such as vehicle cost, driving range, and charging infrastructure availability. Family members, mechanics, and charging station operators are considered secondary users of the product. Secondary users cannot purchase the product directly, but they can use it for transportation. Users cannot use and buy the product but are actively involved in the process of policy-making and planning, which is considered a tertiary product user. Early adopters or lead users, play a significant role in experiencing and advancing technology.

Stakeholders in the electric vehicle industry consist of a variety of entities. For market expansion, vehicle manufacturers have to focus on manufacturing, customer preferences, and technological advancements. These things require capital, and then individual or corporate investors come in.

Table 2.1: Classification of Users and Stakeholders

Customers	**Who that purchased vehicle for use**
User	**Primary Users**: Individual Customer, organization. **Secondary Users**: Family members or colleagues of Primary Users. **Tertiary Users**: Policy makers, Urban Planners, Insurance people.
Lead User	Early vehicle buyers, car enthusiasts, and specific mobility users.
Stakeholder	Individual investors or entities.

2.3 Target Group

The OMotion 2 is a three-wheeler electric car that offers an exhilarating open-air experience and impressive speed. However, its higher price point means it is not accessible to everyone. Therefore, the primary target group for this product includes affluent customers with a strong interest in automotive technology.
Additional potential target groups include

Tourism and Leisure Companies Businesses that offer unique transportation experiences for tourists, such as guided city tours or rental services, might find this vehicle an attractive addition to their fleet.

Adventure Seekers People who crave exciting, open-air driving experiences and love exploring the outdoors in a unique vehicle.

Young Car Enthusiasts A younger audience with a strong passion for sports cars.

Service Companies The car can also be used by service companies for maintenance work. Its compact design allows for easy navigation in urban areas, and the open-air layout provides quick access to tools. The electric power train ensures eco-friendly operation, making it a practical choice for modern service fleets.

Rural Area Personal Transport The car is well-equipped to tackle various terrains, making it ideal for undeveloped roads and rural areas. Its robust design ensures smooth travel, providing a reliable option for personal transportation in the countryside.

Further discussion about the target group and user study will be done in the following chapters.

2.4 Project Prerequisite

2.4.1 Previous work

The current model being developed for this thesis builds on a vision originally conceived by Ola Svensson in 2013 in Lund, southern Sweden with an initial prototype, the OMotion ETR. Following this, an improved version, OMotion 2, was introduced. While maintaining the same frame, the OMotion 2 offered enhanced range and speed, powered by a rear-wheel hub motor capable of delivering 24 kW peak power and 11 kW continuous power. This vehicle was registered under the L category of EU-type approval and priced between 169,000 SEK and 180,000 SEK. The OMotion 2 was designed with a sporty aesthetic, featuring an open-top configuration and lacking space for additional luggage. However, the attachment of the body to the frame presented some aesthetic challenges.

2.4.2 Current situation

OMotion is aiming to elevate its design with an upgraded version of the OMotion 2. The new model will incorporate several significant changes, including:

- An attachment method for the body to the frame, reduces the visibility of exterior screws for a cleaner look.
- An updated design that includes additional luggage space.
- A wind deflector that directs airflow over the passenger.
- Upgraded lamps for enhanced visibility and aesthetics.

These enhancements collectively contribute to a completely redesigned exterior for the new model.

2.4.3 Limitations

The design of the new exterior body brings several important considerations into focus, including:

- The chassis of the new updated model should have the least possible changes to the previous model.
- The same manufacturing limitations that apply to the previous model shall apply to the new concept.
- Durability, ensuring the body can withstand wear and tear without any delicate protruding parts.
- Minimizing the number of parts in the exterior body to reduce costs.
- The exterior body's parts should be made so that they can be manufactured by previous methods used by the company.
- Standard parts, such as headlights and attachments, should be used when possible.
- Since the vehicle is registered under the L category according to EU type approval, its dimensions are limited to a maximum length of 4,000 mm (about 13.12 ft), width of 2,000 mm (about 6.56 ft), and height of 2,500 mm (about 8.2 ft). For more details, refer to the EU Regulation [13].
- To achieve an open-air experience, the design concepts must include an open roof.
- All new design concepts should take into account the additional luggage space required for the new model.

2.5 OMotion Brand

OMotion AB, a startup company, is in the initial stages of building its brand and product line. The company's vision is deeply rooted in climate consciousness, striving to balance environmental responsibility with an exhilarating driving experience. OMotion aims to become the leading developer and manufacturer of light electric sports vehicles, prioritizing sustainability and innovation in every aspect of design and production.
The company has highlighted its innovation at numerous events, including

- **ECAREXPO GOTHENBURG 2023**
  Date: 2023-12-01 to 2023-12-03
  Location Svenska mässan (Swedish fairs) - Gothenburg

- **EL FÖR ALLA 2023**
  Date : 2023-08-20 to 2023-08-21
  Location Scandinavian Raceway - Anderstorp

  EL FÖR ALLA 2022
  Date 2022-08-20 to 2022-08-21

Figure 2.2: OMotion car at the track event. [2]

Location Scandinavian Raceway - Anderstorp

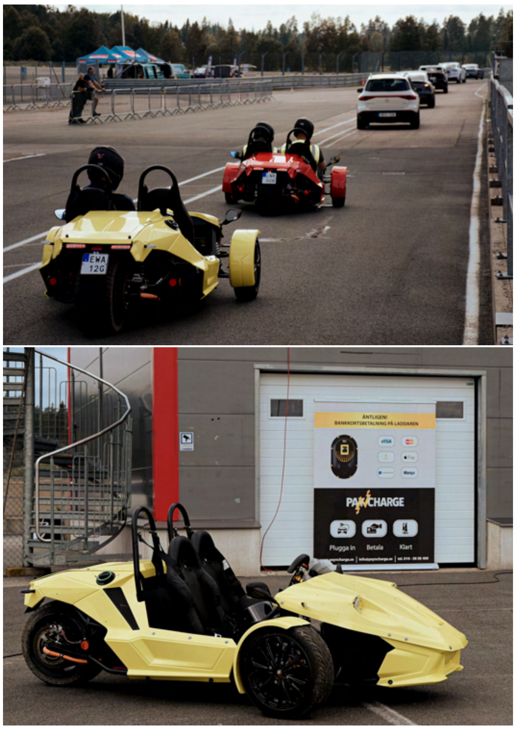


Figure 2.3: Electric three-wheeled vehicles on track [2]

With this participation, OMotion has begun to establish its market presence and demonstrate its commitment to revolutionizing the electric sports vehicle industry.

2.6 Market positioning

The electric vehicle market has seen significant growth over the past decade, with a surge in consumer interest and technological advancements. However, the category of vehicles that OMotion manufactures targets highly niche customers primarily car enthusiasts and businesses that cater to this passionate community. In the current market, the dominant players are those companies that recognized and tapped into this niche segment early on, allowing them to effectively meet the unique demands of these customers.

To successfully compete in this space, OMotion must strategically align its marketing efforts to address the specific needs and preferences of this niche audience. This includes understanding the values and desires that drive car enthusiasts, such as performance, customization, and exclusivity, and tailoring marketing messages that resonate with these aspects.

Perhaps the most critical factor contributing to the potential competitive advantage of OMotion lies in the ever-growing demand in the market for EVs. The rising numbers naturally translate to a higher potential for the niche segment traditionally brand loyal to begin considering and preferring new alternatives more fittingly attuned to their tastes, which have changed toward sustainability, innovative technology, and high performance. This could not come at a better time for OMotion to address the car market in search of something new and different in electric vehicles. The vehicle should be reliable in combination with greater efficiency to distance itself from the existing market competitor. The driving experience must resemble the comfort of the car but at the same time have the benefits of the three-wheeler car like agility, speed, and compactness.

In the following report, a detailed analysis of competitors will be done to identify existing players' strengths and weaknesses in the marketplace. The analysis will underline not only areas that OMotion could leverage to create differentiation but will also open areas in which it could use its unique design philosophy and technological superiority. OMotion can better understand the competitive environment and exactly which factors speak to its niche segment. Only in this way can a position be tailored that has some chance of attracting customers who are loyal to the brand and making it more visible in a busy marketplace, thus touting an offering that separates it from the rest.
Figure 2.4 serves a significant function in situating the vehicle design in relation to the current market by depicting the interplay among aesthetics, functionality, and sustainability across different models of three-wheelers. The horizontal axis delines a continuum ranging from functional utility on the left side to elevated aesthetics on the right side, while the vertical axis quantifies sustainability, extending from low at the bottom to high at the top.
Within the scope of this thesis, the graph serves as a tool for evaluation in determining the positions of the existing designs of three-wheelers in relation to these critical elements, enabling the determination of an optimal balance for the proposed design.

The goal is to develop a vehicle that would not only meet functionality criteria but also come close to meeting the aesthetic criteria and, therefore, appeal to a broader category of target consumers. Moreover, the focus on sustainability illustrates the increasing consumer demand for products that are environmentally conscious. Recognizing deficiencies in the market it guides the design process to guarantee that the resulting product provides a harmonious solution—integrating functionality, visual appeal, and sustainability.

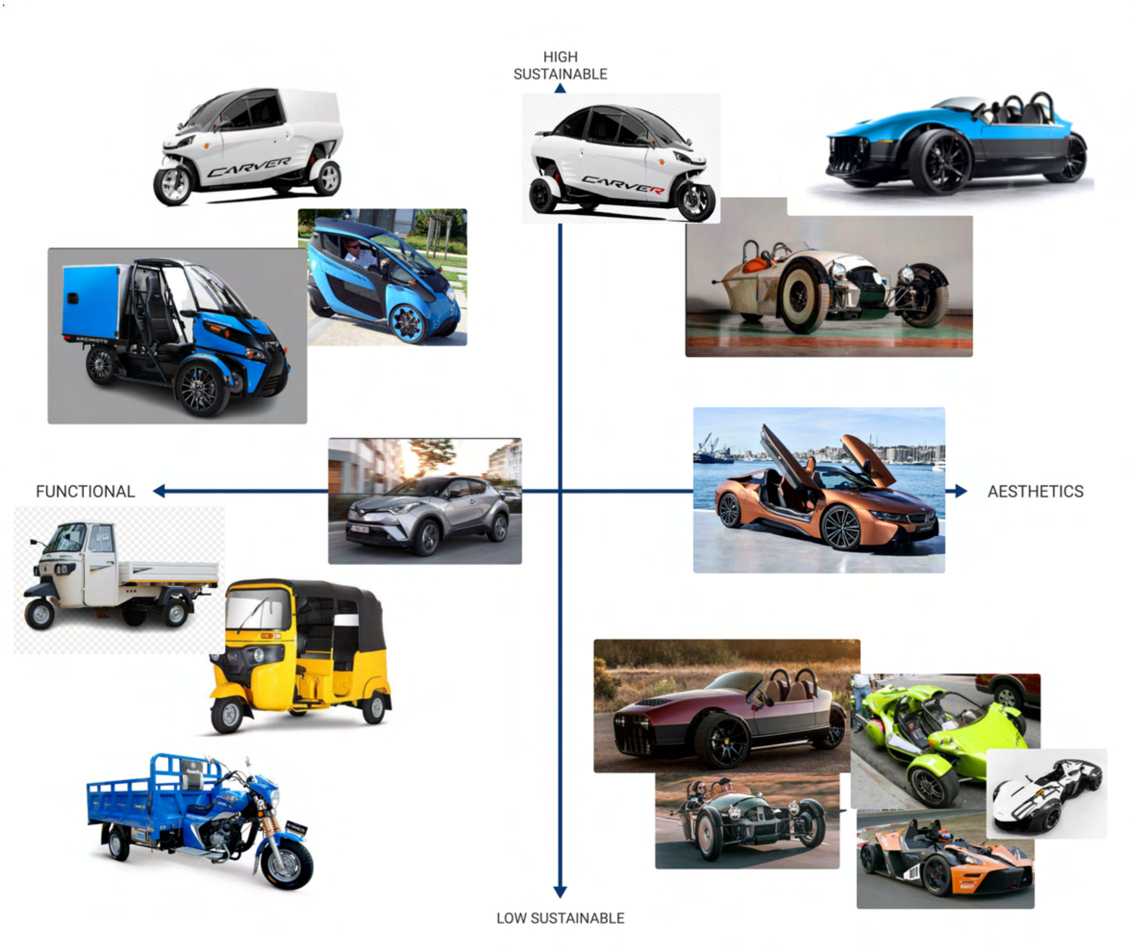


Figure 2.4: Market positioning

3

Information Gathering

The information gathering phase was conducted in such a way that we could get the right amount of information in time to start our actual requirement finalising. We began by reviewing the old class notes and related materials to understand the various areas of study that our project would touch on. This research was followed up by gaining a deeper understanding of topics and collecting that information in one document.

3.1 Theoretical Research

3.1.1 Market Analysis

This section of the report provides insights into potential challenges and trends in the overall electric vehicle market. In recent years, the electric vehicle market has been growing and customers are taking an interest in this segment. Companies are also investing money in research and development, such as battery technology and charging. In Europe, the total number of electric vehicles reached nearly 3.2 million units in 2023 and observed an almost 20% increase compared to 2022.
However, the European Union has set ambitious goals to reduce greenhouse gas emissions and air pollution caused by vehicles. They are targeting a 37.5% reduction in CO2 emissions level from vehicles by 2030. Furthermore, their aim is to have 30 million electric cars on European roads by 2030. Easily, we can say that the EU is actively promoting sustainable transport solutions.[14].

Table 3.1: Market share of electric vehicles (BEV and PHEV) by region [12]

Year	Europe	China	USA
2020	42%	41%	11%
2021	41%	41%	12%
2022	27%	40%	18%

According to IEA statistics, global market share of electric vehicles (BEV) in 2020 was 3.8% and it significantly increased to 14.6% in 2023, as illustrated in (Figure 3.1). This pattern indicates global markets are focusing on environmentally friendly transportation options. This massive shift is not possible without primary policy and charging infrastructure.
Electric vehicle (BEV) sales saw significant growth from 2013 to 2023 and observed a slowdown in sales this year quarter. Sales have been slowing down for some quarter's

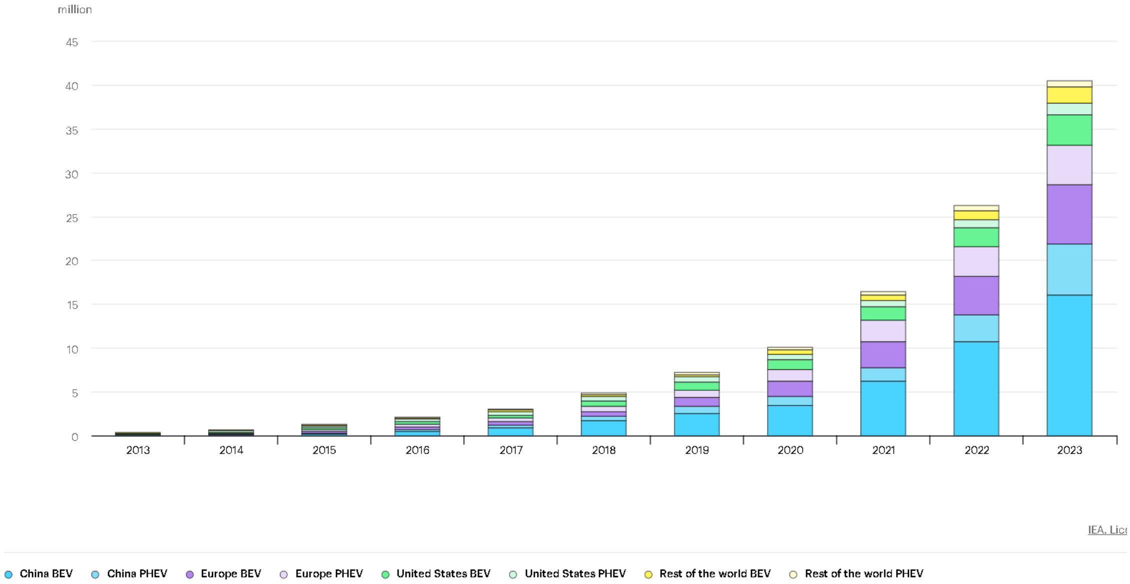


Figure 3.1: Global Electric Car Stock from 2010 to 2022 [3]

but projected it will take acceleration in two years. [15] Also The European Union is promoting electric vehicles by putting strict regulations in place (June 2022), including a 2035 ban on new gasoline and diesel car sales, and this highlights a shift towards zero-emission vehicles.

Regional Breakdown

As of now, several countries are leading in electric vehicle sales (including both BEVs and PHEVs). In 2020, Europe held the largest share globally at 42%, but now China is a big competitor. Statistics on car sales indicate that within the EU region, Norway had the highest number of electric cars and sales last year with 88%, indicating that almost 9 out of 10 new cars sold were electric. (Figure 3.2)

In Sweden by 2023, EV registration share reached 54% and showed balanced growth between both BEVs and PHEVs. This reflects a commitment to reducing emissions and investment in technology and renewable energy. Also, Germany is one of the largest automotive markets in the European region and sales shares of EVs reached 31%. However, when compared to Norway and Sweden, this growth is still considerably low, especially given the country's large population and strong automotive industries.

Market Segmentation

To meet needs and applications, the electric vehicle market is segmented based on a variety of factors.

- **Product Type** Battery Electric Vehicle (BEV), Fuel Cell Electric Vehicle (FCEV), Hybrid Electric Vehicle (PHEV).
- **Application** Passenger cars and commercial vehicles.
- **Region** Asia Pacific, Middle East, Africa, Europe, North America and Latin America.

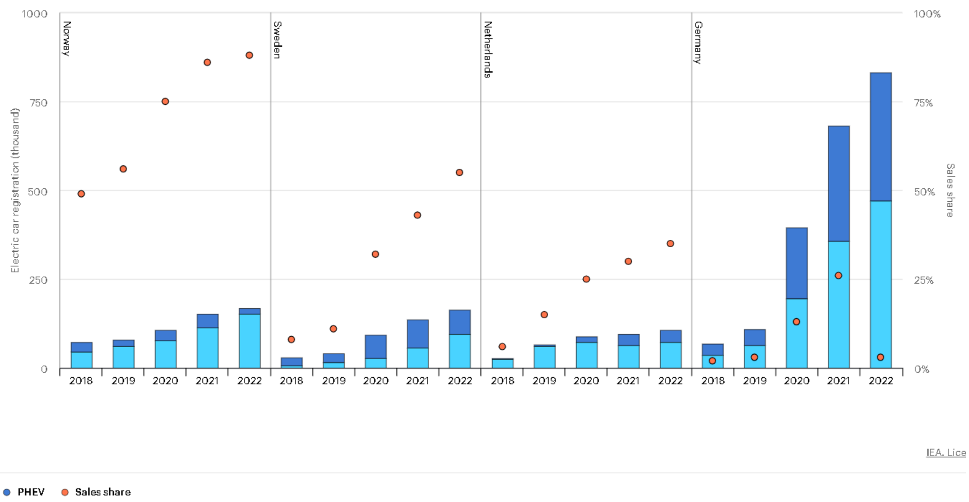


Figure 3.2: Electric car registrations by country from 2018 to 2022 [4]

Table 3.2: Electric Vehicle Registrations by Country (2023)[12]

Countries	Electric Vehicle Percentage
Norway	88%
Sweden	54%
Netherlands	35%
Germany	31%
UK	23%
France	21%

Challenges

- Compared to traditional cars, electric vehicles have a higher cost.
- Limited charging infrastructure
- Competition from traditional gasoline-powered vehicles.

In conclusion, the European electric market shows promising growth due to environmental concerns, government support, and technological advancements. Despite the challenges, the trend towards sustainable transportation is clear and continues to gain momentum.

Discussion

The overall sales of battery electric vehicles (BEVs) are increasing. Highlighting growing market interest (Figure 3.1). BEVs are categorized into various segments, including small, medium, large cars, crossovers, and SUVs, based on powertrain and vehicle size. However, the availability of specific data for each vehicle category is limited, making it challenging to analyse trends within specific subcategories in detail. As we know OMotions vehicle comes under the small type category. In Europe, small cars represent for 19% of all vehicles in Europe. (Figure 3.3) As competition is increasing and new models are introduced in the EU market. It is crucial for OMotion to focus on various key areas to capture and succeed in the electric vehicle market. These areas include reducing vehicle costs without compromising safety, unique selling features or the range of vehicles. The company can use its electronics expertise to enhance vehicle efficacy in terms of range and acceleration. Currently, OMotion sells its vehicles throughout European region. However, focusing on a specific geographic market could give further sales growth. For instance, the OMotion current design offers an open-air experience while driving a vehicle. Southern Europe is known for warm weather. By strategic marketing in these regions, OMotion could attract more customers and capitalise on favourable conditions.

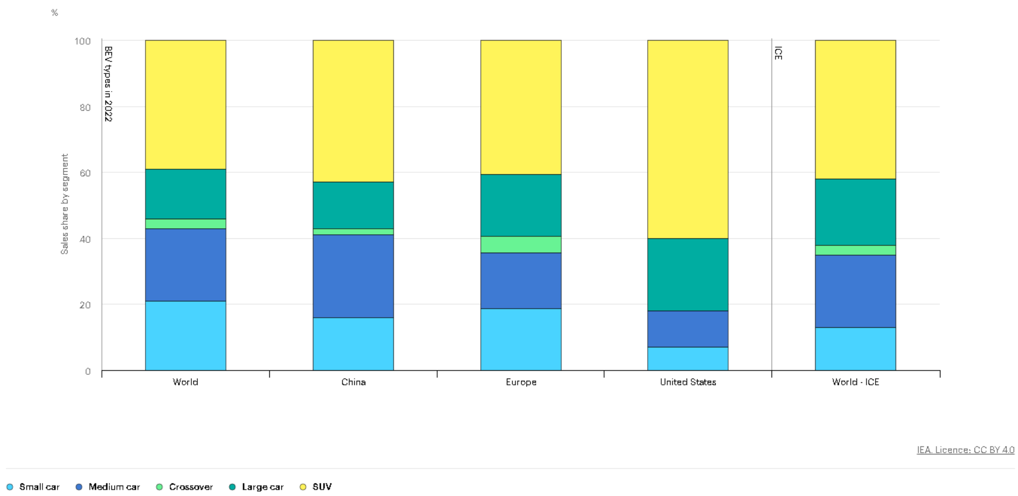


Figure 3.3: Breakdown of total available cars [3]

In conclusion, to evolve in the market, OMotion must focus on cost and range factors. Additionally, they should strategically target regions where they can create market opportunities and increase sales growth.

3.1.2 Product legal demands

The European Union (EU) has set regulations for each category of vehicle. That covers various aspects of vehicle safety and environmental standards. These regulations are intended to protect the person inside the vehicle as well as other road users. The legal requirements for vehicles registered under this registration are regulated by European Parliament Regulations (EU) No. 168/2013 and the Swedish Transport Agency, Transportstyrelsen. [13]
The main purpose of ths section is to study the legal requirements for the L5eA type vehicle. Specifically, parts of the vehicle such as headlights, indicators, position lights, brake lights, reflectors, windshields, and side mirrors.
This is an overview of the regulations for these components

Headlights
The EU regulations have set guidelines for the position of headlights on vehicles. Also, these regulations provide guidance on the functionality and proper visibility of headlights. According to regulations, headlights must emit white or yellow light.

Headlights should be positioned in such a manner that they can be seen from some distance, and this helps other drivers to easily understand what the vehicle in front is doing. Companies that produce L5eA-type cars must adapt to these rules and regulations. In order to ensure that headlights meet these brightness and visibility requirements, they must be designed and fitted properly on vehicles. This ensures that headlights not only function properly but are also easily visible to other vehicles.

Furthermore, EU Regulation No. 168/2013 specifies the requirement for both high and low-beam lighting. When it's dark and clear, high-beam headlights should be able to illuminate a road for at least 50 metres. Low-beam headlights must shine light in a way that is suitable for right-hand traffic and should illuminate at least 35 metres ahead of the vehicle in both dark and clear circumstances. The height placement of high and low beams must range between a minimum of 500 mm and a maximum of 1200 mm. Since OMotion is currently developing and selling its own L5eA-type vehicles, it is crucial to follow these regulations. While designing the outer body of the vehicle, these legal requirements must be taken into consideration.

In conclusion, the development and manufacturing of vehicles that are in the L5eA category must follow the headlight regulation. By implementing these regulations into the design process, companies can improve the safety and reliability of their vehicles.

Indicator

Every vehicle is fitted with an indicator light, also commonly known as a turn signal light. These signal lights are a very useful safety feature that helps us to communicate our driving intentions to another vehicle drivers on the road. Turn signals make driving much safer and help avoid accidents that could have occurred if a vehicle makes a sudden turn or lane changes without giving a signal.

According to the European Union (EU), L-type vehicles (including mopeds and electric scooters) must have an orange turning signal light. These regulations demand that the light must be bright enough and easily visible from both the front and rear sides of the vehicle. When light is in use it should be visible from a distance of at least 30 meters.

Additionally, there are also more specific rules regarding space between other lights such as position lights and headlights. According to the rules, lights should be mounted a minimum of 40 mm away from other lights and 500 mm from the edge of the vehicle on the side. In some cases, where it is impossible to meet minimum distance requirements, exceptions might be allowed based on vehicle construction and design requirements.

Position Lights

A position light is commonly known as a parking light. It improves the visibility of vehicles, especially in low light conditions and indicates the width of the vehicle. According to European Union (EU) regulations, L5eA-type manufactured vehicles by OMotion AB also require position lights. These regulations specify the colour and position of the lights. For example, the light should be white or yellow in colour, and it shall be positioned on the front side of the vehicle.

The maximum allowable distance from the edge should not be more than 400 mm and height placement should range between 350 mm and 1500 mm from the ground. It depends on vehicles design or structure requirements. In some cases, exceptions may be allowed for extra height. Along with this, a minimum standard distance of 500 mm is required to divide two position lights.

Overall, these regulations are intended to provide a safer and more efficient transportation environment. Standardisation of position lights ensures good visibility for all drivers on the road.

Brake Lights

Brake lights are an essential part of vehicles' road safety. The EU has established specific regulations for brake lights, understanding their importance in vehicle safety. These regulations mandate that these vehicles must be equipped with one or more red brake lights. The regulations describe the exact position criteria for brake lights. For maximum rear-side visibility, the light should be positioned between 250mm and 1500mm from the ground. Additionally, there is a minimum distance requirement of 500mm between two lights in order to ensure their separateness and easy visibility.

In conclusion, EU rules ensure that L5eA vehicles are equipped with bright red brake lights that are easily visible from the rear side of the vehicle.

Reflectors

Reflectors are one of the essential safety components in these types of vehicles (L5eA). Every vehicle has its own light source but a reflector's function is to reflect light that is received from other vehicles headlights. This increases visibility for vehicles in low-light conditions or in foggy weather.

According to the European Union (EU), vehicles should have a red non-triangular reflector positioned on the back side of the vehicle. This regulation specifies a minimum distance between two reflectors, which should be a distance of 600 mm. In some cases, this can be reduced to 400 mm. Additionally, the reflectors should be positioned between 250 mm and 900 mm from the ground.

Windshields

Windshields are an essential part of any vehicle and we know that windshields provide protection to passengers from the outside wind and external particles. For L5 types of vehicles, the European Union (EU) has set high standards for safety regulations addressing concerns, such as impact resistance, light transmission, and visibility. However, there are no specific requirements such as shape, position regulations, for windshields in this category of vehicles (L5eA). Generally, standardized CE markings ensure that the windshield meets EU regulation requirements, and it provides protection to passengers and, at the same time, offers clear visibility to the driver.

Side Mirrors

As we already know, safety is a top priority for the European Union (EU) when it comes to vehicles on the road. The EU has added a directive requirement for rear-view mirrors in all types of vehicles. Mirrors provide a wider field of view to drivers allow them to see what is coming up behind them and help to reduce blind spots. There are no regulations regarding blind spot reduction and mirror positions for L5eA-type vehicles. position of mirrors is based on a choice of design.

In conclusion, regulations play an important role while designing the external body of a vehicle. These regulations ensure that the components are properly positioned. By following these regulations, OMotion gets clearance to sell their vehicles in the EU region. While designing a car body, it is essential to consider these regulations for the position of parts. This consideration will help the process to identify available design space for design. The EU regulations include detailed constraints regarding vehicle weight, dimensions, and engine power. Weight is the main criteria for classification into different classes.
following lamps shall be installed on the vehicle

- Two forward directed Headlights.
- Two forward directed position lights.
- One right and one left forward facing indicator light.
- One right and one left rearward facing indicator light.
- Two rear-facing red lights (Brake Light).
- Two non-triangular rear facing red reflexes.
- Two non-triangular sides facing yellow reflexes.

3.1.3 Category of vehicle

The L5e category is classified according to UNECE standards and EU regulations. The EU's technical regulations are structured around WVTA (Whole Vehicle Type Approval). Which allows manufacturers to certify and sell vehicles across EU member states without the need for additional testing. This procedure simplifies market entry for manufacturers, and it maintains the same level of safety and performance in each vehicle. These tricycles can achieve speeds exceeding 50 km/h and are equipped with internal combustion engines of at least 50 cm^3. [16] The OMotion Model 2 is a notable example of an L5eA type vehicle. According to the United Nations Economic Commission for Europe (UNECE), the maximum seating capacity for this type of vehicle is 5 seats. Additionally, the total mass of the vehicle including passengers' and driver's mass must not exceed 1000 kg. Furthermore, L5e vehicles are equipped with extra essential features or components such as a speedometer, side mirror, fog light, licence plate and its light.

3.1.4 Manufacturing and materials

Understanding the limitations and strengths of relevant manufacturing methods is very essential while designing vehicle body parts. Basically, this section gives an overview of various manufacturing processes that are cost-effective for small quantities of part manufacturing. At present, OMotion is using a vacuum-forming process for manufacturing car body parts. company has already started car production but they are planning to increase production of vehicles to 300 per year.[17] To manufacture parts requires equipment and machinery; it is a very capital-intensive process.

Our purpose is to discover alternative methods for part manufacturing to minimize costs and build the best quality product. As a result, it would help to design a CAD model for that specific manufacturing process.
Generally, in automotive industry, various manufacturing processes are used for part manufacturing. Here are some manufacturing methods:

3.1.4.1 Vacuum forming

Vacuum forming is considered a cost-effective method for making customized parts using thermoplastic material. Typically used for manufacturing lightweight components. In this method, the plastic sheet is heated at a controlled temperature and stretched over a mould. The final plastic component is ejected using striker pins from the mould.

Process Overview

- **Material Selection** ABS, polystyrene, and PVC.
- **Heating** A plastic sheet is clamped and heated at a controlled temperature until it becomes soft.
- **Forming** A heated sheet is stretched over a mould, and a vacuum is applied to pull the plastic tightly against the mould.
- **Cooling** cooling and solidifies in shape of mould.
- **Trimming** Excess material is trimmed away to get finished.

Pros and cons

- Cost effective for low volumes as compared to injection moulding (initial tool cost).
- Easy setup and easy manufacturing of large parts with simple geometries.
- Part precision and detail compared to injection moulding is not that.
- During the vacuuming process, uneven wall thickness can occur.
- Limited material options (thermoplastics).

Design Considerations

While designing parts for specific manufacturing processes there are some precautions and measurements that should be taken into consideration, like draft angle, fillet, and thickness. A draft angle of at least 1 to 3 degrees is recommended for easy removal of parts from mould. (Figure 3.4) The angle should be positive in the Z-axis direction, and a neutral or negative draft angle will cause mould to stick. A uniform edge fillet is another aspect to consider for vacuum forming to ensure proper material distribution in corners.

3.1.4.2 Injection moulding

This method is commonly used in the automotive industry to manufacture complex design parts with high precision. This process allows for mass production of parts with precision and repetition.

Process Overview

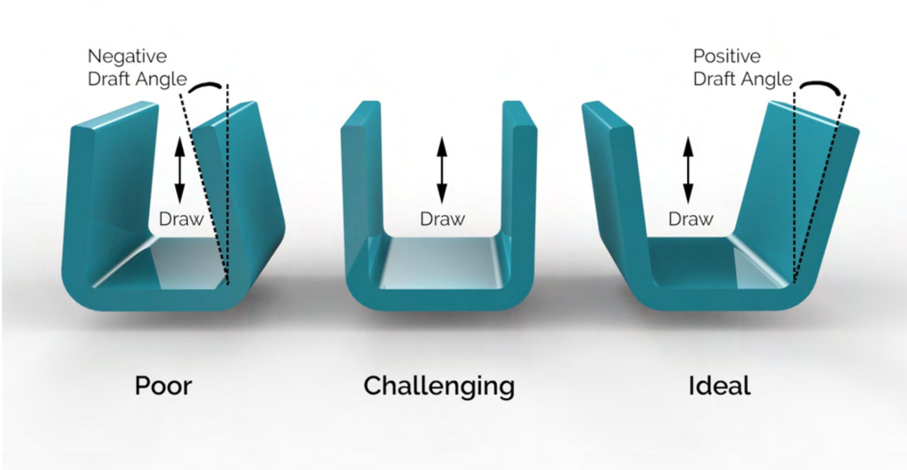


Figure 3.4: Draft Angle [5]

- **Material Selection** Polypropylene (PP), polyethylene (PE), acrylonitrile butadiene styrene (ABS), polycarbonate (PC).
- **Injection** Plastic small granules are melted and injected into a mould under high pressure.
- **Cooling** Plastic solidifies as it cools inside the mould.
- **Ejection** Part is ejected from the mould once it cools down.
- **Finishing** Post-processing, such as trimming or surface finishing.

Pros and cons

- High precision and the ability to design complex parts.
- Good surface finish.
- High initial cost for mould design and manufacturing.
- Time-consuming and costly process for complex parts.

Design Considerations

The draft angle of the product is also considered in this manufacturing process while designing. Typically, it is needed 1 to 3 degrees per side of the product, but more may be required for complex geometries. (Figure 3.4) To avoid warping and sink marks on the parts, give uniform wall thickness. If we reduce the thickness of the part this saves the raw material usage, but it also affects the strength and durability.

3.1.4.3 Material

Material selection and manufacturing are two important aspects of vehicle component design. The chosen material affects the performance, durability, production efficiency and cost-effectiveness of the product. In the automobile industry, it is essential to select materials that can withstand operating environments and are compatible with selected manufacturing processes. Understanding the operating environment of components is the first step in the material selection process. This includes factors such as temperature, exposure to liquid and mechanical impact.
To select the perfect material from the process, a systematic approach is required.

This four step material optimization method is focused on a balance of performance, cost and manufacturability.[18]

- **Define functional requirements** Understand the primary tasks of the component.

- **Determine constraints** Identify parameters that are maintained for the component to function safely and effectively. Example tensile strength, stiffness, durability and weight.

- **Identify free variables** Determine variables that can be modified without compromising component functionality.

- **Rank materials based on performance** Evaluate materials based on results or terms. Terms like weight, cost, and manufacturing.

Discussion
The surface finish of each part is important for better performance and attention from customers (Aesthetically). Currently, the company uses the vacuum-forming method for part production, which is well-suited for small-batch manufacturing. While the surface finish achieved through vacuum forming is average, this method is effective for producing large, simple parts like side panels, front bonnets, and bumpers. However, parts that are more complex in design such as an air intake grill or radiator grill are not easy to manufacture by using the vacuum forming method. Both methods have their own pros and cons, and the choice of method depends on part design and manufacturing quantity. As OMotion is planning to increase a production plant capacity, in that case manufacturing limitations become more significant. If a company increases production of parts, then parts per unit cost using the injection moulding process will decrease.
The Material section is also important for process selection and product quality. Currently, the company is using PVC material for manufacturing and it works seamlessly with the vacuum forming process. But a balance between cost and material performance is essential. For example, reducing material thickness will help to cut the cost but it may weaken strength (stretch unevenly along the bend, causing wrinkles or thin spots) and surface finish. To strengthen parts vehicle OMotion can consider materials like ABS for big parts and polypropylene.
In addition to performance of material and cost factors, sustainability is an important factor in material selection. Choosing materials that have a lower impact on the environment, recycled and have a low carbon footprint. OMotion can contribute by using these sustainable or recycled materials for manufacturing those parts such as PET and bioplastics (Bio-PLA). This will help to reduce environmental impact compared to traditional petroleum-based plastics. [19]
In conclusion, OMotion should continue large parts manufacturing by using the vacuum forming method. Additionally, using sustainable or recycled materials shows OMotion's commitment to sustainability goals. As production scales up and increases needs for complex parts, then it will be beneficial to shift to injection mould-

ing. This shift will improve the quality, fit and finish of parts and the overall performance of vehicles.

3.1.5 Sustainability

> "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
>
> – Gro Harlem Brundtland

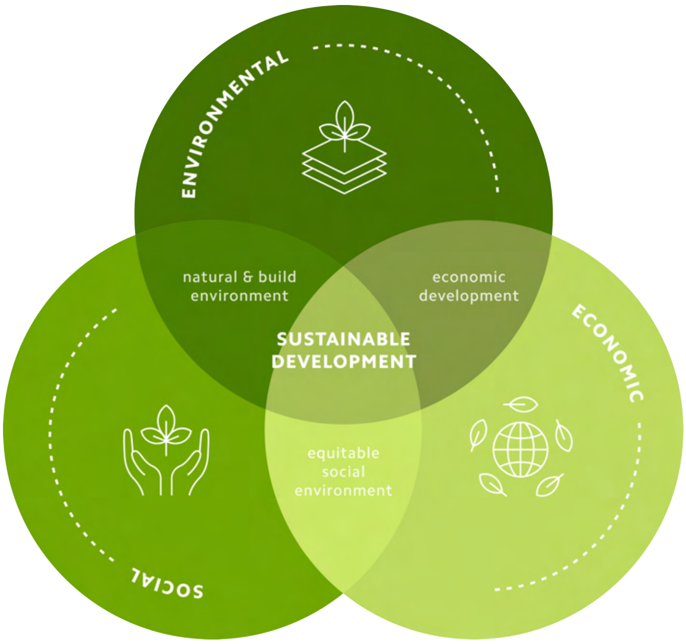


Figure 3.5: Three Pillars of Sustainability [6]

Sustainability comes in various forms, from material selection to manufacturing, all the way till the end of the product life cycle. Sustainability is a balance of economic development, environmental protection, and social factors (Figure 3.5). EVs are a strong contender in sustainability initiatives, and this offers significant sustainability advantages over traditional gasoline vehicles. Companies entry into the EV market is their first step towards achieving sustainability goals. Due to time restrictions, we're not examining each part of the product, its energy consumption, and its entire life cycle. But if you consider the overall body of a car it's made of plastic. We've already discussed alternative materials that are more eco-friendly than traditional petroleum-based plastics.[19]
In this way, OMotion not only reduces ecological impact but also aligns with the EU's ambitious sustainability goals. However, balancing cost and sustainable materials is also very challenging. Sustainable materials and production methods can be more expensive than regular ones. But as production of products scales up, the cost per unit part price will decrease and it will allow companies to use more sustainable materials.

3.1.6 Competitor's

The thesis project's success is significantly influenced by a thorough analysis of market competitors. Understanding the strengths and weaknesses of these competitors provides a crucial framework for designing the conceptual model and identifying key requirements. This competitive analysis enables a deeper insight into industry standards, customer expectations, and potential market gaps. Leveraging this knowledge, the project can be tailored to address unmet needs.
Since OMotion AB plans to target the European market, the competitor analysis focuses exclusively on European competitor's with the same configuration of three wheels. An overview of various competitors is presented below.

Carver

Figure 3.6: Carver Sports [7]

Carver, a Dutch company, develops and manufactures three-wheeled electric enclosed vehicles. Their core technology, Dynamic Vehicle Control, enables the vehicle to automatically tilt in steep curves without losing stability, making it easy for the driver to control.
Carver offers two models the Carver and the Carver Cargo. The Carver has two seats, one in front of the other, and a small cargo space, making it ideal for daily commuting. The Carver Cargo, on the other hand, has a single seat and more cargo space, designed for those who need to transport goods. The Carver comes in three varieties, all fully electric with a top speed of 80 km/h and a range of 100 km. Classified as L2e-P vehicles, Carvers feature an enclosed design for all-weather access and a compact build, making parking and travel easier.

Morgan Motor Company
The Morgan Motor Company, a renowned British manufacturer since 1910, has

Figure 3.7: Morgan Motor 3 [8]

been celebrated for its three-wheeler vehicles, which provide an exhilarating, open-air driving experience reminiscent of vintage aircraft. The company currently offers a single model with various exterior designs. This model features a five-speed manual gearbox and can reach speeds up to 209 km/h. Amid the growing shift towards electric vehicles, Morgan is developing an electric prototype known as the XP1. However, this model is still in the prototype phase and has not yet been released to the market.

Figure 3.8: XP1 [9]

The Morgan Motor Company shares a similar three-wheel configuration with the

OMotion, featuring an open design and lacking a luggage compartment. Known for its premium craftsmanship and exhilarating driving experience, the Morgan three-wheeler comes at a significantly higher price point, costing more than twice the current OMotion model.

Vanderhall

Figure 3.9: Vanderhall Santarosa [10]

Vanderhall is an American-based automobile company that has established a strong presence in the European market. The company offers a diverse range of models, including four-wheel and three-wheel vehicles, with fully electric options available. The average cost of these models ranges from 390,000 SEK to 450,000 SEK. Since its inception in 2010, Vanderhall has been a notable player in the market, competing in the same category as OMotion. Vanderhall vehicles are renowned for their sleek, sporty design, featuring options for open or closed roof attachments but no luggage compartment.
In conclusion, after conducting extensive research on the competitive landscape within the same domain as OMotion, it is clear that there are relatively few direct competitors beyond those previously mentioned. This analysis provides a solid background and key considerations for the conceptual phase, helping OMotion to distinguish itself from the existing market players. It is important to note that while many three-wheel vehicle companies primarily focus on transporting goods, they were not included in this competitor analysis due to their different market segment targets. By understanding the current competitive environment, OMotion can strategically position itself to stand out in the market.

3.2 User Study

One risk in early product development is making assumptions that are later treated as facts. To avoid this, it's important to get firsthand information about the people involved, the environment where the OMotion car will be used, the systems it will connect with, and the users. This has been a key part of the project, especially during the requirement capture phase, which involves gathering information and studying users. Different methods were used to collect data, depending on the context of the user studies. Usually, multiple methods were combined in one study to gather as much information as possible. The main focus was on collecting detailed, qualitative data.

Several different methods were used to gather information on current market needs and development updates. This comprehensive approach was taken to understand the requirements from the customers' standpoint in depth.

3.2.1 Methodes

3.2.1.1 Social Media Survey

Social media platforms like Facebook and Instagram can provide valuable insights into customer needs for the current three-wheel vehicles, including those from companies like Vanderhall and OMotion. To gather comprehensive information, various platforms were searched extensively. While social media is a rich source of information, it can be unreliable and may cause deviations from the final requirements, so careful consideration was necessary.
A wide range of platforms across Europe were explored, and surveys(see Appendix) were distributed through these channels. However, the responses were not always satisfactory, though some provided useful insights. Additionally, numerous blogs about three-wheel vehicle companies, such as Vanderhall and OMotion, were reviewed to extract relevant information.
This thorough approach further helped in creating detailed personas. These personas represent different types of customers, capturing their needs, preferences, and behaviors, which are crucial for developing the updated OMotion car. Images were also downloaded and used as references for the later stages of the process. These images are mentioned below in Figure 3.10 .

3.2.1.2 Interviews

Interviews play a crucial role in the concept development process, as they provide firsthand insights and detailed feedback that other methods might miss. By engaging directly with stakeholders and enthusiasts, interviews help to uncover specific needs, preferences, and pain points that can inform the design and development of a product. This direct interaction allows for a deeper understanding of the user's perspective, enabling the creation of more tailored and effective solutions. Furthermore, interviews can validate assumptions, challenge preconceived notions, and reveal new opportunities that might not be evident through surveys or secondary research.
In this project, two in-person interviews were conducted: one with a stakeholder and one with a car enthusiast. These interviews were carried out individually to ensure focused and uninterrupted discussions. Main questions were prepared in advance, with follow-up questions to explore topics in greater detail (see appendix). Notes were meticulously taken during the interviews to capture key insights and observa-

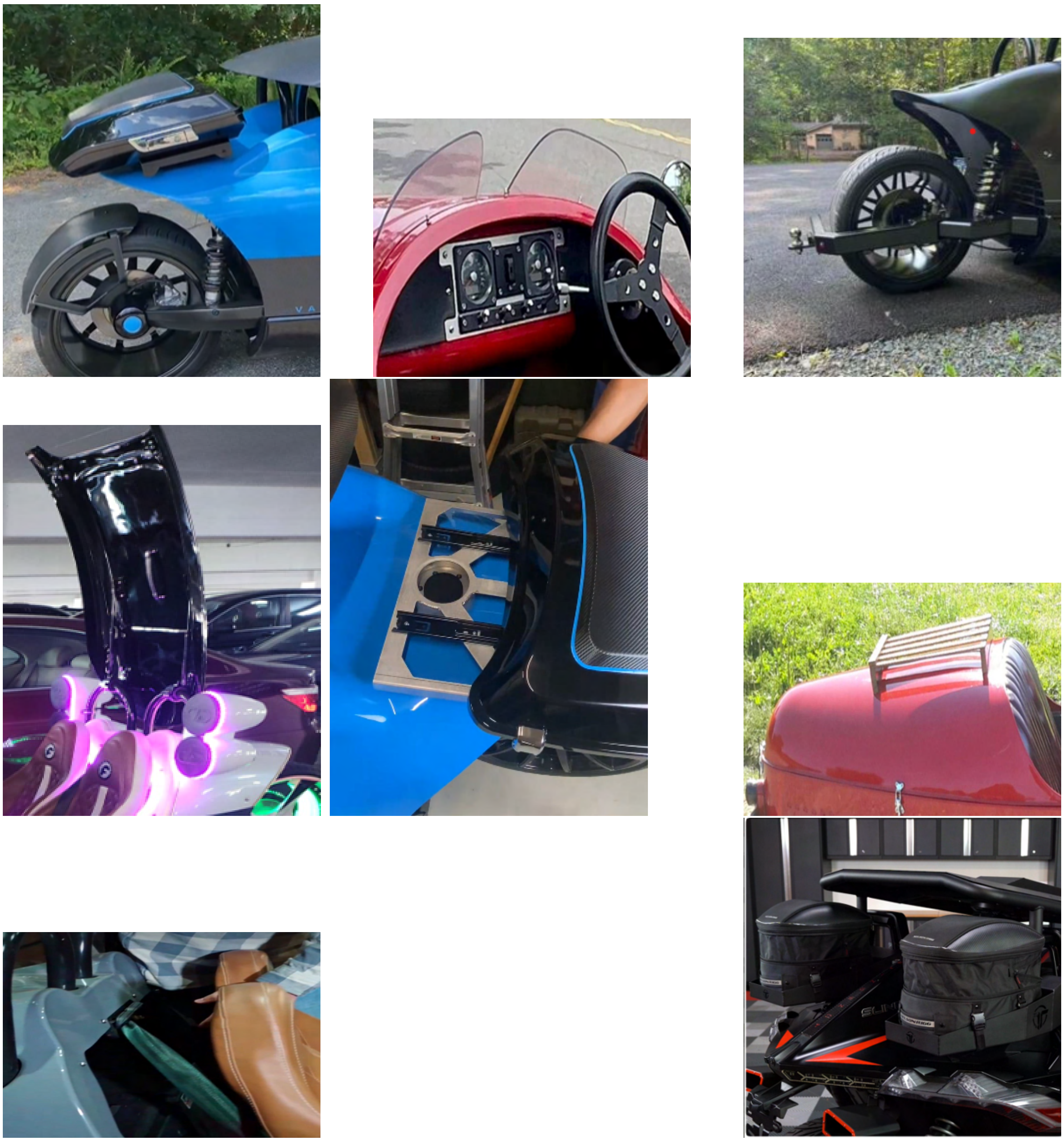


Figure 3.10: Image bank from social media survey.

tions. These notes proved invaluable during the concept generation phase, providing concrete references that guided the development of the OMotion car, ensuring it met the specific needs and desires of its target audience.

3.2.2 Observations

To gain firsthand experience with the existing product and better understand its requirements, we decided to use the vehicles ourselves (Fig.3.11). This hands-on approach was crucial for observing how the product performs in real-world conditions and for identifying potential areas of improvement. Direct interaction with the product provides valuable insights into its usability, functionality, and overall user

experience, which are essential for refining the concept and addressing any issues that may not be apparent through secondary research alone.
Additionally, the team aimed to connect with previous owners of the OMotion vehicle to learn about their experiences and the environments in which they use the product. This interaction would have offered deeper insights into practical usage and potential challenges faced by users. Unfortunately, reaching out to previous customers proved difficult for various reasons. Despite this setback, our firsthand observation of the vehicle itself was instrumental in shaping our understanding of its strengths and limitations, guiding the conceptual development of the updated OMotion car.
During our observations, several issues became apparent. The seating was notably compact, making it uncomfortable for extended use. There was also insufficient space for luggage, limiting the vehicle's practicality for longer trips. Additionally, the absence of a windshield caused significant disturbance due to wind flow at high speeds. These insights were critical for informing the design improvements needed in the next iteration of the OMotion car.

3.2.3 Generic User descriptions

Purpose
The development of the OMotion car is influenced by the diverse needs of various target groups, each with distinct requirements. Consequently, it is crucial to identify and emphasize the unique characteristics that differentiate these groups. This differentiation must be presented clearly and concisely to ensure comprehension by both the project team and external stakeholders involved in future development.
The persona method offers a solution by transforming collected insights into concrete representations. These personas facilitate discussions during critical decision-making processes and compromise negotiations. By providing a clear and shared vision of the end user, personas help align the project team's understanding and objectives, ensuring that the OMotion car meets the varied needs of its target audience effectively.

Method
Data gathered from a variety of sources such as observations, interviews, surveys, social media, and other secondary resources has been consolidated to create personas. These personas are fictitious characters that represent different potential users, each with unique needs and preferences for the final product. By identifying these distinct user types, we can better understand and address their specific requirements. In the subsequent stages of concept generation, these personas will play a crucial role. They provide a clear and detailed picture of the target audience, enabling the design team to tailor the final concept design to meet customer preferences in the most optimal way. The personas serve as a valuable tool for ensuring that the diverse needs of the users are considered and integrated into the design process, leading to a more user-centric and successful product.

Furthermore, personas help facilitate communication within the project team and

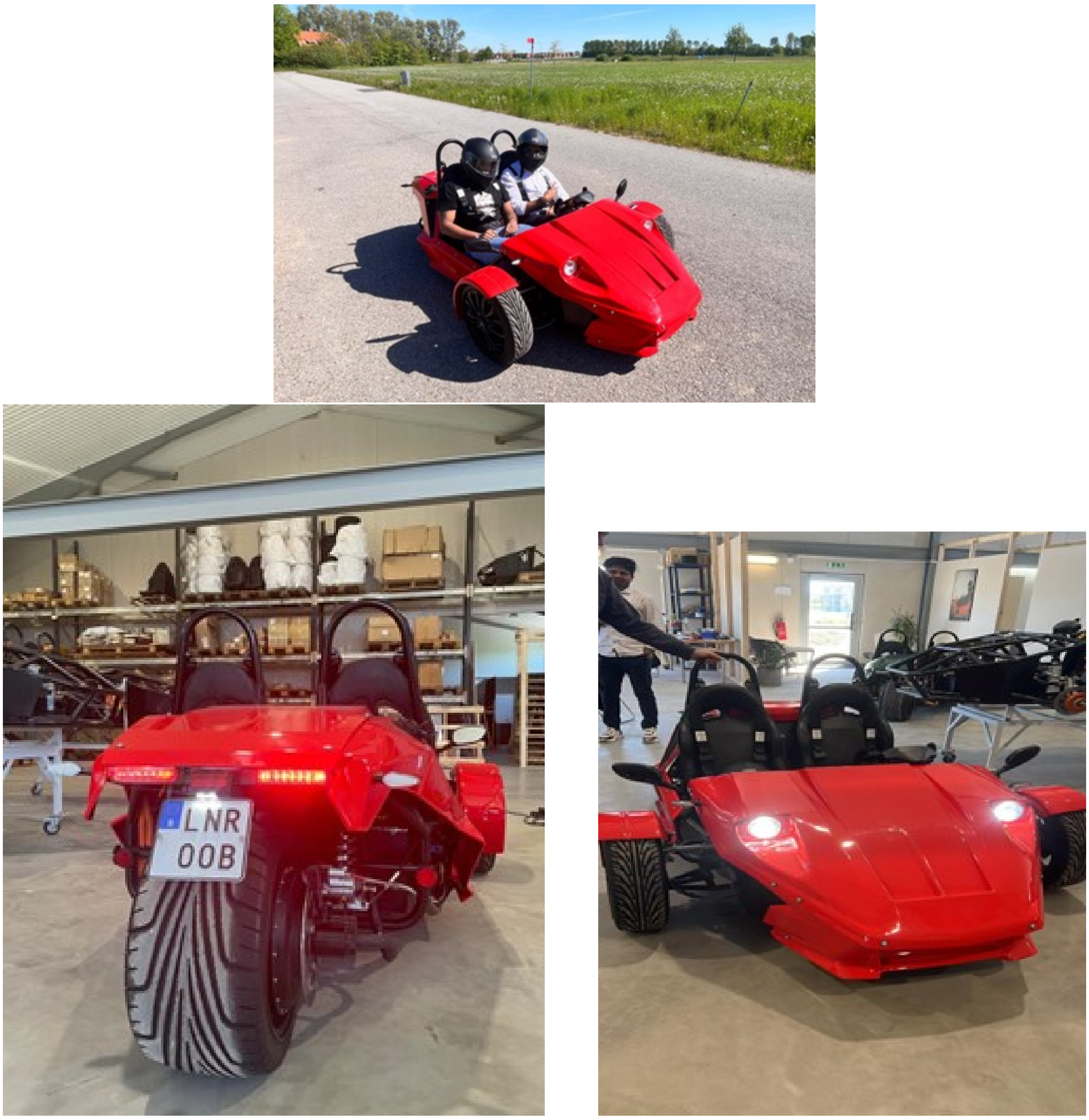


Figure 3.11: Company Visit

with external stakeholders. They create a common understanding and reference point that can be used during discussions, decision-making, and compromise negotiations. This shared vision helps align the team's efforts and ensures that the OMotion car development remains focused on delivering a product that resonates with its intended users. By leveraging the insights provided by the personas, we can enhance the overall design process and deliver a vehicle that truly meets the needs and expectations of our diverse target audience.

Persona

- **Mr Rich**
  Description
  A bachelor stockbroker who constantly keeps himself busy. He spends most of

his day, sometimes evenings, in the office. The remaining time he prefers to work out, travel, and keep to himself.

Demographics
Age: 32
Gender: Male
Location: Stockholm
Occupation: Stockbroker
Income range: 1 million sek - 1.2 million sek

Goals and needs
- To try new things.
- To find a vehicle which has desired leisure, comfort, and luggage space.
- To take part in a vehicle which has a proper top hood, as well as a windshield.

Moods and personality
- Motivated
- Disciplined
- Resilient

Problems
- Busy with his work the majority of the time
- Prone to come off as an introvert

Challenges
- Tends to sometimes easily get irritated when things don't go according to plan
- At times, finds himself uncomfortable in the unknown
- Would like to have a car which can go 'under the radar' as well as be as efficient as possible when it comes to comfort and space

Selling points
- Luggage space
- Comfort in riding
- Sporty experience

• **Race Car Driver**
Description
A professional race car driver with interest in the mechanicals behind a car's development. The interest was inherited from her father, an ex-professional racer, which helped her onto the path of racing. In her downtime, she prefers to spend time with her family, boyfriend and her friends.

Demographics
Age: 25
Gender: Female
Location: Spain
Occupation: Professional race car driver

Income range: 8million sek

Goals and needs
- To learn more about the aerodynamics behind the manufacturing of the car.
- To take part in a high-efficiency car, in a different way than what she is used to.
- To attain knowledge and experience about the custom, comfort, and design of another type of car.

Moods and personality
- Friendly
- Passionate
- Extroverted

Problems
- Still hasn't found her dream car when it comes to design and comfort
- Prone to being critical without giving it a try

Challenges
- Quite particular about how her car is supposed to look, as well as feel
- Would like to have a car which is efficient and good looking
- Lives with the motto: One shot is all you've got

Selling points
- Better Ergonomics
- High Efficiency in terms of the drag force
- Appearance of the car

- **Car Enthusiast**
  Description

  A social and family-oriented husband and father of two sons. He spends his weekdays in the office and his weekends with his wife and children. In his spare time, he likes to watch cars race, either in real life or on a screen. He also likes to take his sons out for some quality time in which they very often go out to fish.

  Demographics
  Age: 39
  Gender: Male
  Location: Skane, Sweden
  Occupation: Telemarketer
  Income range: 80,000 sek - 120,000 sek
  Goals and needs
  - To take part in a new and different experience.
  - A curious guy who needs to be up-to-date when it comes to innovations and cars.

  Moods and personality
  - Happy
  - Family-oriented

- Curious

Problems

- Spends a lot of money going on expensive trips to see cars race in real life
- Works a lot of overtime so that he can afford to pay for his trips, as well as his children's after school activities

Challenges

- Tends to put other people's happiness and needs before his own
- Can sometimes get too engrossed in his interest in cars, and might even come off as obsessed
- Has a difficult time letting go of things
- Lives with a constant need of adrenaline and trying new things

Selling points

- New innovative design
- Different from the crowd

These refined personas provide a clearer and more structured representation of the potential users of the OMotion car, helping to better understand and address their unique needs and preferences

3.2.4 Result

The survey was distributed across various social media groups dedicated to three-wheelers and car enthusiasts. Despite efforts to reach a broader audience, the survey gathered only 19 responses, significantly fewer than the anticipated 100. This lower-than-expected turnout can be attributed to the niche nature of the vehicle, which naturally limits the pool of potential respondents. Nevertheless, the data collected was invaluable. Each response provided unique insights into the preferences and needs of the target audience. To better understand and analyze this data, various graphs and charts were created. These visual tools helped to identify trends, preferences, and areas of concern among the respondents.
The analysis revealed key patterns that are crucial for the development of the OMotion car. Even with a smaller sample size, the insights gained were significant and highlighted specific requirements and expectations from the vehicle. By understanding these needs, the project team can tailor the design and features of the OMotion car to better meet the desires of its target users.

The demographic findings of the survey are illustrated in the accompanying Figure 3.13, which highlights the age and location distribution of the respondents. Notably, 100% of the respondents were male, with over 55% falling within the 30-50 age group (Figure 3.12). The survey also achieved a diverse geographical spread, with many participants hailing from southern Europe.
The graph in Figure 3.14 illustrates the features respondents prioritized in the survey. Notably, modular storage and aesthetics emerged as the most desired features.

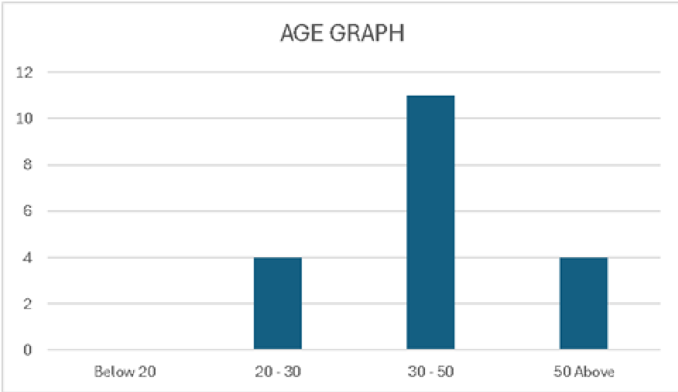
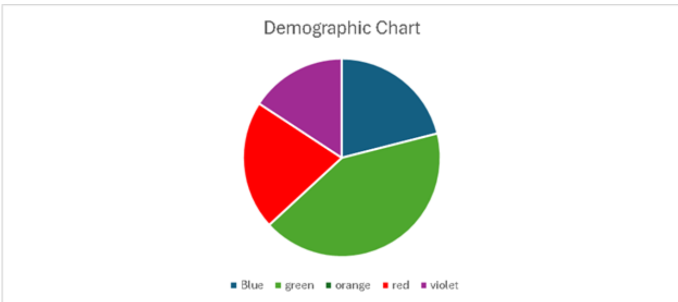


Figure 3.12: Age Graph



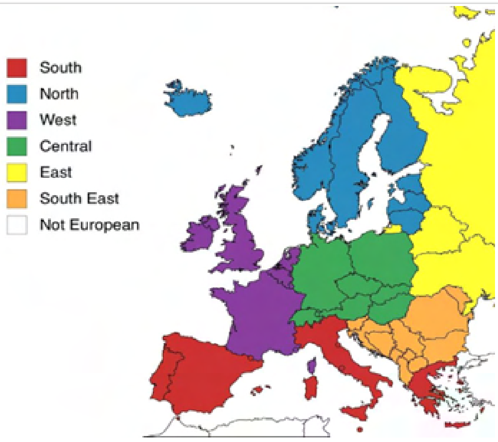


Figure 3.13: Location of the respondent [11]

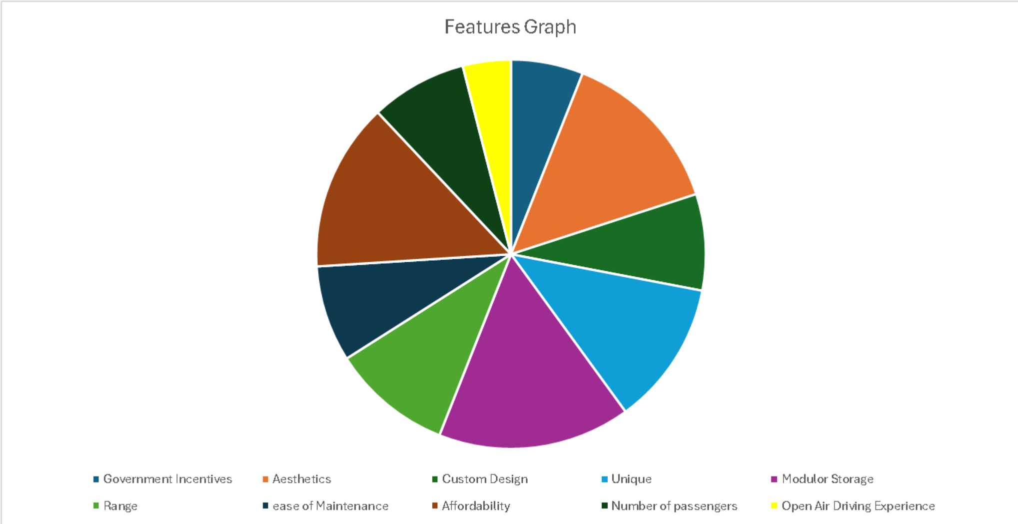


Figure 3.14: Features Graph

3.2.5 Discussion

The subsequent section delves into the findings of the user study, which proved instrumental in identifying both the project's potential and limitations. These insights served as a foundation for refining the requirement list.

Analysis of Findings
The user study offered preliminary insights into customer needs and market trends. While the survey yielded valuable data on customer preferences, including a strong emphasis on modular storage and aesthetics, its limitations must be acknowledged. Specifically, the sample size was smaller than desired, and participation from Northern Europe and Scandinavia was limited. Market analysis revealed a promising growth trajectory for electric vehicles. However, predicting the specific trajectory for three-wheelers remains challenging due to market immaturity. To establish a comprehensive requirement list, a meticulous balance between user insights, market trends, EU regulations, and stakeholder priorities is essential.

To optimize manufacturing efficiency and reduce costs, maximizing the use of standardized components will be a key design consideration. The subsequent section provides a comprehensive overview of the finalized requirements for the project, detailing each critical aspect.

3.3 Requirement finalization

The subsequent section outlines a comprehensive requirement sheet organized into eleven primary categories. Each category specifies target values and their corresponding evaluation methods.

Table 3.3: Final Requirement Sheet

Sr. No.	Category	Statement	Target Values	Req/Wish	Importance	Unit	Justification	Evaluation
1	**Weight**	Must be a lightweight Design	<1000	R	High	Kg	"Motor cycle" means any two-wheeled vehicle, with or without side-car, which is equipped with a propelling engine. Contracting Parties may also treat as motor cycles in their domestic legislation three-wheeled vehicles whose unladen mass does not exceed 1000kg.	CAD-model evaluation
2	**Design**	The Body should not have a complex design	-	W	moderate	-	Easy to Manufacture	DFAM-analysis
		open design to give freedom of motorcycle	-	R	High	-	to integrate both car and motorbike	
		Aesthetically Pleasing (Sporty)	-	R	high	-	Stake holder Requirment	
		Ergonomic Design	-	R	moderate	-	The design needs to fit person upto110kg	
		Fit and Finish	-	R	High		Fittings are not visible from outside	
		Robust Design	-	W	moderate	-	Safety purposes	
3	**Aerodynamics**	Low drag coefficient	limits to be set by previous model CAE	R	moderate		Reduced energy consumption	CAE - Analysis
		Smooth and continous Curves	-	W	moderate		Minimal flow separation	CAD-analysis
4	**Manufacturing**	Must be easy to assemble	Time to assemble	R	High		Design for Assembly	DFA-analysis
		Should be easily manufactureable by technologies and tools already or Commonly Used	-	R	High		Being a startup company the finnancial expenses needs to cut down as much as possible	Engineering assessment
		No visibility of the attachement of the out body	Min as possible	w	High			
	Regulations	Headlight	>500	R	High	mm	As per the EU regulations	CAD-analysis
			<400	R	High	mm	As per the EU regulations	CAD-analysis
5	**Performance**	vibration tolerable wrt to car body	0	R			The attcahment of the car body with the body chasis should be effecient enough to dampen vibrations	
		Robust design at high Velocity	150	R		Km/hr		CAE-Analysis
6	**Size**	Design should be compact	4*w*h	R	High	m	As per the EU regulations	CAD
7	**User Environment**	Withstand Surrounding Environment	Suitable for All weather Conditions					
8	**Cost effectiveness**	Low lifecycle cost	-	R	Low	Euro	low part replacement and Maintance cost	Cost analysis
9	**Sustainability**	Low Carbon Footprint	-	R	moderate	Kg		Grant - Edupack
10	**Product Lifecycle**	Product Life	20	R	High	Year		
11	**Materials**	Water Resistance/corrosion Resistance	-	R	High			Granta -Edupack
		Recycle material	-	W	moderate			Granta-Edupack

4
Idea Generation

4.1 Brainstorming

Brainstorming is a technique, that is used for generating a large number of creative ideas during the product development process. The concepts generated through this method do not need to be directly related to the main product but should be relevant to its sub-functions. The team members utilised this technique multiple times throughout the concept development phase to achieve better results.
Brainstorming sessions typically range from 15 to 60 minutes, depending on the complexity of the problem statement. [20] Each session started with a clearly defined problem statement or questions that generated ideas that were relevant to discussions. This approach helped the team members to keep brainstorming sessions on topic and aligned with the project objective. Visual things such as diagrams and sketches were used to bring ideas to real life. By using this method, brainstorming sessions became highly effective tools for generating a diverse range of ideas.
In the early stages of the project, these sessions were used to explore creative concepts and identify potential functional areas of the vehicle's body parts that aligned with design requirements. The generated ideas were then structured into the morphological matrix based sub-functions. In the later phase, brainstorming was used specifically focused on concept generation for particular vehicle body parts, incorporating all sub-functions defined in the Function-Means Tree. Inspiration boards served as references to guide thinking toward the most promising ideas. (Figure 4.1)
In conclusion, the goal was to generate as many ideas as possible and then at a later stage identify and eliminate those that were not meeting requirements.

4.2 Function-means tree

To gain a deeper understanding of product complexity, team members need to focus on a structural approach. This method helps team members to systematically analyse and prioritise functions to address requirements and needs. The approach involves identifying the product's primary function along with potential solutions (mean) and each selected solution will require its own supporting function. [21]

In short, this creates a repetitive pattern in a more ranked structured way. During the process one challenge was faced; when the team started breaking down primary functions into sub-functions, it was complex to break down initial stages and prioritise

them. However, this is an iterative process and after several trees, the team finalised the function tree (Figure 4.1).

4.3 Inspiration Board

An inspiration board serves as a reference tool for team members during the initial stage of concept generation. It includes images, keywords, and ideas that help team members develop creative concepts for the project. The main aim is to gain some knowledge of various vehicle body types, available features and vehicle design languages. Additionally, the board can be used as a reference point in later stages for idea refinements (chapter 5).

Method
The creation of the inspiration board involved a systematic process of collecting and organizing images based on relevant keywords. In the initial stage, images were gathered from various sources using specific keywords to capture features of vehicle and parts design. These images were sorted into various groups by sub-functions, so they could easily be accessible during the concept generation phase (sketching). Approximately, 70 images were collected. The collected images include a variety of cars, such as sports cars designed with similar body types, and specific features.

Discussion
Inspiration boards play a crucial role throughout the concept development process for OMotion's external body design. These collected images act as a visual database and help team members identify and explore various possibilities of each sub-function.
Since work is done remotely, the inspiration board was created digitally to ensure accessibility for all team members. Each sub-function, such as storage, rear-side air intake, or light positioning, is identified and categorized on the board. (Figure 4.2).
During the concept development process, the team observed that the digital board has an advantage in that it allows the team to easily add and remove images from the board. This flexibility is beneficial as it allows for quick updates and adjustments.
In short, inspiration boards are an effective tool for communicating, sharing design intentions and easily highlighting the differences between various ideas during the concept development process.

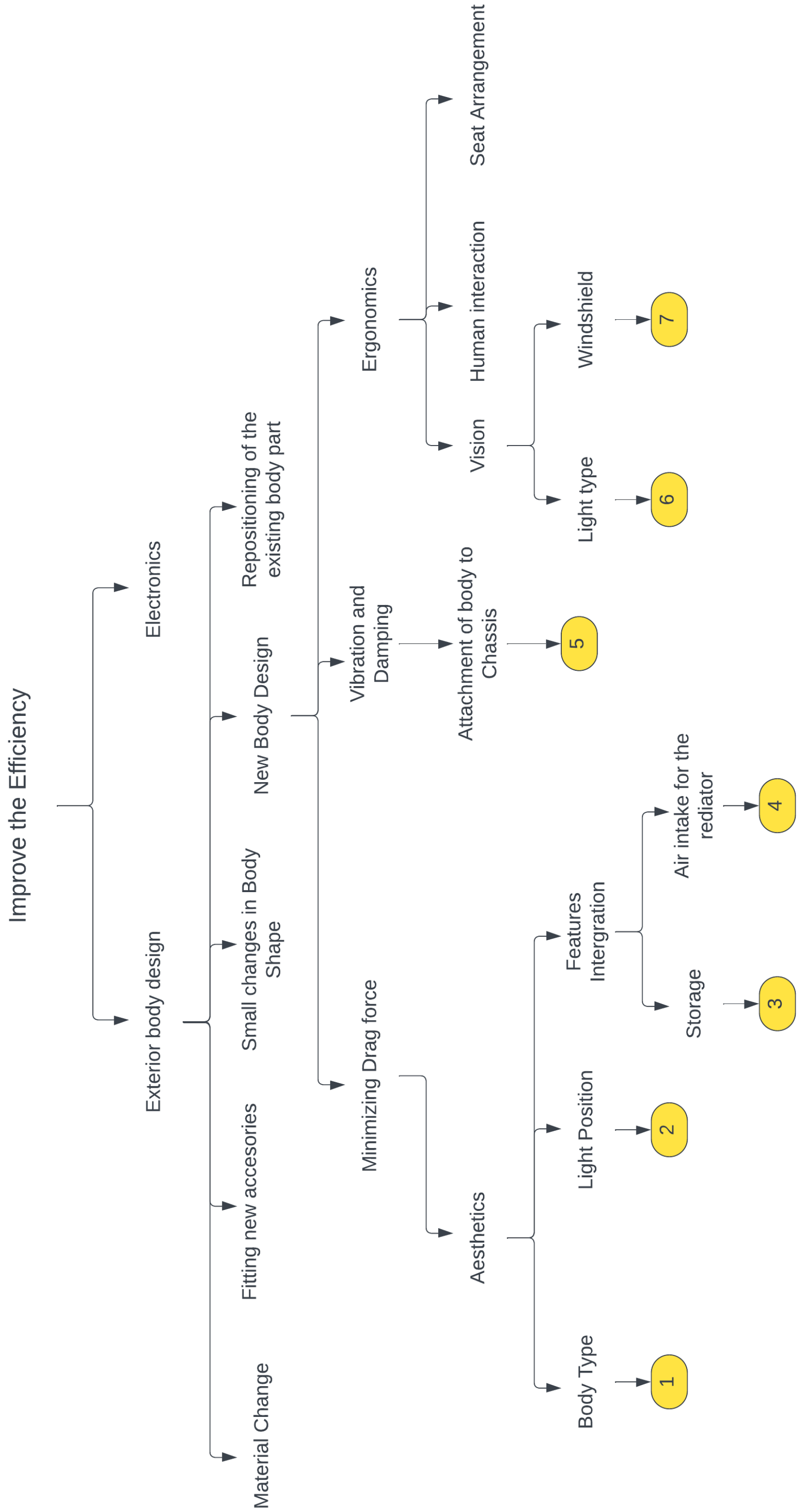


Figure 4.1: The Final Function-Means Tree

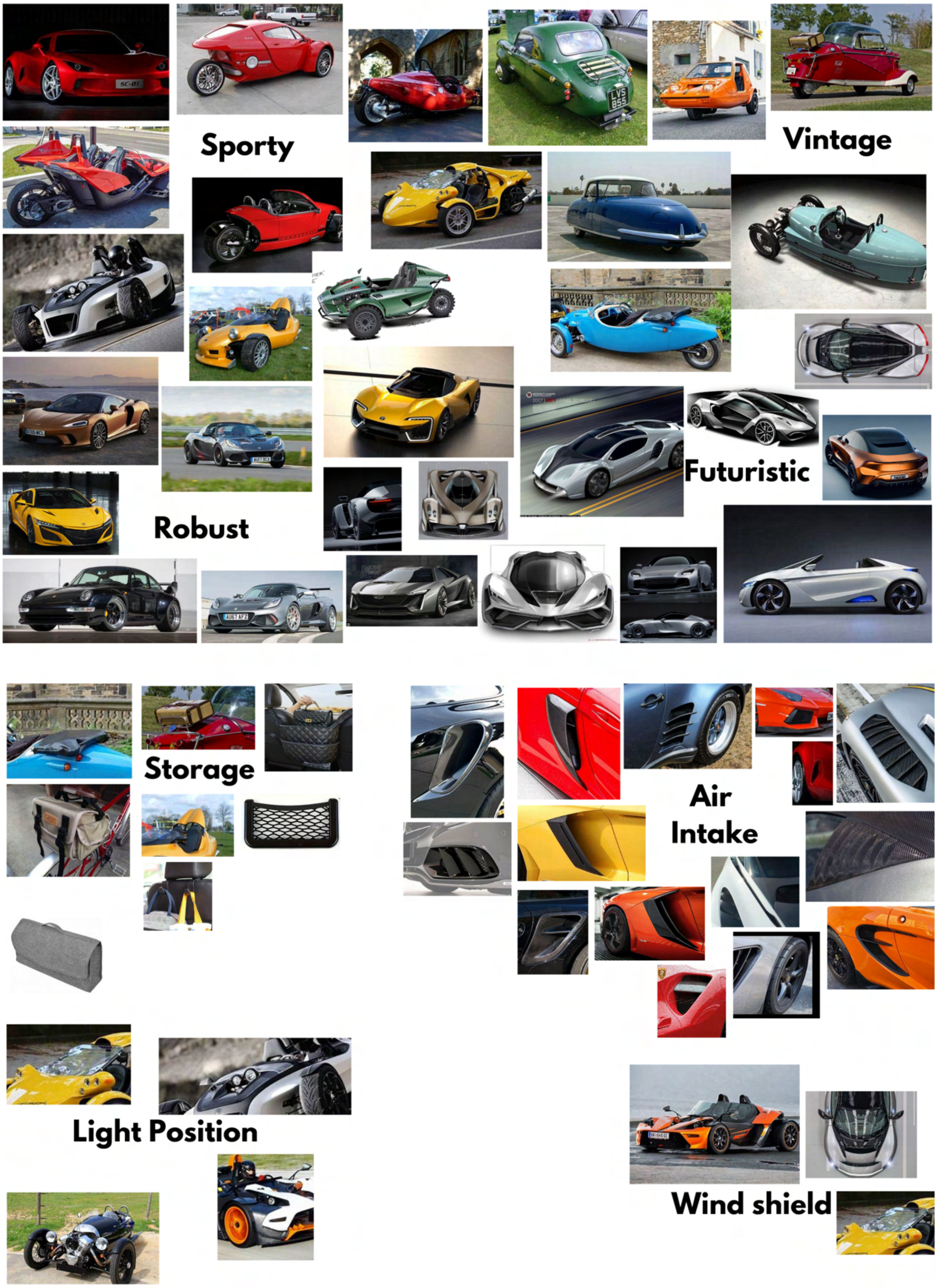


Figure 4.2: Digital Inspiration Board

5

Initial Concept Generation and Elimination

This section delves into the process of concept generation and the subsequent elimination of proposed ideas to arrive at the final design concept. Various methods, such as the morphological matrix, elimination matrix and Pugh matrix, will be utilized to identify and refine the optimal concept.

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5.1 Phase 1

Table 5.1: The initial Morphological matrix

SUB FUNCTION ↓ / SUB SOLUTION →	1	2	3	4	5
Light type	SINGLE MODULE (H,L,P)	DOUBLE MODULE (H,L\P)	TRIPLE MODULE		
Wind Shield	Shrinkable	Removable	Foldable	Single Short Height	Single full glass length
Attachment of body to chasis	Strap Fitting	Covering bush	Snap Joint	Push Fit Clamp	Adhesives
Air intake for the rear	REAR SIDE INTAKE	MIDDLE REAR INTAKE	Front side Intake		
Storage	covered compartment	Fixed side Outer Compartment	Straps Hang	Modular Rails	Open Storage
Light Attachment Position	On Front Bumper	Side panel	On Hood	Over the Wheel	
Body Type	SPORTY				

In the initial stage of concept generation, all the information gathered in the previous section, along with insights from the user study, was used to create our own

ideas. The idea generation process was conducted using a morphological matrix, as presented above in table 5.1 .
The morphological matrix comprises sub-functions and corresponding sub-solutions for each sub-function, determined through brainstorming and research. To streamline the concept generation process, a refined Morphological Matrix was created, incorporating only the best sub-solutions from the initial set as shown in table 5.2 The eliminated sub solution along with their reasons are mentioned below in Figure 5.1.

Table 5.2: The Morphological matrix after eliminating certain sub-solution

SUB FUNCTION ↓ / SUB SOLUTION →	1	2	3	4	5
Light type	SINGLE MODULE (H,L,P)	DOUBLE MODULE (H,L\P)			
Wind Shield		Removable		Single Short Height	Single full glass length
Attachment of body to chasis		Covering bush	Snap Joint	Push Fit Clamp	
Air intake for the rear	REAR SIDE INTAKE		Front side Intake		
Storage	covered compartment	Fixed side Outer Compartment		Modular Rails	
Light Position	On Front Bumper	Side panel	On Hood		
Body Type	SPORTY				

After completing the refined Morphological Matrix, certain sub-functions that could be used later were removed to simplify categorization and focus on generating the best possible outcomes as shown in Figure. 5.3. The sub-functions that significantly contributed to the design were retained. The two sub-functions which are wind shield and attachment of body to chassis will be reconsidered and potentially incorporated into concept designs later. The figure below illustrates the morphological matrix after the elimination of the sub-functions. This refined matrix will be used to generate all possible outcomes, which will then be evaluated using the elimination matrix.
In the initial screening process, the 30 ideas' feasibility was evaluated to see if they met the basic requirements of the final product. The elimination matrix is shown in Table 5.4. In the Elimination Matrix, ideas that meet a criterion are marked with a '+', and those that do not are marked with a '-'. Throughout the elimination matrix's development, various key factors were thoughtfully assessed, all informed

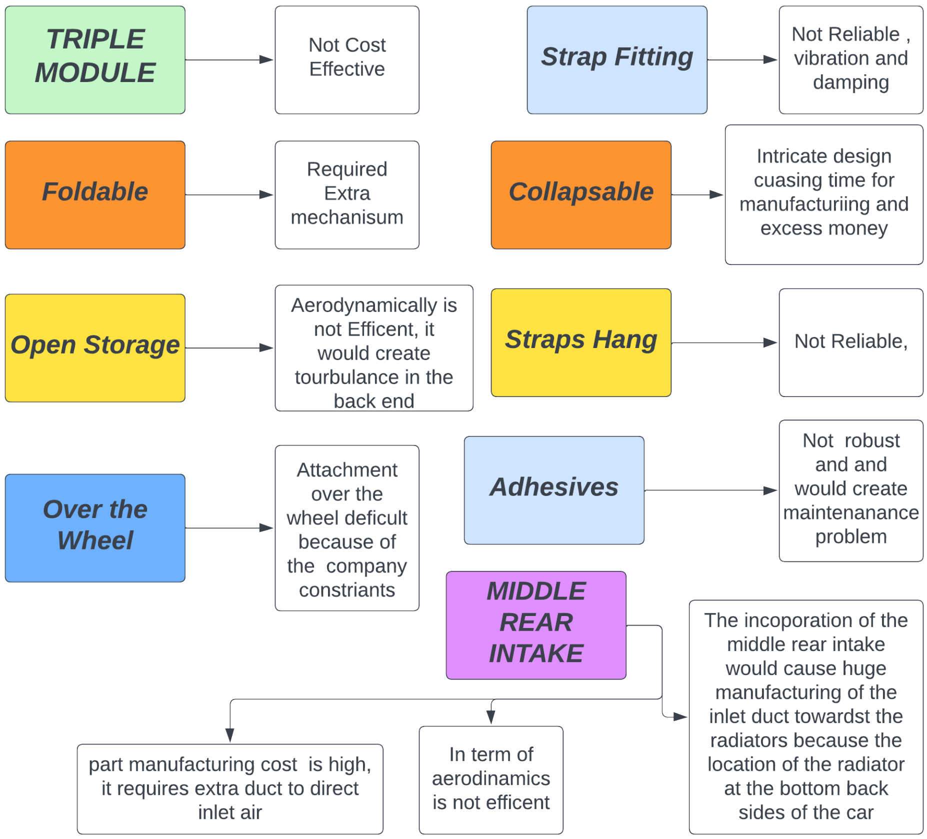
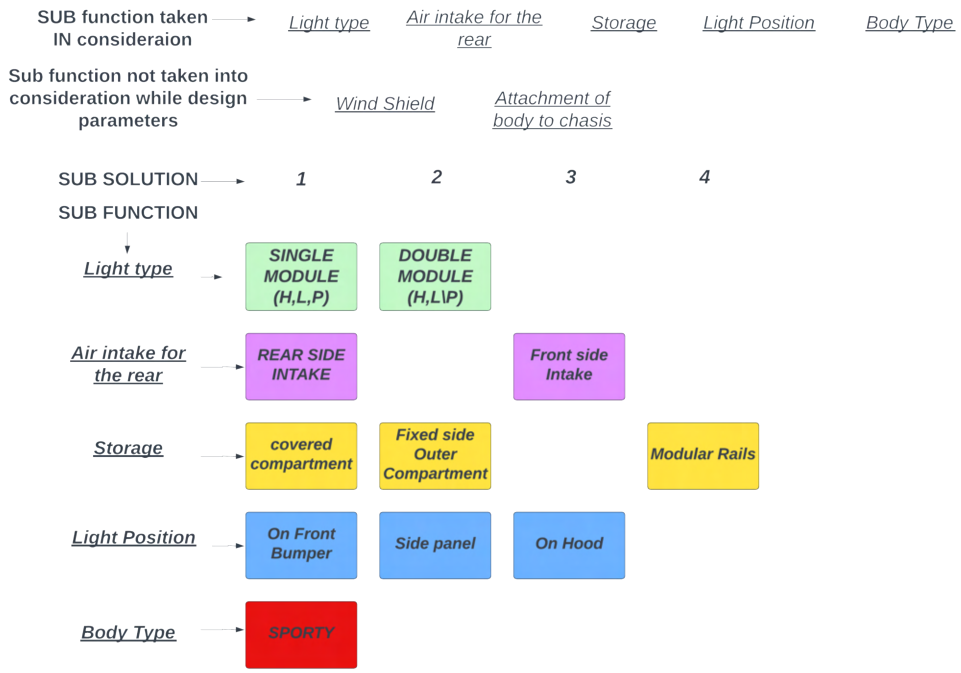


Figure 5.1: Reasons For Elimination

by engineering principles. These factors, listed below, were instrumental in shaping the decision-making process and ensuring the matrix's thoroughness and technical accuracy. The points mentioned below highlight the essential elements that were considered (Table 5.4).

- **Front Bumper Light Position** Integrating lights into the front bumper during manufacturing could be simpler and cheaper than adding them to the side panels or hood, which might require additional brackets or wiring.
- **Covered Compartment** This storage option might be more cost-effective to manufacture compared to modular rails, which often require more complex engineering and materials.
- **Front Bumper Light Position** Placing lights on the front bumper can reduce drag compared to side panel or hood placement, as it minimizes disruptions to the airflow over the body.
- **Covered Compartment Aerodynamics** A covered storage compartment (as opposed to open rails) can help maintain a smoother airflow over the rear of the vehicle, minimizing turbulence and drag.
- **Single Module Light** The single module light will have less aerodynamic hindrance as compared to the double module light.
- **Rear Side Intake** This placement can improve engine cooling and potentially reduce drag by directing air more efficiently into the radiator.

Table 5.3: Final Morphological Matrix



5.2 Phase 2

The second phase of the scoring process was carried out to gather specific information during the actual concept development process. A Pugh matrix was a good choice as an effective tool for this phase of concept scoring. It provides a systematic method for comparing multiple concepts against a set of criteria with one concept used as a reference. In order to select criteria for this matrix, the team reviewed the requirement sheet. Additionally, the team discussed the plan with stakeholders to get feedback on the criteria that the team should use for concept screening and scoring.

In the last phase of elimination (phase 1), out of 36 combinations, the team has selected 8 combinations that were screened out during this phase (Table 5.4). Using criteria such as manufacturing cost, aerodynamics and more, the team created a matrix. The matrix listed all criteria in rows and concepts as columns. In this matrix, ideas that are better than the reference are marked with a '+', those ideas equally good as the reference are marked with a '0' and those ideas considered worse are marked with a '-'. To carry out a process of evaluation, one concept must be considered a reference concept to which all other concepts will be compared. This was done by selecting one concept from each Pugh matrix, for details (see appendix). After creating and combining multiple Pugh matrixes, the team ended up selecting 4 concepts from all Pugh materix. However, some concepts had minor differences in the means (solutions), so the team decided to merge those concepts with a remark. At the end of the evaluation process the team finalized 2 concepts for the next concept development in the next stage.
After scoring and merging concepts from Pugh matrix, these combinations were

Table 5.4: The Elimination Matrix

Elimination Matrix										
Concepts					Criteria					DECISION
Light Type	Air Intake	Storage	Light Position	Body Type	Reasonable Cost	Aerodynamics	Legal Demands	Stakeholder demands	Manufactturing Complexity	
Single	Rear Side Intake	Covered Compartment	On Front Bumper	Sporty	+	+	+	-	+	fail
Single	Rear Side Intake	Covered Compartment	Side Panel	Sporty	+	+	+	-	+	fail
Single	Rear Side Intake	Covered Compartment	On Hood	Sporty	+	-	+	-	+	fail
Single	Rear Side Intake	Fixed Side Outer Compartment	On Front Bumper	Sporty	+	-	+	-	-	fail
Single	Rear Side Intake	Fixed Side Outer Compartment	Side Panel	Sporty	+	-	+	-	-	fail
Single	Rear Side Intake	Fixed Side Outer Compartment	On Hood	Sporty	+	-	+	-	-	fail
Single	Rear Side Intake	Modular Rails	On Front Bumper	Sporty	+	+	+	-	+	fail
Single	Rear Side Intake	Modular Rails	Side Panel	Sporty	+	+	+	-	+	fail
Single	Rear Side Intake	Modular Rails	On Hood	Sporty	+	-	+	-	+	fail
Single	Front Side Intake	Covered Compartment	On Front Bumper	Sporty	+	+	+	-	+	fail
Single	Front Side Intake	Covered Compartment	Side Panel	Sporty	+	+	+	-	+	fail
Single	Front Side Intake	Covered Compartment	On Hood	Sporty	+	-	+	-	+	fail
Single	Front Side Intake	Fixed Side Outer Compartment	On Front Bumper	Sporty	+	-	+	-	-	fail
Single	Front Side Intake	Fixed Side Outer Compartment	Side Panel	Sporty	+	-	+	-	-	fail
Single	Front Side Intake	Fixed Side Outer Compartment	On Hood	Sporty	+	-	+	-	-	fail
Single	Front Side Intake	Modular Rails	On Front Bumper	Sporty	+	+	+	-	+	fail
Single	Front Side Intake	Modular Rails	Side Panel	Sporty	+	+	+	-	+	fail
Single	Front Side Intake	Modular Rails	On Hood	Sporty	+	-	+	-	+	fail
Double	Rear Side Intake	Covered Compartment	On Front Bumper	Sporty	+	+	+	+	+	pass
Double	Rear Side Intake	Covered Compartment	Side Panel	Sporty	+	+	+	+	+	pass
Double	Rear Side Intake	Covered Compartment	On Hood	Sporty	+	-	+	+	+	fail
Double	Rear Side Intake	Fixed Side Outer Compartment	On Front Bumper	Sporty	+	-	+	+	-	fail
Double	Rear Side Intake	Fixed Side Outer Compartment	Side Panel	Sporty	+	-	+	+	-	fail
Double	Rear Side Intake	Fixed Side Outer Compartment	On Hood	Sporty	+	-	+	+	-	fail
Double	Rear Side Intake	Modular Rails	On Front Bumper	Sporty	+	+	+	+	+	pass
Double	Rear Side Intake	Modular Rails	Side Panel	Sporty	+	+	+	+	+	pass
Double	Rear Side Intake	Modular Rails	On Hood	Sporty	+	-	+	+	+	fail
Double	Front Side Intake	Covered Compartment	On Front Bumper	Sporty	+	+	+	+	+	pass
Double	Front Side Intake	Covered Compartment	Side Panel	Sporty	+	+	+	+	+	pass
Double	Front Side Intake	Covered Compartment	On Hood	Sporty	+	-	+	+	+	fail
Double	Front Side Intake	Fixed Side Outer Compartment	On Front Bumper	Sporty	+	-	+	+	-	fail
Double	Front Side Intake	Fixed Side Outer Compartment	Side Panel	Sporty	+	+	+	+	-	fail
Double	Front Side Intake	Fixed Side Outer Compartment	On Hood	Sporty	+	-	+	+	-	fail
Double	Front Side Intake	Modular Rails	On Front Bumper	Sporty	+	+	+	+	+	pass
Double	Front Side Intake	Modular Rails	Side Panel	Sporty	+	+	+	+	+	pass
Double	Front Side Intake	Modular Rails	On Hood	Sporty	+	-	+	+	+	fail

discussed with the stockholder before starting actual sketching of the concepts. Following in detailed discussion, the team concluded that rear side air intake and front bumper headlight positions were convenient options for manufacturing vehicles as it did not add any extra cost or increase the number of parts in design.
To demonstrate an example of how the team has filled matrix, a comparison made between concepts 26 and 36 is elaborated below (Table 5.5)

- **Manufacturing cost** Because of its complexity and modular rails, Concept 36 requires extra body parts. This increases manufacturing costs compared to the reference concept.
  Decision Worse than reference.

- **Design complexity** Concept 36 features a front-side air intake. This design requires internal parts to be rearranged to fit properly, and additional arrangements are needed to accommodate the modular rails and bulky body parts.
  Decision Worse than reference.

Table 5.5: The Pugh matrix

Pugh Matrix 3rd combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	+	+	ref	-	+	+	-	-
Design complexity	+	+		0	+	+	0	-
Aerodynamic	+	+		-	+	+	-	-
Non-compliance with Regulations	0	0		-	0	-	0	0
Stakeholder Impact	+	+		+	-	-	-	-
Σ+	4	4	0	1	3	3	0	0
Σ-	0	0	0	3	1	2	3	4
ΣS	1	1	0	1	1	0	2	1
Net Value	4	4	0	-2	2	1	-3	-4
Further Development	YES	YES	No	No	YES	YES	No	No
Ranking	1	1	4	5	2	3	6	7

- **Aerodynamics** In Concept 36, modular rails are used for storage. Compared to covered storage, this disrupts airflow and increases drag, resulting in noise and vibrations while driving.
  Decision Worse than reference.

- **Non-compliance with regulations** Both concepts meet the required safety standards.
  Decision Same as reference.

- **Stakeholder impact** Standardized parts in vehicles allow for minimal changes. However, Concept 36 requires major changes to the rear structure of the chassis compared to the reference.
  Decision Worse than reference.

6

Concept Development

After narrowing down the options and discarding the less suitable concepts, one design was chosen that aligns with all the required criteria. The selected concept is a "Rear side air intake with a covered compartment and dual lights on the front bumper." This design has been finalized and is further developed in the following section, complete with sketches, models, attachments, and renderings.

6.1 Overall Concept Idea

After a thorough evaluation and elimination of various design concepts, the final selection centres on a car featuring a rear air intake positioned at the back, complemented by a covered luggage compartment. This design incorporates dual front lights: one serving as the position lamp, and the other offering both high and low-beam functionalities, strategically mounted above the front bumper. This configuration not only enhances aerodynamic efficiency but also optimizes lighting performance, ensuring both style and safety are seamlessly integrated into the vehicle's design.

While the overall layout of the car's key features has been established, the next chapter delves into various design iterations that were explored. Throughout this process, regular meetings with stakeholders were held to ensure they remained informed and engaged as the design evolved. This ongoing collaboration and refinement continued until the final design was fully developed and approved. The attachment of the exterior body to the chassis is a critical consideration in the design process. In the previous OMotion model, the chassis attachment points were visible, which negatively impacted both the vehicle's aesthetics and its aerodynamic efficiency. During the design phase, it is essential to plan the attachment points in a way that minimizes their visibility. This approach will help maintain a sleek appearance while also optimizing aerodynamic performance.

6.2 Form Development

During the concept generation phase, it is important to recognize certain key factors that impose constraints on the design process. Given that OMotion is a startup with limited capital, the company aims to minimize changes in the new model, which places specific restrictions on the development of new concepts.

The limitations set by OMotion for the new model were as follows:

- The chassis of the new model should undergo minimal changes from the previous model.
- The new model will use the same manufacturing method as the previous version, specifically vacuum forming. This decision introduces certain design constraints, as the process requires the new design to be compatible with the existing manufacturing setup. Vacuum forming, while cost-effective and efficient for producing lightweight components, limits the complexity of shapes and features that can be incorporated into the design, necessitating careful consideration during the concept development phase.
- To minimize manufacturing costs, the exterior body should be designed with as few parts as possible. Reducing the number of components will decrease the need for additional moulds, which can significantly lower production expenses.
- The company plans to scale up production to 300 vehicles within a year, so the design must be adaptable to this level of production with minimal changes to the existing manufacturing process.
- As a startup, the company aims to avoid the substantial costs associated with developing entirely new lighting systems. Therefore, ECE-approved standard lights will be utilized to keep production expenses manageable.
- A good way of fitting the exterior body to the chassis without the attachment being visible.

6.3 Sketching

Purpose
Sketching is a crucial part of the idea generation process. While it may not deliver a fully detailed concept, it serves as a foundational tool for exploring various possibilities and refining ideas. Through initial sketches, a range of concepts can be visualized and evaluated, paving the way toward the development of a final design. Regular sketching sessions, combined with ongoing meetings with stakeholders, fostered collaboration and allowed for continuous feedback, ultimately guiding the project toward a well-informed and successful outcome.
The process of sketching was carried out simultaneously with regular meetings and brainstorming sessions hence all the sketches are not placed chronologically.

Method
In the sketching phase of the three-wheeler OMotion design, we did a lot of iterations based on various themes. We showed these to stakeholders at every stage and took their feedback. Their collaboration was very important to understand their vision and refine the sketches until we got an exact sense of what they wanted and what they were aiming for.
Most of the sketches were developed using the problem-solving method. This provided us with an opportunity to explore multiple solutions by selecting different shapes, themes, and design ideas for the sub-functions of the vehicle while keeping the wheel configuration the same as that of OMotion. For example, if one chooses a theme like "snake," the shapes and design elements will be inspired by the snake's

fluid and dynamic characteristics. We worked across many themes, iteratively refining the rough sketches to get the best design.
By doing this, we were able to come up with some creative concepts that were not only visually interesting but met the technical requirements and vision of the stakeholders.

Results
We then followed up on the draft designs with meetings for review and refinement of ideas with stakeholders. During the sessions, we went through a process of filtering out and isolating those sketches that best related to what the stakeholders envisioned for the project. We ended up with two final promising options.
These two sketches captured most of the ideas that the stakeholders were looking for and provided a great foundation from which to tackle the next phase of development. With their approval, we moved into 3D CAD moulding, where we would begin to turn these concepts into detailed, three-dimensional designs. This gave us the opportunity for further iteration and refinement of the designs, providing a certain guarantee that the final product will meet the technical requirements and fulfill the project's creative and aesthetic purposes.
Below the sketches that went on to the next phase are shown in Figures 6.5 and Figure 6.4.

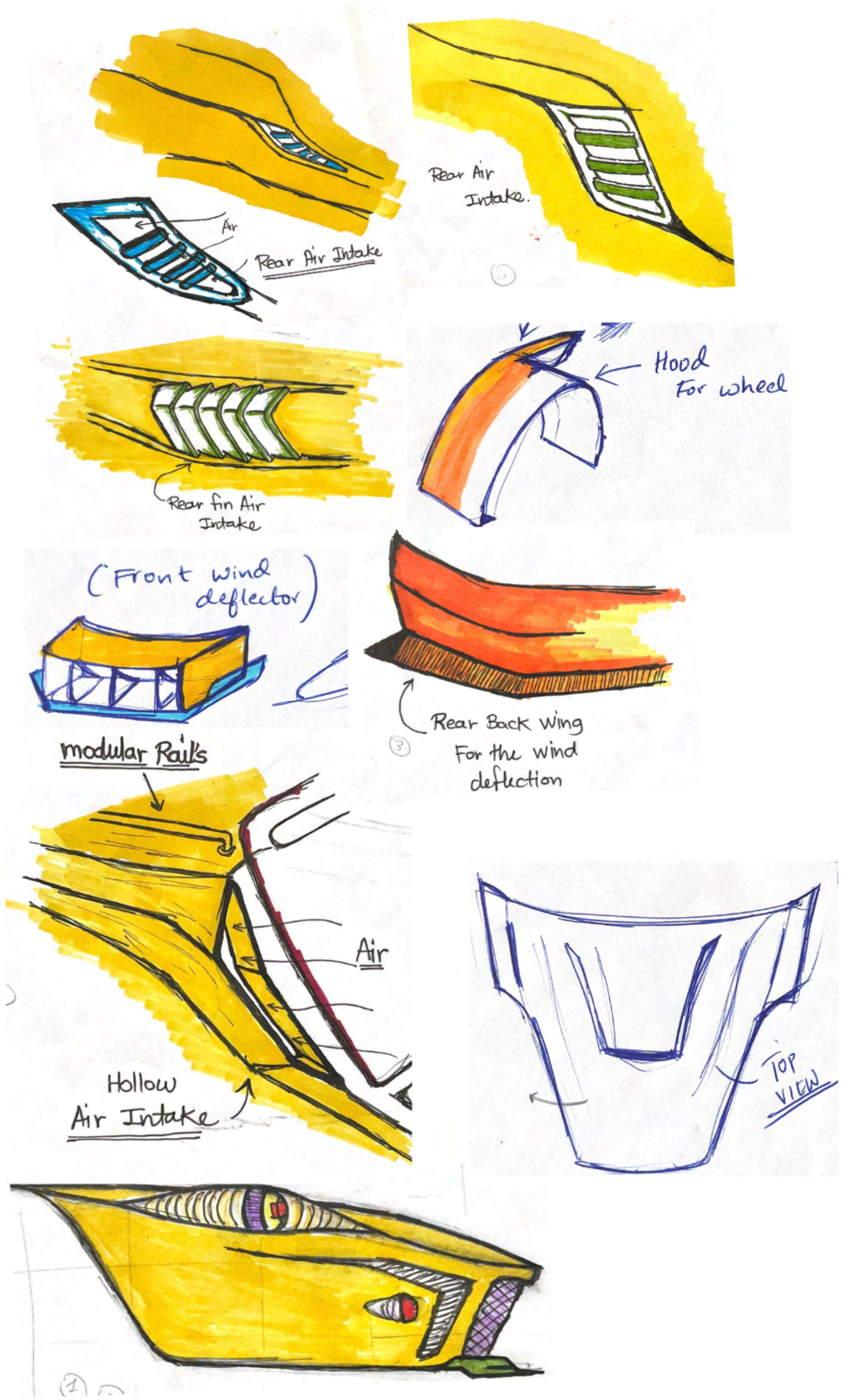


Figure 6.1: Basic sketching ideas for air intake

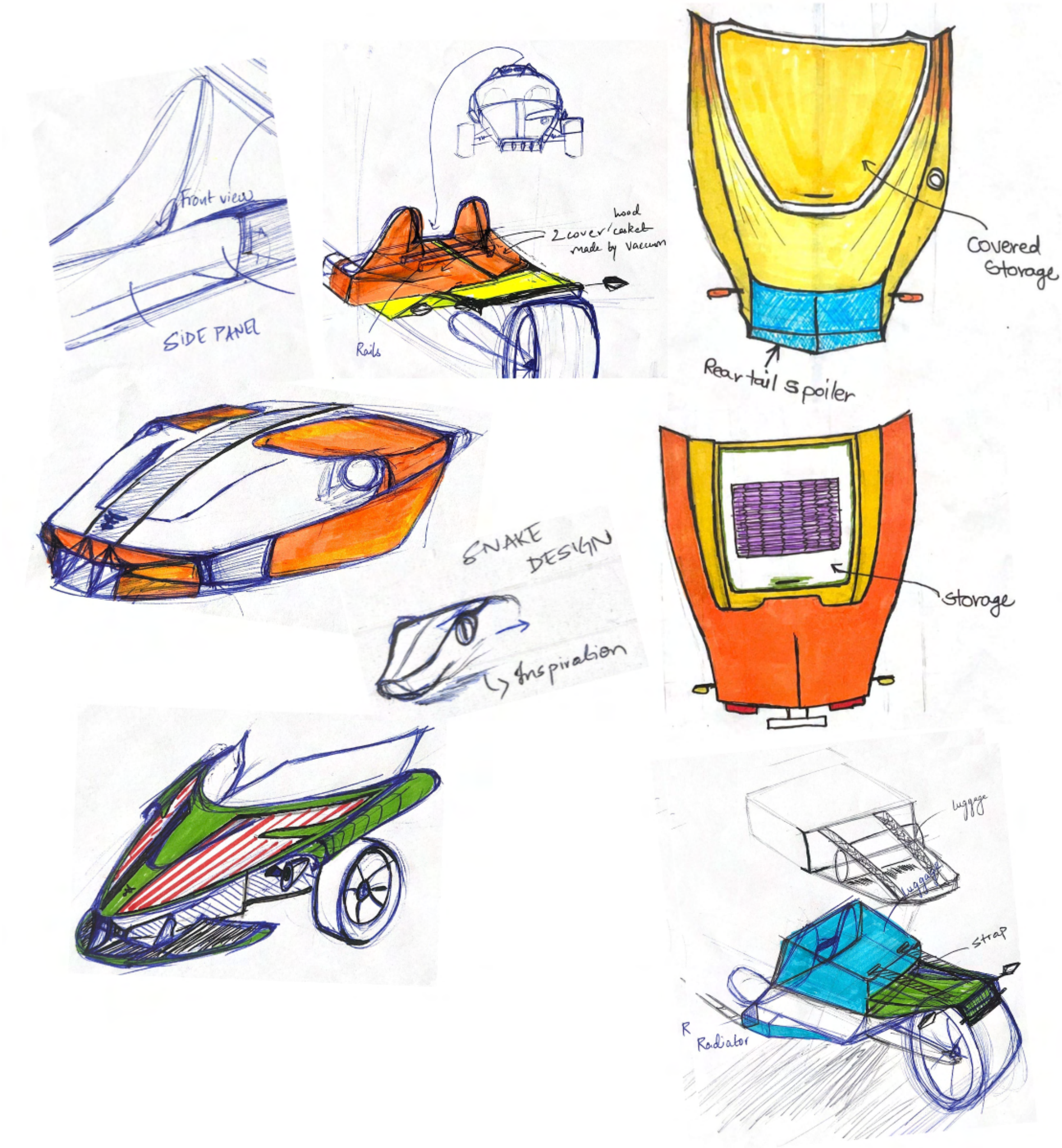


Figure 6.2: Ideas for storage compartment

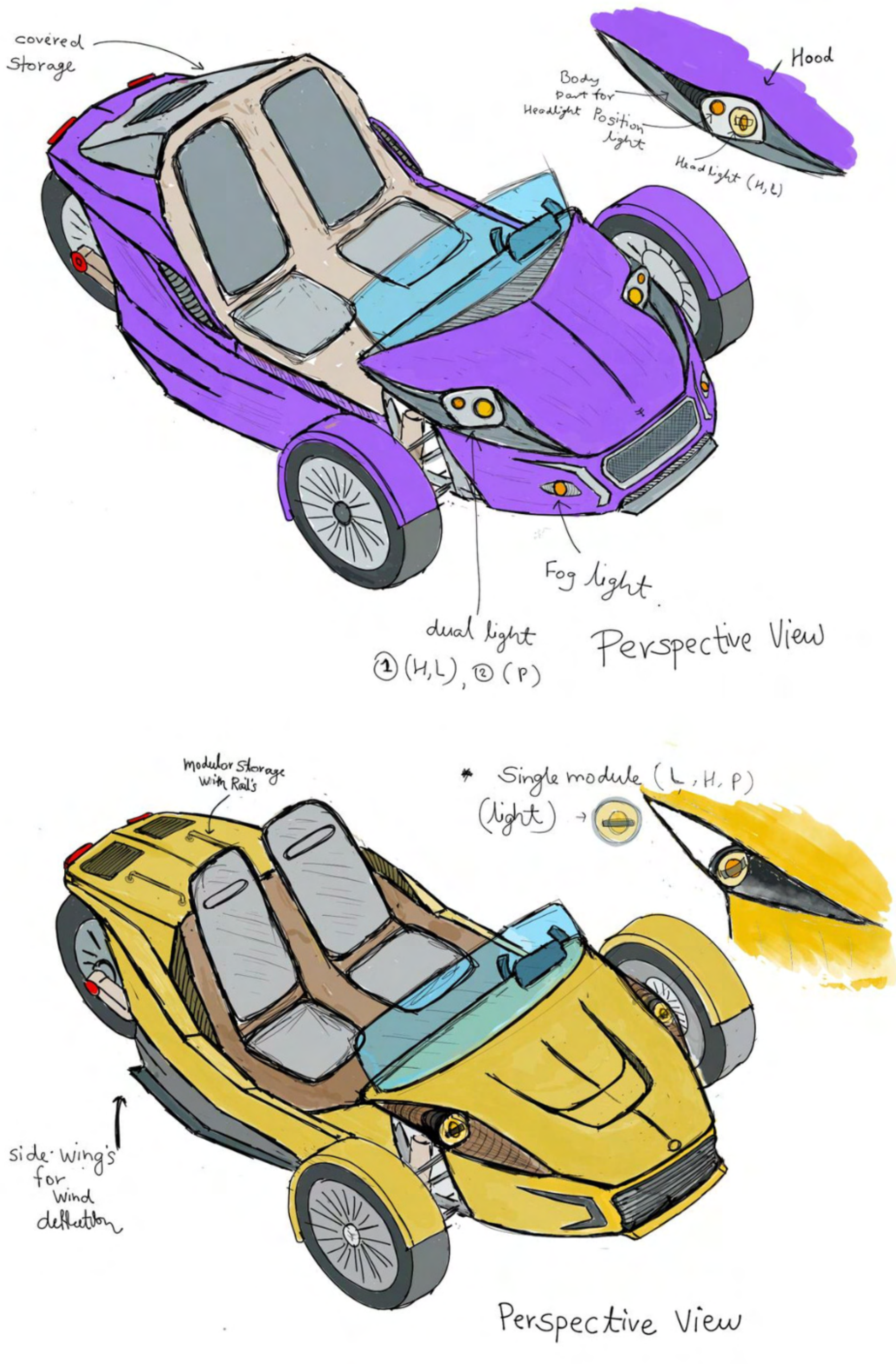


Figure 6.3: Sketches for basic vision of the car

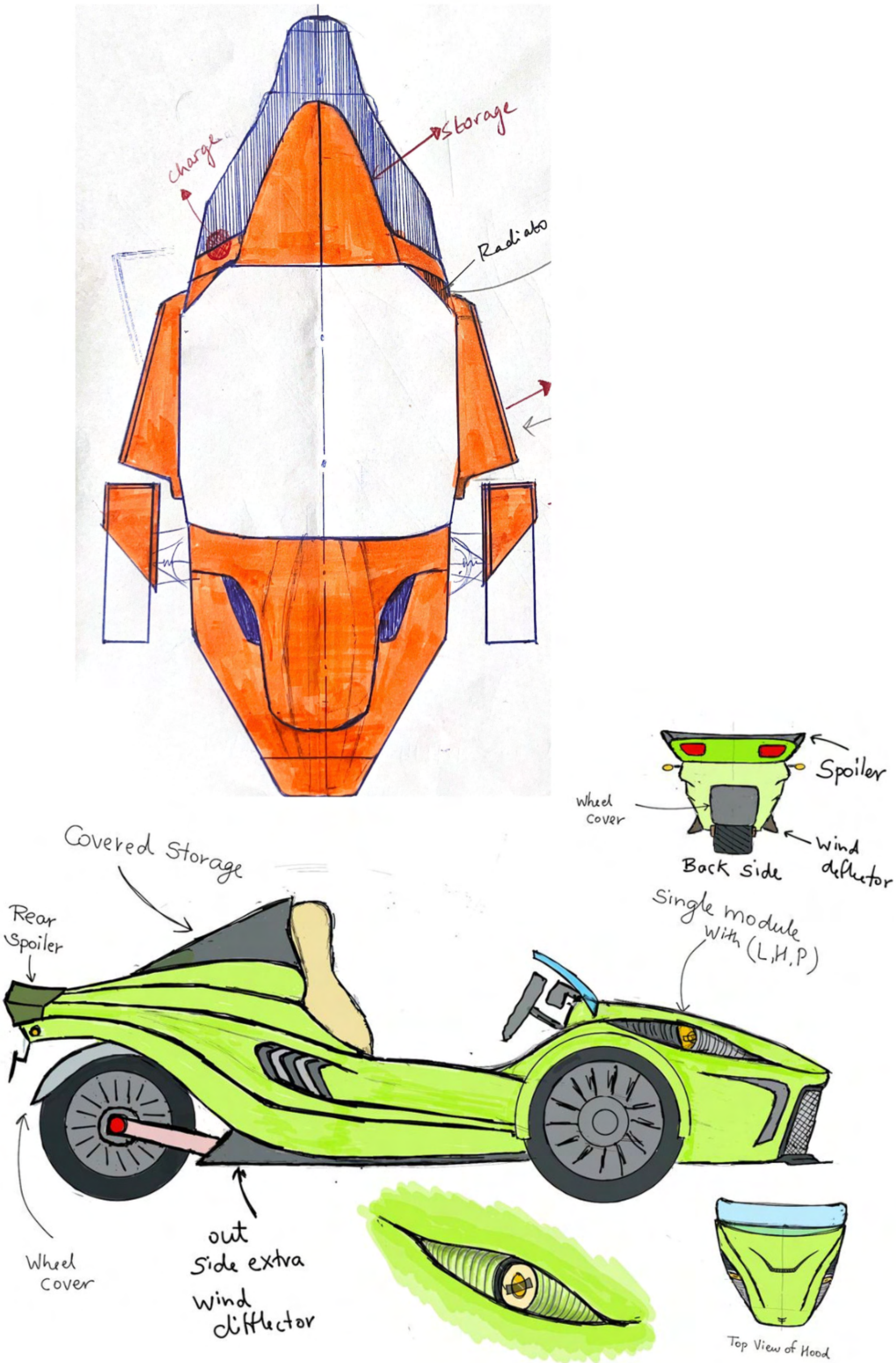


Figure 6.4: Sketches that went to the next phase of CAD modeling

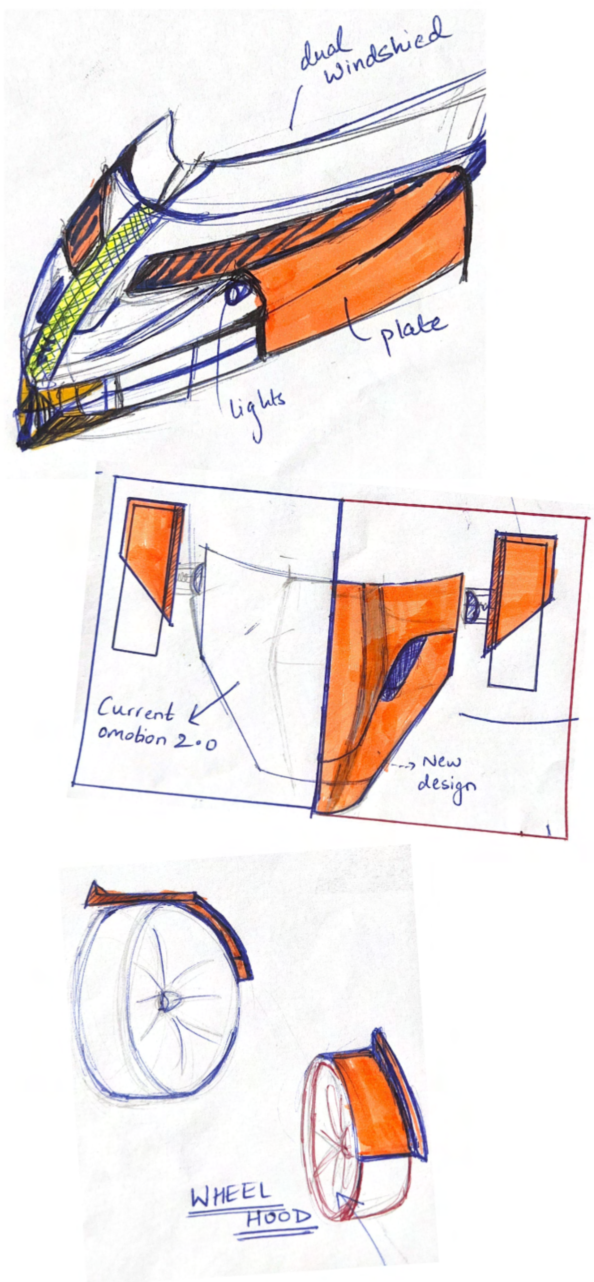


Figure 6.5: Sketches that went to the next phase of CAD modeling

7
Final Concept

This chapter presents the final outcome of the master's thesis project and provides an overview of the actual CAD design process. It started with an explaining of how our team started sketching the final idea in Alias Software and progressed to creating the final CAD model. It highlights the steps and how the team took to transform concepts into a fully developed design.

7.1 Devlopment Stage

In the concept development phase, the team finalized several design sketches that would be used as the basis for the final CAD model. Autodesk Alias software [22] was used in this development stage to design the vehicle's initial surface. This software is widely used in the automotive industry to create high-quality Class-A surfaces, which are crucial for achieving good finished vehicle parts.

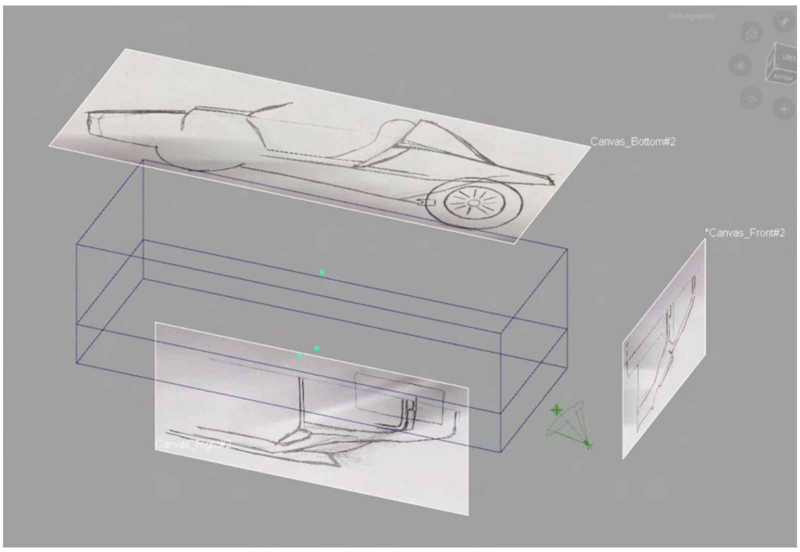


Figure 7.1: Canvas and Design Space

In order to start the actual design process, the team created a reference box to understand the actual available design space. This reference box is important for future processes as it provides a clear understanding of the vehicle's dimensions. The team then imported 2D drawings of side views of the final concept into the software and used them as reference canvas. (Figure 7.1) It is important to note that the dimensions of the reference box were the same as those of the current production vehicle.

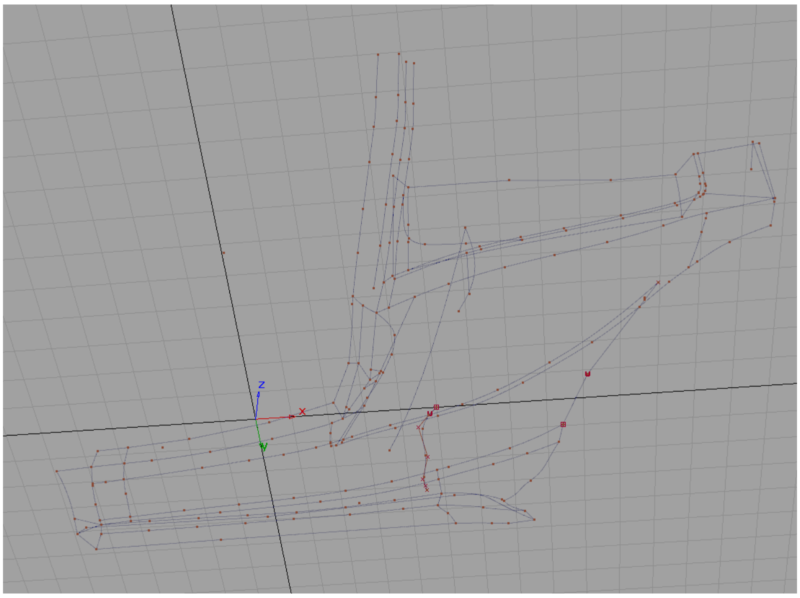


Figure 7.2: Initial Plotted Curves

Method
After setting up the basic references in the software, the team started the initial curve plotting process to define the vehicle's shape. These curves were plotted with a minimal number of spans and a maximum degree of 6 (a term specific to Alias software), ensuring the smoothest possible curves. (Figure 7.2)

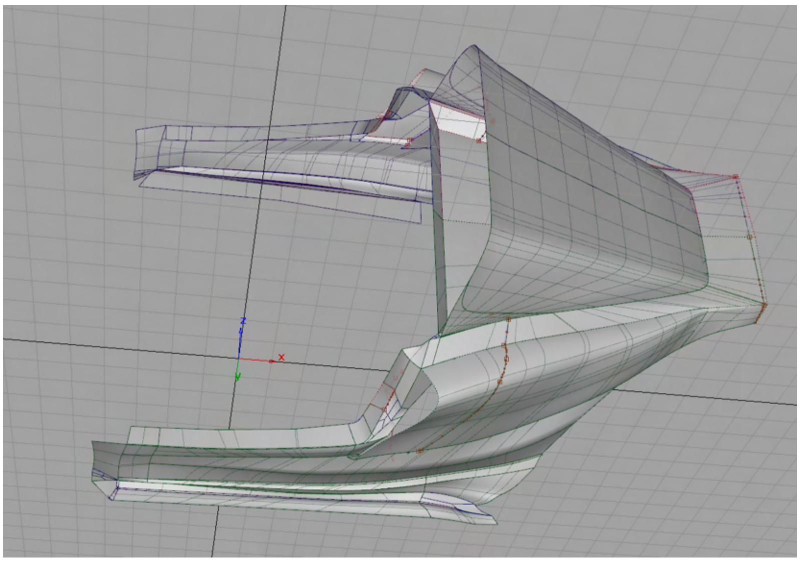


Figure 7.3: The Finished Surfaces

Using these curves as foundation, the team started to create surfaces. After the surface, the next step involved trimming these surfaces to shape the actual com-

ponents of the vehicles. This was the most challenging work of the process, as it involved trimming excess surfaces and refining the edges by adding curvature and fillets. These adjustments were crucial for smoothing out any sharp edges, ensuring that the final design was both aesthetically pleasing and functionally effective.
Once the basic shape of the vehicle parts were established, the team started adjusting the design using curves and control vertices (CVs) to achieve smooth, finished surfaces. This adjustment allowed the team to fine-tune the shape of each part, ensuring it aligned with the team's final design (imagination). (Figure 7.3)

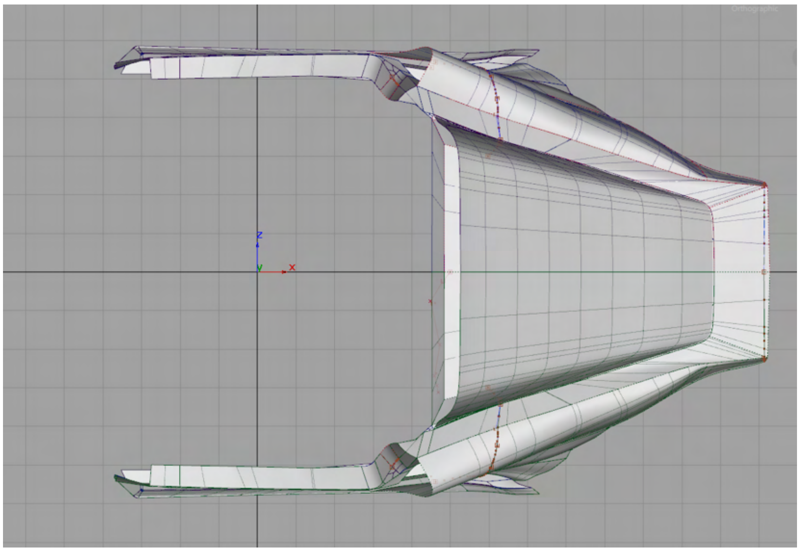


Figure 7.4: The Finished Surfaces Top Veiw

7.2 Detailed Development of Design

The detailed design phase focuses on modelling the actual 3D CAD parts at their full scale. After creating surfaces in Alias, the team imported that file into CAD software to develop each component. This process involves converting surfaces into thickened sheets, preparing each part for manufacturing and ensuring proper placement of each part for easy assembly. Additionally, the team considered Design for Manufacturing and Assembly (DFMA) principles to ensure efficient and cost effective production.

Method
The team has started this stage in a step-by-step manner to achieve a detailed design. First, the surfaces created in Alias were grouped in NX software and converted into thickened parts. Adding thickness to the surface was important for converting them into a sheet, repairing those surfaces and trimming away excess material to form the actual shape of each part. Generally, the vacuum forming process uses a sheet with a thickness of 4 to 6 mm for part manufacturing. For this project, the team chose a thickness of 4 mm for the CAD model parts.

One key requirement was that screws should not be visible from the outside. To meet this requirement, the team adjusted or designed each part to hide these screws from the front-facing surface while ensuring ease of assembly. Each part was fixed on a minimum of 3 sides to ensure proper attachment to the chassis. DFMA principles were also applied to each part, keeping manufacturing efficiency in mind. For example, the team aimed to reduce the number of parts and complexity of each design to lower production costs and improve assembly speed. Special attention was given to ensuring that gaps between two parts were uniform so that all parts would fit together correctly without noticeable gaps or misalignments.

The team also carefully thought of appropriate manufacturing processes for each part. Once the basic shapes were completed, the team moved on to the detailed finishing touches. This involved adding fillets to smooth out sharp corners, which was important for improving the appearance of the parts. A minimum fillet radius of 4 mm was used for each part, considering both manufacturing and aesthetic requirements.

Finally, the teams carefully checked each and every part to confirm it fit properly according to design and manufacturing requirements. The next step involved assembling all these parts on the chassis. For assembly, the team made minor adjustments to the main chassis, such as modifications to the attachment solutions and structural modifications. This was a stakeholder requirement, as the goal was to use the same main chassis for the new vehicle with only minor changes to the current design. By following DFME principles, the team ensured that the final design was functional and ready for smooth production and assembly.The numbering in the assembly figures indicates the sequence of each assembly part.

As illustrated in the final design renderings, these are the final parts of the final concept. The team grouped all parts into main categories

Front Side parts
The front parts assembly consists of four sub-parts (Figure 7.5)
Front bumper, Side panel, Top hood, Headlight module.
Leg side parts
The leg side parts assembly consists of two sub-parts (Figure 7.7)
Leg side panel, Tire protection.
Back side parts
The back side parts assembly consists of six sub-parts (Figure 7.9)
Air intake vents and their support, Main panel, Top panel, Tail panel, Air deflection sheet.
Top parts
The top parts assembly consists of three sub-parts (Figure 7.11)
Storage door, Storage door support, Top frame
Each group was designed with specific functions and an assembly sequence for proper fittings.

7.2.1 Front Side Parts

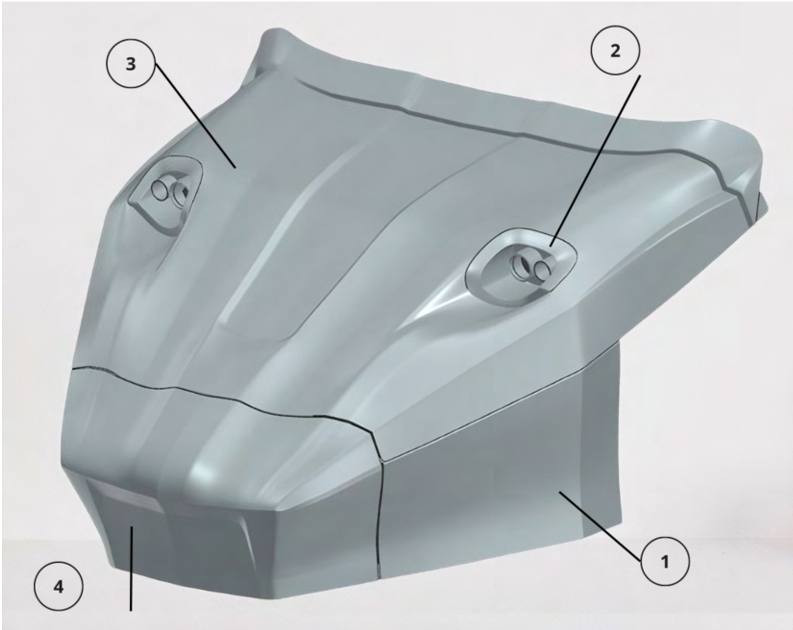


Figure 7.5: Front Side parts

The front side assembly includes all components that form the vehicle's front section in the final design. These parts are designed not only to enhance the aerodynamics and aesthetics of the vehicle's front side but also to provide protection and meet stakeholder requirements. It includes various parts.
The front bumper is a critical component designed to minimize drag , maintain a smooth airflow over the vehicle while providing protection to the front end. The manufacturing process chosen for the front bumper is vacuum forming, a method well-suited for creating lightweight and durable parts with complex shapes. During assembly, the bumper is bolted to the lower side of the vehicle's frame as well as internally to ensure a secure fit. This design ensures that the bumper remains well aligned with the vehicle's aerodynamic profile.(Figure 7.6)
The side panel extends from the front bumper, contributing to the vehicle's continued aerodynamic profile. This panel is relatively simple in design but plays an important role in ensuring the continuity of the aerodynamic shape from the front to the sides of the vehicle. It is also manufactured using a vacuum-forming process. The panel is assembled onto the chassis after or before the front bumper and it is secured from three sides.
The front hood is the main part of the front side and it covers all critical equipment and electronics fixed in the vehicle's front compartment. To maintain the aerodynamic efficacy, the hood is designed as a single panel. This panel is the last fitting part in the front assembly, following the installation of the headlight module. The screws used to attach the hood part are located on the lower side and back side, ensuring they are not visible on the front surface while providing easy access for assembly and maintenance. (Figure 7.6)
The headlight module is designed for headlights and position lights. According to

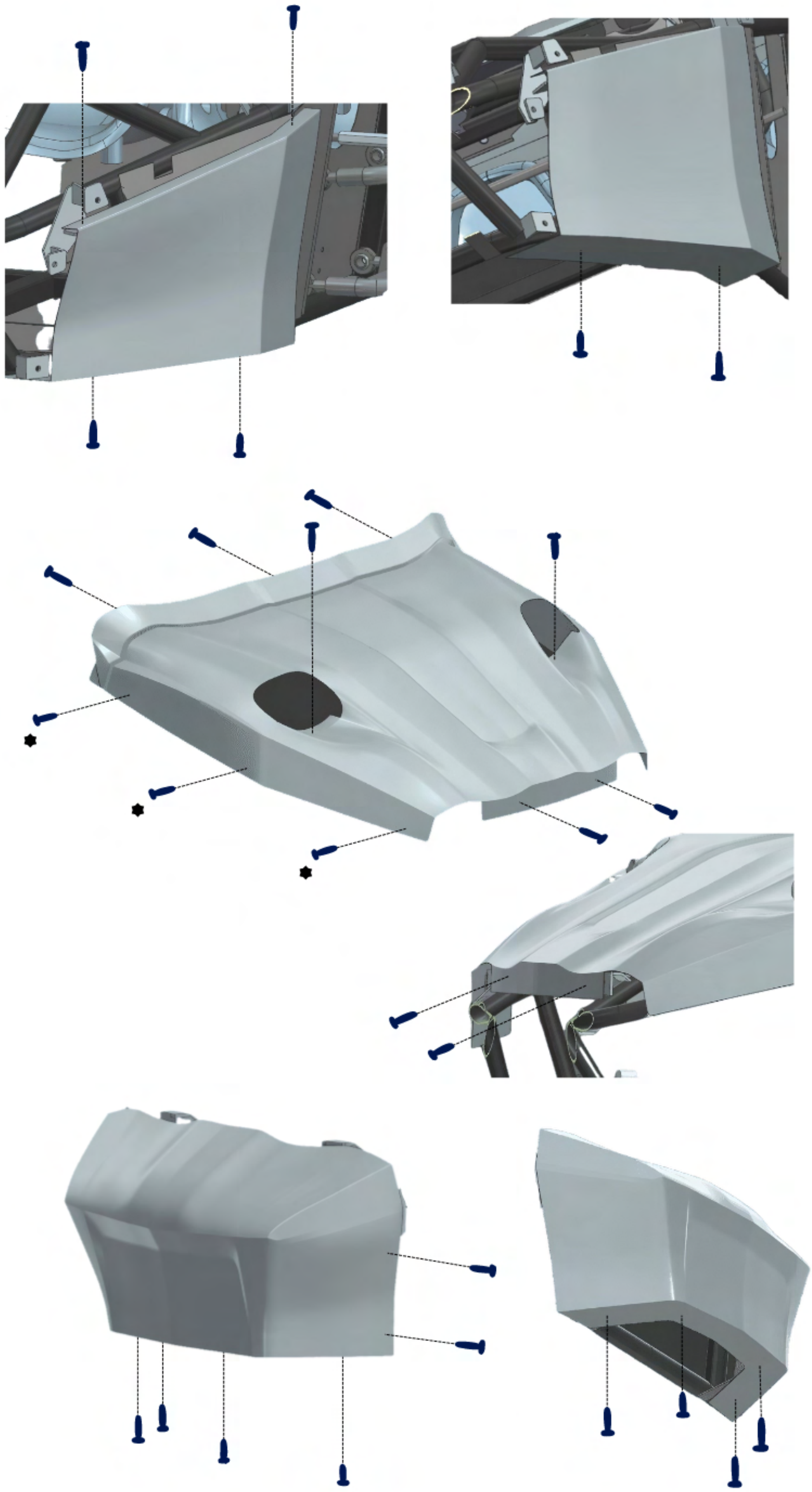


Figure 7.6: Front Parts Assembly

EU guidelines, a minimum distance of 40mm is required between these lights, and this specification has been included in the design. Due to the need for a precise finish and the exact alignment of components, vacuum forming is not suitable for this part. Instead, injection moulding is a suitable option, as it allows for greater precision and ensures the proper fitting of the headlight lenses. The headlight module is installed before the top hood and fastened securely to the frame with mounting brackets.
In conclusion, the assembly sequence of all parts is shown in (Figure 7.5) This sequence ensures efficient assembly and minimizes any potential interference between components.

7.2.2 Leg Side Parts

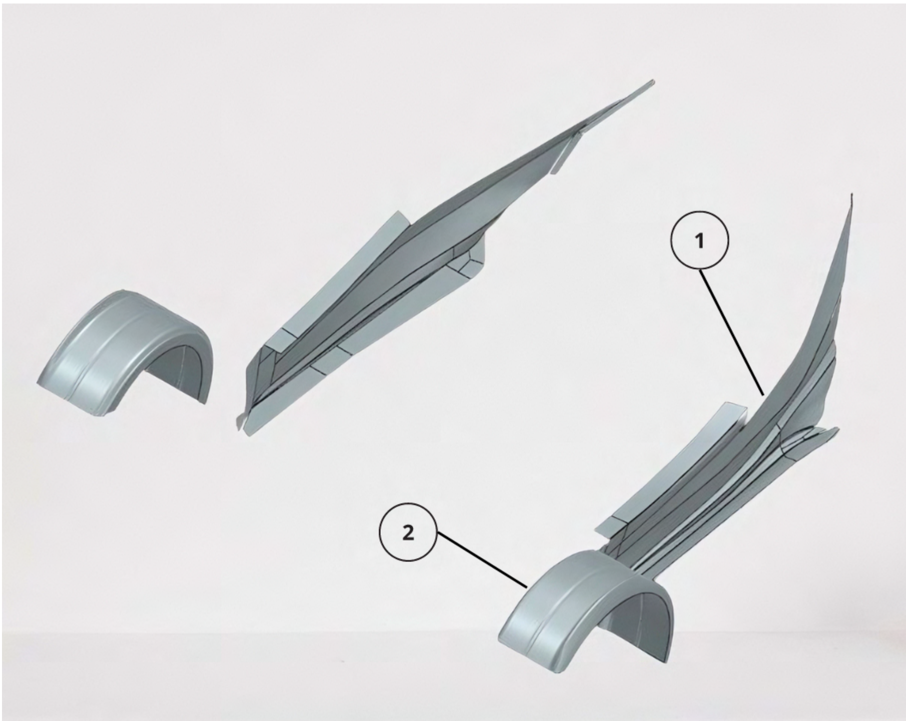


Figure 7.7: Leg Side Parts

The leg side parts group focuses on side panels and protective components that enhance a vehicles functionality and safety . These parts are essential for protecting and covering the sides of vehicles and ensuring overall stability.
Tyre protection parts such as mudguards, are designed to shield vehicles from mud and debris thrown up by the tires. These parts are strategically designed and positioned to avoid collisions with the leg side panels or the car body during turns. A distinctive extension or "bump" runs along the outer edge of the tyre protection part to improve the aerodynamic flow around the wheel wells. Due to the simple design of parts, they can be manufactured by the vacuum forming process. Tire protection parts can be fitted either early in the assembly process or at the very end.
The leg side panel extends along the vehicle side, providing a streamlined appearance while covering and protecting the lower portion of the vehicle. Due to its larger

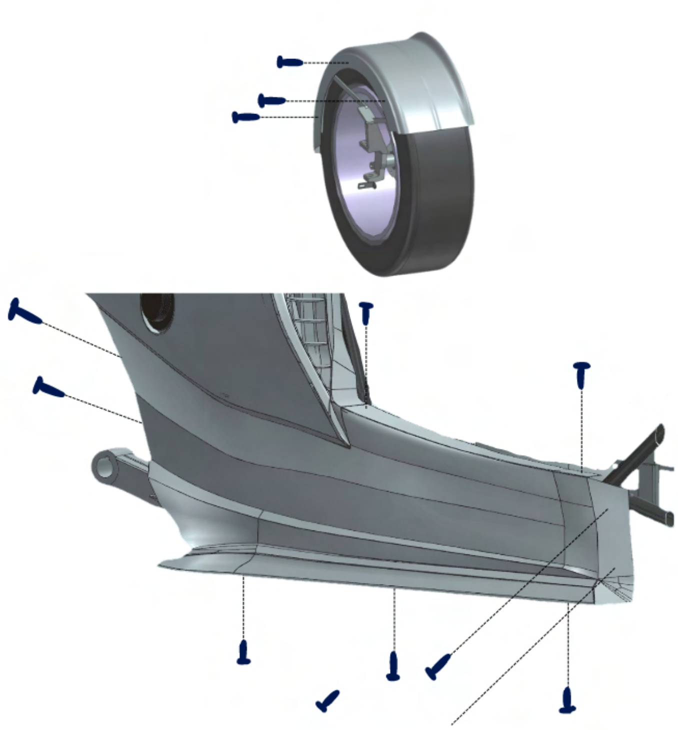


Figure 7.8: Leg Side Parts Assembly

size and streamlined design, injection moulding is considered the appropriate manufacturing process for these plastic panels. These panels are assembled after the back side parts and are installed at multiple points along the bottom side, back lower side, and top side to the chassis. (Figure 7.8)

7.2.3 Back Side Parts

The back side parts group consists of components that shape the vehicle's rear section, focusing on air ventilation, structure support and aerodynamics.

Air intake vents are designed to channel airflow to the radiator and engine components. These vents, along with their support components and an air deflection sheet, are manufactured using different processes based on their complexity. The support part and air deflection sheet have relatively simple shapes and they are easily manufactured by using the vacuum forming process. However, the air intake vent part is one of the more complex parts of the whole car body requiring a high-quality fit and finish. Therefore, injection moulding is a more suitable manufacturing method for these vents, as it provides the necessary precision and surface quality. During assembly, the support panel is installed first to provide a base, followed by the installation of the air intake vents to ensure proper alignment and fit.

The main back panel serves as a key surface in the overall rear design, providing support and covering the rear interior components of the vehicle as well as other body parts. Because of its relatively straightforward shape, it can be easily manufactured using vacuum forming. This panel is installed after air intake vents, because it serves as a base for mounting other components, such as the top back panel.

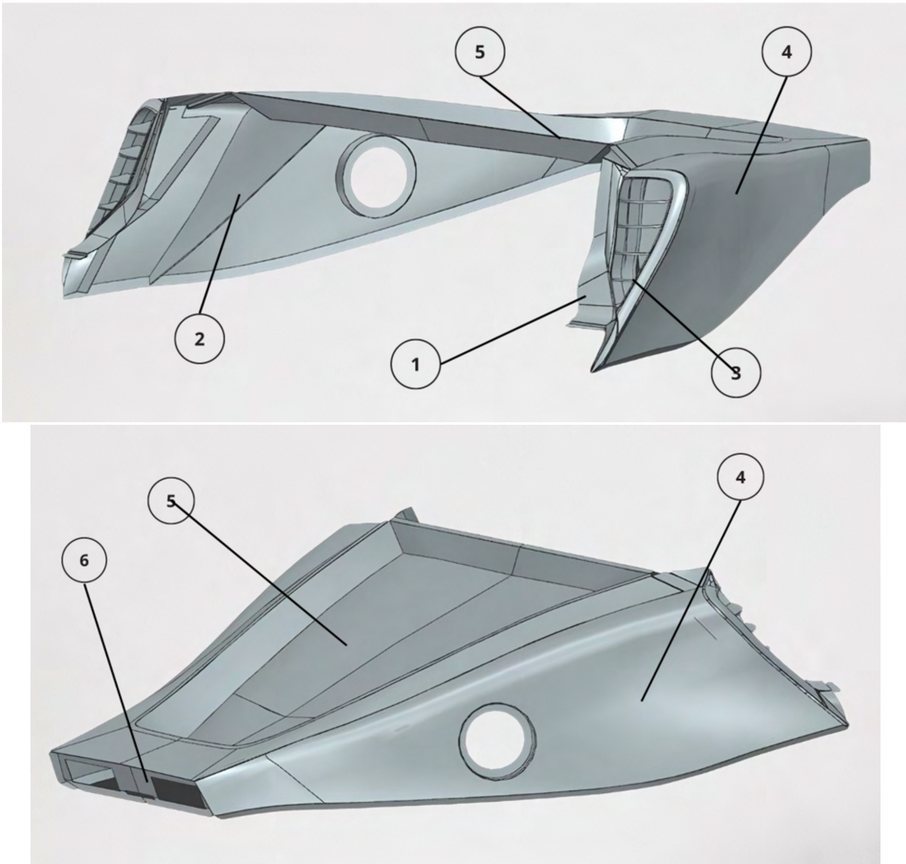


Figure 7.9: Back Side Parts

The top back panel is designed to provide support and cover components in the design, protecting the internal electronics from above while also providing support for the upper assembly parts. (Figure 7.10)

The tail light panel houses and supports the tail lights and the number plate assembly. This panel can be easily manufactured using sheet metal due to its simpler shape. It is assembled before the main back panel to simplify easy assembly and electrical connections for the tail lights.

7.2.4 Top Parts

The top parts group includes components that are installed after the rear section assembly to support key features, such as the storage door and its supporting element, as well as finishing parts like the seat back cover panel.

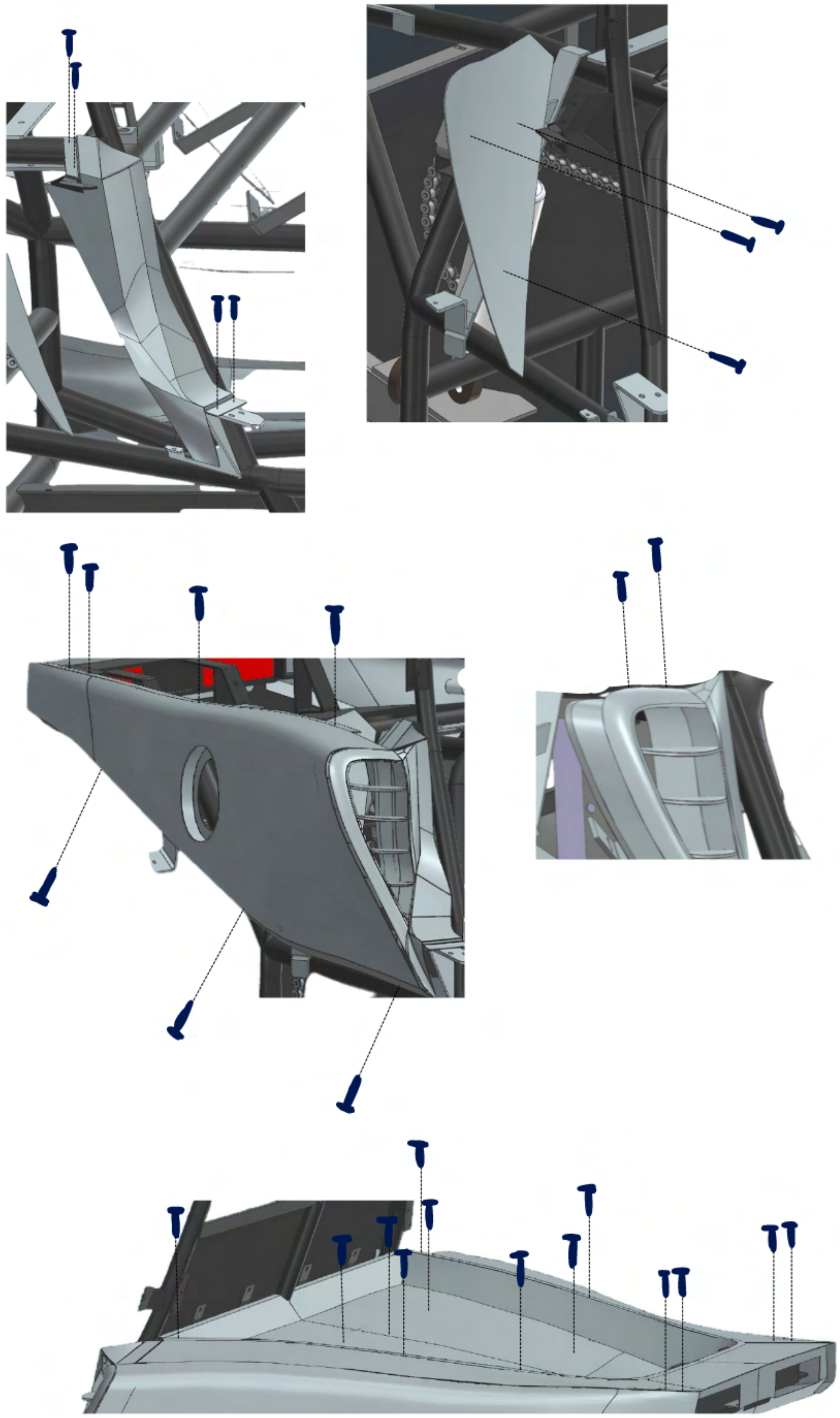


Figure 7.10: Back Side Parts Assembly

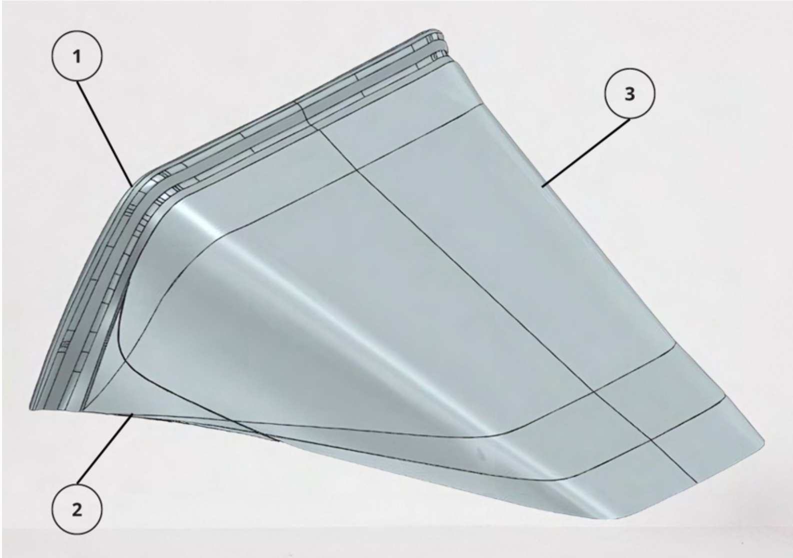


Figure 7.11: Top Parts

The top frame is the main component in this group of assemblies. Its primary purpose is to cover the structure of the main chassis while providing support for other components. The frame is designed to integrate seamlessly with the rear assembly parts, effectively covering any gaps between them to ensure a continuous and smooth flow. This not only enhances the vehicle's aesthetic appeal but also contributes to its aerodynamic efficiency. (Figure 7.12)

The storage door and its supporting parts are designed as a hinged panel that provides access to a storage compartment. The design is lightweight but strong, with smooth contours and a sleek exterior that aligns with the overall vehicle's design language. This ensures that the storage door is both visually appealing and aerodynamically efficient. The door opens upward, allowing for easy access to the store.

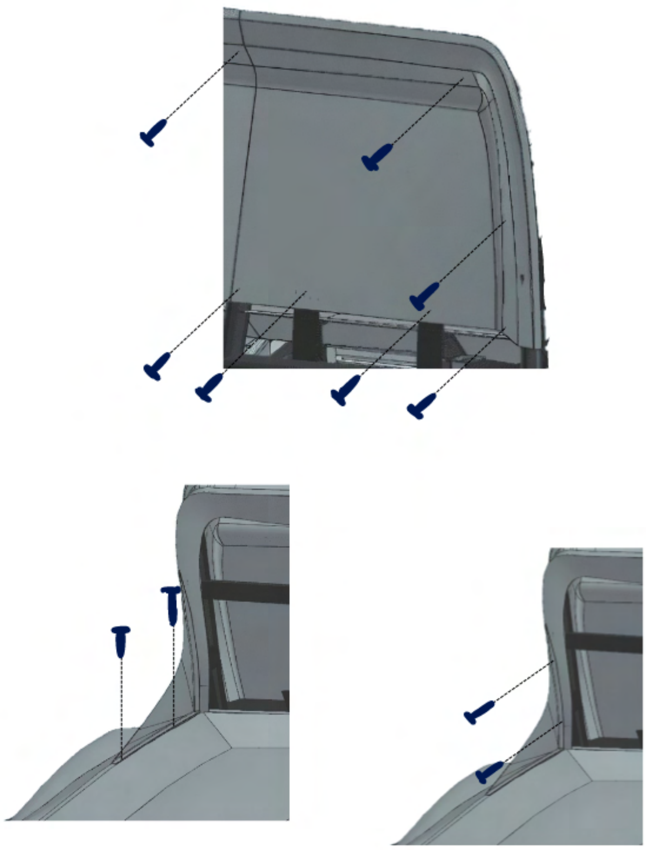


Figure 7.12: Top Parts Assembly

8

Design Evaluation

8.1 Simulation

This section presents the evaluation of the final design concept for a three-wheeler vehicle concerning its aerodynamic performance. Simulation plays an important role, offering verification of the design and its efficiency in general before the physical prototype stage. We can develop an understanding, through aerodynamic simulation software, of how the vehicle interacts with airflow and begin to identify improvement areas that will allow the design to meet our desired performance criteria. These simulations greatly enlighten us as to the efficiency, stability, and overall effectiveness of the vehicle to refine the design and move closer to a final, optimized product.

8.1.1 Method

Aerodynamic simulations for the final design of the three-wheeler have been done using Simcenter STAR-CCM+ software [23]. This advanced tool gives us a platform for performing detailed fluid dynamics analysis, hence enabling us to predict the correct behavior of the vehicle's aerodynamics. The entire simulation process was done in five steps, in a structured manner that helped in detail performance evaluation of the design:

- **Geometry Cleaning** The preparation of the CAD model of the three-wheeler was first done to ensure that the geometry of the model was perfect and devoid of imperfections. Geometry cleaning is a necessary part of model preparation; it involves the removal of all extra details that are too complex for simulations.

- **Meshing** It is one of the discretization processes of a model into a finite number of small cells to solve complicated model equations governing fluid flow. The mesh quality is important since it directly affects the accuracy and stability of the simulation. The mesh was generated, emphasizing finer meshes around the areas of interest for example, wheels and body,where the flow would be highly complex.

- **Setting Initial Conditions** Once the mesh was prepared, the setup of the simulation was started by defining the initial conditions. This mainly includes the definition of parameters like airflow speed, pressure, and temperature that realistically represent actual operational conditions.

- **Running the Simulation** After defining the initial conditions, the simulation was run. This software analyzes the flow in contact with the vehicle and the atmosphere that surrounds it based on resistance, lift, and turbulence factors. Sometimes, this is a computationally heavy process, which takes hours to complete, depending on the complexity of the model and the accuracy of the mesh. The outcome of this simulation shows detailed information about the aerodynamic efficiency of the vehicle.

- **Evaluation of Results** The final step of the process was verification and analysis of the simulation results, including detailed analysis of different outputs such as pressure distribution, airflow characteristics, and drag coefficients. From these analyses, it was possible to identify the aspects in which the design is top-notch and aspects that need improvement according to the needs of the requirements of the final design.

8.1.2 Geometry Cleaning

Geometry cleaning involved removing all model components deemed unnecessary and would not significantly impact the simulation results. This step is necessary to reduce the complexity of the model and shorten the overall time taken for the simulation. Figure 8.1 below shows the components and surfaces retained for the simulation, focusing mainly on the outer surfaces, chassis, and tires.

Figure 8.1: Model used for the simulation

This cleaning geometry process could have been optimized by simulating only half of the vehicle since the whole simulation time and computational resource requirements would have been significantly reduced. Given the symmetric configuration of the three-wheeler, only one side needed to be modeled and then reflected to represent the complete vehicle's aerodynamic characteristics. This is a common approach used to make simulations more manageable while still arriving at accurate assessments of the vehicle's performance.

However, it was decided to simulate the full vehicle. The whole model visualization was essential in the in-depth understanding of the flow behavior, which otherwise might be poorly represented in a half-model simulation by explaining the complex airflow phenomena.

Further in the phase of geometric cleaning, a virtual tunnel was created to simulate the surrounding effect as shown in Figure 8.2. Subsequently, boundary conditions were applied within this virtual wind tunnel to replicate real-world driving conditions.

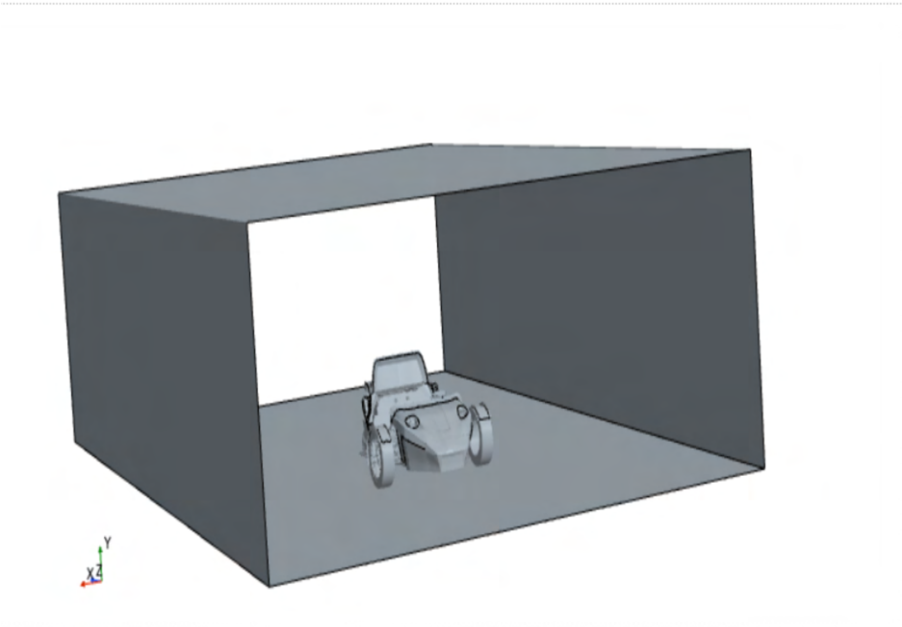


Figure 8.2: Domain used for the model simulation

8.1.3 Meshing

During the meshing process, this model was divided into thousands of tiny elements; each is analyzed separately for its contribution to the overall flow characteristics. Such division is necessary for accurate simulation of the complex aerodynamic vehicle interactions with the surrounding airflow. However, due to the complexity and the high number of components involved in the model, some minor defects in the form of overlaps and intercepts were observed in the model, as shown in Figure 8.3.

These issues were overcome with a procedure called surface wrapping, which created a new clean surface layer over the existing geometry. This successfully smoothed minor defects without affecting the overall shape of the model. The result of this procedure ensures that the mesh generated within the model is of high quality and well-defined, non-intersecting elements provide an accurate and reliable aerodynamic simulation. Figure 8.4 and Fig 8.5 shown below depict the surface wrap on the new conceptual model.

Geometry Diagnostics

#	Display	Error Description	Count
1	✓	Self Intersection	21
2	✓	Invalid Spline Definition	0
3	✓	Invalid Geometry	0
4	✓	Tolerant Geometry	17
5	✓	Overlapping Entities	16
6	✓	Topology Errors	2
7	✓	Non-Manifold Geometry	0
8	✓	Bad Part/Assembly/Instance Data	0

Figure 8.3: The minor defects in the model

After the surface wrapping process was over, the model was taken for meshing as shown in Figure 8.6. This mesh was then prepared using the given initial conditions to conduct the simulation.

8.1.4 Setting Initial Conditions

The simulation of the vehicle's aerodynamic performance was conducted for two different cases. The first case provided the model of the vehicle at a velocity of 40 km/h, which is representative of typical low-speed applications such as in-city driving and other low-speed maneuvers. This case is necessary since it helps understand how the vehicle's aerodynamics interact with performance during lower velocities, where characteristics of airflow may be substantially different from those encountered at high speeds.
The second criterion involved simulating the vehicle at a reasonable speed of 110 km/h, a factor necessary for characterizing its performance conditions typical of highway driving or quick acceleration. Simulations carried out with a high-speed vehicle provide much-needed information regarding the reaction of the vehicle to increased aerodynamic forces acting on it, including drag and lift, and their implications for stability and fuel efficiency.
By inspecting the performance of the vehicle at 40 km/h and at 110 km/h, one is able to get a proper feel for the aerodynamics of the vehicle. The analysis will ensure that the design meets all the required performance and safety standards over a wide range of operational speeds.

8.1.5 Running the Simulation

Once the model was ready with cleaned-up geometry, a mesh was created, and boundary conditions were applied, then the actual simulation run for the aerodynamics was performed. This involved the setup of the simulation software to com-

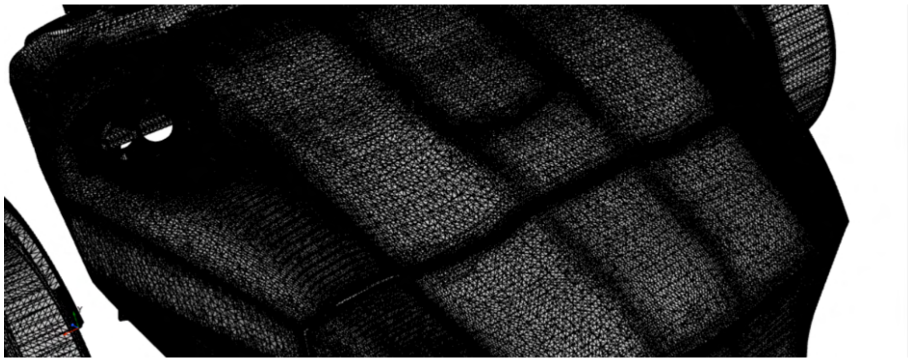


Figure 8.4: Surface wrapping of the front section of the model

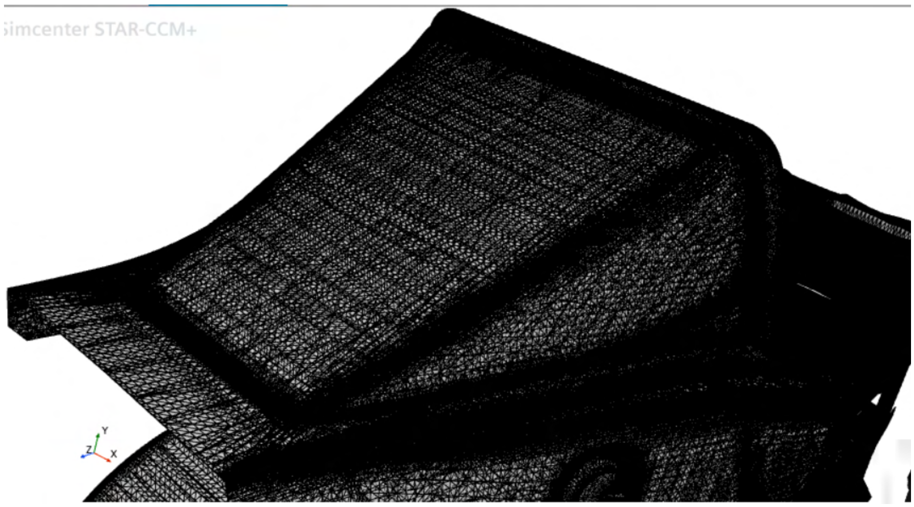


Figure 8.5: Surface wrapping of the back section of the model

pute certain key aerodynamic factors important for the vehicle's performance. Drag force and downforce were selected as factors for analysis; both are key indicators of how the vehicle interacts with airflow at different speeds.
Besides computation for the drag force and downforce at high-speed and low-speed conditions, respectively, a close examination of airflow around the vehicle was done. This analysis would help ascertain any ill effects on its aerodynamics, such as turbulence, vortex formation, or flow separation, which would adversely affect the efficiency and stability of the vehicle. By studying the pattern of airflow, valuable insight was gained into specific areas of the design that might need further refinement to make sure any weaknesses in the current design get worked out for improved performance in future iterations.
These factors having been defined, the simulation was run under both low-speed conditions of 40 km/h and high-speed conditions of 110 km/h to see how the vehicle would perform aerodynamically.

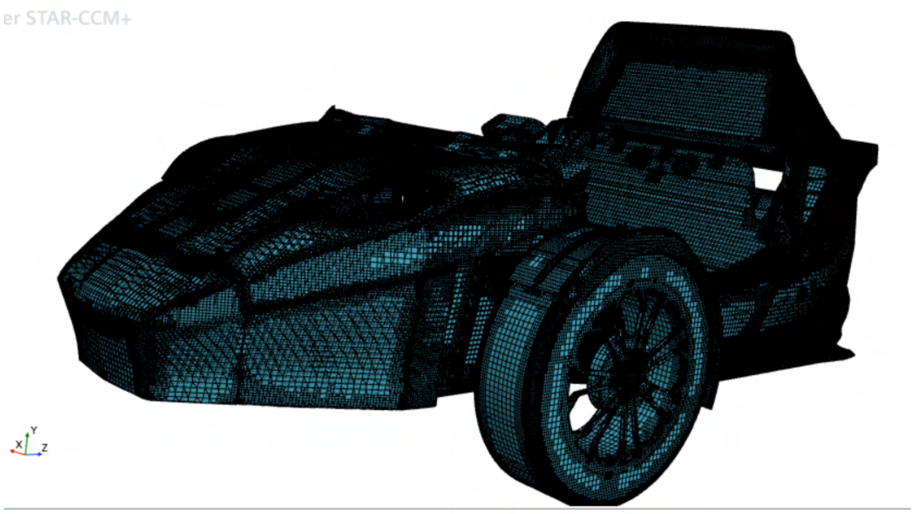


Figure 8.6: Meshing of the model

8.1.6 Evaluation of the results

These simulation results gave insight into the great details of aerodynamic performance and enabled a thorough check on the overall efficiency and areas that needed improvements. Two basic issues have been under assessment: forces of an aerodynamic character and behavior of airflow.

Evaluation results for slow speed

During the vehicle simulation at a speed of 40 km/h, specific surfaces were selected to assess the drag and downward forces. These surfaces, crucial for evaluating the vehicle's aerodynamic performance, are highlighted in the Figure 8.7.

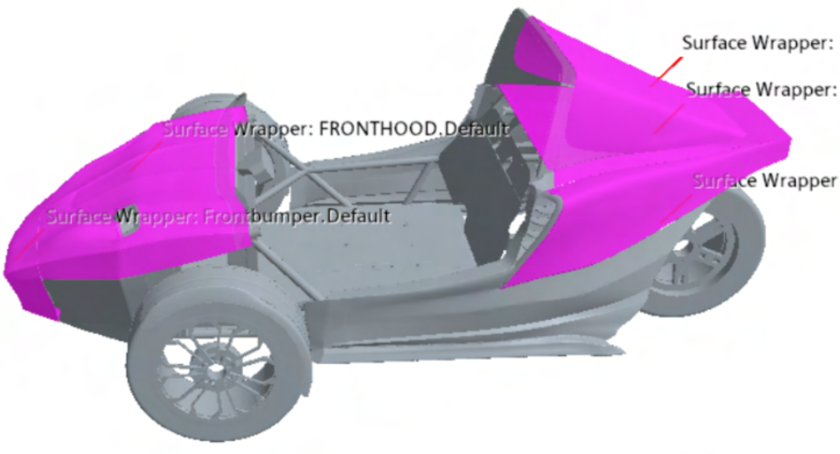


Figure 8.7: Surfaces considered in the simulation

After the simulation, the results are represented in Figures 8.8 and 8.9. The graph plot shows the drag force on all surfaces, the drag force on the hood alone, and the downward force across all surfaces.

At a speed of 40 km/h, the downward force generated by all surfaces of the vehicle is approximately 5.8 Newtons which is quite minimal. This small amount of downforce is expected at lower speeds, where the aerodynamic forces acting on the vehicle are relatively weak.

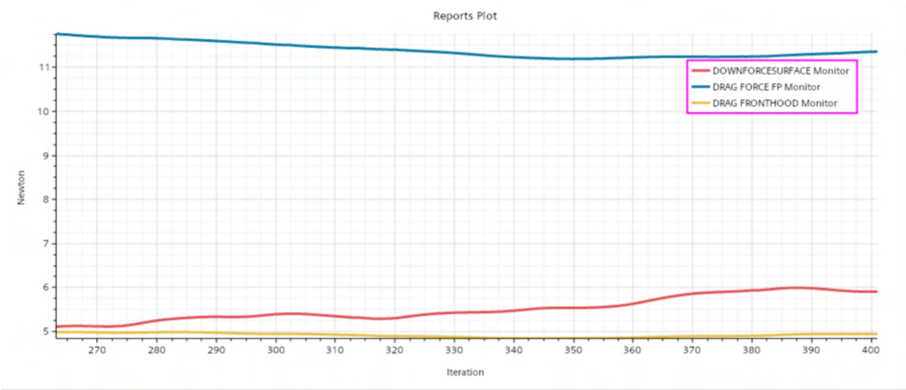


Figure 8.8: Results for the slow speed simulation

The two other parameters plotted in the graph are the total drag force produced by all the surfaces, which was quantified to 11.3 Newtons, and the drag force due to the front hood alone, estimated at 5 Newtons. These figures give a good insight into the distribution of the aerodynamic resistance, showing that the front hood carries a considerable amount of the total drag.

The results of the simulation at 40 km/h indicate that the vehicle's aerodynamic performance is well-optimized for lower speeds. The downward force of 5.8 Newtons is minimal, as expected, ensuring that the vehicle maintains stability without excessive downforce, which could increase drag and reduce efficiency. This balance demonstrates that the design is suitable for everyday driving conditions, such as city traffic, where aerodynamic efficiency and vehicle control are essential. The reduced downforce indicates that the vehicle effectively limits superfluous aerodynamic drag, thereby enhancing fuel efficiency when operating at lower velocities.
The verification of the drag forces is further evidence to prove the efficiency of the design. An overall drag force of 11.3 Newtons and 5 Newtons that is created from the front hood shows that the aerodynamic resistance is well distributed across all the vehicle's surfaces.

Below in Figure 8.10 is the pressure variation of the airflow along part of the automobile. This gives useful information on the vehicle's aerodynamics concerning areas where pressure gradients are experienced and, hence, areas where there is a high possibility of turbulence or separation. Some improvement regarding the flow of the air around could be further made. The effective improvements include lengthening the windshield. A longer windscreen should, in theory, provide an easier flow of air over the vehicle and reduce turbulent areas, hence reducing aerodynamic drag. This could further be enhanced by the addition of a glass protector, which would reduce turbulence in the air as it moved over the windscreen. This can then be more streamlined and generally enhance the aerodynamics, thus improving fuel efficiency and stability at higher speeds.

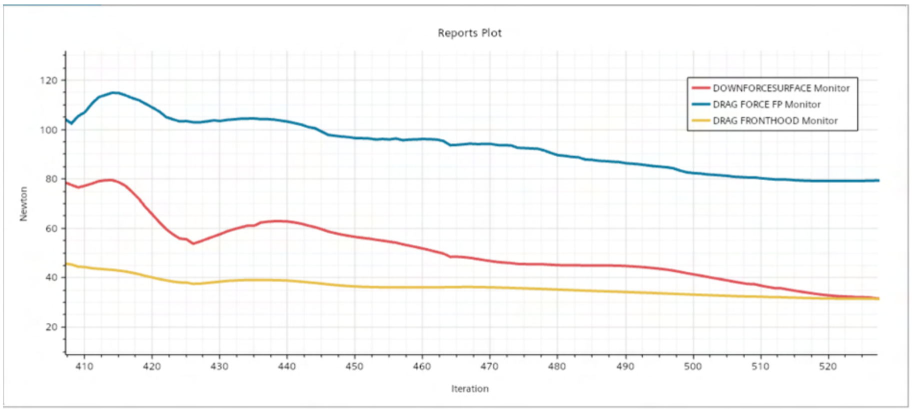


Figure 8.9: Results for the high speed simulation

Evaluation results for High speed
In the high-speed simulation, the vehicle's speed was increased to a speed of 110 km/h. Then, this simulation was done with the same surfaces tested during the low-speed study. The results of the so-called high-speed simulation are presented in the Figure 8.9, serving as a comparison of the aerodynamic performance at higher speeds.
At higher speeds, the downforce is very significantly increased to reach approximately 40 Newtons, much higher than the level realized at low-speed levels. The improvement in the vehicle's stability is highly necessary, and high aerodynamic forces ensure better traction and control of the vehicle on the road. This is clearly evident from the graph, whereby one sees the increase in downforce has a positive effect on the vehicle's performance by acting with greater pressure against the roadway.
It should be noted that the present analysis considers only the forces due to the aerodynamics on the external surfaces of the vehicle. The underbody and the rear parts of the vehicle are left out of the study, which would further increase the downforce force. This increased downforce would help in providing better stability and traction of the road by the car, enabling it to maneuver at high speeds. The fact that the higher the speed, the more downforce recorded, further emphasizes that it greatly contributes to vehicle stability and performance at increased velocities.

This graph further explains two more important aerodynamic variables: the total drag force exerted on the full vehicle body and the drag force solely created by the front hood. The total drag force across the entire vehicle body is an approximate value of 80 Newtons, while the drag force solely due to the front hood is 40 Newtons.

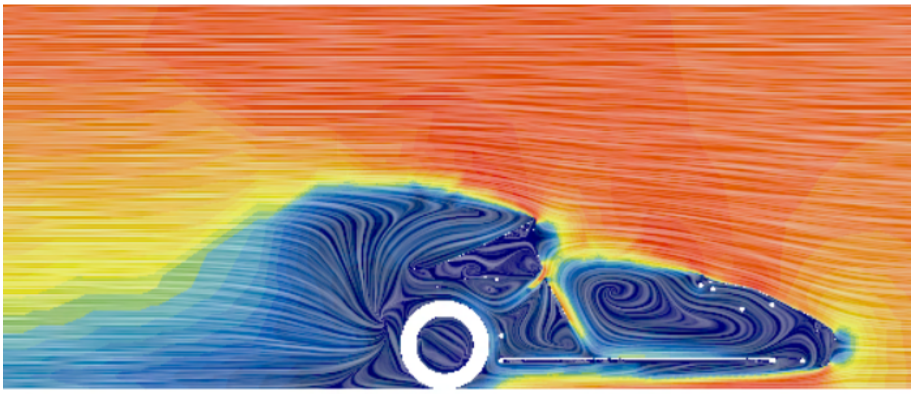


Figure 8.10: Pressure variation of the air around the middle plane

Given the context of the analysis, the mean drag force a compact three-wheeled vehicle usually experiences when traveling at highway velocities is between 50 and 150 Newtons. Based on this projected range, the total drag force recorded for this vehicle was 80 Newtons, further indicating its aerodynamic characteristics. The significant drag force created by the front hood highlighted a vital area in which improvements could be realized. By addressing the drag issues in this region, improvements can be introduced that will provide better fuel efficiency along with performance. Also, the patterns of the airflow trace with this high speed are somewhat similar to those we trace from the earlier low-speed simulation in Figure 8.10.

8.2 Final Concept Visuals

Figure 8.11: Top Side view of Final Result

The final design concept was rendered using Autodesk VRED [24], a software widely used in the automotive industry for creating photorealistic images. The rendered output generates a comprehensive overview of the final vehicle design from multiple angles and perspectives. These include front, side, top, and isometric views that collectively highlight key features and integration of various components. To enhance the visual presentation further, the final design was displayed in different lighting conditions and environments.

Figure 8.12: In Different Environment

Figure 8.13: Side View of Final Result

Figure 8.14: Back Side View of Final Result

Figure 8.15: Final Result

9

Discussion

The present thesis represents the exterior design development of a three-wheeler vehicle by using a structured approach in product development. Throughout the process, a perfect balance between aesthetics, functionality, and aerodynamics has been paid full attention to in order to construct a ride which is both fitted to the users' wants and performing well. The aerodynamics simulation was not the primary focus of this project, but it was really helpful in terms of checking the design and showing how the vehicle will work in the real world.

Design Process and Methodology

The development of the three-wheeled vehicle followed the structured product development methodology, starting with the concept generation stage to the complete detailed design. The aim was to ensure that it resulted in an exterior body that was not only visually attractive but also had a high degree of aerodynamic efficiency, while functionally being suitable for the proposed vehicle's operational requirements. Key factors were vehicle dimensions, surface smoothness, airflow management, and practical features such as storage, all integrated from the start into this design.

One of the key findings from the user surveys conducted in the preliminary stages of the project was the requirement for adequate storage. With this feedback in mind, the design incorporated a specific storage compartment that was integrated into the vehicle structure without compromising its aerodynamic features. This storage solution was designed to be functional yet subtle, hence not compromising the external aesthetics of the vehicle, which needed to be sleek and streamlined. Another important challenge during the design process was how the vehicle's body would be attached to the chassis. A plan was developed to make these attachment points as inconspicuous as possible, thus maintaining an uncluttered and refined look for the exterior of the vehicle. The design successfully buried the chassis attachments into the lines of the vehicle to reduce visual clutter without sacrificing structural strength and allowing easier maintenance. This methodology enhanced the aesthetic appeal of the vehicle and eased the attainment of the design objective of a cohesive, refined look.

Role of Aerodynamic Simulation in Design Validation

Aerodynamic simulations were therefore run, after fixing the exterior design, to evaluate the vehicle's performance in terms of airflow around the car, drag, and downforce. While the simulation was not the focus of this thesis, the results obtained from the CFD analysis provided ample evidence that justified the validity of the decisions behind the chosen design.

The findings from the simulation indicated that at reduced velocities, the automobile produced a negligible downward force of 5.8 Newtons. Such a degree of downforce

is sufficient to ensure vehicle stability in urban driving contexts while avoiding the creation of excessive drag. The cumulative drag force recorded at a speed of 40 km/h was quantified at 11.3 Newtons, of which 5 Newtons originated from the front hood. These values emphasize the efficiency of the vehicle at lower speeds, which is in agreement with the main design goal: to create a vehicle suitable for urban transportation, which would have improved aerodynamic characteristics. At high speeds, namely 110 km/h, simulation showed a sharp increase in the forces of aerodynamics.
This downward force reached 40 Newtons, thereby considerably increasing the stability of vehicles on highways. The cumulative drag force went up to 80 Newtons, with 40 Newtons contributed by the front hood. These results fall within the expected range for small three-wheel vehicles and further solidify the aerodynamics of the exterior setup. Similarity in flow patterns at different velocities suggests that the basic design choices enable operating performance at both low and high speeds.

Insights Gained from Simulation

The aerodynamic simulation provided important insights into how the vehicle's exterior body behaves under different driving conditions. One key takeaway is that while the design performs well, particularly in terms of stability at higher speeds, the front hood contributes significantly to overall drag. This suggests that future iterations of the design could focus on further refining this area to reduce drag and enhance efficiency without compromising the vehicle's aesthetic and functional characteristics.
Additionally, the airflow patterns observed in both low and high-speed conditions were consistent, indicating a stable aerodynamic profile. However, small design tweaks, such as increasing the length of the windshield and optimizing the rear profile, could further streamline airflow and reduce turbulence, improving the vehicle's overall performance.
The chassis attachment design also proved to be a successful solution in maintaining the vehicle's clean, aerodynamic profile. By hiding the attachment points, the design achieved a sleek look without sacrificing structural integrity or ease of assembly. This approach not only enhanced the visual appeal but also contributed to the vehicle's overall aerodynamics by reducing potential drag points.

10
Future Work

While this thesis has advanced our understanding of the vehicle and its design considerations, several key areas need to be further investigated and developed to enhance its market viability and performance. This section covers these important areas and outlines directions for future research and practical improvements.
The following key areas need to be evaluated

- **Customization and Regional Adaptations**
  This product category is a niche, and the brand's current competitive advantage is rooted in its established market presence. To attract new customers, future work should focus on enhancing product customization and adapting features to specific regional needs. For example, in countries like Sweden, where winter conditions are harsh, integrating features such as removable or foldable top coverings and modular storage solutions could significantly improve the user experience and appeal. Research should explore how these adaptations can be seamlessly incorporated into the design without compromising functionality or aesthetics.
- **Physical Prototyping and Testing**
  The physical prototyping and testing phases of this thesis were not conducted due to time constraints, which are critical for validating and refining the product. Develop physical prototypes to test and validate the design concepts presented in this study. This will provide insights into the practical challenges and performance of the product. Conduct comprehensive testing under various conditions to ensure the design meets safety, durability, and usability standards. This will also help identify any necessary adjustments before full-scale production.
- **Windshield Flow Optimization**
  The flow continuity analysis of the vehicle demonstrated that while the airflow is continuous in simulations, there is potential for improvement. Future work should explore the design and implementation of a larger windshield to enhance the continuity of airflow. This involves investigating aerodynamic principles and conducting simulations to optimize the windshield's shape and positioning for better performance.
- **Manufacturing and Assembly Adjustments**
  The transition from CAD models to real-world manufacturing often reveals actual problems and challenges that require adjustments. Evaluate the need for additional support structures to ensure the stability and performance of each vehicle part. This includes assessing the practicality of manufacturing processes and making necessary modifications. Investigate potential changes to

the manufacturing process to satisfy design requirements and improve overall production efficiency. Collaboration with manufacturers to refine techniques and materials based on practical insights gained from prototype testing could be beneficial.

11
Conclusion

This study has focused on designing a new exterior body for OMotion AB to enhance vehicle performance. The team started by establishing technical needs and requirements, then created various design ideas while balancing aesthetics and functionality. As a result, a solution has been successfully achieved that aligns with the company's core values and requirements.
The design process involved a theoretical study, market analysis, competitor analysis, CAD modelling, and design analysis through simulation. In the design process, the team also considered Design for Manufacturing (DFM) principles to ensure that the final design was not only aesthetically pleasing but also practical and cost-effective for production. Using function analysis, the team generated some ideas for each sub-function. An iterative approach was used to achieve a promising solution. Concepts were created, evaluated, refined, and re-evaluated, focusing on various factors to reach the project goals. To verify, concept feasibility and functionality were thoroughly evaluated through CAD modelling and simulation.
While the project has met its initial goals, including the creation of a detailed and optimized vehicle design, further development is required to move from concept to production. Future work should focus on prototyping and testing to validate the design in real-world conditions. Additionally, exploring the commercial viability of the design will be essential to ensuring a successful market introduction.

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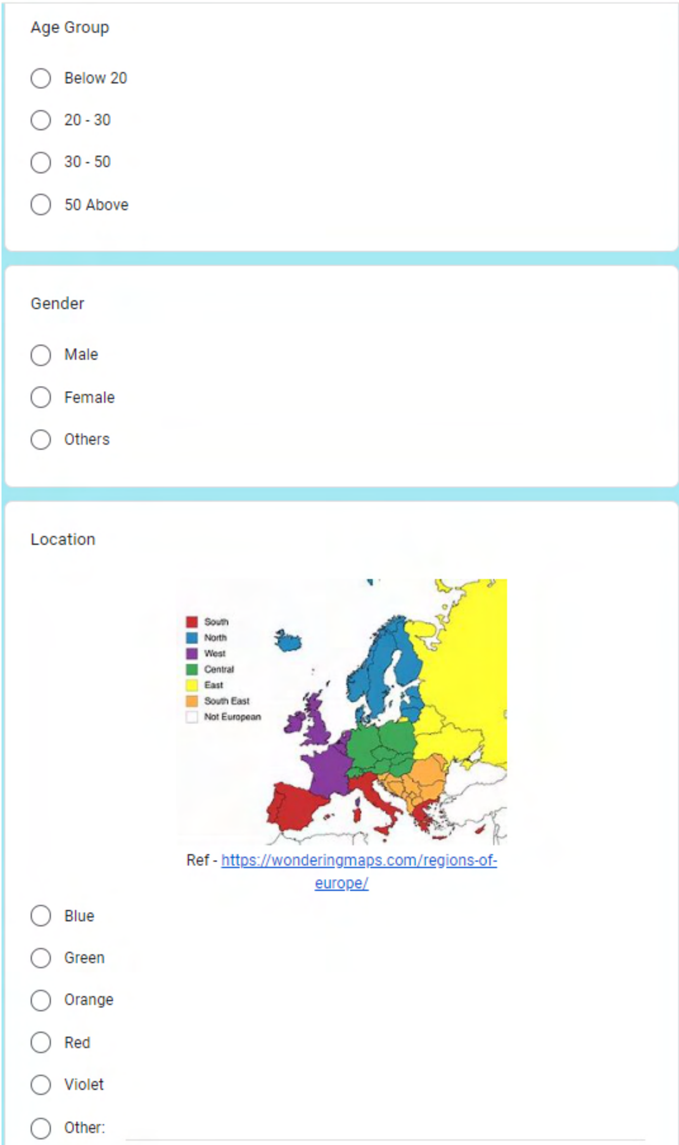
A

Appendix

Question for the Interview -

1. What factors influence your decision to consider purchasing an electric car?
2. What incentives or benefits would encourage you to switch to an electric 3-wheeler car?
3. What features do you consider essential in an electric car? (e.g., speed, charging infrastructure, cargo capacity)
4. How concerned are you about the environmental impact when choosing a mode of transportation?
5. What are your perceptions regarding the performance and reliability of electric 3-wheeler cars compared to traditional gasoline-powered vehicles?
6. How important is the availability of charging infrastructure in your decision to purchase an electric 3-wheeler car?
7. Are there any specific concerns or reservations you have about electric 3-wheeler cars?
8. How familiar are you with electric 3-wheeler cars?
9. Have you ever driven or ridden in an electric 3-wheeler car before?
10. What is your perception of the maintenance costs associated with owning an electric 3-wheeler car compared to a traditional gasoline-powered vehicle?
11. How important is the design and appearance of an electric 3-wheeler car to you?
12. What safety features do you believe are crucial in an electric 3-wheeler car?
13. Would you be willing to pay a premium for advanced technological features in an electric 3-wheeler car, such as autonomous driving capabilities or advanced connectivity options?
14. How do you perceive the resale value of electric 3-wheeler cars compared to traditional gasoline-powered vehicles?
15. What are your thoughts on the infrastructure for electric vehicle charging in your area?
16. How concerned are you about the potential limitations of electric 3-wheeler cars, such as range anxiety or limited availability of charging stations?
17. Are you aware of any government incentives or subsidies available for purchasing electric vehicles in your region?
18. How likely are you to consider purchasing an electric 3-wheeler car in the next 5 years?

Social media survey -



Age Group

- Below 20
- 20 - 30
- 30 - 50
- 50 Above

Gender

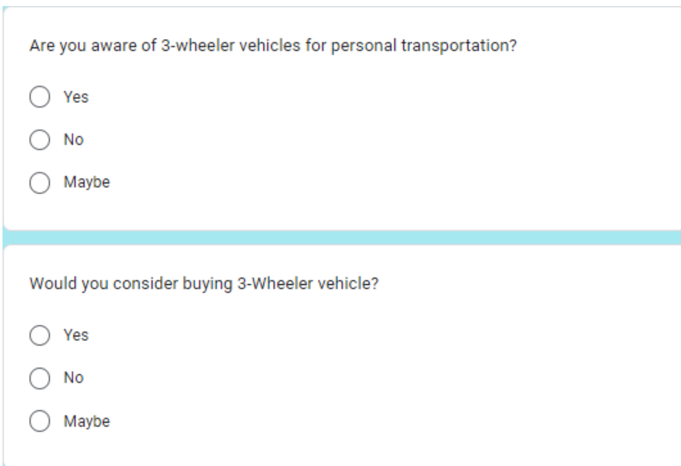
- Male
- Female
- Others

Location

Ref - https://wonderingmaps.com/regions-of-europe/

- Blue
- Green
- Orange
- Red
- Violet
- Other:

Figure A.1: Survey Questions



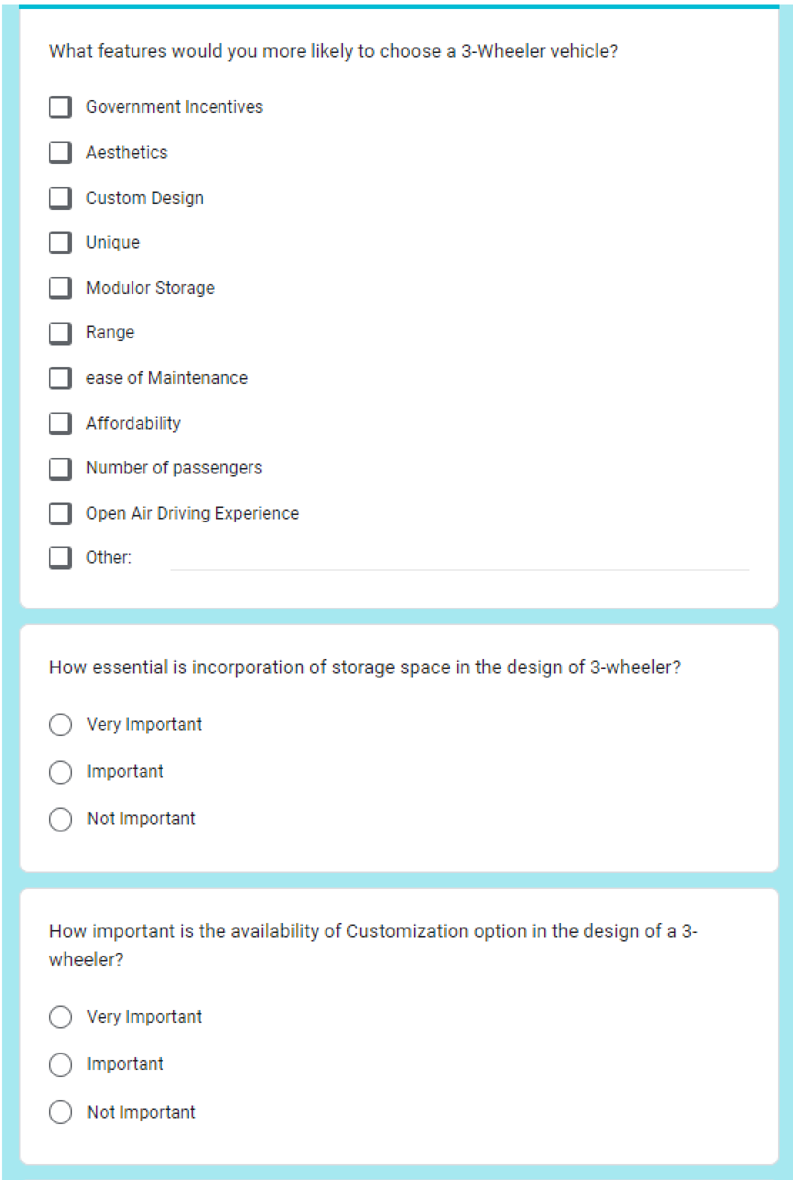
Are you aware of 3-wheeler vehicles for personal transportation?

- Yes
- No
- Maybe

Would you consider buying 3-Wheeler vehicle?

- Yes
- No
- Maybe

Figure A.2: Survey Questions



What features would you more likely to choose a 3-Wheeler vehicle?

- [ ] Government Incentives
- [ ] Aesthetics
- [ ] Custom Design
- [ ] Unique
- [ ] Modulor Storage
- [ ] Range
- [ ] ease of Maintenance
- [ ] Affordability
- [ ] Number of passengers
- [ ] Open Air Driving Experience
- [ ] Other: ____

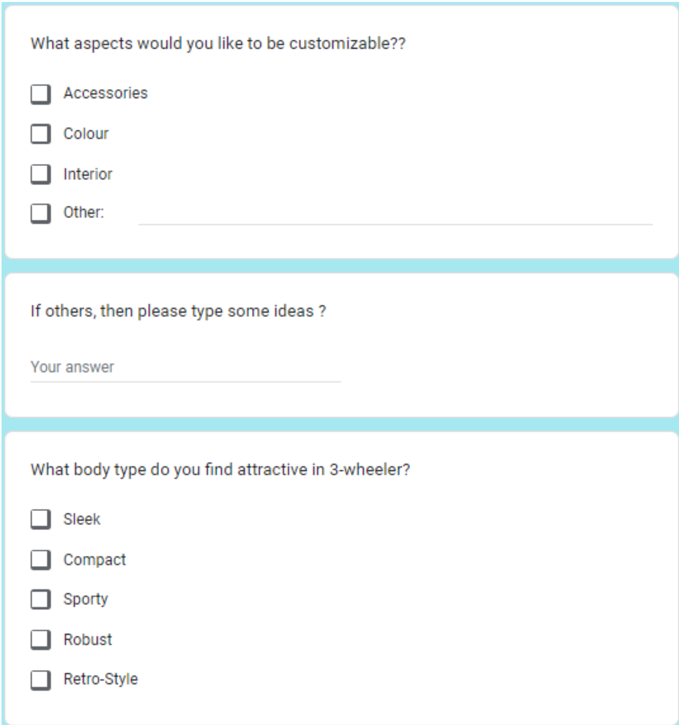
How essential is incorporation of storage space in the design of 3-wheeler?

○ Very Important
○ Important
○ Not Important

How important is the availability of Customization option in the design of a 3-wheeler?

○ Very Important
○ Important
○ Not Important

Figure A.3: Survey Questions



What aspects would you like to be customizable??

- [ ] Accessories
- [ ] Colour
- [ ] Interior
- [ ] Other:

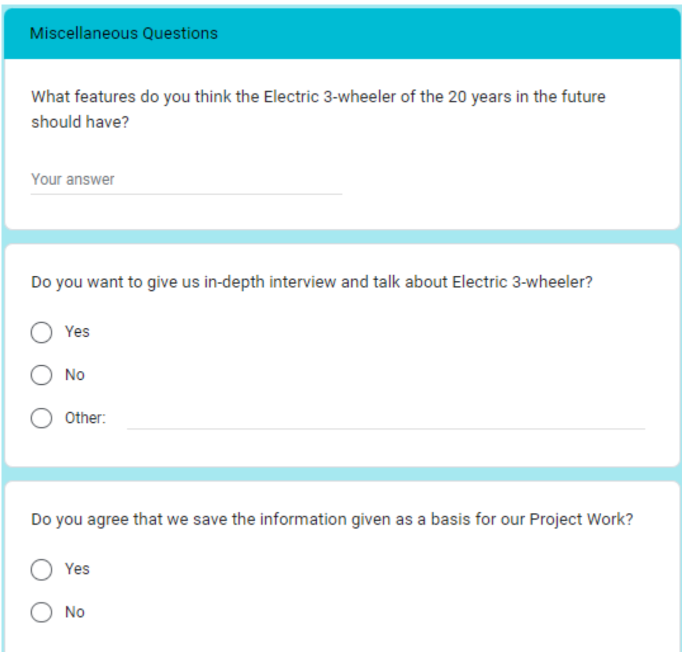
If others, then please type some ideas ?

Your answer

What body type do you find attractive in 3-wheeler?

- [ ] Sleek
- [ ] Compact
- [ ] Sporty
- [ ] Robust
- [ ] Retro-Style

Figure A.4: Survey Questions



Miscellaneous Questions

What features do you think the Electric 3-wheeler of the 20 years in the future should have?

Your answer

Do you want to give us in-depth interview and talk about Electric 3-wheeler?

- Yes
- No
- Other:

Do you agree that we save the information given as a basis for our Project Work?

- Yes
- No

Figure A.5: Survey Questions

Pugh matrix combinations -

Table A.1: The Pugh matrix 1st combination

Pugh Matrix 1st combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	ref	0	-	-	0	-	-	-
Design complexity		0	0	+	0	-	-	-
Aerodynamic		+	-	-	0	0	-	-
Non-compliance with Regulations		+	-	-	0	0	-	-
Stakeholder Impact		0	0	0	+	-	0	0
Σ+	0	2	0	1	1	0	0	0
Σ-	0	0	3	3	0	3	4	4
ΣS	0	3	2	1	4	2	1	1
Net Value	0	2	-3	-2	1	-3	-4	-4
Further Development	No	YES	No	No	YES	No	No	No
Ranking	3	1	6	5	2	4	7	7

Table A.2: The Pugh matrix 2nd combination

Pugh Matrix 2nd combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	0	ref	-	-	0	0	-	-
Design complexity	0		0	-	+	-	0	-
Aerodynamic	0		-	-	0	-	-	-
Non-compliance with Regulations	0		-	0	-	0	-	0
Stakeholder Impact	+		-	-	+	0	+	-
Σ+	1	0	0	0	2	0	1	0
Σ-	0	0	4	4	1	2	3	4
ΣS	4	0	1	1	2	3	1	1
Net Value	1	0	-4	-4	1	-2	-2	-4
Further Development	YES	No	No	No	YES	No	No	No
Ranking	1	2	4	4	1	3	3	4

Table A.3: The Pugh matrix 4th combination

Pugh Matrix 4th combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	+	+	0		0	-	0	0
Design complexity	+	+	0		0	-	0	0
Aerodynamic	+	+	-	ref	+	+	-	-
Non-compliance with Regulations	-	0	-		-	0	-	0
Stakeholder Impact	+	+	-		+	+	-	-
Σ+	4	4	0	0	2	2	0	0
Σ-	1	0	3	0	1	2	3	2
ΣS	0	1	2	0	2	1	2	3
Net Value	3	4	-3	0	1	0	-3	-2
Further Development	YES	YES	No	No	YES	No	No	No
Ranking	2	1	6	4	3	4	6	5

Table A.4: The Pugh matrix 5th combination

Pugh Matrix 5th combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	+	+	-	-		0	-	-
Design complexity	+	+	0	0		+	-	-
Aerodynamic	0	0	-	-	ref	0	-	-
Non-compliance with Regulations	0	-	0	-		0	0	-
Stakeholder Impact	0	0	-	-		0	-	-
Σ+	2	2	0	0	0	1	0	0
Σ-	0	1	3	4	0	0	4	5
ΣS	3	2	2	1	0	4	1	0
Net Value	2	1	-3	-4	0	1	-4	-5
Further Development	YES	YES	No	No	No	YES	No	No
Ranking	1	2	4	5	3	2	5	6

Table A.5: The Pugh matrix 6th combination

Pugh Matrix 6th combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	+	+	-	-	0		-	-
Design complexity	+	+	0	0	0		-	-
Aerodynamic	+	0	-	-	+	ref	-	-
Non-compliance with Regulations	0	0	0	0	0		0	0
Stakeholder Impact	0	0	-	-	0		0	-
Σ+	3	2	0	0	1	0	0	0
Σ-	0	0	3	3	0	0	3	4
ΣS	2	3	2	2	4	0	2	1
Net Value	3	2	-3	-3	1	0	-3	-4
Further Development	YES	YES	No	No	YES	No	No	No
Ranking	1	2	5	5	3	4	5	6

Table A.6: The Pugh matrix 7th combination

Pugh Matrix 7th combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	+	+	0	0	+	+		0
Design complexity	+	+	0	0	+	+		0
Aerodynamic	+	-	0	-	+	-	ref	-
Non-compliance with Regulations	0	-	0	-	0	-		-
Stakeholder Impact	+	+	-	0	+	+		0
Σ+	4	3	0	0	4	3	0	0
Σ-	0	2	1	2	0	2	0	2
ΣS	1	0	4	3	1	0	0	3
Net Value	4	1	-1	-2	4	1	0	-2
Further Development	YES	YES	No	No	YES	YES	No	No
Ranking	1	2	4	5	1	2	3	5

Table A.7: The Pugh matrix 8th combination

Pugh Matrix 8th combination								
Concept/Criteria	Concept 20	Concept 21	Concept 26	Concept 27	Concept 29	Concept 30	Concept 35	Concept 36
Manufacturing cost	+	+	0	0	+	+	0	ref
Design complexity	+	+	+	+	+	+	0	
Aerodynamic	+	0	-	0	+	+	-	
Non-compliance with Regulations	0	0	0	0	0	0	0	
Stakeholder Impact	+	+	-	-	+	+	0	
Σ+	4	3	1	1	4	4	0	0
Σ-	0	0	2	1	0	0	1	0
ΣS	1	2	2	3	1	1	4	0
Net Value	4	3	-1	0	4	4	-1	0
Further Development	YES	YES	No	No	YES	YES	No	No
Ranking	1	2	4	3	1	1	4	3

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