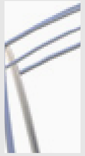
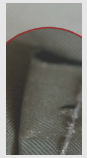
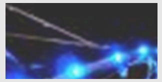
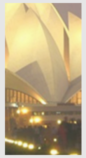
Lightweight Roof System of a Sustainable Vehicle

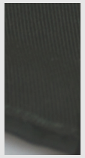
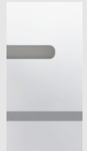
Name: Alieke Josette van Oostrum

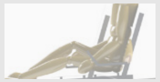
Program: Industrial Design
Univeristy: University of Twente

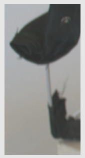
Date: 02-10-2013
Company: Greenolution

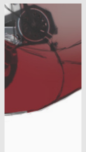
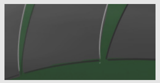





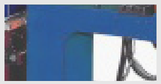
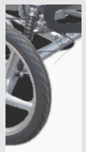
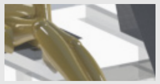






Lightweight Roof System of a Sustainable Vehicle

Name: Alieke Josette van Oostrum
Student number: s1116398

Program: Industrial Design
Univeristy: University of Twente
Date: 02-10-2013
Company: Greenolution, Amersfoort

Exame committee:
H. Schotman
M. C. van der Voort

On behalf of the company:
Christian Suurmeijer

Table of Content

English Summary ... 6

Dutch Summary ... 7

1. Introduction ... 8

2. Analysis of the Quattrocycle ... 10

2.1 Vision of the Quattrocycle ... 10

2.2 Requirements of the Roof System ... 11

3. Constructions, Materials and Processes for a Lightweight Roof System ... 12

3.1 Constructions for a Lightweight Roof System ... 12

3.2 Materials for a Lightweight Roof System ... 15

3.3 Production Processes for a Lightweight Roof System ... 17

3.4 Summary and Conclusion of the Analysis ... 18

4. General Concept Directions for a Lightweight Roof System ... 20

4.1 General Concept Directions ... 20

4.2 Concept Evaluation ... 22

4.3 Conclusion and Summary of the Concept Generation ... 22

5. Additional Research on the Quattrocycle ... 24

5.1 Entering and Leaving the Quattrocycle ... 24

5.2 Line of Sight ... 25

5.3 Attachment Points from the Roof System to the Quattrocycle ... 25

5.4 Solar Energy ... 26

5.5 Concept Directions for the Two Chosen Concepts ... 29

5.6 Conclusion and Summar on Additional Research of the Quattrocycle ... 29

6. Development of the Two Concepts ... 30

6.1 Concept Outdoor ... 30

6.1 Concept Car ... 32

6.3 Concept Selection ... 34

7. Development of the Final Concept ... 36

7.1 The Frame ... 36

7.2 The Body ... 37

7.3 The Rain Protector ... 39

7.4 Materials, Processes and Price Calculations ... 40

7.5 Conclusions on the Final Concept ... 41

8. Conclusions and Recommendations ... 42

8.1 Conclusions ... 42

8.2 Recommendations ... 43

List of Credentials ... 44

Attachment Overview ... 46

English Summary

The aim of this bachelor thesis is to design a concept for a lightweight roof system for the Quattrocycle and give recommendations about the materials and the constructions. A Quattrocycle is a four person bike with bike support. The main question that has to be answered is:

“Which concept for a lightweight roof system can be recommended based on materials, constructions, processes and the requirements of the client?”

The Quattrocycle can be used for doing grocery shopping, bringing kids to school, visiting friends in other cities or in the country side, and for going on holidays. The roof system should offer protection against rain from the front and above. The Quattrocycle has to become a sustainable vehicle that runs on 80% human power and 20% solar energy.

The requirements of the client, the Dutch laws, a user scenario and an analysis of lightweight materials and constructions are used as a base for five general concept directions for a lightweight roof system. In order to choose which of the two concepts should be developed further, additional research was done on the line of sight, entering and leaving the Quattrocycle, attachment points and solar energy.

The two concepts are:

- Concept Car, based on carbon fibre composites
- Concept Outdoor, a tent-based concept

These concepts were to be developed further, based on the conclusions of the previous researches. Both concepts have an aluminium frame and a rain protector against rain from the sides. Those concepts were compared to the requirements. After the end of the discussion concept Outdoor was chosen as the final concept.

The concept Outdoor was therefore developed in more detail and some changes in the design were made. The costs, production processes and the assembly are described as well. At the end of the chapter conclusions are made based on the vision and the requirements. The final concept weights 16kg and the roof can be partially removed. The requirement of 20% solar energy is reached easily. Therefore the final concept met nearly all of the requirements and some of the wishes of the client. Recommendations for the rain protector, solar energy, maintenance and the baggage are also given.

Dutch Summary

Het doel van deze bachelor thesis is om een concept voor een lichtgewicht overkapping te ontwerpen voor de Quattrocycle, om aanbevelingen te geven voor het gebruik van lichtgewicht materialen en voor de constructie voor de overkapping. De Quattrocycle is een vierpersoonsfiets met elektrische fietsondersteuning. De hoofdvraag die beantwoord moet worden is:

“Welk concept voor een lichtgewicht overkapping kan worden aanbevolen, dat is gebaseerd op materialen, constructies, productieprocessen en de eisen van de opdrachtgever?”

De Quattocycle kan gebruikt worden voor boodschappen, het naar school brengen van de kinderen, bezoeken van vrienden in andere steden of op het platteland en voor vakantie. De overkapping zal bescherming bieden tegen neerslag van bovenaf en van voren. De Quattrocycle moet een duurzaam voertuig worden dat door 80% menselijke energie en 20% zonne-energie wordt aangedreven.

De eisen van de opdrachtgever, de Nederlandse wetgeving, een gebruiksscenario en een analyse van lichtgewicht materialen en constructies wordt gebruikt als basis voor vijf algemene concepten richtingen voor een lichtgewicht overkapping.

De volgende twee concepten waren gekozen:

- Concept Car, gebaseerd op koolstofvezel composieten
- Concept Outdoor, gebaseerd op een tent constructie

Om een richting te geven aan beide concepten is er extra onderzoek gedaan naar de zichtlijnen, het in- en uitstappen van de Quattrocycle, bevestigingspunten en zonne-energie.

Beide concepten hebben een aluminium frame en een regenschild, die beschermd tegen regen van de zijkanten. Deze concepten zijn vergeleken met het programma van eisen. Aan het einde van die afweging is concept Outdoor gekozen als het eindconcept.

Daarom is concept Outdoor meer in detail ontwikkeld en er zijn er een aantal veranderingen in het ontwerp doorgevoerd. De kosten, productieprocessen en het assembleren worden ook beschreven. Aan het einde van het hoofdstuk worden conclusies getrokken die gebaseerd zijn op de visie en het programma van eisen. Het eindconcept weegt 16kg en de overkapping kan deels verwijderd worden. De eis dat de Quattrocycle op 20% zonne-energie moet rijden wordt ook gehaald. Daarom voldoet het concept aan bijna alle eisen en sommige wensen van de opdrachtgever. Ook wordt er een aanbeveling voor het regenschild, zonne-energie en de bagage gegeven

1. Introduction

Intorduction

This report is written for my bachelor assignment that is under the authority of Greenolution.

Greenolution is a company founded by Christian Suurmeijer. It is a one man company located in Amersfoort. Greenolution researches the possibilities for future sustainable and lightweight vehicles, called 'World Wagon'. This is a platform for future sustainable vehicles. It uses new technologies, functionalities, usage- and business models around mobility, energy and leisure.

The goal of Greenolution is to start a pilot project that demonstrates the possibilities of a family vehicle powered by only sun, wind and human power. To reach this goal the company researches new lightweight materials, lightweight constructions and smart electrical systems.

Greenolution is owner of a Quattrocycle. The Quattrocycle is used as starting point for the World Wagon. The aim of this bachelor assignment is to design a concept for a lightweight roof system for a future World Wagon and give recommendations about lightweight materials and constructions. The frame of the Quattrocycle will be used as base for the roof system. The following question will be answered:

"Which concept for a lightweight roof system can be recommended based on materials, constructions, processes and the requirements of the client?"

Read Manner

Chapter two discusses the requirements for the roof system of the Quattrocycle based on the current Quattrocycle and a user scenario.

In chapter, three an analysis of lightweight constructions, lightweight materials and processes is described. The end of the chapter will show a conclusion on how those three aspects can be combined.

Chapter four will show five general concept directions based on the conclusion from chapter three. The chapter ends with two concepts that were chosen for further development.

Additional research on entering and leaving the Quattrocycle, line of sight, attachment points and solar energy is shown in the fifth chapter. This analysis will be used to give a direction to the two chosen concepts.

The development of the two chosen concept is described in chapter six. That chapter ends with the selection of one concept.

In chapter seven the selected concept is described. Furthermore a visual model, working principles, indicated price and assembly processes are presented. The report ends with conclusions and recommendations in chapter eight.

Image 1.1: The Current Quattrocycle [1]

2. Analysis of the Quattrocycle

2.1 Vision of the Quattrocycle

The Current Quattrocycle

The Quattrocycle is a bike made for four to seven persons, four adults and three children. Four persons are able to pedal and have their own gears. Three extra child seats with safety belts can be placed on the back of the Quattrocycle. The person sitting in the left backside steers the vehicle, he or she is also the only person able to break. The Quattrocycle can be used on the road and on the cycling paths, because it is classified as a bike. The vehicle has wide tires and springs for suspension for unpaved roads. There is an option to use electrical pedal support, if needed.

The target groups for the Quattrocycle are the following: Recreation for camping's, hotels, resorts, organized sightseeing tours, activities with elderly or disabled, and cycling holidays.

The weight of the Quattrocycle is 122 kg. It has a length of 280 cm and a width of 132 cm. Each seat has three gears for the pedals. [1]

Redesign of the Quattrocycle

The roof system will be designed for the current version of the Quattrocycle. Different functions and requirements will be kept in mind while designing this roof system. Those functions and requirements are based on a written scenario and the vision of the client. The scenario can be found in attachment B.

The Quattrocycle has to become a sustainable vehicle that runs on 80% human power and 20% sustainable energy. The roof system has to provide the sustainable energy through the use of solar panels. The wish of the client is that it can reach a speed of 25 km per hour. To achieve this, the roof has to be lightweight.

The vehicle will be used for doing weekly grocery shopping, bringing kids to school, sporting or other activities, visiting friends in other cities or in the country side, and for going on holidays. Therefore there must be room for four persons and their baggage. The vehicle should offer protection against rain from the front and above. The scenario shows that users will use rain protective clothes and bags, however it is desirable to find a solution for that.

The Quattrocycle will be equipped with a battery to store energy collected by the solar panels. This also adds the possibility to store energy when the vehicle is not in use. It is preferred that the roof can be removed by the user to enjoy good weather and give a more outdoor feeling experience. The roof will be designed for the Dutch climate, but it can be used in other countries as well.

The redesign of the roof system consists of three main parts: The design of the basic shape, removing or partially removing the roof and entering or leaving the car.

Image 2.1: The Current Quattrocycle [1]

2.2 Requirements of the Roof System

The scenario and the vision of the client were translated into requirements, listed below, as well as the laws for bicycles by the Dutch government.

Requirements of the Client

- The vehicle has a width of maximum 132 cm
- The vehicle has a length of maximum 380 cm
- The vehicle has four seats
- The vehicle has space for 80 litres of baggage
- The vehicles runs on 80% human power and 20% sustainable energy
- The roof system has a maximum weight of 30 kilograms
- The roof system provides a part of the sustainable energy needed
- The roof system protects against wind, rain, hail and snow from the front and above
- The roof system does not obstruct the user by entering and leaving the vehicle
- The roof system will not deform with a wind speed of 90 km/h
- The roof system does not resonate
- The roof system can handle 150 kilo grams of weight without permanently deforming or breaking
- The roof system gets a dent of maximum 5 cm by a collision at a speed of 5 km/h
- The roof system can withstand 10 cm of snow without permanently deforming

Wishes

- The roof system should be partially removable
- The materials used are bio-based or recyclable
- The production uses sustainable processes
- The vehicle can reach a maximum speed of 25 km/h
- The vehicle provides protection from rain, hail and snow from the sides
- A new solution for entering and leaving the Quattrocycle

Legal Requirements

At the moment the Quattrocycle is covered by the bicycle laws. The requirements are based in the Dutch laws for bicycles and electrical bicycles. [2, 3]

- The vehicle has two white or yellow lights on the front
- he vehicle has a red light on the back
- The vehicle has red reflectors on the backside, not a triangle
- The vehicle has white reflectors on the front
- The wheels or tires has white or yellow reflectors on the sides
- The vehicle has a maximum width of 150 cm
- The vehicle is not allowed to have sharp parts that can cause injuries in case of a collision
- he vehicle has a bell audible on a distance of 25 meters
- The engine has a power of maximal 250 watt
- The engine only works while peddling
- The engine stops working at a speed of 25 km/h
- The vehicle is allowed to have two yellow turn signals on the back and front

3. Constructions, Materials and Processes for a Lightweight Roof System

This chapter shows analysis of lightweight constructions, lightweight materials and processes. The analysis is inspired by the automotive industry, aeroplane industry, outdoor industry and biomimicry. The paragraphs about materials and processes makes out differences between materials and processes for the body and for the frame of the roof system. This chapter ends with a conclusion on how the constructions, materials and processes can be combined.

3.1 Constructions for a Lightweight Roof System

For a lightweight roof system not only light materials are necessary, but also a construction that is lightweight, meaning that the construction allows you to use as little material as possible and still fulfil the functions that are needed. Inspiration for such constructions can be found in the automotive, aeroplane, outdoor industries, as well as biomimicry and buildings. Collages that were used to act as inspiration can be found in attachment C. This study will result in a morphologic schedule with possible solutions for different design problems.

Main Principle

For a construction to be lightweight, it needs to be balanced. Therefore the construction has to be divided between tension and compression. These are called ‘tensegrity structures’. The materials have to be chosen on those qualities. Examples of this principle are space frames and thin-shell structures. Tubes are the best way to deal with compressions because they have a high weight inertia coefficient. Ropes are an efficient to deal tension. [4]

Constructions in the Automotive and Aviation Industry

In the automotive industry the concept of a space frame is used. This is a construction from short interlocking tubes, forming triangles. The triangles have to have equal sides to obtain a totally rigid structure. The kind and size of the tubes prevents buckling. The forces that are transmitted through each tube are either tensile or compression. The body panels of the car are attached to the frame and do not have a structural function. An advantage of this construction is that torsion forces are better resisted. The frame however uses a lot of volume, which can hinder the driver from entering the car or from accessing the engine. [5, 6]

Monocoque or stressed skin is a way of constructing that is used in the automotive industry and aviation industry. It supports forces through an external skin. In this type of constructions the frame is integrated with the body. This principle was used by Greenteam Twente 2013 to reduce the weight of their racing car. Semi-stressed skin is when the vehicle has a compressive structure reinforced by a tensile shell.

Constructions from the Outdoor Industry

A tent construction can be based on two different principles. The first one is to span the cloth over poles, putting tension on the structure. The second one is to wrap mats around

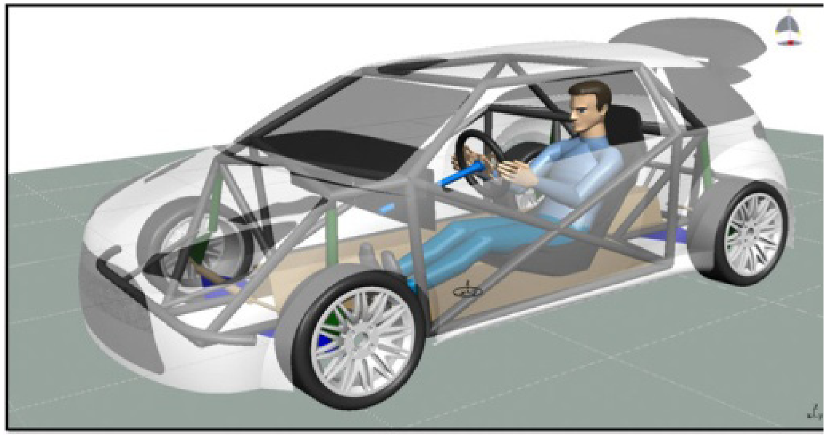


Image 3.1: Space Frame Structure [5]

a wooden framework so it can stand on its own. Tension is important to minimize the amount of material in cover structures.

The best way to deal with one-dimensional tension is through short fibres wrought together in threads, ropes or cables. Fabrics are two-dimensional counterpart of strings and cables. They're able to absorb tension and stress in more directions. Therefore they're ideal for creating light objects. The tension in a tent structure is two-dimensional, the textile is stretched with cables on a supporting structure. The structure is compressed by the textile. [4]

Constructions based on Biomimicry

Nature has found a lot of solutions for problems that we still experience in the world. One of them is lightweight constructing. One of those solutions can be found by looking at bones. Bones are relatively light for the amount of force the can handle.

Bone exists of a foamy substance and they are adapted to grow bone tissue on places where it is needed, making an optimal structure. This structure is called the Michell structure. The structure is able to turn a bending force into tension and compressions forces in separate bars.

Another solution are hexagons. Hexagons are a formed as a result of forces from all sides in a two dimensional view. When pressed together it minimizes the total distance between points in a series of line segments. This is a minimum energy structure. An example is honeycombs and pineapple skins. This principle is already used in cardboard and sandwich panels with a honeycomb structure on the inside. [4, 7]

Building Structures

Thin-shell structures use shell elements, shell elements are triangular elements that are used in a 3D-orientation. The triangular elements are transformed in various shapes creating a complex structure. An example of this structure is the tessellated roof of the Ceiling of Great Hall of the British museum, that can be seen in image 3.3. The tessellated roof is a self-supporting frame. It uses interlinking beams, similar to a woven fabric. Columns are used to keep the construction standing. This type of construction is used for glass roofs and walkways for buildings. [8]

A reciprocal frame is a self-supporting structure made of three or more beams which requires no centre support to create roofs. Instead all the beams support each other, as can be seen in image 3.4. When one beam is removed the structure will collapse. The outer ends of the beams are put on support, which means you need a big surface to attach the roof to. For example a wall or the ground. These kind of structures are also used to make circular forms. [9-14]

Removable Roof

In cars as well as in carrier tricycles for kids the roofs can be removed or partially removed. The mechanisms of those roof systems have been used as inspiration on which possibilities there are for removing the roof system. The collage is shown in image 3.5.

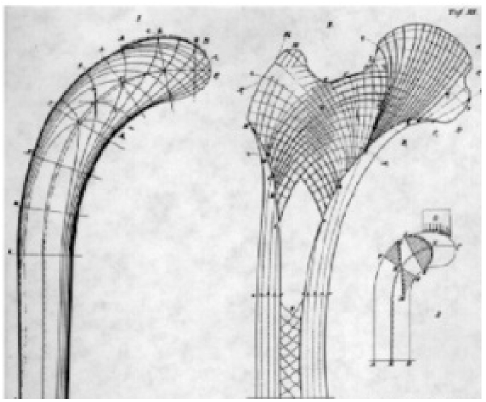


Image 3.2: Bone Structure [10]

Image 3.3: Tessellated roof of the Great Hall [9]

Image 3.4: Reciprocal Frame Structure [13]

Image 3.5: Collage of Removable Roof Systems

Morphologic Schedule

All the constructions are summarized in a morphologic schedule. Different solutions from different design problems can be used to generate concepts. There are four categories, basic shapes, constructions, doors and roof systems. In attachment D there will be a complete explanation for each solution.

The solutions that are marked green are possible solutions that can be used for the roof system of the Quattrocycle. Those solutions are based on how feasible they are, keeping in mind a lightweight construction and the possibility on how they are going to be attached to the frame of the Quattrocycle.

In the first column the basic shapes are chosen. Most of the shapes seem possible, except the last two. Attaching the frame to the Quattrocycle is most likely going to be a problem with those shapes, that is why they are not included.

The second column shows construction possibilities. The solutions that are marked green show hollow tubes, tent based constructions and stressed skin principles. Because they are already used in vehicles it is likely that they offer a possible solutions. The last solutions (B8-B10) are used in buildings and they need a lot of frames and contact area. This will be a problem with removing the roof system and attaching the roof to the frame of the Quattrocycle.

There are several possibilities for the doors. One of the wishes is to create a new experience when entering the Quattrocycle (C2, C5 and C6). Another possibility is that the Quattrocycle is open and is easy to enter.

The last column shows a lot of different possibilities for the roof system. Some of the possibilities increase the width or the length of the Quattrocycle. This is not desirable. Some other solutions are not possible in combination with solar panels on top of the roof. Therefore most of the possibilities that are marked green, the solar panels are slid away.

In the next chapter those solutions will be combined into general concepts directions to explorer the different possibilities.

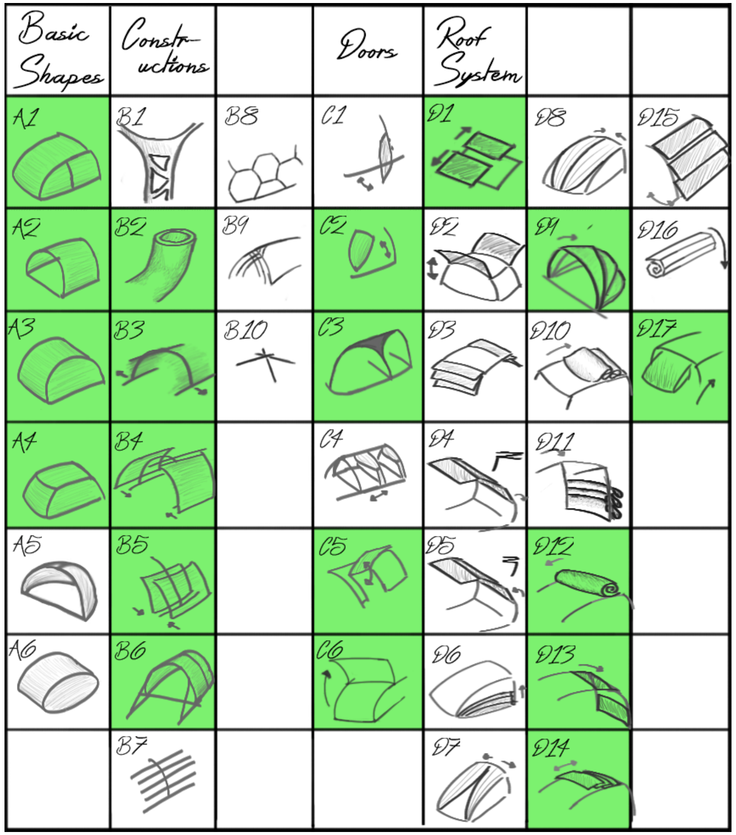


Image 3.6: Morphologic Schedule

3.2 Materials for a Lightweight Roof System

Different materials were analysed by looking at different industries: the car industry, the aeroplane industry and the outdoor industry. Advantages and disadvantages will be described for the materials in the different industries. This paragraph ends with a conclusion on which materials are suitable for the body and for the frame of the roof system. In attachment E tables with the described materials can be found.

Metals

In the car industry most car structures are still made of steel, because of its low cost, consistent supply, recyclability, and ease of forming. In the outdoor industry steel poles are used for caravan tents, but they are sensitive to corrosion and it lacks flexibility. In both industries steel is slowly replaced by aluminium alloys, because aluminium is much lighter than steel. The cost of aluminium alloys is higher in comparison to steel.

There is a variety of aluminium alloys used in the different industries. In the aeroplane industry, the 2xxx alloys are used against fatigue and the 7xxx alloys are used for strength in most cases. In the car industry the 5xxx series is used for body panel production. In the outdoor industry there are two different kinds of tent poles available: bendable and non-bendable. 5xxx series are used for panel production. At last in the outdoor industry there are two kinds of poles available: bendable and non-bendable. The non-bendable poles are used for bungalows and ridge tents and the bendable poles ware used for dome tents. The main alloys that are used are the 6xxx and the 7xxxx. The 6xxx Aluminium alloys consist of aluminium, magnesium and silicon and is used in yachts and bicycles as well. This alloy is resistant to corrosion. The 7xxx Aluminium alloy consists of aluminium and zinc, this alloy has the highest tensile strength and yield. [15,16]

To save even more weight, magnesium alloys are used in the car and aeroplane industries, but the costs are high due to the available production methods. The production volumes of these alloys are limited to medium and high volumes. [17]

Plastics and Fabrics

Most plastics which can be used for the roof designed are in the form of fabrics or as adhesives for composites. In the car industry plastic parts are used for the interior and some exterior panels that don't have to withstand a lot of force. In the outdoor industry different fabrics are used for different purposes of camping. Some of the most common materials that are used in this industry are: cotton, nylon, polyester and combinations of those materials. The materials are strengthened in order to prevent tearing and ripping. This is done by using a weaving technique called Ripstop. A thicker nylon thread is woven crosshatched into the base material.

Fabrics can be penetrated by water. The Hydrostatic Head (HH) is used to indicate the amount of pressure of water that is required in order to penetrate the fabric. The Hydrostatic Head depends on the fabric and the coatings that are used. The durability of the textile depends on the conditions where it is used. UV-radiation, dirt, and air pollution has impact on the lifespan of the materials. UV-radiation damages the structure of the textile causing the technical properties to change. Most textiles use coatings to make a tent waterproof, lower the burning speed or to make it UV-resistant. The coatings that are used are a polyurethane coating for the cheaper tents or a silicone impregnation for the more expensive tents. The basic materials and their properties such as climate, density and lifespan are listed below. The lifespan is an indication on the timespan the tent cloth can be used outdoor without downgrading. The time in storage is not included in the lifespan. [18, 19, 20, 21]

Cotton is heavy compared to the other materials and it absorbs a lot of water making the cloth even more heavy in rainfall. The cloth has a high breathability and protects against heat and cold, therefore it allows tents to have a nice climate. Cotton is not sensitive to UV-radiation and the lifespan ranges from 30 to 55 weeks, depending on the density of the fabric.

Nylon is a really light and cheap material. However, it is easy to tear and it is sensible to UV-radiation. The material has a low breathability, making it uncomfortable to sit under in direct sunlight but it dries quickly after a rainfall. The lifespan of nylon is 12-30 weeks.

Polyester is available in different qualities. It as a strong material and is often used in combination with cotton to get the advantages of both materials. Just as nylon the material has a low breathability, making it uncomfortable in direct sunlight. Polyester does not absorb water and dries quickly.

The combined material is lighter than normal cotton and stronger than polyester. The material is resistant to UV-radiation. This material is the most expensive. The climate in a poly-cotton tent is better than a tent made with synthetic materials.

Composites

Composite materials are used in all industries. The fibres that are used in composites are carbon, glass and aramid fibres. Carbon fibres are the strongest fibres and also the most expensive fibres. They are used to make tent poles, but can also, be used for body panels for racing cars and aeroplanes. Carbon fibre skin is the best choice for sandwich constructions. For the normal automotive industry the supply is not consistent enough and the material and processing prices are high. Glass fibres were used for tent poles, but they break easily and are now replaced by aluminium poles. [16, 22]

Natural fibres in cars are used for interior and some exterior parts in cars, which is not put under a lot of force. These fibres are cheaper and lighter than glass fibres, but also lower in strength and lower in stiffness. The properties of the natural fibres are not consistent because they depend on the harvesting season, harvesting region, and other factors. [23]

Materials Suitable For the Frame of the Roof System

The frame of the Quattrocycle has to be lightweight, sufficient stiff and available for small productions. As described above the following materials are used in the different industries for producing frames: aluminium alloys, steel, carbon fibre and glass fibre.

Steel has a high density and glass fibre poles break easily. Aluminium alloys are very suitable for the frame, because of their low density and price. Aluminium is widely available and easy to process. Carbon fibre tubes are stronger and lighter compared to aluminium, but they are too expensive and production is very labour intensive and therefore not a suitable option for the frame.

Materials Suitable for the Body of the Roof System

The body of the Quattrocycle has the same requirements as the frame, lightweight, sufficient stiff and available for small productions. The following materials are used for the bodies of the object in the different industries, listed above: steel, aluminium alloys, different fabrics, magnesium and carbon fibre.

Steel and magnesium are unsuitable for the body: steel because of its high density and magnesium because it can only be produced in medium to high production volumes. From the fabrics a combination of polyester and cotton is most desirable, this because of the comfort while sitting under the fabric and the weight.

Aluminium and carbon fibre can both be used for the roof. Aluminium has a higher density, but is cheaper and easier to process. For a lightweight roof carbon fibre has the preference, but the biggest disadvantage is the price.

Depending on the design of the Quattrocycle aluminium, carbon fibre or a blend of polyester and cotton is suitable for the body of the roof system.

3.3 Production Processes for a Lightweight Roof System

When selecting production processes the following criteria have to be kept in mind: production volume, tooling costs, unit cost and shape function. These criteria are applied to the roof system. The roof system will be used for prototyping and for low volumes, it is therefore preferable that the tooling costs are low. This can be done by using no tooling or standard tools that already exist. Only processes that can be used with the materials are suitable to use for the body and for the frame, as described in the previous paragraph. In attachment F production processes used in the different industries can be found.

Frame

For the frame aluminium was chosen as the most suitable material. There are however several aluminium alloys and product shapes available. The best way to construct a lightweight frame is using hollow tubes. Those tubes are available in various diameters, thickness and length. Since the tubes can be bought the raw processing of the material is already done. For the production it only needs to get it final shape. There are only a few production processes available for producing the frame in low volumes. The following two processes match the criteria the best and might be needed for constructing the frame.

Swaging: Swaging is a production method that manipulates the metal of tubes, rods or wires. It is used to reduce the cross section of tubes by stretching out the material, but can also be used to expend the diameter of the pipe. It can be used to form friction fit and formed bonds. This technique is used by tent poles to connect them.

Tube and Section Bending: There are two types of tube and section bending, mandrel bending and ring rolling. Mandrel bending is used for making small radii and ring rolling is used to form continuous and larger bends. CNC machines can be used to make different and discontinuous bends. [24]

Depending on the design of the Quattrocycle one or both processes can be used to process hollow aluminium tubes.

Body

For the body various materials were found suitable. Depending on the design of the Quattrocycle the chosen materials are either aluminium, or carbon fibre, or a poly-cotton fabric. The fabric can be bought in pre-cut pieces and afterwards sewed into the desired pieces for the body. For the other materials it can be assumed that some kind of plates will be needed and these plates would have to be shaped. Aluminium plates can be bought. After that panel beating can be used as processing process. It is a process where the panels are formed by hand by beating on them with a hammer. It is used for prototyping in the automotive industry. The products are handmade and therefore the unit costs are high and the results will vary a little for each unit. [25]

The carbon fibre plates can be formed with different processes. From those processes available, composite laminating is the most suitable one. For every production method there are high tooling costs involved and this process has the lowest costs of them. There are three different types of laminating, these are: wet lay-up, pre-preg and resin transfer moulding. Resin transfer moulding is used for larger production and pre-preg is the most expensive. Wet lay-up is the best production method in this case, because it is the cheapest option. Mats of fibre are impregnated with resins and draped into a mould. For more precise products heat and pressure can be applied during the curing phase. [24]

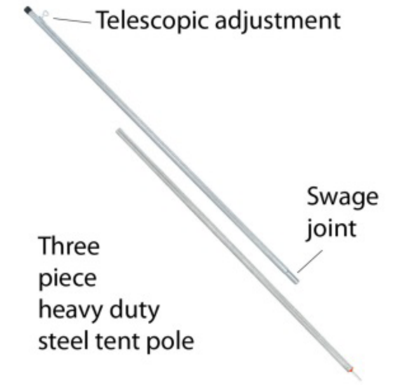


Image 3.7: Example of Tent Poles where Swaging is used [26]

Image 3.8: CNC machine for Tube Section Bending [27]

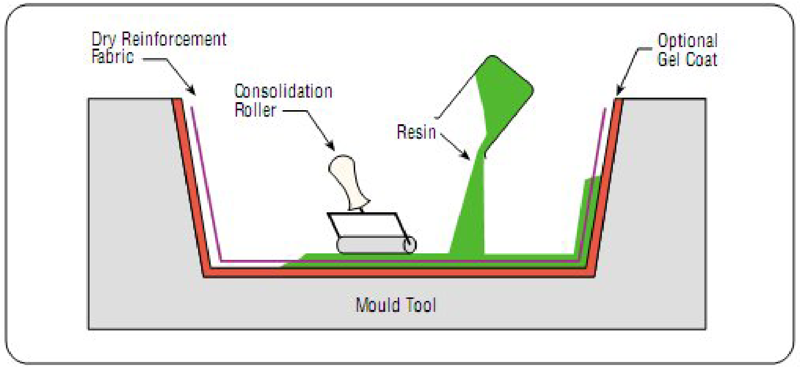


Image 3.9: Wet Lay-UP for Composites [28]

3.4 Summary and Conclusion of the Analysis

In the previous paragraphs possible constructions methods, and materials, and processes are described that can be used to construct a lightweight roof system. To generate different concepts, those aspects need to be combined.

The frame of the roof system will be made out of hollow aluminium tubes. The production method for tube and section bending can be used to bend it into the right shape.

The aluminium frame can be used in the different constructions that are shown in the morphologic schedule.

The body of the roof system can be made out of different materials depending on the design. Those materials are aluminium, poly-cotton fabric and carbon fibre.

The poly-cotton fabric can be used for the tent-based construction. The fabric can be used to put tension and thus stability to the frame. The material is ready to buy and can be sewed to get the right shape and functions.

The aluminium can be bought as plates and after that the production process panel beating can be used to shape it into nearly any possible shape. This means that the aluminium plates can be used for all basic shapes and types of constructions for the roof, except the tent-based constructions.

The carbon fibre is the most expensive material but it is also one of the lighter ones. It weighs about the same as the poly-cotton fabric which is ideal for a lightweight roof. It can be processed by wet lay-up laminating using a mould. By using the stressed-skin principle, the frame can be integrated in the carbon fibre. The carbon fibre can be used for the same applications as the aluminium.

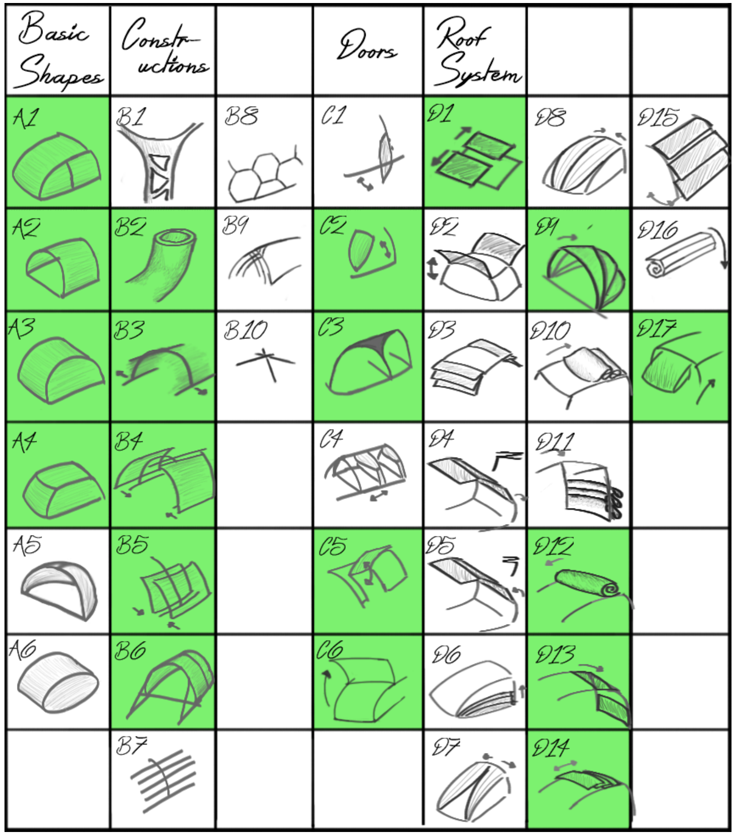


Image 3.10: Morphologic Schedule

4. General Concept Directions for a Lightweight Roof System

In the previous chapter is discussed which materials, constructions and production processes can be used for a lightweight roof system. Those aspects will be combined into five general concept directions that are presented below. Finally two concepts will be chosen to develop further.

4.1 General Concept Directions

Five concept directions were selected. Shapes, doors, constructions and roof systems from the morphologic schedule will be shown to explain the principles used in the concepts. Those principles are combined with the most suitable materials. This is based on the different construction principles and the properties of the materials. A describtion of the icons can be found in attachment D.

Concept One

This concept is made of a combination of poly-cotton fabric and carbon fibre composites. The top of the roof is made out of carbon fibre to offer stability using a stressed-skin principle (B4). The sides are made out of fabric. The front side is a made out of a more solid material like the roof, in this case glass. The sides of the roof system are open for fresh air (C3). The roof can be opened by pushing the solar panels to the sides (D1). The advantage of this concept is that the sides are open. A problem can arise when the user is entering the front seats of the Quattrocycle.

Concept Two

This concept is a tent-based concept where the body is made out of poly-cotton fabric. In the front ropes are used to put stress on the constructions (B6). The solar panels and the fabric can be rolled up towards the top for entering and leaving the Quattrocycle (C5, D12). The front and the back of the roof system can be folded as well. This way the whole body can be removed. The visibility for the users in this concept is worse compared to the other concepts because the sides are closed. The advantage with closed sides however, is that when it is raining everyone is protected.

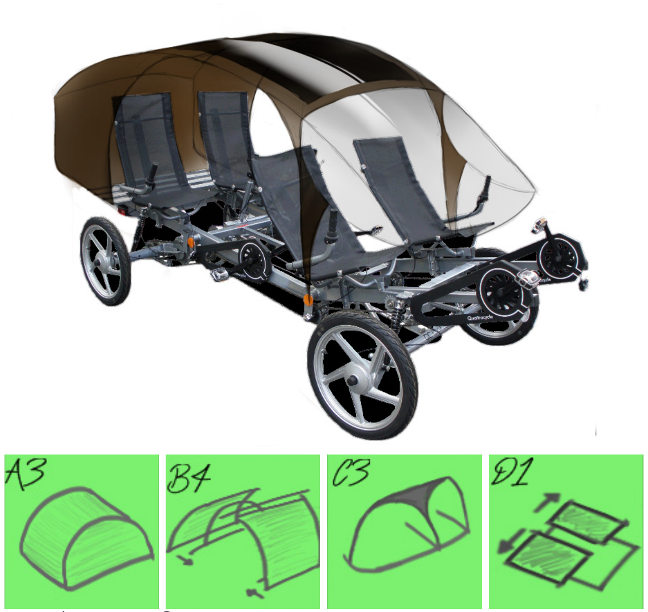


Image 4.1: Concept 1 and the solutions form the morphologic schedule

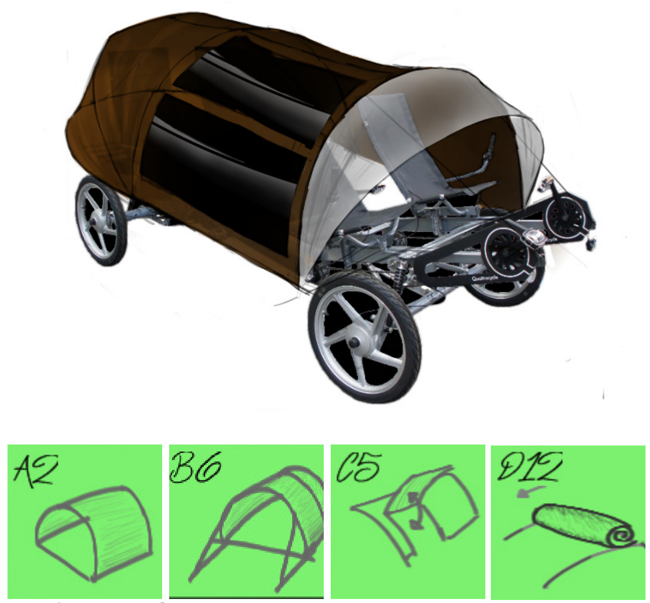


Image 4.2: Concept 2 and the solutions form the morphologic schedule

Concept Three

This concept is fully made out of composites using a stressed-skin principle (B5). The solar panels are located in different segments of the roof and each segment can slide backwards if the users wish to open the roof (D14). The front is closed, to protect against rain and mud. The front can not be opened. The sides are open, so the user can enter and leave the Quattrocycle easily (C3). The back is extended for extra luggage room. This concept is likely to be more expensive than the other concepts because of the amount of carbon fibre.

Concept Four

The front window is made out of glass and can be pulled inwards along rails in the roof in order to enter Quattrocycle from the front (D17). The body is made out of carbon fibre composite, using a stressed-skin principle (B5). The sides are partially closed to protect against rain, only places were the user can enter the Quattrocycle are left open (C3). The solar panels on this concept are fixed in place, but there is a possibility to remove a part of the roof for fresh air.

Concept Five

This concept is made out of different segments. The segments are covered with fabric using a tent-based principle, using bendable poles to put stress on the fabric (B3). On top of those are the solar panels. The segments can be moved to the back guided by a rail (D9). There is no protection on the front of this concept or from the sides, this in order to get a more open feeling (C3). This concept is expected to be the lightest, because it uses the least material.

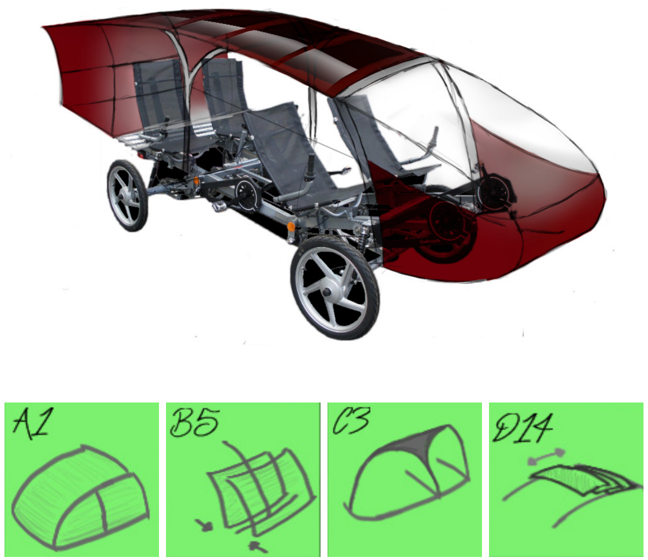


Image 4.3: Concept 3 and the solutions form the morphologic schedule

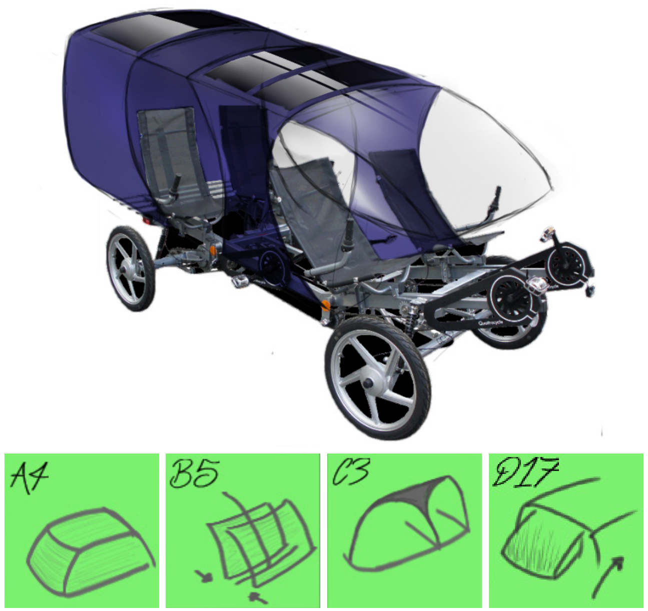


Image 4.4: Concept 4 and the solutions form the morphologic schedule

Image 4.5: Concept 5 and the solutions form the morphologic schedule

4.2 Concept Evaluation

The concepts were evaluated in a meeting with the client. The purpose of this meeting was to decide which concepts should be developed further. The decision was based on a selection of the requirements and wishes, shape and the difference between the concepts. The shape had to be attractive and should not catch too much wind. The selected requirements and wishes are based on the following functionalities:

- The vehicle has space for 80 litres of baggage
- The roof system protects against wind, rain, hail and snow from the front and above
- The roof system doesn't obstruct the user by entering and leaving the vehicle
- The roof system should be partially removable (wish)
- The vehicle provides protection from rain, hail and snow from the sides (wish)

The five concepts are shown below in order from one to five.

The client wanted an attractive and modern looking shape. The second and the fourth concept did not have that, although the idea of being able to enter to Quattrocycle from the front was appealing. The first and the fifth have both a more organic shape and curve. Especially the fifth concept had similarity with the segments of an insects.

All of the concepts protect against rain, hail and snow from above. The second and the fourth concept protect form the sides as well, hereby obstructing entering the Quattrocycle and obstructing the line of sight. For these reasons the concept two and four were not chosen.

The third concept is appealing because of the extra luggage area and that it is made of lightweight materials. Finally the third and the fifth concept were chosen. Two different concepts were chosen because it is preferable to explore two directions, each with a different material for the body of the Quattrocycle. In this case the first concept was too similar to the fifth concept. The fifth concept was chosen because of the different segments, creating a more outdoor feeling. And the window in the first concept could be a problem when entering the Quattrocycle.

In both concepts it is difficult to enter the Quattrocycle and to attach the roof system to the frame. Therefore further research is done on the attachment points, solar energy, line of sight and entering and leaving the Quattrocycle. This will give direction in the design of both concepts. This will be presented in the next chapter.

4.3 Conclusion and Summary of the Concept Generation

This chapter started out with five concepts, each one has its own advantages and disadvantages. Concepts three and five were chosen for further development. The decision was based on shapes, some of the requirements and wishes and the differences between the concepts.

These concepts were chosen because:

- Attractive and modern looking shapes
- Entering and leaving the Quattrocycle
- Luggage space

Two concepts were chosen because it is preferable to explore two directions. Additional research for these concepts will be done in the next chapter.

Image 4.6: Concept 1

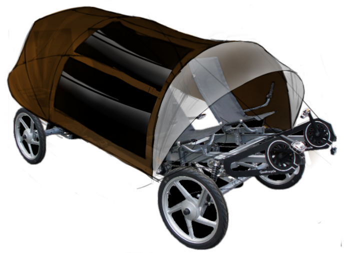


Image 4.7: Concept 2

Image 4.8: Concept 3

Image 4.9: Concept 4

Image 4.10: Concept 5

5. Additional Research on the Quattrocycle

Additional research had to be done before the two chosen concepts can be further developed. Research was done on entering and leaving the Quattrocycle, the line of sight, attachment points to the Quattrocycle and the solar panels. At the end of the chapter, a developing directions will be given for the two concepts.

5.1 Entering and Leaving the Quattrocycle

Designing the roof system it is important that the roof should not obstruct the user while he or she is entering or leaving the Quattrocycle. Therefore a brief study was done how the user enters and leaves the Quattrocycle normally. This has been done for the front and back seats. Some solutions to cope with these problems have been designed.

Front Seats

For entering the Quattrocycle by the front there are two possibilities. The first one is through the sides, by stepping over the front wheel. This is shown at image 5.1 and 5.2. And the second one is through the front, between the two seats. This is shown at image 5.3 and 5.4.

As shown on image 5.1 the roof is obstructing the user when entering the Quattrocycle, because the user has to step over the front wheel and in front of the arm support. This way the roof has to go up steeply. Another possibility is using seats with a foldable arm support. Then the user can step over the wheel, right into the seat.

The second option is shown at image 5.3 Here the user finds his seat through the front. First the roof has to be lifted upwards. In this scenario the most critical point is attaching the roof system to the frame of the Quattrocycle again, as shown in the last pictures.

Back Seats

The back seats can only be entered by the sides by stepping on to the frame. After the user has stepped over the frame he can easily sit down in the seat. In this case the roof does not obstruct the user. The user already bends forward when he steps on to the frame. Even if the frame of the roof would be lower it would not obstruct the user.

Image 5.1: User sitting down by stepping over the front wheel

Image 5.2: User sitting in the front chair

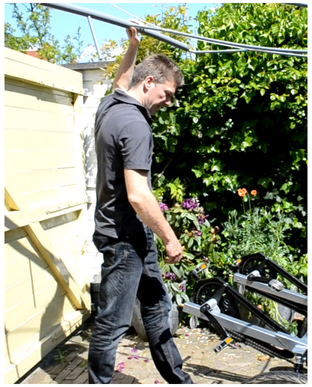


Image 5.3: User sitting down by lifting up the front window

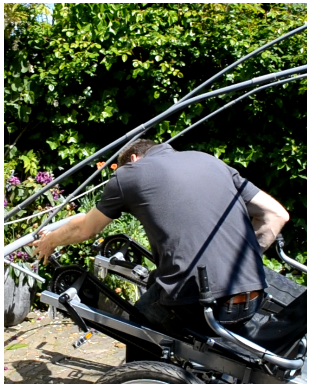


Image 5.4: User closing the front window after sitting down

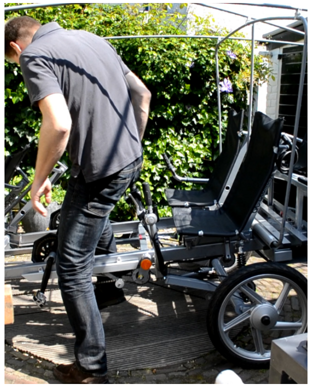


Image 5.5: User sititng down in the back chair by stepping over the frame

Image 5.6: User sitting down in the back chair

5.2 Line of Sight

The Quattrocycle will be used in cities and in the middle of regular traffic. Therefore a clear line of sight on the road, traffic lights and other traffic is essential. The Quattrocycle is driven by the person in the left back, so it is important that this person has a total view over the road. Since the sides of both concepts are open, the sides will not be discussed.

In order to decide what area that the driver needs to have an overview of, a situation has been sketched. Traffic lights and sign posts are the tallest objects that the Quattrocycle can encounter during a trip and because of that the traffic lights are used for this situation. According to the Dutch laws the traffic lights for bikes are three meters high. In the city the Quattrocycle has the possibility to stand right next to the traffic light, and most of the time there are smaller traffic lights at eye height. Outside the city however, the traffic lights stand at a distance of three meters, the picture to the left is based on that. The blue lines give the line of sight for the person in the back seat and the red lines give the line of sight for the person in the front seat. The area between the blue lines needs to be clear, so the driver can have clear view on the traffic lights. [29]

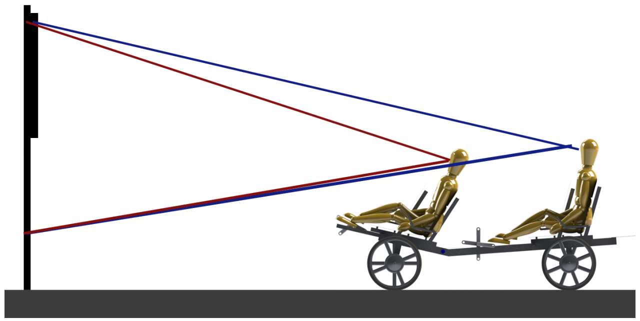


Image 5.7: Line of sight

5.3 Attachment Points from the Roof System to the Quattrocycle

The roof system has to be attached to the Quattrocycle and therefore it is important to know where on the Quattrocycle that is possible. The points will be explained further below. The blue points are based on a prototype roof that was built on the Quattrocycle and on tests that were done for entering and leaving the Quattrocycle, so the roof does not hinder the user.

The two hollow tubes in the front of the Quattrocycle can be extended and used as attachment points. These points can be used for support, as shown in image 5.8 This is the only place on the front of the Quattrocycle where the roof system can be attached without making any bigger changes to the original frame.

Another point where the roof system can be attached to is the tube behind the front wheel. This tube can be extended until it passes the arm support of the front seats. This extended tube can be used to support the frame of the roof system. This is shown at image 5.9.

In the middle of the Quattrocycle is one bar that can be used as support, as shown in image 5.10. The ends are most stable because they rest on the mainframe. Those points can only be used for supporting vertical bars going to the roof without obstructing the user.

The last image 5.11 shows the last point at the back of the Quattrocycle. It simulates the baggage rack. The frame of the roof can be attached to it and depending on the design of the roof system, the baggage rack can be extended even further.

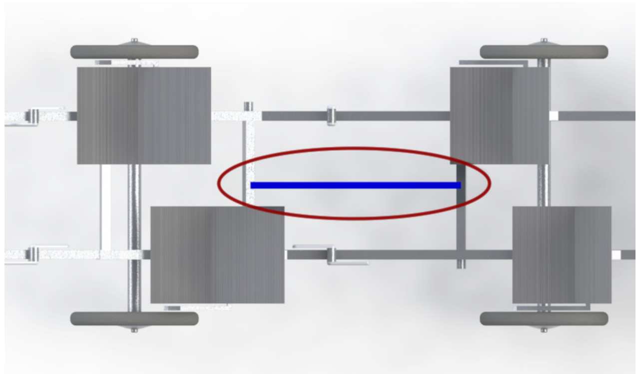


Image 5.10: Middle bar

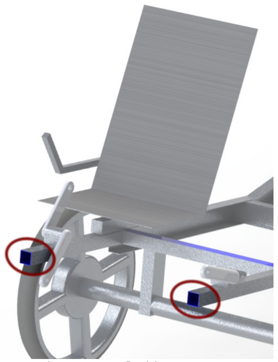


Image 5.8: Hollow tubes

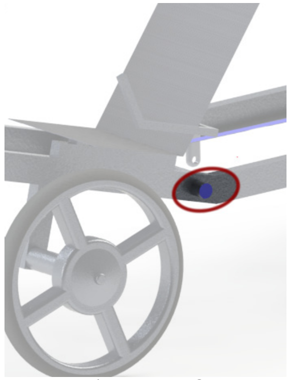


Image 5.9: Side point

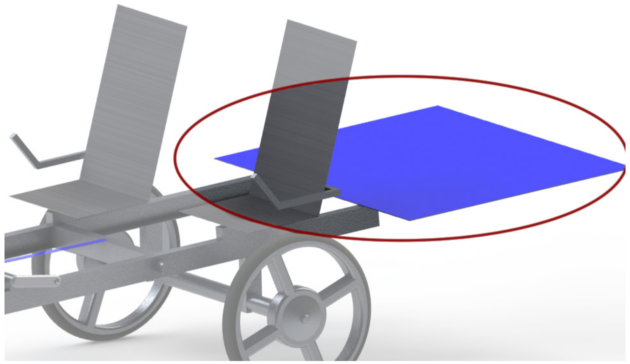


Image 5.11: Extended baggage rack

5.4 Solar Energy

At the moment there are a lot of developments in solar energy. There are solid, flexible, foldable and flexible organic solar cells available at the moment, each using a different technique.

In order to decide what model of solar panel that will be used the type of solar panels must first be decided. Furthermore there will be calculated how much energy the solar panels should be able to deliver and how much area of solar panels that is required. There was tried to contact the Solar Team Twente for information, this was not possible.

The Type of Solar Panel

The rigid solar panels have, on average, a better efficiency. The durability of these panels are also higher than the other types. The weight of the rigid solar panels is however a lot heavier. The total weight of the solar panels required to produce 300 Watt will be 30 kg, therefore they are not suitable for a lightweight roof system. [30, 31]

There are two kinds of flexible solar cells. The first one is dye-sensitized solar cells, they are really lightweight and they have low production costs but the efficiency is only up to 7%. The other kind is a thin-film called CIGS solar cells. They can get an efficiency up to 20% and they are self-repairing. Those are the solar cells that will be used for the roof system because they are the most efficient and flexible solar cells available at the moment and they keep a low weight. [31, 32, 33]

Calculations on the Required Energy

In order to calculate how many solar panels that will be needed for the roof system there should first be calculated how much solar energy that is needed to give maximum output of the solar panels. This depends on the following factors: Speed (v), acceleration (a), mass (m), efficiency, rolling resistance (Rroll), air resistance (Rair), wind direction, wind speed and the steepness of the hill. The chosen values will be explained below. The exact calculations will be shown in attachment G. [37]

According to the requirements the vehicle needs to be powered by 80% human power and 20% solar power, the engine is only allowed to support up to a maximum of 25 km/h. Since the Quattrocycle is powered 80% of human power, there need to be calculated how much energy that can be delivered by the users. An adult between the age of 25 and 40 years can deliver an output of 150 Watt for one hour. He or she is able to deliver up to 750 Watt for a few minutes, for example by accelerating. Therefore the engine only needs to help the user to maintain the average speed and is not used for acceleration or climbing a hill. In the scenario there will not be any wind so those parameters are set to zero. The efficiency for using energy of the Quattrocycle will be set to 95%. This leaves speed, mass, rolling resistance and air resistance as parameters that need to be set. [37]

The air resistance is based on the drag coefficient (Cw), the frontal area (A), speed (v) and the relative density of the air. The frontal area depends on the width and the height of the roof system. The Quattrocycle has a maximum width of 1,5 meters and it will be assumed that the roof system has a maximum height of 1,6 meters. This gives a frontal area of 2,55 m^2. The relative density of air is 1,23 kg/m^3. The drag coefficient depends on the aerodynamic shape of the roof, the most ideal shape is a streamlined body. Loose tubes, uneven surfaces and accessories increase the drag coefficient easily. Most cars have Cw of 0,4 and a normal bike have a Cw of 1,1. It is assumed that the Quattrocycle will have a value somewhere in between leaning towards bikes, therefore a Cw of 0,8 is chosen for the calculations.

The rolling resistance is based on the mass (m), gravity (g) and the roll coefficient (Cr). The roll coefficient will not be explained, because it is not part of the roof system. The Quattrocycle uses puncture proof tires, since it is used for leisure. The roll resistance for a bike on a normal road is 0,007, which is the roll resistance for the whole vehicle, not per tire. This value is used for the calculations. [38]

Image 5.1: Rigid solar panel 8.25 kg [34]

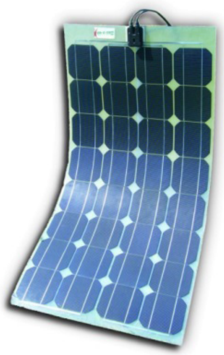


Image 5.2: Flexible solar panel 1.3 kg [35]

Image 5.3: Flexible solar panel on a car [36]

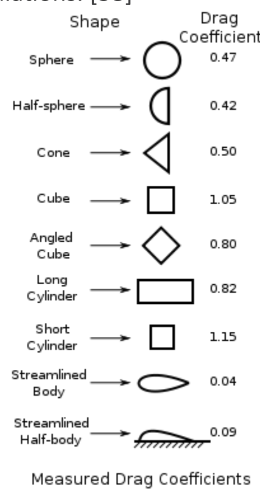


Image 5.4: Drag coefficient for different shapes [39]

For the calculation, the scenario from attachment B is used as a base. This is the scenario with the highest total load. The Quattrocycle including the roof system (120 +30 kg) is driven by two adults (2x 75kg), two kids (2x 30kg) and contains some baggage (80kg). This gives a total mass of 440 kg. Both the adults deliver 150 Watt per hour. It is assumed that the children support 30 Watt per hour. This gives a total of 360 Watt. Based upon these parameters the Quattrocycle can reach a maximum speed of 20 km/h on human power.

Now all the parameters for the calculations are known. There are two scenarios to decide to how much energy the solar panels must deliver, based on the requirements or based on the wishes.

- Requirement: The vehicle must be powered on 20% solar energy
- Wish: The vehicle can reach a speed up to 25 km/h

Both the requirement and the wish are calculated and the results are shown in the table 5.1. It gives the amount of Watt the users deliver, the speed reached and the amount of Watt the solar panels have to deliver.

	Requirement	Wish
Users	360W	360W
Speed	21,4 km/h	25 km/h
Solar Panels	90W	276W

Table 5.1:Results of the energy caluclations

To reach the ideal speed of 25 km/h the solar panels need to deliver 276 Watt. However, the requirements are already reached when the solar panels deliver 90 Watt. In the following calculations 276 Watt will be used.

By looking at the different formulas for calculating the amount of energy needed, there can also be determined where energy can be saved. The parameters which can be influenced are the drag coefficient and the mass.

Looking at the formulas in attachment G the mass of the Quattrocycle is used in all resistances. Therefore lowering the mass will result in lower resistance, especially when accelerating or going uphill. The air resistance has a lot of impact on the required power, especially at higher speeds, so it is preferable to minimize the frontal surface area and the drag coefficient.

Calculations on the Required Solar Panel

In the previous section was calculated that the solar panel should deliver 276 Watt to reach a speed of 25 km/h. The selection of the type and size of the solar panel depends on how much solar radiation that falls on the surface, the efficiency of the solar panel and the amount of Watt the solar panel can produce.

The efficiency of the thin-film flexible solar panels is 20%. This means that to get an output of 276 Watt the input needs to be 1385 Watt. That is the amount of energy that needs to be collected by the surface area of the solar panels.

The amount of solar radiation on a surface depends on a lot of different factors, for example: Month, time of day, cloudiness, longitude, tilt towards the sun etc. For this calculation the latitude is 52 (the Netherlands), the average cloudiness in the Netherlands and the monthly average daily radiation are used. For these calculations the average radiation between 08:00 and 19:00 is used. The calculations will be done with two different values for the cloudiness, the first one is the average cloudiness during July, which is 60%. And the second one is a cloudiness of 5%, a sunny day. When the amount of Watts needed is divided by the average radiation the amount of surface area needed can be found. The average radiation and the corresponding surface area is given in the table. [40, 41]

	5%	60%
Average radiation	658Wh/m^2	364Wh/m^2
Surface area needed	2,1m^2	3,8m^2

Table 5.2: Average radiation

In attachment H values of the average radiation can be found for the other months.

Different flexible solar panels can be found that will deliver the right amount of energy. Only two of them will fit the dimensions of the roof system, specification are shown in table 5.3. Both of the solar panels collect the needed amount of watt. The question that is left is: Is the surface area of large enough to get enough solar radiation?

The surface areas of both solar panels can be compared to the surface area needed showed in the table 5.2. The solar panels need to match the needed surface area as close as possible. The surface area of the SunPower panels is too small to deliver the amount of energy needed. The Enecom panels are chosen because they are able to collect the amount of energy needed on a sunny day, fulfilling the wish. On a cloudy day the requirement is still fulfilled.

	5%	60%
Average radiation	658Wh/m^2	364Wh/m^2
Surface area needed	2,1m^2	3,8m^2

Table 5.2: Average radiation

Amount	Solar Cells	Watt	Weight (kg)	Total weight	Total Watt	Surface Area (m^2)
3	SunPower 100 Watt (SP100-L)	100	1,5	4,5	300	1,7982
4	Enecom flexible solar panel 70W	70	1,3	5,2	280	2,322816

Table 5.3: Specifications of the two chosen solar panels

5.5 Concept Directions for the Two Chosen Concepts

Based on the morphologic schedule, a meeting witht the client and the additional research a few changes to the concepts were made.

Concept three will be developed with the possibility to enter the Quattrocycle from the front through the window by lifting up the front side of the body. In this way the attachment point next to the front seat can be used as support. Further the solar panels can be moved to the back of the roof by sliding the segments where the solar panels are attached to. The body will be made out of carbon fibre composite. This concept will be further on referred to as: 'concept Car', because of its solid and car-like looks.

Concept five will be developed without the moving roof segments, instead there will be openings in the roof that can be removed for more sunlight. The Quattrocycle will be entered from the sides, for both the front and the back seats. The frame will be attached to the points at the front and the back of the Quattrocycle. This concept will be further on referred to as: 'concept Outdoor', because of its tent based construction.

5.6 Conclusion and Summar on Additional Research of the Quattrocycle

Additional research was done before starting the development of the two chosen concepts. The research topics were entering and leaving the Quattrocycle, line of sight, attachment points and solar energy. After the research directions were given to the two chosen concepts.

There are two possibilities to enter and leave the Quattrocycle by the front. The first is stepping over the front wheel from the sides. The second is lifting the front upwards so the user is able to enter from the front. The back seats can be reached from the sides by stepping over the frame.

The line of sight for looking at traffic lights is used, since they are high placed. The image can be used as a guideline for the size of the front window.

The two main attachment points are in the front and the back of the Quattrocycle. Other points that can be used are the ones in the middle of the points between the front wheel.

The calculations on solar energy show that it is possible to drive at a speed of 25km/h on a sunny day, fulfilling one of the wishes. When using four Enecom flexible solar panels.

With this knowledge the concept Car (three) and the concept Outdoor (five) will be developed.

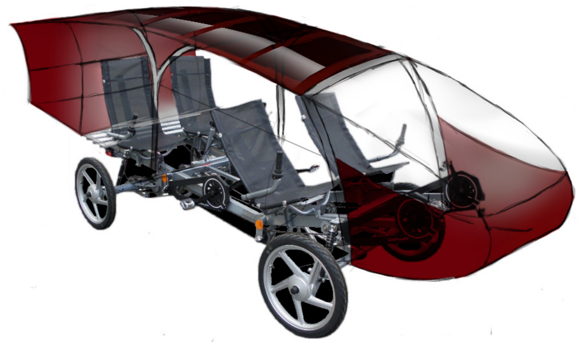


Image 5.5: Concept 3

Image 5.6: Concept 5

6. Development of the Two Concepts

The two chosen concepts were developed further. Materials, price, weight, construction and mechanics is explained for both concepts and at the end of the chapter the concepts are compared with each other and a final concept is chosen.

6.1 Concept Outdoor

	Material	Weight (kg)	Price (€)
Frame	Aluminium 6060	7,22	60
Body	TenCate Solair	1,21	41,95
Window	tpPVC	2,51	20,39
Mechanisms	Combination	1,80	17,96
Solar panels	Enecom Flexible 70 W (4 pieces)	5,2	3820
Total		17,97 kg	€ 3960,-

Table 6.1: Specifications of the outdoor concept

The price is based upon the material cost. The materials are standard products that can be bought from the shelve. So no special parts have to be produced. The price of the TenCate Solair canvas is unknown, therefore a price of a similar material is taken to give an indication. The only exception is the aluminium the frame which aluminium tubes need to be bend into the right shape. This can be done by standard bending machines. This is not included in the calculations.

Design

The design is inspired by the pangolin and the pangolin backpack. The roof exists of different segments that are used for the solar panels and could originally be moved to the back of the Quattrocycle. Now only one part of the roof is removable, the top segment. The other segments are the one for the back and the front window.

The solutions were made to avoid mechanical parts that would have added unnecessary weight to the roof system. The solutions were also made so that the Quattrocycle will be more stable with its solid frame.

The placement of the top segment was chosen so that when removed fresh air can enter the Quattrocycle while keeping the sun from reaching the heads of the persons in the back which provides more comfort.

At the moment entering the Quattrocycle in the front is a little difficult because the user has to step over the front wheel because of the armrest. There are seats available where the armrest can be folded up, making it more comfortable to enter the Quattrocycle. These seats are used in this design. To protect the user from rain an extra transparent canvas for the sides is provided, using the same material as the front window, only thinner. This canvas can be pulled down in case of rain. It covers half of the side of the Quattrocycle, preventing most rain from reaching the passengers.

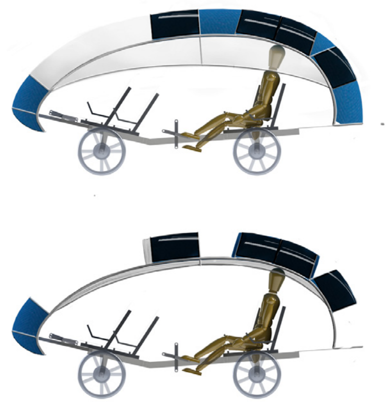


Image 6.2: An open and closed version of the Outdoor concept

Image 6.1: Panglin back pack [42]

Image 6.3: Foldable arm rest [43]

Material

The body is made of TenCate Solair Canvas. This is a poly cotton fabric, it consists of 50% cotton and 50% polyester. The core of the material is polyester and the cotton fibres are spun around it.

By using a mix of polyester and cotton the advantages of both materials are combined. The material will be lighter and more durable than just cotton because of the polyester. The canvas will be treated with sprays to provide colour, UV resistance, mould protection and water resistance. The material will need regular maintenance for extended durability. The material can be processed by sewing. The Ten Cate material is chosen because the client has contacts and wants the roof system to be produced as much as possible in the Netherlands.

The frame will be made out of Aluminium alloy 6060. This alloy is chosen because it can be bought from stock. It is available in different shapes, diameters and wall thicknesses. For the main frame a 25 mm tubes will be used and for the crossbars 12mm tubes. The processing method that can be used is called tube and section bending and is used in the automotive industry. After they are bend in the right shape they can be welded together.

The material that will be used for the window is transparent PVC. It is the same material that is used for windows in tents. The material is very clear, so seeing through it won't be a problem. This PVC can be processed by sewing.

Construction

The construction is inspired by tent constructions. This means that the whole construction is based on tension. The frame consists of two aluminium profiles that are hold together by aluminium ribs. The frame is connected to the Quattrocycle in the back and in the front of the Quattrocycle. The frame of the roof will be made longer than necessary, so it needs to bend when it's connected to the Quattrocycle. This way tension is added to the roof. The canvas is spanned around the crossbars, as can be seen in image 6.4, and the frame, giving stability in both directions to the construction.

The solar panels will be glued on top of the canvas. There are ribs on the sides of the solar panel, offering extra support.

Mechanism

The rain protector can be attached to the Quattrocycle with a zipper along the frame of the roof. In the middle of the rain protector there is a support bar made out of aluminium. The aluminium support is used to make the protector stand out from the body of the Quattrocycle. This way it protects better against rain falling in from the sides. The support can slide into a crossbar of the roof in the middle of the Quattrocycle. The support is kept in place by small pins on the top and the bottom of the bar. On the bottom there is a clip that holds the canvas of the protector. While raining, the frame with the rain protector can be pulled down from the roof and zipped to the sides of the frame. When it is not raining the protector can be rolled up against the top of the frame, removing it with the zipper and pushing the support into the frame, or it can be removed entirely.

The solar panels are fixed to the roof canvas in this concept. The front window and different segments of the roof can be moved up for fresh air. The canvas of the roof covers only parts of the roof frame, this way it can be moved without stacking a lot of material. Velcro straps will be used to wrap around the cloth and keep it in place.

Image 6.4: A tent with the canvas under tension

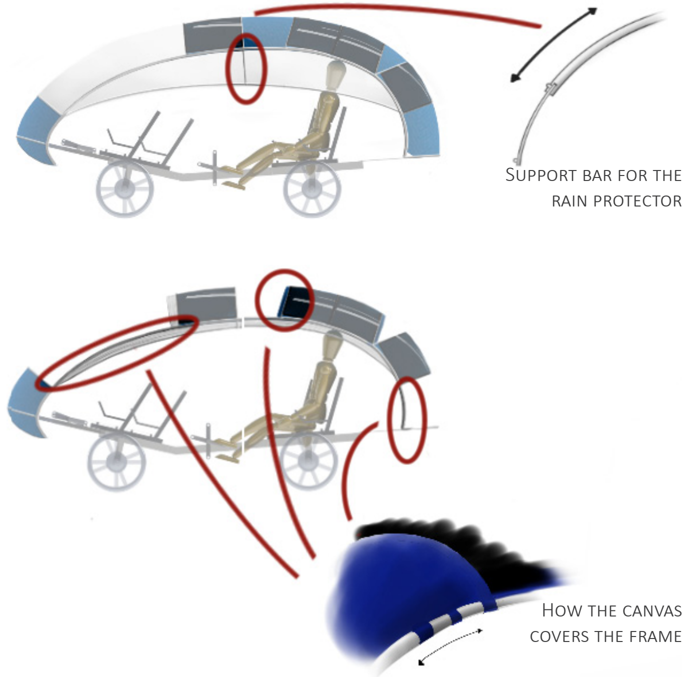


Image 6.5: Overview from the mechanisms

6.1 Concept Car

	Material	Weight (kg)	Price (€)
Frame	Aluminium 6060	4,86	66,18
Body	Carbon Fibre Epoxy	4,16	79,04
Window	Gorilla Glass	5,99	7,84
Mechanisms	Combination	6,58	18,62
Solar panels	Enecom Flexible 70 W (4 pieces)	5,2	3820
Total		26,80 kg	€ 3991,-

Table 6.2: Specifications of the outdoor concept

The price is based on material prices of standard products. Some materials need processing. The price for Gorilla Glass is unknown, the price for soda-lime glass is used. However, the Gorilla Glass is expected to be more expensive but this difference will have a minor difference on the total price.

Design

The design of this concept is based on entering and leaving the car. You can enter the Quattrocycle in the front by lifting up the front together with the front window. Entering by the front is more comfortable for the user than entering by the sides. This also allows the frame to be lower on the sides, making the Quattrocycle look more compact and lowering the air resistance.

The top of the roof is used for the solar panels. Those can be moved to the back of the Quattrocycle by lifting them off and sliding them to the back one by one on top of each other. A further explanation of the mechanics can be found below.

This concept has a more solid and car look because of the materials that are used are more solid and stiff.

Material

The body is made of epoxy filled with carbon fibres, this is chosen because it is lighter and stronger than aluminium. The disadvantage is that the material and the processing processes are expensive. Filament wending is the processing process that can be used to produce the body panels.

The frame is made of aluminium square tubes. Aluminium is a light material that can be loaded on compression. Square tubes instead of round tubes are chosen because it is easier for mounting the mechanisms on to it. On the front of the Quattrocycle there is a piece of the roof frame that can be integrated in the carbon fibre panel.

The window is made out of Gorilla Glass. This is a glass that is much stronger than normal glass due to chemical strengthening, this allows a lighter construction of the windows. The glass is much more flexible than normal soda lime glass. This material is chosen because of its strength and its scratch resistance. This glass also fits into having a more solid car concept with a solid roof.

Construction

The construction is based on the strength of the materials being used. There are four parts of the main frame that are supported with aluminium tubes. There are two aluminium tubes in the front of the Quattrocycle connecting to the roof. The vertical one is used to support the roof and the window when its lifted up by the air springs. The other tube that is tilted is used to support the hinge for the front which can be lifted up. It also gives the vehicle stability in the length of the Quattrocycle. There are two additional other tubes that give support to the back of the car.

There are two more horizontal tubes connecting the both parts of the main frame. The one in front is also used to support the hinge for the front, which can be opened. In the back of the car a cross is spanned with lines to prevent the vehicle from moving in the left and right direction.

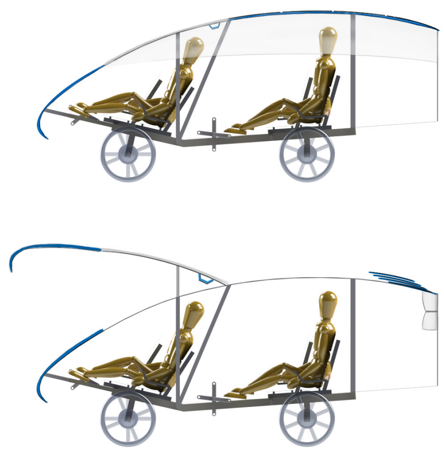


Image 6.6: An open and closed version of the Car concept

Mechanism

There are two mechanisms in this concept. The first mechanism is opening the roof. The roof consists out of four carbon fibre plates. On top of each plate a solar panel is glued on. And on the bottom of each plate there is an aluminium profile. There is a curvilinear rail connected to the frame of the roof. The aluminium profile of the plates can move along the curvilinear rail by pushing the plates up one by one and moving them to the back of the car, stacking them on top of each other. The user will need to get out of the Quattrocycle in order to do this.

The other mechanism is used for entering the Quattrocycle from the front. The sides in the front of the roof are too low for a person to enter the vehicle comfortably. Therefore the front side of the Quattrocycle can be lifted, this includes a part of the body and the window. The front is held down by a click mechanism. The pin is cone shaped and is pushed outwards by a spring. By applying force to the spring it will be pushed inwards and the front can move up. This movement is supported by two air springs like the ones used in regular cars for the bonnet. When the roof is lifted, the air cylinder holds the window open, so the user can find his seat.

On both sides of the window there will be a handle. One or both of the handles can be used to pull down the window.

The handle is located near the rotational point, so it does not get out of reach when the window moves up. The user can pull down the window while he is seated, or in case of a child the person behind him can assist with pulling the window back down.

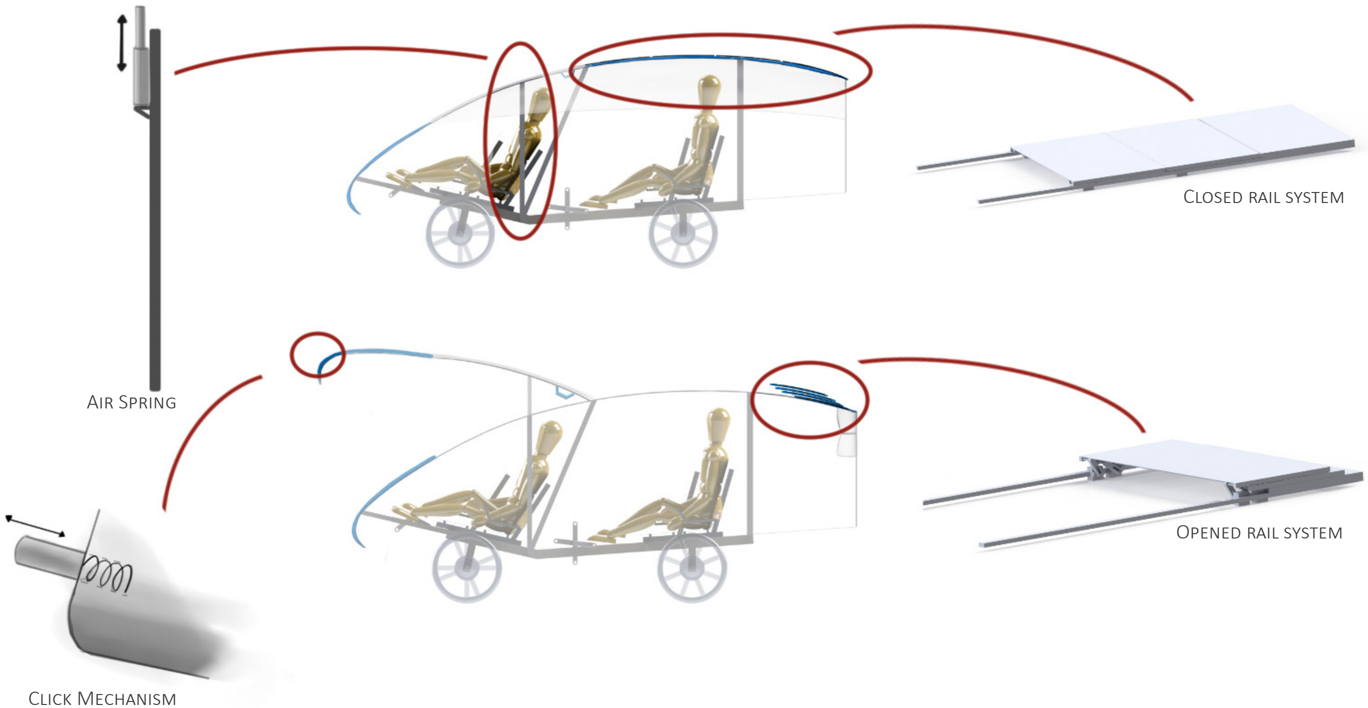


Image 6.5: Overview from the mechanisms

6.3 Concept Selection

Concept selection is based on the requirements, wishes and the preference of the client. All these factors will result in the selection of one concept. The factors are listed below.

Requirements

Both concepts will be compared to the requirements. Both concepts meet most of the requirements, but there can be a difference in how well they do. Therefore those requirements will be explained further.

- Requirement: The roof system has a maximum weight of 30 kilograms.

Both concepts fulfil this requirement. But the Outdoor concept is 9kg lighter than the Car concept, since the mechanisms for the solar panels and the glass window weights more.

- Requirement: The vehicle has space for 80 litres of baggage.

The Car concept has more space for baggage than the Outdoor concept, because the shape of the Car concept. The back of the Car concept is open, so the baggage needs to be protected against rain.

- Requirement: The vehicles runs on 80% human power and 20% sustainable energy
- Wish: The vehicle can reach a maximum speed of 25 km/h.

The solar panels of the Outdoor concept are less efficient, because some of the panels will be on the back on the car on a surface that is not horizontal. those panels will deliver different amount of energy depending on their position towards the sun. Sometimes more energy than needed but most of the time less. The energy production in the panels of the Outdoor concept depends on the direction you cycle. In the Car concepts solar panels always have to same efficiency. Both concepts fulfil the requirement and are able to fulfil the wish depending on the direction of the sun.

- Wish: The roof system should be partially removable.

The roof system of the car concept is partially removable, including the solar panels. So when the roof system is removed in case of good weather, the solar panels do not deliver energy. This is different from the Outdoor concept. In the Outdoor concept the solar panels are fixed in place and because of that deliver always energy. Parts of the roof are still removable. They both fulfil the wish. But for the Car concept this contradicts with the requirement to deliver solar energy.

- Requirement: The roof system does not obstruct the user by entering and leaving the vehicle.

For the Outdoor concept it is harder to enter compared to the Car concept. In the Car concept the front window can be lifted up to enter the Car from the front instead of the sides. This makes it easier to enter. In the Outdoor concept you enter the car from the side. When the front window is closed it can obstruct the user from entering or leaving the car.

- Requirements: The roof system gets a dent of maximum 5 cm by a collision at a speed of 5 km/h.
- The roof system can handle 150 kg of weight without permanently deforming or breaking.
- The roof system can withstand 10 cm of snow without permanently deforming.
- The roof system will not deform with a wind speed of 90 km/h.

These requirements are hard to measure and it is hard to say something about the stability of both concepts without models to test. But an estimation was made based on the construction principles. The Outdoor concept will have a more stable construction than the Car concept because it is based on tension and has mostly fixed components. This gives more stability left to right than the Car concept. The solar panels on the tent concept will be more vulnerable when putting pressure on it, because the cloth will deform.

Both concepts fulfil the following requirements on an equal level:

- The vehicle has a width of maximum 132 cm
- The roof system protects against wind, rain, hail and snow from the front and above
- The vehicle provides protection from rain, hail and snow from the sides

The Outdoor concept was recommended because of its lower weight and the solar panels that always deliver energy and do not have to be removed for fresh air.

Preference of the Client

The client was informed with the design, weight, costs and mechanisms of both concepts. In his opinion the Car concept has more space left for luggage and is it easier to enter the Quattrocycle. The design of the Outdoor concept looked better than the design of the Car concept, this is because of the two arcs. The Outdoor concept is more feasible in this stadium of design and realisation. The Car concept is more expensive because of the used materials and the mechanisms for the roof system and the front window.

The preference of the client is the Outdoor concept. The following points where suggested for further development:

- Using the two main arcs more as roof, by making the space on top of the roof wider than in the front and in the back, creating a bigger roof.
- The tent cloth at the back of the car, shielding the baggage from rain, might act as wind catcher.

Conclusion

The selected is the Outdoor concept. This concept will be further developed. The suggested points by the client will be kept in mind. And it is preferable to find another solution for entering and leaving the car and the vulnerability of the solar panels.

7. Development of the Final Concept

The Outdoor concept was chosen as the best concept in the previous chapter. In this chapter the concept will be developed in more detail and some changes to the design were made. Also a visual model was made of the concept. This model was used to test the principles that were used in the design and for experience on how the cloth pieces should be sewed. Especially the rain protector was tested, but also how the fabric can be spanned over the frame. First the frame, the body and the rain protector will be described. That is followed by production processes, assembly and a price calculation. This chapter ends with conclusions on the final design.

7.1 The Frame

The Frame

The frame exists of two main tubes. The main tubes are lower on this design than the previous, because it lowers the frontal surface area and this minimizes the drag coefficient. The second change is to let the roof stand out over the frame. This way the user is better protected against rain without the rain protector and the available roof surface for the solar panels is increased.

The main tubes are connected by eight ribs in contrast to the previous design, which had eleven ribs. This change is done because the construction was oversized. Therefore the ribs that did not have a function except stability have been removed. The eight ribs in the current design all have a different diameter and a different length. The different diameters are because in the front and in the back there is needed more space than on the top of the roof. This in combinations with the top roof being wider results in the ribs having different lengths.

Attachment from the Frame to the Quattrocycle

The frame is attached to the Quattrocycle at the second and the eighth rib. On the front this is done by welding two square tubes onto the frame. The square tubes will go into the hollow tubes at the front of the Quattrocycle and then screwed in place.

On the back of the Quattrocycle there is a rack for the baggage. For the design of the roof the baggage rack has to be extended because otherwise the solar panels would not fit. The rack can be shaped in the same shape of the eighth rib. The eighth rib can then be welded around that. The extended rack can be fixed in place to the existing rack by using screws.

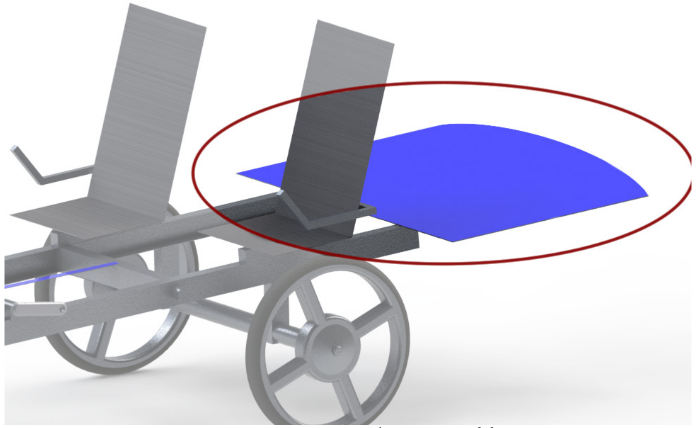


Image 7.3: Modified baggage rack

Image 7.1: Frame of the roof system

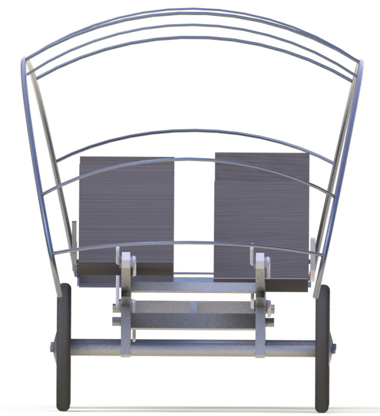


Image 7.2: Front view of the roof system

Image 7.4: Connection between the frame and the roof

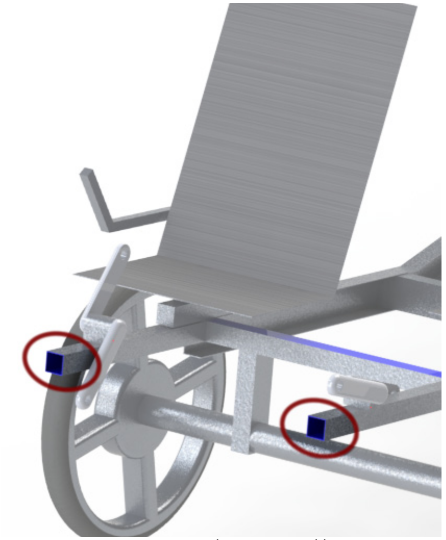


Image 7.5: Hollow tubes for attaching the roof

7.2 The Body

The body of the roof systems exists of three parts: the front part together with the window, the middle part with the first solar panel and the back with the remaining three solar panels. The cloth of the body is wrapped around the frame and then closed with Velcro[1], this way the user is able to remove body from the frame. The body can be stored during winter, increasing the life span of the body.

The cloth pieces are kept in place with so called ‘tabs’. Those tabs can be put around the frame and then closed with snap buttons. By placing the tabs at the same places as the ribs, tension is created. This makes the cloth look nice and smooth and gives stability to the frame and the solar panels.

Three pieces of the cloth can be rolled together for the sun, as described earlier. After rolling them they can be fixed in place by two click buckles on each side. The transparent cloth on the front can be rolled and then folded inwards, so it does not stand out from the frame.

Below an explanation is given how each piece of cloth and the solar panels can be attached to the frame of the Quattrocycle. Image 5.10 shows the frame with numbered ribs is shown to the right. In attachment K drawings can be found of the cloth pieces.

The Front Part

The front part of the body exists out of two pieces. The lower piece is cotton-polyester cloth and a PVC piece, is sewed on to it. On both sides of the cloth piece there is a column. Those columns will be put around the two main tubes, until it reaches the first bar. The cloth goes over the first bar. At the height of the second bar there is a tab, which will hold the cloth piece in place.

After the second bar the PVC-piece continues and will follow the frame. At the end it will be attached to the middle piece on top of the roof with Velcro. After the pieces are in placed the cloth and PVC can be wrapped around and closed with the Velcro.

In case of good weather the PVC-piece can be rolled and folded inwards the Quattrocycle and is kept in place with a buckle belt.

1: Hook and loop fastener. In Dutch: ‘klittenband’.

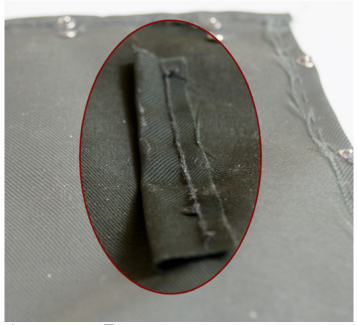


Image 7.7:The tab in the visual model

Image 7.8: Click-buckle [44]

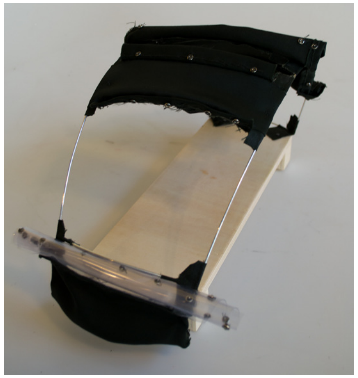


Image 7.9: Rolled front window

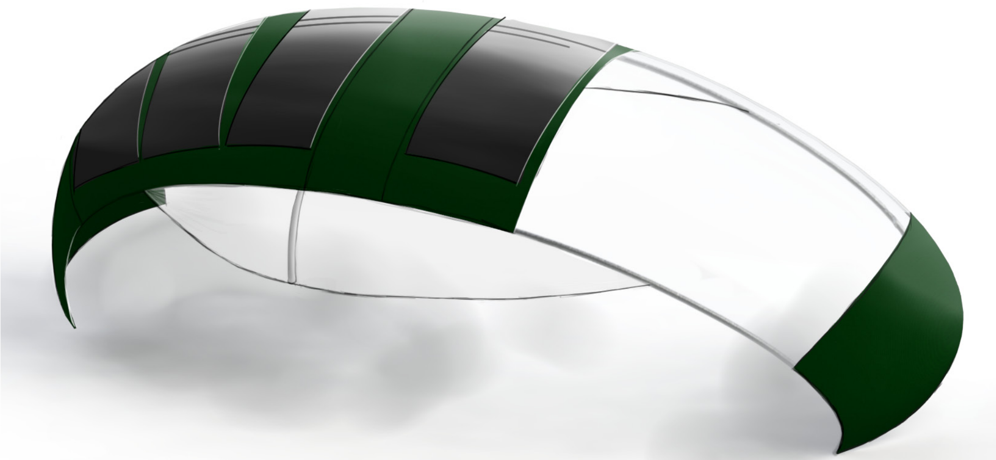


Image 7.6:The roof with the canvas and the rain protector

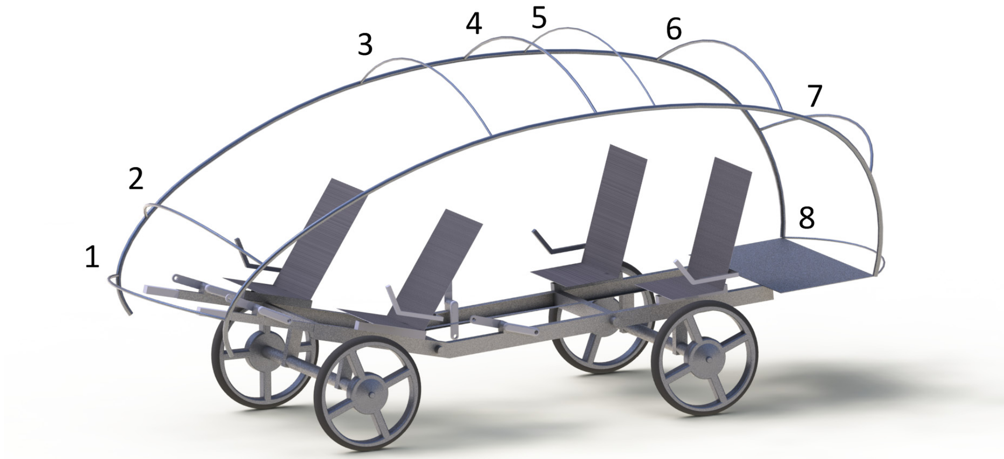


Image 7.10: Numbered ribs of the frame

The Middle Part

The middle piece is stretched around the third and the fourth rib. The fabric is a bit longer as the length between the two ribs, because the front and back pieces need to be attached to the middle piece. Velcro can be sewed on the extra length, for attaching the front and back piece (snap buttons in the picture). The tabs will be sewed on the exact place as the ribs, so the tabs can be wrapped around it as described above. This piece has a solar panel on it and cannot be opened.

The Back Part

The back piece covers the rest of the frame. It is spanned with tabs around the fifth and the seventh rib. The three solar panels are located between those two ribs. The sixth rib is used as support the big and curved canvas piece in the back. On the bottom there are three clips, who attach the bottom part to the eighth rib. The front of the piece will be attached to the middle piece on top of the roof. The frontend and the backend of this piece can be rolled.

The rain protector is connected to the back piece and will also be stored on the inside of the back part. How this exactly works is explained in the paragraph about the rain protector.

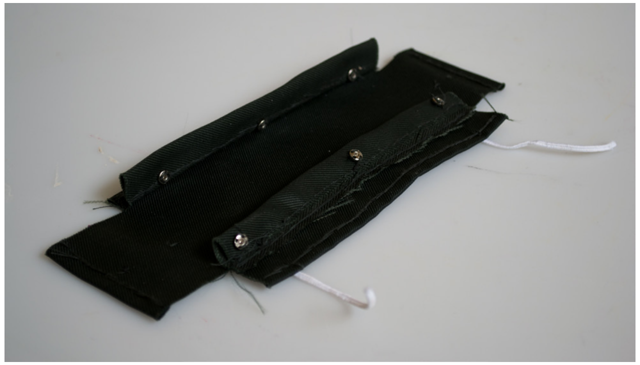


Image 7.11: Middle cloth piece

The Solar Panel

The solar panels have plugs for the wiring and therefore the decision was made to attach the solar panels with Velcro to the fabric. This way the solar panels can be easily removed when one is broken or to be stored when not in use.

In the fabric there is small grommet. The wires of the solar panels can go through that grommet under the fabric. After that the wires can be guided along the frame all the way to the battery. The fabric can be spanned around the frame, so the wires are out of sight and protected. On top of the body there is a small flap that can be put over the loop with the wire, to protect against the rain.

Image 7.12: Rolled back part of the back piece

Image 7.13: Rolled front part of the back piece

Image 7.14: Wires for the Solar Panel

Image 7.15: Clips [45]

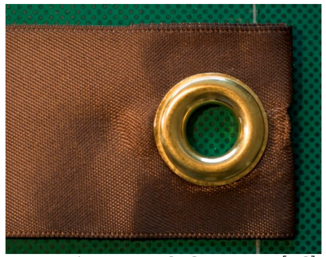


Image 7.16: Grommet [46]

7.3 The Rain Protector

The rain protector is redesigned, because the mechanism that was explained in chapter six did not work after testing. The rain protector still exists of one aluminium tube that is used to make the rain protector stand out from the Quattrocycle, so the water does not leak inside the Quattrocycle or that the rain protector makes the user feel uncomfortable by narrowing down the space. The rain protector covers a smaller area of the frame, this to make it easier for the user to fix the rain protector in place and since the roof is wider than before, it already protects better against rain. For the redesign it was a wish that the rain protector could be used with one simple action, this solution was not found. The users has to preform three actions:

1. Removing the rain protector from storage
2. Attach the rain protector to the frame with snap buttons
3. Pull out the frame of the rain protector

Those actions will be explained in more detail.

1. When the rain protector is not in use it can be left home. The canvas can be removed with snap buttons and the aluminium tube can be removed by removing the plastic clip. This way the whole rain protector can be left home, saving weight and space. The rain protector can be stored in the Quattrocycle as well by folding it inside the back piece. On the inside of the back piece there is extra cloth that can be folded over the PVC and the aluminium tube. This way it is kept in place and the user will not get wet from the wet rain protector.
2. The transparent fabric is attached with snap buttons to the downside of the frame, so that the rain that flows of the roof falls on the rain protector. The PVC is attached with five snap buttons spread from the middle of the window to the middle of the back piece.
3. On the fifth rib there will be an additional tube that is used to make the rain protector stand it. This tube can be slid out when it is raining by pulling it out while rotating. The frame of the rain protector is held by two objects. The first one is a grommet in the cloth and the second one is a plastic piece that is clipped around the frame. It is the blue piece in the pictures to the right. In the piece of plastic there is a hole that is used to put the tube of the rain protector through. On both ends of the tube there is a rubber piece, so it does not slip all the way through, there is also space left around the tube of the rain protector at the grommet and the plastic piece. This way the tube can be slide in and out. On the place where the aluminium tube is placed against the fabric there are two straps to keep it in place.

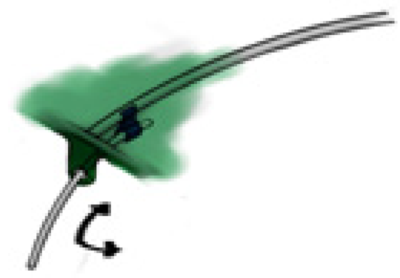


Image 7.18: Aluminium tube can be turned and slide inside

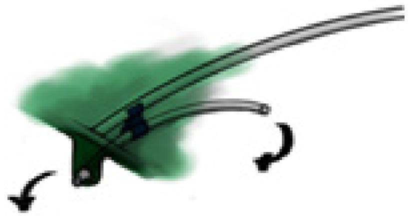


Image 7.19: Aluminium tube slided inside

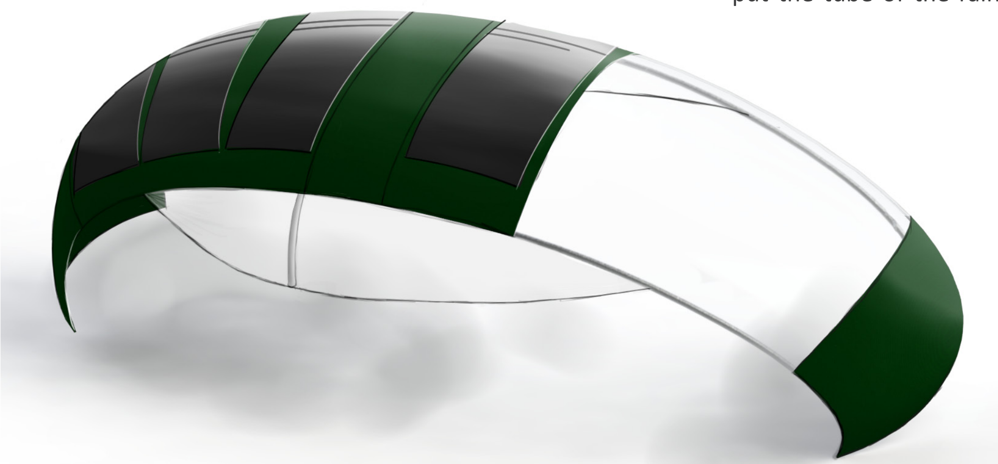


Image 7.16:The roof with the canvas and the rain protector

Image 7.17: Rain Protector attached from the inside

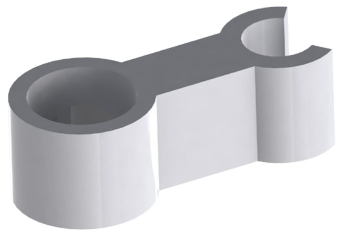


Image 7.20: Plastic piece that can be attached to the frame

7.4 Materials, Processes and Price Calculations

	Weight	Price
Body	6,09	116,43
Frame	3,95	54,54
Rain Protector	0,43	3,92
Solar Panels	5,2	3880
Total:	15,67	4054

Table 7.1: Specifications of the final concept

The price of the materials and the production processes were calculated and the table shows the price and the weight of the body, frame, rain protector and the solar panels. In this paragraph it is explained how the parts will be produced and also an indication is given of the price needed for the tools. In attachment J and K a detailed list of materials can be found as well as a work plan for the production and the assembly.

The Frame

The frame exists of two main tubes and eight ribs. To get the right curves for the tubes the production method 'tube and section bending' is used. CNC machines can be used to obtain the right shape. However for transport of the frame is it easier to split the frame in three sections. There are split in the middle of the second and third ribs and in the middle of the sixth and seventh rib.

After all the tubes are bended in the right shape, the end of the main tubes can be swaged, so the fit into each other. Before the ribs can be welded to the different parts of the main frame, the ends need to be milled, so the ribs fit on the frame. The frame will exist of three parts. This makes it easier to transport. It is expected that for bending and swaging standard tools can be used, so the tooling costs are low in comparison to using custom built tools.

The Body

The fabric that is used for the body is TenCate Solair fabric, this can be sewed, just as the transparent uPVC that is used for the front window and the rain protector. There are no special tools needed for this process. To create all the pieces of fabric takes a lot of time. Every other component for the body can be attached to the body by sewing, this includes the Velcro, except for the snap buttons and the grommets. Those can be attached to the cloth by making a hole in the cloth.

The Rain Protector

The rain protector exists of three parts: the internal frame, the transparent and the part that connects the internal frame to the frame of the roof.

The internal frame is bended, just like the frame of the roof, for this the same tools can be used. There are rubber ends fixed to the ends of the internal frame. The transparent pvc can be sewed as well. One half of the snap buttons is attached to the transparent pvc, the other half of the snap buttons are attached to the fabric of the roof system.

The part that connects the internal frame to the frame of the roof is made out of ABS. This material is elastic and therefore can be clicked around the frame of the roof. This piece can be 3D printed by an extern company and therefore the tooling cost and the man hours are not included in the calculations.

Production and Assembly Costs

To calculate the production costs several estimations were made. These are: tooling costs, man hours, and the labour price. The assembly and production will be done in the Netherlands, therefore the labour price was set on 20 Euros per hour. The man hours are based on the time it takes to produce one unit. After all the units are produced the roof system has to be assembled. This is estimated to take eight hours for two persons.

The production of the frame will cost more by less pieces, because the machine has to be configured before use. Once that has been done it will take less man hours.

	Production method	Tooling cost	Total man hours	Total price
Body	Sewing	0	12	240
Frame	Milling	50	1,6	82
	Bending	250	3	310
	Friction Welding	250	1,6	282
Rain Protector	Bending	0	0,2	4
	Sewing	0	2	60
	3D Printing	0	0	0
Assembly	-		16	320
Total:	-		20,4	1234

Table 7.2: Cost calculation

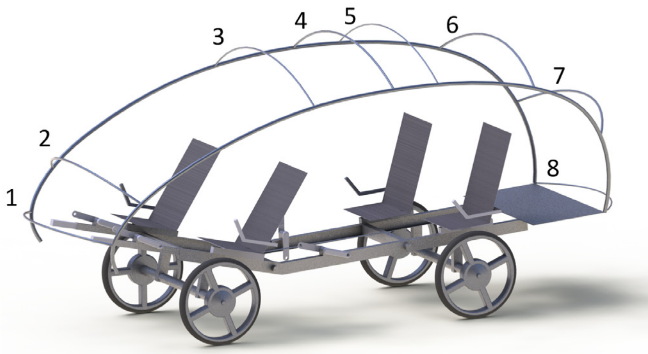


Image 7.21: Numbered frame

7.5 Conclusions on the Final Concept

In the beginning of the report a vision on the redesign of the Quattrocycle based on a scenario is written. Here conclusions will be made based on that vision and the requirements. Most of the requirements that could be measured and checked are met, even some of the wishes are met. The requirements about the dimensions and the baggage, were not met.

Dimensions

The requirement of the client was that the vehicle had a maximum width of 132 cm. This requirement was set so that the Quattrocycle could pass by poles on the cycling lanes. Therefore it is not a problem that the top of the Quattrocycle is a bit wider because it is still within the width of 150 cm which is the maximum width for bicycles according to the Dutch law.

The Baggage Area

The baggage space was set to 80 litres. The space on the back of the Quattrocycle is 50 litres. The baggage area turned out smaller because the roof is made as low as possible without hindering the user and thus resulting in a as smaller baggage compartment.

The Rain Protector

According to the requirements, the roof system should be able to protect the user against wind and rain from the front and above. The user still would need rain protective cloths and bags. Therefore a rain protector has been designed. The rain protector can be stored against the roof on the inside when it is not needed or can be entirely removed. This way it does not close the sides of the Quattrocycle permanently.

Solar Energy

The dimensions and weight of the final design are used to calculate the amount of solar energy needed. The dimensions of the front are 1,5m by 1,7m. The design looks like a trapezoid seen from the front or the back. In total this gives a frontal surface area of 2,4 square meters. This is more than the value that was calculated in paragraph 3.5. The weight of the final concept is just below 16,67 kg, which is about half of the weight which was used in the previous calculations. When the amount of power was recalculated using the new surface and weight it was almost the same as in the previous calculations. The conclusion is that the saved weight is neutralized by the extra surface area.

The Solar Panel

The most expensive part of the roof system is the solar panels. The roof is designed in such way that modular solar panels can be applied. The roof can be used without the solar panels or with fewer than the maximum amount depending on the budget of the user. Fewer solar panels results in less support for the electric motor.

Maintenance on the Fabric

Fabric is not as durable as aluminium or carbon fibre, therefore it needs more maintenance. UV-radiation, dirt, and air pollution have impact on the lifespan of the fabric. The fabric can be treated with different coatings, such as hydrophobic spray, to lengthen the life span. But even when using coatings the user still needs to keep the fabric clean and let it dry before folding it and storing it. Storing the fabric inside during winter will also lengthen its lifespan.

8. Conclusions and Recommendations

In this chapter the conclusions from the different chapters are gathered to give an overview and to find the answer for the main question that is formulated in the beginning of the report. After that a few changes in the design are recommended if someone wants to further develop the roof.

8.1 Conclusions

The main question that this report tried to answer is:

‘Which concept for a lightweight roof system can be recommended based on materials, constructions, processes and the requirements of the client?

The materials that be can recommended depend on the type of construction. Carbon fibre composites and aluminium plates can be used for the body for basic shape constructions. The fabric is most the suitable for tent-based constructions. For the frame of the roof system aluminium is the most suitable material.

The production process that can be used for the aluminium plates is panel beating. Carbon fibres plates can be formed with wet lay-up. Two production processes are available for the frame: ‘Swaging’ and ‘Tube and Section bending’.

The front seats on the Quattrocycle can be entered in two ways. The first one is to enter it from the sides, this is possible if the seats have a foldable arm rests. The second one is to enter the Quattrocycle from the front by lifting up the front of the roof.

The roof system can be attached at the following points: Two hollow tubes in the front, the tube behind the front wheel and the baggage rack. There is a bar in the middle of the Quattrocycle that can be used as extra support if needed.

The solar panels are able to deliver enough energy to reach a speed of 25 km/h on a sunny day. On days with less sun the panels will be able to deliver 20% of required energy which also was one of the requirements for the roof system.

A tent-based concept was chosen as final concept. The concept was lighter and the roof could be partly removed without losing the function of the solar panel. This concept was also preferred by the client.

The final concept has a weight below 16 kg including four solar panels. Parts of the roof can be removed without removing the solar panels, so the solar panels keep fulfilling their function. The solar panels and the canvas can be removed for winter storing, increasing the lifespan of the fabric. A rain protector can be attached to the frame for protection against rain falling in from the sides. The roof system can be used without the solar panels, reducing the total cost for the roof.

8.2 Recommendations

The Rain Protector

At the moment the rain protector can be stored against the inside of the roof of the Quattrocycle when it is not needed. Depending on how much the user will use the rain protector a design that allows the user to take the rain protector out in one or two handlings would be more desirable than the current design.

Solar Energy

The solar panels are at the moment one of the most expensive part of the roof system. To reduce the amount solar energy needed the air resistance should be lowered. This can be done by lowering the weight, the frontal surface area or the drag coefficient, not only for the roof system but also for the Quattrocycle itself. Another option is to use solar panels with a higher efficiency and thus delivering more power.

The Baggage Area

The baggage area is smaller than the requirement from the client. If the area is too small it can be made bigger by making the Quattrocycle and the roof longer. Changing the curve would help as well, but not very much and that would influence the look. Changing the curve is recommended together with making the roof higher, in this way the curve would not look weird. This will however increase the frontal surface area which must be taken into consideration. By making the baggage area bigger it will possible to add the three children seats in the back.

Weight of the Quattrocycle

The weight of the current Quattrocycle is 122 kg. It would be preferable if the weight of the frame would be lower. With a lower weight the amount of energy needed from the solar panels would be less. This can be done by making the frame out of aluminium instead of steel and redesigning the whole frame. If the production becomes aboven the 50.000 pieces magnesium is an option for the frame of the Quattrocycle, as the frame of the roof system.

Position of the Driver

At the moment the Quattrocycle is steered from the chair left-back. It is hard to get a good overview from this position. So when the frame is redesigned it is preferable that the driver's seat will be moved to the front chair making it possible to reduce the area of the transparent pvc window. This will save weight and give extra surface area for eventual solar panels.

Electronics

The solar panels were selected based on the amount of watt they could deliver and the surface area. Before implementing them in the design additional research has to be done for the batteries and the engine and if they are able to work together and how the electrical circuit works.

The Canvas

It was a wish from the client that the roof system was made out of a biodegradable material. For the final concept a poly-cotton fabric was used. This material is not biodegradable. The lifespan of a biodegradable material is shorter. Tests can be done to look at the lifespan of cotton, if it is desirable to have a biodegradable material.

Legal Requirements

At the moment not much attention has been paid to the legal requirements. Only the maximum support speed of 25km/h has been kept in mind. But before the vehicle can enter the road it needs to be safe, therefore lights and reflectors needs to be placed on the roof system or the frame.

List of Credentials

Chapter 1 & 2

1. Suurmeijer, C. Quattrocycle experience. 2012 [cited 2013, May]
2. Fietsersbond. Wettelijke regels elektrische fiets. 2009 [cited 2013, May]
3. Rijksoverheid. Wat zijn de regels voor fietsverlichting en reflectie op een fiets? [cited 2013, May]

Chapter 3

4. Adriaan Beukers, E.v.H., Lightness, the inevitable renaissance of minimum energy structures2005, Netherlands: 010 Publishers
5. Rallycrossworld, Jrx Concept 03, jrx_concept_03, Editor: http://www.rallycrossworld.com/wp-content/uploads/2012/05/jrx_concept_03.jpg.
6. Davies, G., Chapter 2 - Design and material utilization, in Materials for Automobile Bodies2012, Butterworth-Heinemann: Oxford. p. 17-91
7. Michigan, U.o. Mechanically Mediated Bone Adaptation. [cited, 2013 11 July]
8. Autodesk. Shell Elements. [cited 2013 11 July, May]
9. McGinn, British Museam - Great Court, 2005, Wikipedia Commons: http://en.wikipedia.org/wiki/File:British_Museum_-_Great_Court.JPG
10. Douthe, C. and O. Baverel, Design of nexorades or reciprocal frame systems with the dynamic relaxation method. Computers & Structures, 2009. 87(21–22): p. 1296-1307
11. Forward, D. Reciprocal Roofs. 2003 [cited 2013, May 11th]
12. J.C. Chiltion, B.S.C., O. Popovic. Reciprocal Frame 3-Dimensional Grillage Structures. [cited 2013, May 11th]
13. Ysjournal, What are Tilings and Tessellations and how are they used in Architecture, 2009: Young Scientists Journal
14. Campus, E.H., R.F. Structures, Editor 2011: http://eat-a-bug.blogspot.nl/2011_08_01_archive.html
15. Davies, G., Chapter 3 - Materials for consideration and use in automotive body structures, in Materials for Automobile Bodies2012, Butterworth-Heinemann: Oxford. p. 93-143
16. Rineman, J. Comparing Materials in Tent Poles. 2013; Available from: http://www.life123.com/sports/camping/tent/comparing-materials-in-tent-poles.shtml.
17. Davies, G., Chapter 5 - Component manufacture, in Materials for Automobile Bodies2012, Butterworth-Heinemann: Oxford. p. 193-239
18. Outdoorgear. Hydrostatic Head. [cited 2013, May
19. Schijndel, D.W. Tent kopen: welke tent kiest u? [cited 2013, May]
20. Holidaysport. Onderhoud tenten. [cited 2013, May]
21. ANWB. Tentdoek - ANWB Kamperen. [cited 2013, May]
22. Davies, G., Chapter 9 - Future trends in automotive body materials, in Materials for Automobile Bodies2012, Butterworth-Heinemann: Oxford. p. 357-396
23. Koronis, G., A. Silva, and M. Fontul, Green composites: A review of adequate materials for automotive applications. Composites Part B: Engineering, 2013. 44(1): p. 120-127
24. Thompson, R., Manufacturing Processes For Design Professionals, 2007, Thame and Hudson: United Kingdom. p. 527
25. Davies, G., Chapter 5 - Component manufacture, in Materials for Automobile Bodies2012, Butterworth-Heinemann: Oxford. p. 193-239
26. Tentpolestore, Heavy duty steel tent pole, 3_piece_tent_pole, Editor 2013: www.tentpolestore.com
27. Taiwantrade, CNC tube bending machine, 2013: www.taiwantrade.com
28. Carbonfiberguru, Curtosity of Gurit, 2013: www.carbonfiberguru.com

Chapter 5

29. Overheid. Regeling verkeerslichten. 2013; Available from: http://wetten.overheid.nl/BWBR0009151/geldigheidsdatum_16-09-2013
30. Lee, H.-M., et al., Transparent and flexible amorphous In-Si-O films for flexible organic solar cells. Applied Physics Letters, 2013. 102(2): p. 021914-5.
31. Maehlum, M.A., Which Solar Panel Type is Best?, 2012, Energy Informative: energyinformative.org.
32. Pagliaro, M., R. Ciriminna, and G. Palmisano, Flexible Solar Cells. ChemSusChem, 2008. 1(11): p. 880-891.
33. Pele, A.-F., Flexible solar cell reaches 20,4% efficiency. 2013
34. Sunstore, 12v 100w Monocycstallline, 2013: www.sunstore.co.uk
35. SelectSolar. 2013; Available from: http://www.selectsolar.co.uk/uploads/prod_img/2_1011_e.jpg
36. Dricus, Fisker Karma solar roof, 2011: Sinovoltaics
37. Velofilie. Vermogen en krachten. 2013; Available from: www.velofilie.nl/vermogen.htm
38. Velofilie. Rolweerstand. 2013; Available from: http://www.velofilie.nl/rolweerstand.htm

39. TheOtherJesse. Drag coefficient. 2008; Available from: http://upload.wikimedia.org/wikipedia/commons/thumb/3/37/14ilf1l.svg/200px-14ilf1l.svg.png
40. Bond, R., Solar Radiation Calculations. 2013
41. KNMI, daggegevens, http://www.knmi.nl/kd/daggegevens/

Chapter 6

42. AskNature. Pangolin backpack. 2011 [cited 2013, May]
43. Suurmeijer, C., Wegklapbare armleuning, 2013: http://quattrocycle-experience.nl/?page_id=12

Chapter 7

44. BlueWaterSports, Two 25mm Double Lock Quick Release Buckle, 2013
45. Vogtschmidtoutdoorcenter, Tentclip met sleuf nylon, 2013, http://www.vogtschmidtoutdoorcenter.nl
46. Shelly, How To: Install a Grommet, 2013.

Attachment Overview

Attachment A - Plan of Approach ... 48
Attachment B - Scenario ... 50
Attachment C - Inspiration Collages ... 51
Attachment D - Explaination of the Morphologic Schedule ... 52
Attachment E - Material Tables ... 53
Attachment F - Production Processes Tables ... 54
Attachment G - Calculations on Required Power ... 55
Attachment H - Monthly Average Daily Radiation ... 55
Attachment I - Extra Images of the Final Concept ... 56
Attachment J - Detailed Materials ... 57
Attachment K - Production and Assembly Steps ... 60
Attachment L - Pictures of the Visual Model ... 61

Attachment A - Plan of Approach

Introduction

Fossil fuels are about to run out and the emission of CO_2 is increasing. This causes our climate to change and threatens the environment for future generations. Therefore new solutions that use sustainable energy and materials have to be researched. There are vehicles on that achieved world records using solar energy, but those vehicles never reached the global audience. Those vehicles are for one or two persons only and don't have space for baggage.

Organization

Greenolution is a company founded by Christian Suurmeijer. It's a one man company located in Amersfoort. Greenolution researches the possibility for a new experimental vehicle platform, called 'World Wagon'. This is a platform for future sustainable vehicles. It uses new technologies, functionalities, usage- and business models around mobility, energy and leisure.

The goal of Greenolution is to start a pilot project that demonstrates the possibilities of a family vehicle powered by only sun, wind and human power. To reach this goal the company researches new lightweight materials, lightweight constructions and smart electrical systems.

To explore these areas Greenolution is searching for potential partners in the following companies: One planet, Moorgen, RWE, Solar, Soios, Refitech, TenCate,Fluke, Universiteit Twente, Vausde, ANVR and WWF. They also obtained an innovation voucher to explore the possible energetic sustainable options and its limits and opportunities of available merging technologies.

Background

Greenolution is an owner of a Quattrocycle. This is a cycle whereby four persons are able to pedal. There is room for up to seven persons, four adults and three children, and extra baggage and provides pedal support for all four places. At the moment the Quattrocycle is only used for recreation. Greenolution wants to use this vehicle as a base for the first prototype of a future World Wagon. The concept has to use sustainable energy and has room for four to six people and extra baggage. To accomplish this research has to be done in different subareas.

At the moment Greenolution has a market research of sustainable vehicles, bicycles and concept cars. They've a vision for different kinds of World Wagons and how they have to be used and by whom. For this assignment the idea for a family car will be used. The vehicle has to run mostly on human power and for a small part on solar energy. One of the research areas is a lightweight roof system that offers protection against different weather circumstances. The roof system should provide a part of the sustainable energy that is needed. Other subareas are a lightweight frame with steering possibilities and the energy system. In the end this will all be combined to one concept.

Aim of the Project

Greenolution researches the possibilities for future sustainable and lightweight vehicles, called 'World Wagon'. The Quattrocycle is used as starting point for the World Wagon. The aim of this bachelor assignment is to design a concept for a lightweight roof system for a future World Wagon and give recommendations about lightweight materials and constructions. The frame of the Quattrocycle will be used as base for the roof system.

This will be accomplished by making an analysis of new lightweight materials, lightweight constructions and sustainable processes. Those results will be used to make a concept design of the roof system. The requirements of the client will be used as base for concepts of a lightweight roof system.

This assignment will result in recommendations about the materials and the construction for the roof system that can be used for different concepts. Those recommendations will be used to make a final concept. A visual display of the final concept will be made. All of this will be done in a time span of three months.

Research Questions

Main Question

Which concept for a lightweight roof system can be recommended based on materials, constructions, processes and the requirements of the client?

Sub Questions

1. What are the requirements for a lightweight roof system?
    - a. What are the requirements of the client?
    - b. What are the requirements of the government?
2. Which constructions can be used to design a lightweight roof system?
    - a. Which constructions are used in the automotive industry?
    - b. Which constructions are used in the aviation industry?
    - c. Which constructions can be used from biomimicry?
    - d. Which constructions are used from the outdoor industries?
3. Which materials can be used to design a lightweight roof system?
    - a. Which materials are used in the automotive industry?
    - b. Which materials are used in the aviation industry?
    - c. Which materials are used from the outdoor industries?
    - d. Which new materials are being developed?
    - e. Which materials are suitable for the vehicle body?
    - f. Which materials are suitable for the framework?

4. Which processes can be used to make a lightweight roof system?
    a. Which processes are used in the automotive industry?
    b. Which processes are used in the aviation industry?
    c. Which processes are suitable to make the framework?
    d. Which processes are suitable to make the vehicle body?
5. How can the materials, constructions and processes be combined into concepts for a lightweight roof system?
    a. Which combination of materials, constructions and processes can be used to generate energy?
    b. What are the best combinations of materials, constructions and processes for the frame?
    c. What are the best combinations of materials, constructions and processes for the vehicle body?
    d. Which concepts meet the requirements?
    e. Which concept is recommended based on the requirements?
    f. Which concept has the preference from the client?

As can be seen in table to the left and from the research questions there has to be done research about materials, constructions and how they're processed. Finding the right experts can be a problem in this situation. This analysis in combination with the requirements from the client will form the base for the design phase. This has to result in a concept for a lightweight roof system.

*Small models: Models used for idea generation.

Questions	Strategy	Materials
1a	Interview	Client
1b	Research	Documents
2a	Interview, research, observation	Experts and literature
2b	Interview, research, observation	Experts and literature
2c	Research	Literature
2d	Interview, research, observation	Experts, outdoor shops and literature
3a	Interview, research, observation	Experts and literature
3b	Interview, research, observation	Experts and literature
3c	Interview, research	Experts and literature
3d	Interview, research, observation	Experts, outdoor shops and literature
3e	Interview, research	Experts and literature
3f	Interview, research	Experts and literature
4a	Interview, research, observation	Experts and literature
4b	Interview, research, observation	Experts and literature
4c	Interview, research	Experts and literature
4d	Interview, research	Experts and literature
5a	Combining information from the analysis	Analysis of materials, constructions, processes
5b	Combining information from the analysis and small models*	Analysis of materials, constructions, processes. Small models*
5c	Combining information from the analysis and small models*	Analysis of materials, constructions, processes. Small models*
5d	Check with requirements	Concepts, requirements
5e	Check with requirements and vision	Concepts, requirements and vision
5f	Interview client	Results of 5d and 5e and the concepts, client

Attachment B - Scenario

Around a year ago Jasper de Vries bought a new Quattrocycle for his wife and two kids. The idea of having a four person bike with a roof providing solar energy appealed to him, because the design looked cool, saved energy, and it could be used for family trips. They use the Quattrocycle from spring to autumn for shopping, bringing the kids to school, and visiting friends in other cities. During the winter they usually took the car and if not they would have to dress up warm.

But now summer vacation is here and they have decided to go on vacation taking the Quattrocycle instead of the car. All the luggage for the trip is put into waterproof bags, instead of using plastic crates as they usually did. Jasper is putting the bags into the back of the bike. While he is packing everything the rest of the family is raising the solar roof, so it can gather as much solar energy as possible. They can use the energy that is stored from the solar panels as cycle support during the trip. Now when they are finally ready to go, the weather is great. The sun is shining and they barely have any wind. Because of all the sunlight they barely used the energy stored in the batteries, so they cycled all the way to the first cabin with support from the sunlight. To enjoy the good weather, they remove the roof, instead of using it to give shade from the sun.

Sadly, tomorrow that was going to change according to the weather forecast Jasper had seen earlier. The weather forecast predicted a cloudy day with a few showers. After everything they needed was unpacked from the bike, they closed the roof, which was still open, again. This way the solar panels can collect energy that they can use tomorrow.

The next day the forecast seemed to be wrong. When family de Vries left the cabin it was still sunny so they decided to remove the roof again. But after two hours of cycling the weather, sadly enough, changed. It became cloudy and started to rain. The whole family put on rain protection clothes, because the sides of the Quattrocycle are open and the roof system does not keep all the rain out of the vehicle.

The roof protects like an umbrella, keeping the rain out of their faces. The open sides provide a better line of sight when dealing with other traffic. Luckily for the family the next cabin isn't that far away, but they still had to cycle the last half hour without the support. Usually the solar panels deliver enough energy to support the bike, but because it was so cloudy and windy they had to use the battery a lot, ending up with a drained battery.

After two days of good weather they got home. The whole family was tired, but they had a nice and active vacation. The children were enthusiastic about going on more trips with the Quattrocycle, not only for vacations but for small trips as well.

Attachment C - Inspiration Collages

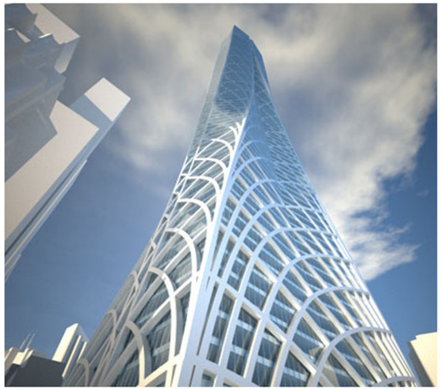
These collages were used as inspiration in the early design processes.











Attachment D - Explaination of the Morphologic Schedule

An explanation of each possible solution in the morphologic schedule will be described here. The images will be described per column, from the top to the bottom.

Basic Shapes

- A1 – A car-shaped form, with a curved front
- A2 – A tent shaped form spanned over the width of the Quattrocycle
- A3 – A tent shaped form spanned over the length of the Quattrocycle
- A4 – A car shaped form, with a steep front
- A5 – A dome shape
- A6 – An elliptical form around the frame of the Quattrocycle

Constructions

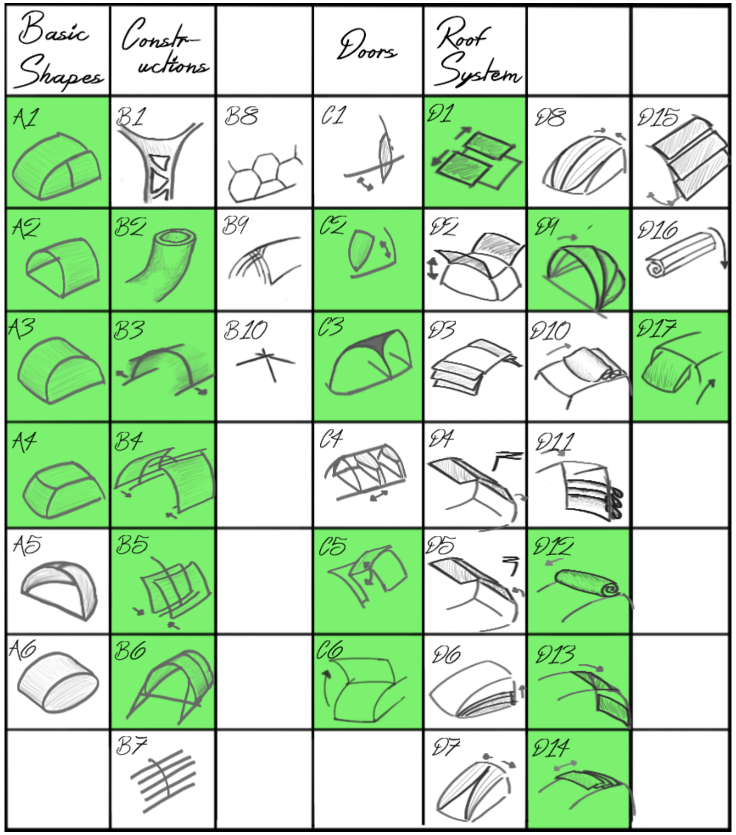
- B1 – Material is cut out in triangles where the material is not needed, in order to save weight
- B2 – The use of hollow tubes
- B3 – A tent based construction, using fabric to put tension on the frame
- B4 – A frame with body panels put against it, the panels do not offer stability to the frame
- B5 – The frame is integrated with the body panels, following the stressed-skin principle
- B6 – A tent based construction, using tension wire
- B7 – A construction that uses bars in the horizontal length to offer stability to the body panels
- B8 – A construction made out of hexagons
- B9 – A construction based on the Michell structure
- B10 – A reciprocal frame construction

Doors

- C1 – A normal door, opening to the sides
- C2 – A door that opens upwards, using a hinge
- C3 – An open frame, without a door
- C4 – Fabric that can be shoved aside, like curtains
- C5 –The front opening upwards

Roof System

- D1 – The solar panels slide to the sides of the roof
- D2 – The sides from the roof system can be moved up and down
- D3 – Different layers of solar panels, which can be folded up and down
- D4 – Solar panels that can be folded down, using the space at the back of the Quattrocycle
- D5 – Solar panels that can be folded down, using the space in the Quattrocycle
- D6 – The sides of the roof system can be folded down, like bird wings
- D7 – The roof can be folded to the sides, like bird wings
- D8 – The roof can be folded to the sides, like bird wings
- D9 – Segments of the roof can be moved to the back of the Quattrocycle
- D10 – The roof can be slid to the back of the roof by folding and stacking the roof
- D11 – The roof can be slid to the back of the Quattrocycle by folding and stacking the roof
- D12 – The roof can be rolled to the back of the roof
- D13 – The solar panels can be slid to the back of the roof in segments
- D14 – The solar panels can be slid to the back of the Quattrocycle in segments
- D15 – Solar panels that are used as the side of the Quattrocycle and can be tipped up
- D16 – Sides that can be rolled like a roll-down shutter



Attachment E - Material Tables

The tables below show the different materials and their material properties that were found during the analysis.

Metals	Industry	Body/Framwork	Density kg/m^3	Compression Strength (Mpa)	Yield Strenght (MPa)	Young's Modulus (GPa)	Price eur/kg	Fresh water resistance	UV Radiation	Recycling	Bio-based
Aluminium 5005	Automotive	Framework, body	2660,00	157-173	157-173	69,5-73	€ 1,30	Excellent	Excellent	Recycable, Downcycle, landfill	No
Aluminium 6061	Outdoor, aerospace	Framework, body	2700,00	157-173	241-266	68-71,5	€ 2,34	Excellent	Excellent	Recycable, Downcycle, landfill	No
Aluminium 7020	Outdoor, aerospace	Framework	2750,00	157-173	318-352	70-74	€ 2,28	Excellent	Excellent	Recycable, Downcycle, landfill	No
Low Carbon Steel	Outdoor, automotive	Framework, body	7900,00	250-395	250-395	200-215	€ 0,54	Excellent	Excellent	Recycable, Downcycle, landfill	No
Magnesium	Automotive	Body	1870,00	70-400	70-215	42-47	€ 2,76	Excellent	Excellent	Recycable, Downcycle, landfill	No

Fabrics	Industry	Body/Framwork	Density kg/m^3	Tensile Strength (Mpa)	Yield Strength (MPa)	Price eur/kg	Fresh water resistance	UV Radiation	Recycling	Bio-based
Cotton	Outdoor	Body	1,60E+03	287-597	100-350	3,02	Acceptable	Fair	Downcycle, combus, landfill, biodegradable, renewable	Yes
Polyamide	Outdoor	Body	1,14E+03	90-165	50-94,8	3,15	Acceptable	Fair	Recycle, downcycle, combust, landfill	No
Polyester	Outdoor	Body	1,40E+03	41-89	33-40	3,25	Excellent	Good	Downcycle, combus, landfill	No

Composites	Industry	Body/Framwork	Density kg/m^3	Compressive Strength (MPa)	Yield Strenght (MPa)	Price eur/kg	Fresh water resistance	UV Radiation	Recycling	Bio-based
Carbon fibre reinforced composites (epoxy)	Outdoor, aerospace, automotive	Framework, body	1,60E+03	440-840	550-1005	32,1	Excellent	Good	Downcycle, combus, landfill	No
Glass fibre reinforced composites (epoxy)	Outdoor, aerospace, automotive	Framework, body	1,97E+03	138-207	110-192	15,6	Excellent	Fair	Downcycle, combus, landfill	No

Attachment F - Production Processes Tables

The tables below show the different production processes and their properties that were found during the analysis. These tables can be used when the production is scaled up.

Metals

Production Process	Industry	Shape function	Tooling cost	Unit cost	Cycle time	Surface quality	Production volume	Scrap production	Compatible materials
Panel Beating	Automotive, Aerospace	Body	Low	High	Long	High	One-off	None	Aluminium, magnesium, steel
Metal Spinning	Automotive, Aerospace	Body, frame	Low	Moderate	Fast	Variable	Low to medium	Recyclable	Steel, brass, copper aluminium, titanium
Deep Drawing	Automotive, Aerospace	Body	Very high	Moderate	Fast	Good	Medium to high	Recyclable	Steel, zinc, copper, aluminium
Super forming	Automotive, Aerospace	Body	Moderate	High	Fast	Good	Low to medium	Recyclable	Superplastic metals, aluminium, magnesium, titanium
Metal injection moulding	Automotive, Aerospace	Body	High	Moderate	Fast	Very high	Low to high	Recyclable	Ferrous metals, stainless steel, magnetic alloys
Investment casting	Aerospace, construction	Body	Moderate	High	Low	Very high	Low to high	Recyclable	Carbon, stainless steel, aluminium, titantium
Roll forming	Automotive, construction	Body, frame	High	Moderate	Fast	Good	Medium to high	None	Stainless steel, carbon steel
Die casting	Automotive	Body, frame	High	Low	Fast	High	High	Recyclable	Non-ferrous metals
Sand Casting	Automotive	Body, frame	Low	Moderate	Moderate	Poor	One to medium	Majority recyclable	Iron, steel, copper, aluminium, magnesium
Metal Stamping	Automotive	Body	High	Moderate	Fast	High	High	Recyclable	Sheet metal, aluminium, magnesium, copper
Press Braking	Automotive	Body, frame	Standard tooling	Moderate	Average	High	Low to medium	None	Steel, aluminium, copper, titanium
Hydroforming	Autmotive	Body, frame	Moderate	High	Moderate	High	Low to medium	Recyclable	Steel, aluminium
Tube and section bending	Automotive	Frame	Standard tooling	Moderate	Fast	High	One-off to high	None	Steel, aluminium, copper, titanium
Swaging	Outdoor	Frame	Moderate	Moderate	Fast	High	One-off to high	None	Steel, aluminium, copper, titanium

Composites

Production Process	Industry	Shape functions	Tooling cost	Unit cost	Cycle time	Surface quality	Production volume	Scrap production	Compatible materials
Thermoforming roll fed	Automotive	Body	Moderate	Moderate	Fast	Depending on material, pressure	Batch to high	Majority recycable	ABS, PET, PP, PC, HIPS, HDPE, PC, PETG
Thermoforming sheet fed	Automotive	Body	Moderate	Moderate	Moderate	Depending on material, pressure	One-off to medium	Majority recycable	ABS, PET, PP, PC, HIPS, HDPE, PC, PETG
Vacuum casting	Automotive	Body	Low	Moderate	Very long	Very high	One-off to low	None-recycable	PUR, PA
Injection moulding	Automotive	Body	High	Low	Very fast	Very high	High	Recycable	Thermoplastics
Reaction injection moulding	Automotive	Body	Moderate	Moderate	Moderate	High	One-of to high	None-recycable	PUR
Rotation moulding	Automotive	Body	Moderate	Moderate	Long	Good	Low to medium	Recycable	PE, PA, PP, PVC, EVA

Attachment G - Calculations on Required Power

The calculations for the amount of power needed to propel the Quattrocycle are displayed below. In the situation described in the Solar Energy paragraph there is no wind, no acceleration and no slope. Therefore the parameters of the acceleration, slope and wind resistances can be set to zero. However, the user will encounter those and therefore the formulas for those situations will be predefined at the end of this attachment.

Power

The power needed to drive the Quattrocycle depends on the efficiency, the speed and the amount of resistance the user experiences. The different resistances are: Air resistance, Roll resistance, Acceleration resistance and the slope resistance. Only the air and roll resistance will be calculated below, the results will be used the formula for

$$P = \frac{Rtot * v}{\eta}$$

$$Rtot = Rair + Rroll + Racc + Rslope, \qquad v = 6{,}94\frac{m}{s}, \qquad \eta = 0{,}95$$

$$Rtot = 56{,}87 + 30{,}21 + 0 + 0 = 87{,}08\ W$$

$$P = \frac{87{,}07 * 6{,}94}{0{,}95} = 636\ W$$

This is the amount of power needed to reach a speed of 25 km/h. In the described situation the users can deliver 360 W, this leaves 276 W for the solar panels and the electric engine.

Air resistance without wind

The air resistance is based on the drag coefficient (Cw), the frontal area (A), speed (v) and relative density of the air. The values of the parameters are explained in the corresponding paragraph about solar energy. This formula can only be used when there is no wind.

$$Rair = 0{,}5 * \rho * Cw * A * v^2$$

$$p = 1{,}23\frac{kg}{m^3}, \qquad Cw = 0{,}8, \qquad A = 2{,}4m^2, \qquad v = 6{,}94\ m/s$$

$$Rair = 0{,}5 * 1{,}23 * 0{,}8 * 2{,}4 * 6{,}94^2 = 56{,}87\ W$$

Roll resistance

The rolling resistance is based on the mass (m), gravity (g) and the roll coefficient (Cr). The values of the parameters are explained in the corresponding paragraph about solar

$$Rroll = m * g * Cr$$

$$m = 440\ kg, \qquad g = \frac{9{,}81m}{s^2}, \qquad Cr = 0{,}007$$

$$Rroll = 440 * 9{,}81 * 0{,}007 = 30{,}21\ Q = W$$

Acceleration resistance

The acceleration resistance is based on the mass (m) and the acceleration (a). Since only the formula is given and there is no acceleration in the calculations, the amount of resistance is zero.

$$Racc = m * a$$

Slope resistance

The slope resistance is based on the mass (m), gravity (g) and the percentage of the slope (%). Since only the formula is given, there is no acceleration in the calculations, so the amount of resistance is zero.

$$Rslope = m * g * \%$$

Attachment H - Monthly Average Daily Radiation

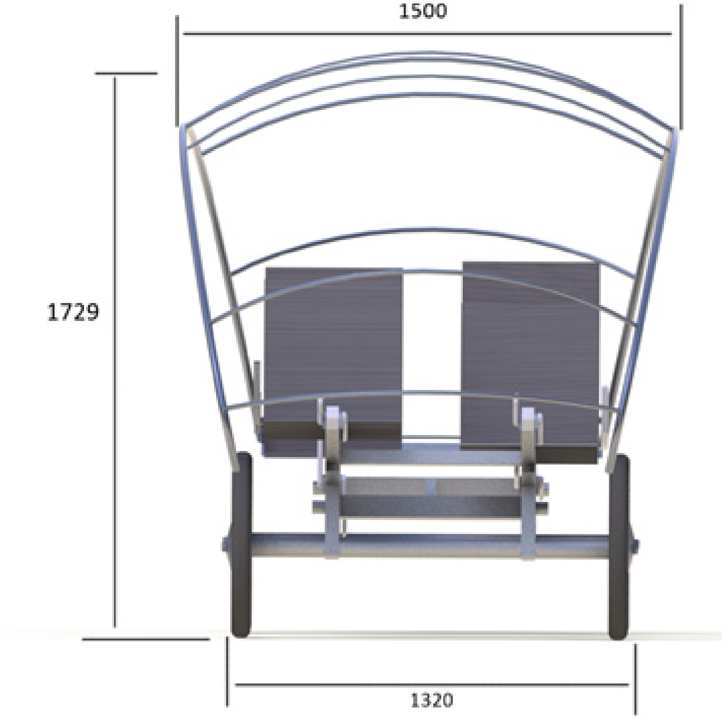
The two tables below will show the monthly average daily radiation that falls on a square meter. The average daily radiation from the period 08:00 till 19:00 is given, because that is the period the Quattrocycle is used the most. This is shown in the third column. In the fourth column an average of those eleven hours is given.

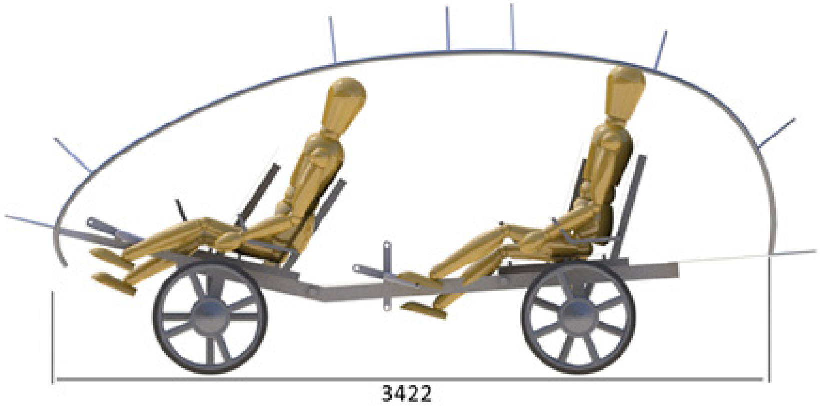
The first table will show the average of radiation with the average cloudiness during that month in the Netherlands. The second tables will show the average of radiation on a sunny day with a cloudiness of 5%.

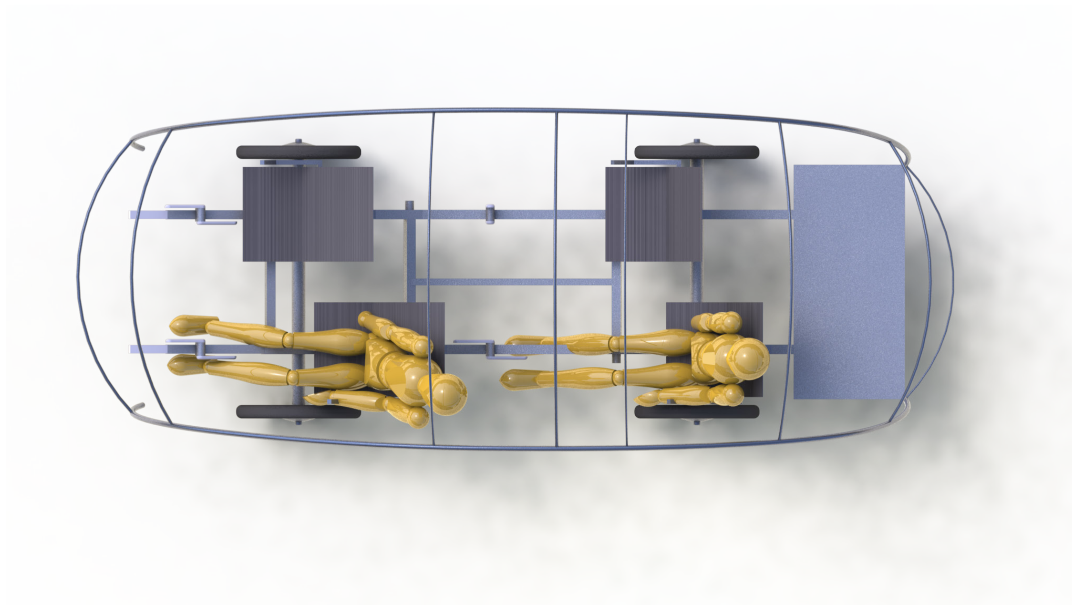
Month	Average Cloudiness (%)	Monthly average daily radiation (Wh/m^2,h)	Monthly average daily radiation per hour
January	75%	635	79
February	65%	1400	127
March	65%	2119	192
April	60%	3463	314
May	55%	3828	348
June	40%	5606	509
July	60%	4008	364
August	55%	3833	348
September	65%	2360	214
October	60%	1738	157
November	75%	710	64
December	80%	430	39

Month	Average Cloudiness (%)	Monthly average daily radiation (Wh/m^2,h)	Monthly average daily radiation per hour
January	5%	1717	156
February	5%	2828	257
March	5%	4281	389
April	5%	6261	569
May	5%	6921	629
June	5%	7411	673
July	5%	7245	658
August	5%	6300	572
September	5%	4769	433
October	5%	3142	285
November	5%	1920	174
December	5%	1418	128

Attachment I - Extra Images of the Final Concept







Attachment J - Detailed Materials

Body

1 Body fabric		
1 Cloth piece front	TenCate Solair	1,5x0,8m
1 Cloth piece middle	TenCate Solar	1,6x0,65m
1 Cloth piece back	TenCate solar	1,7x2,3m
1 Windscreen	uPVC	1,6x1,6m
8 Velcro front	Velcro	0,1x0,03m
8 Velcro front	Velcro	0,1x0,03m
16 Velcro front	Velcro	0,1x0,03m
8 Velcro front	Velcro	0,1x0,03m

5 Span mechanisms

5 Snap buttons 15 mm		
1 Cloth piece	TenCate Solair	0,1x0,03m

3 Fixing the rolled cloth

3 Click buckles 4 cm

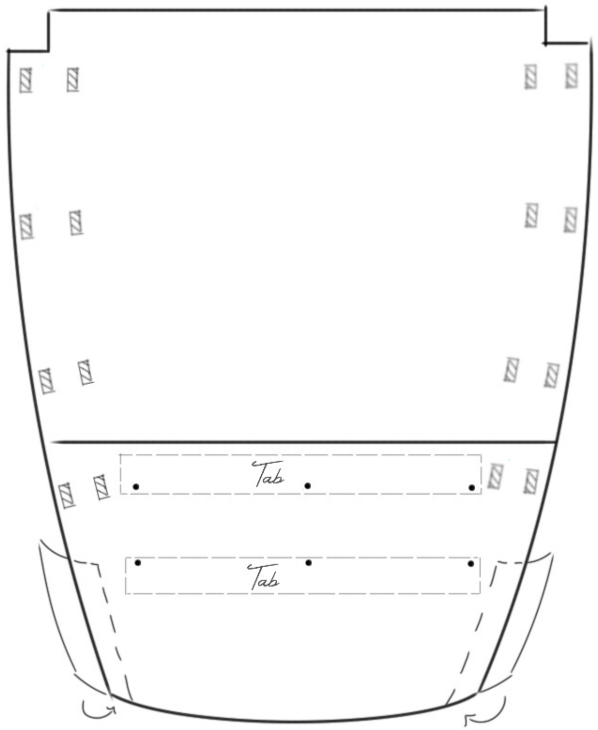
3 Nylon band

3 Tent clips for the back

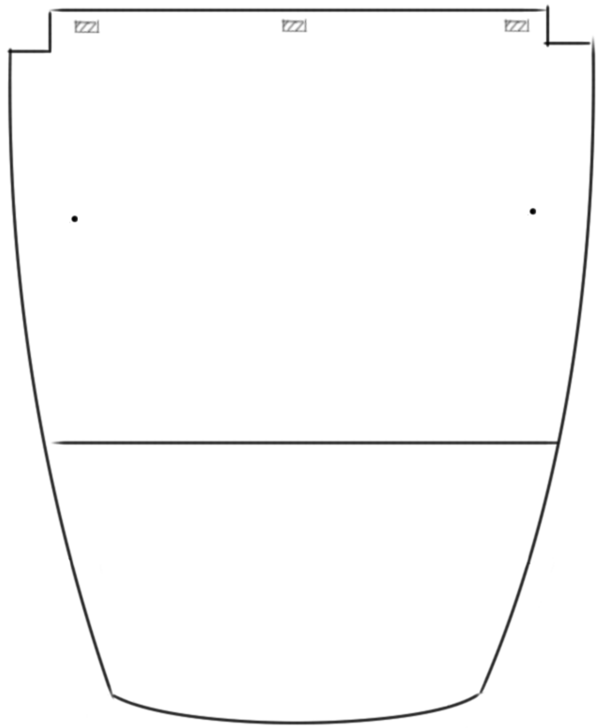
4 Grommets 15 mm for the wires

2 Grommets 15 mm for the rain protector

Front piece - Back side



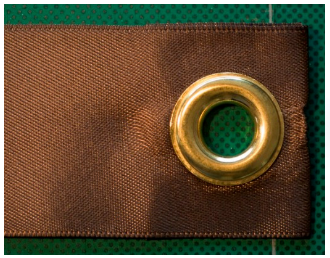
Front piece - Front side



= Velcro
= Snap button
= Grommet
= Bucket
= Clip
= Another piece

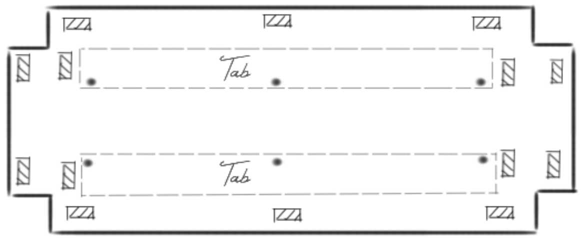
Tent clip

Grommet

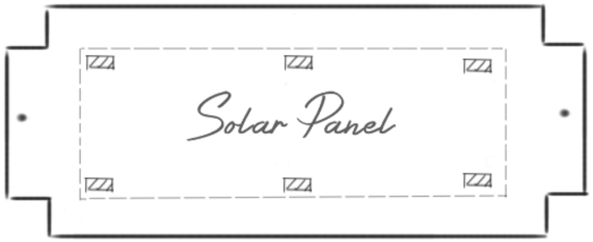


Snap Button

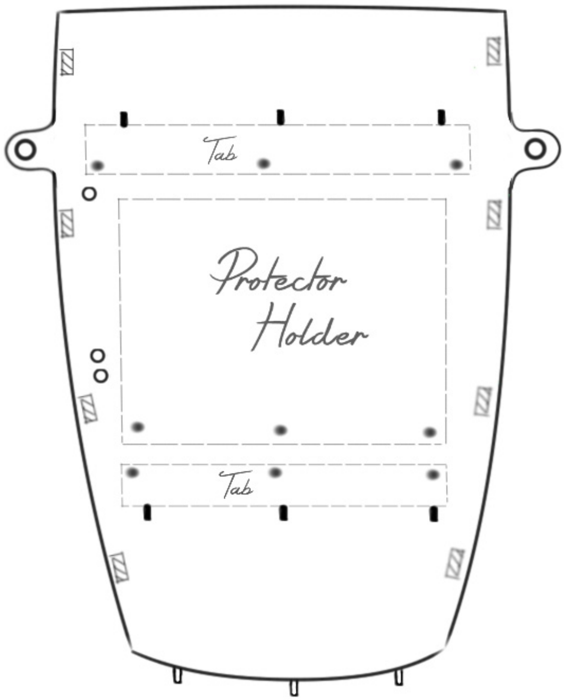
Mid piece - Back side



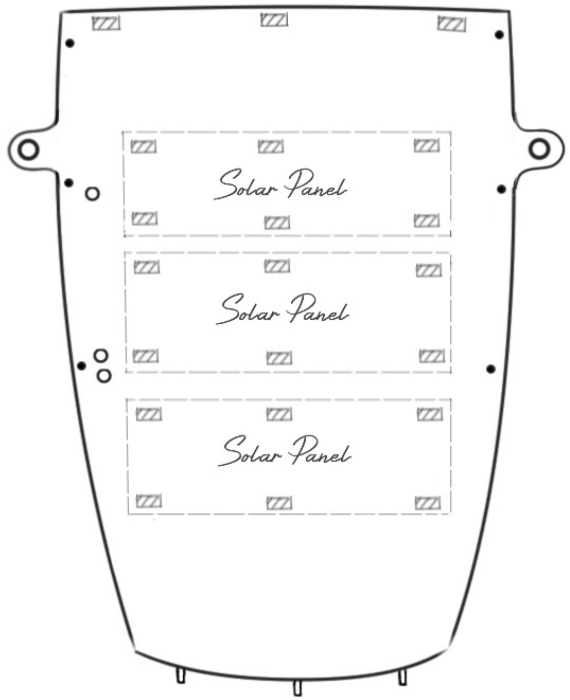
Mid piece - Back side



Back piece - Back side



Back piece - Front side



= Velcro
= Snap button
= Grommet
= Bucket
= Clip
= Another piece

FRAME

Part	Material	Length	Radius	Thickness
Main frame	Round Aluminium Tube	4,522	0,011	0,002
Main frame	Round Aluminium Tube	4,522	0,011	0,002
Rib 1	Round Aluminium Tube 1	1,34	0,005	0,001
Rib 2	Round Aluminium Tube 2	1,42	0,005	0,001
Rib 3	Round Aluminium Tube 3	1,57	0,005	0,001
Rib 4	Round Aluminium Tube 4	1,57	0,005	0,001
Rib 5	Round Aluminium Tube 5	1,58	0,005	0,001
Rib 6	Round Aluminium Tube 6	1,49	0,005	0,001
Rib 7	Round Aluminium Tube 7	1,36	0,005	0,001
Rib 8	Round Aluminium Tube 8	1,15	0,005	0,001

RAIN PROTECTOR

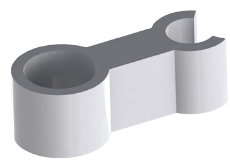
2 Support frame	Round Aluminium rube	0,414x0,05 x 0,0001
2 Connect to frame	ABS	
2 Protectings surfaces	utPVC	2,9x0,6m
10 Snap buttons 10 mm	Aluminium	
1 Protection holder	TenCate Solair	1,5x0,,8
2 Click buckle 4 cm		

Click buckle

Grommet

Snap Button

Connect to Frame - ABS



Attachment K - Production and Assembly Steps

Body Front

1. Sewing the PVC to the cloth
2. Sewing the Borders
3. Sewing the columns on the front
4. Sewing the Velcro on the front and the windscreen
5. Sewing the Velcro on the windscreen for the middle part
6. Sewing the span tabs on the front
7. Sewing the snap buttons for the tabs
8. Sewing the nylon and the click buckles to the cloth

Body Middle

1. Sewing the borders
2. Sewing the Velcro on the middle piece
3. Sewing the span tabs on both sides
4. Sewing the snap buttons for the tabs
5. Sewing Velcro for the windscreen
6. Insert the grommets for the wires of the solar panels
7. Sewing the protective cloth over the grommets for the wires

Body Back

1. Sewing the borders
2. Sewing the Velcro on the sides
3. Sewing span tabs at the height of the fifth and the seventh rib
4. Sewing the snap buttons for the tabs
5. Attaching the tent clips on the back
6. Sewing the nylon and the click buckles in the middle and the back
7. Insert the grommets for the wires of the solar panels
8. Sewing the protective cloth over the grommets for the wires
9. Insert the grommets for the rain protector
10. Sewing the protection holder (cloth) to the back
11. Sewing the click buckles for the protection holder

Frame

1. Mill all the ends of the ribs
2. Divide the two main frame in three parts
3. Swag the ends of the parts of the main frame
4. Bend all the tubes
5. Weld the ribs to the frame
6. Weld the square tubes to the first rib

Rain Protector

1. Bend the two internal frames
2. 3D print the plastic connection pice
3. Sewing the pvc
4. Sewing the tabs on the place where the internal frame comes
5. Sewing the snap buttons on the pvc

Assembly

1. Connect all the pieces of the frame together
2. Extend the baggage rack from the Quattrocycle with screws
3. Attach the frame to the Quattrocycle
    a. The square tubes are inserted in the front tubes, fixed with screws
    b. The back can be welded
4. Slide the front piece cloth around the main frame
5. Span the tab around the second rib, attach it with the snap buttons
6. Span the sides of the cloth and the windscreen around the frame, attach it with the Velcro
7. Span the tabs of the middle cloth piece around the third and the fourth rib, attach it with snap buttons
8. Span the sides of the middle cloth piece around the frame, attach it with the Velcro
9. Attach the windscreen to the middle piece
10. Span the tabs of the back piece around the fifth and the seventh rib. , attach it with the snap buttons.
11. Span the sides of the back cloth piece around the frame, attach it with the Velcro
12. Attach the back side with the tent clips to the eighth rib.
13. Attach the front of the back piece to the middle piece with Velcro
14. Click the plastic connecting piece to the fifth rib
15. Put the internal support frame through the whole of the grommet and the hole of the plastic piece
    a. But the rubber ends on the frame
16. Attach the pvc surface with snap buttons the cloth on the frame
17. Attach the tabs around the internal frame

Attachment L - Pictures of the Visual Model