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Development of an electric day boat concept

A product development project to explore the potential of electric day boats

Master's thesis in Product Development

Jesper Rönnebrand

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
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MASTER'S THESIS 2022

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Supervisor and Examiner: Lars Almefelt, Department of Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Product development
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

As a result from the increasing popularity of electric cars together with the need of working for a sustainable marine leisure industry, electric boats has gained a foothold in the world of boating. Nimbus Group being a leading boat manufacturer in northern Europe and working for sustainable boating has developed some electric boats and are continuing exploring the potential of electric boats. That is were this development project began with the purpose to create a concept for day boat use. The main objectives was to create a boat with functional design, decent performance and environmental benefits compared to equal combustion driven boats.

An extensive study was conducted prior of developing concepts. It involved a research of competitors on the electric boat market and propulsion systems. To identify the market segments and customer needs a study was conducted through interviews and a survey targeted at Nimbus Groups main markets. The study served as a guidance of were to head with the concept development.

Concepts were developed in a systematic process combining different components into concepts. The concepts were then screened out in different phases based on requirements and customer need criterions. After one concept had been decided for further development it was taken into a detailed design process resulting in a 3D model and renderings.

The concept was then evaluated environmentally and economically against an equal combustion driven boat and other electric boats. The results showed that electrical boats does pay off environmentally during its lifetime even at average day boating use. It also shows that from an economical perspective and average day boat usage it is not beneficial to buy an electric boat, however it is beneficial if usage is increased.

Keywords: Electric, Boat, Nimbus, Concept, Design, Sustainable

Preface

The following report is a summary of a product development project conducted as a master thesis (30 credits) at the department of Industrial and Materials Science at Chalmers University of Technology for the company Nimbus Group. The project took place during the spring of 2022.

I would like to thank everyone at Nimbus Group for their support during the project. A special thanks to my supervisors at Nimbus Group, Mats Jacobsson and Joacim Gustavsson. I would also like to thank my supervisor and examiner Lars Almefelt from the department of Industrial and Materials Science at Chalmers for providing me with academical guidance and feedback during the thesis work.

Jesper Rönnebrand, Gothenburg, May 2022

List of Acronyms

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

AC	Alternating Current
CAD	Computer Aided Design
CTO	Chief Technology Officer
DC	Direct Current
DFMA	Design For Manufacturing and Assembly
FRP	Fibre Reinforced Plastic
NM	Nautical Mile
VR	Virtual Reality

Contents

1
Introduction

In this chapter the project will be introduced,starting with a background of Nimbus Group and history of electric boats. Then the purpose and objectives will be stated followed by the key activities that will take place. Delimitations and problem definition will be presented and finally the actors and stakeholders and the expected outcome will be presented.

1.1 Background

1.1.1 Company description

Nimbus Group was founded in Gothenburg 1968. Already from the start it was a success when the first boat Nimbus 26 was introduced and one year later received a prize for best boat of the year. During the years Nimbus has collaborated with renowned designers and celebrities like Björn Borg, establishing itself as a premium boat brand with high quality(Nimbus Group, 2022a).

During recent years Nimbus Group has been in a growth phase and through acquisition of other boat brands in the Nordics, the company is now established as a leading boat manufacturer in Europe. Today Nimbus Group consists of the brands Alukin, Aquador, Bella, Falcon, Flipper, Nimbus and Paragon. The common features that can be found in all Nimbus Groups brands are quality, comfort, environmental focus, safety thinking and Scandinavian design (Nimbus Group, 2022a).

Being one of Europe's largest boat manufacturers Nimbus Group feels a responsibility towards providing leisure boats with a focus on sustainability and environment. Through the years Nimbus Group has proven their work towards sustainability by for example launching the E-power concept already in 2009 and the all electric Nimbus 305 back in 2016. The target for the E-power concept was to improve the relation between boat, human and environment. When Nimbus Group develops a boat the environment is taken into account in every step, from creating an efficient hull reducing the fuel consumption to choosing materials having less impact on the environment (Nimbus Group, 2022c).

1.1.2 Electric boats, then and now

Electric boats first appeared during the late 1830s, however these boats had very limited performance and it took decades until electric boats had something of a golden age from the 1880s until 1920s. When the combustion engines were introduced during the 1920s it quickly took over as the main propulsion solution for motor powered boats. Only a few electric boat models were launched for a long period during the 20th century (Todays Engineer, 2013).

Following the success of electrification of cars in the latest decade combined with the increased focus on environment and sustainability, new electric boat manufacturers have started to pop up with the goal to make the same change to the marine industry as the one that has been going on in the recent years in the automotive industry (Marshall, 2021).

The main disadvantages of existing electric boats is that the range is limited due to the low energy density of batteries compared to diesel or gas. Due to the low energy density of batteries it is difficult to achieve the demands on performance in terms of range and speed that many boaters desire (Tveitdal, 2018).

1.1.3 Nimbus Group developed electric boat

Bella Zero 6.3 is an electric day boat developed by Nimbus Group under the brand Bella and released in the beginning of 2021. The purpose of the boat is to offer an electric day boat to an affordable price. The boat is designed with a semi displacement hull equipped with an 33 kW engine and a 25.9 kWh lithium-ion battery, allowing it to cruise in 5 knots at a distance of 30 nautical miles. The top speed is 14 knots but at that speed the battery only lasts for 35 minutes (Morin, 2021).

Figure 1.1: Picture of Bella Zero 6.3

1.2 Purpose

The purpose of this project is to develop a concept for an electric boat focused on day use, based on the experiences from Nimbus Groups previous electric boat projects.

The study will focus on creating a concept that is a competitive option to boats with combustion engines, where performance in terms of range and speed should meet user needs while at the same time being a viable option economically. Another focus will be to compare the environmental impact from the electric boat concept to a similar fossil fuel driven boat.

Focus will also be on manufacturability, where the concept should be designed in a way to keep assembly and manufacturing time down, and where the concept should fit into Nimbus Groups current production.

The final design of the boat should meet Nimbus Group's values of quality, comfort, safety and Scandinavian design, while being sustainable and creating better experiences for the users.

1.3 Objectives

The objective of the project is to generate a concept that have:

- Functional design
- Decent performance
- Economical benefits
- Environmental and sustainable benefits
- Manufacturing and assembly suited to Nimbus production lines

1.4 Problem definition

The problems that are forming the basis for the project can be divided into market and environmental issues.

Market

The market for day boats is today dominated by fast planing boats with large engines, often over motorized since most of the users rarely drive their boat in more than the economic cruising speeds of planning boats, often between 20-25 knots. When it comes to electric boats the development of batteries has not yet reached a potential where it can compete with fossil fuel in the ability to deliver the energy required both for maintaining a high speed combined with long range. This is the main doubt boat users have when questioning electric boats. Other doubts are the lack of charging infrastructure as well as the initial price is high compared to an equal boat with a combustion engine.

Environmental
The main incentive for boat users to buy an electric boat is to protect the environment. However it is important to remember that environmental friendly in use does not necessarily equals environmental friendly throughout the whole process. An electric boat has a battery with several minerals that has to be mined and the electricity has to be generated either as green energy or with fossil fuels like coal which is common around the world. Boats also include materials that have a negative impact on the environment through extraction and processing, such as fiberglass, aluminum, steel and wood among others.

Hypothesis:
Designing a boat with a hull that is efficient at all speeds without a distinct planing threshold will ensure that the boat can cruise efficiently at long range at low and intermediate speeds and maintain a decent range at maximum speed.

A layout that invites to social and comfortable staying are likely to facilitate slower speeds an more time spent on water.

Questions:
The research question are based on the problem definition and covers some of the questions that might arise when trying to solve the problems. The questions will be used to analyse and validate the outcome of the project.

Is there an interest among boat users to compromise on speed to increase range and spend more time on the boat?

Will the reduced running costs result in economical benefits over the electric boats lifetime?

How will an electric boat impact the environment throughout its lifetime compared to an equal combustion engine boat?

1.5 Delimitations

The following lists describe what delimitations that have been set for the project.

Design

- There will be no hydrodynamic calculations made at the concept stage to evaluate hull types or design the hull. Selection and design of hull type will be based on characteristics of the different types and available data.
- The type of boat should be used mainly for day time activities.
- The concept should be designed to fit into Nimbus Groups manufacturing and assembly process.
- Driveline and other systems will be selected and fitted into the boat but there will be no technical construction made. The approach is rather to design the concept so there is enough space for technical installation.

Analysis

- There will be no structural calculations made, however the design of the concept should be realistic in terms of strength and mechanical properties.
- The environmental analysis is focused on green house gas emissions related to propulsion. The calculations is not taking the emissions from manufacturing of the boat and driveline components into account.

Economical

- The approximated price of the final concept should fit into Nimbus Groups current price range.
- There is no specific budget limit to the project, however a budget has been created where a potential cost might reach a maximum of 30 000 sek.

Outcome

- The final concept will not be ready for production, however considerations will be taken to ensure that the concept will have a smooth transition from concept to production ready boat.

1.6 Thesis Outline

Following the introduction the thesis begin with a chapter of theory to give the reader some knowledge about boats and propulsion of boats. The manufacturing process of boats and how to design for manufacturing are also described. Lastly the in-going data used for environmental calculations are presented.

The theory chapter is followed by the methodology describing the whole process used in the project and the different methods being used.

Then the results are presented including the market study, concept generation and screening phase and lastly a presentation of the final concept design and evaluations both economically and environmentally.

The discussion chapter reflects on the methods use and the outcome of the project. Lastly a chapter of conclusion summarize the key findings of the thesis and suggest recommendations for future work.

2

Theory of boat design and manufacturing

The theory chapter describes different hull types, boat types and propulsion. It also describes the manufacturing process of boats and how boats should be designed for manufacturing. Lastly it includes some in-data of environmental calculations of green house gases.

2.1 Boat terminology

Here some frequently used terms related to boats are explained. In figure 2.1 some of the main terms is explained visually.

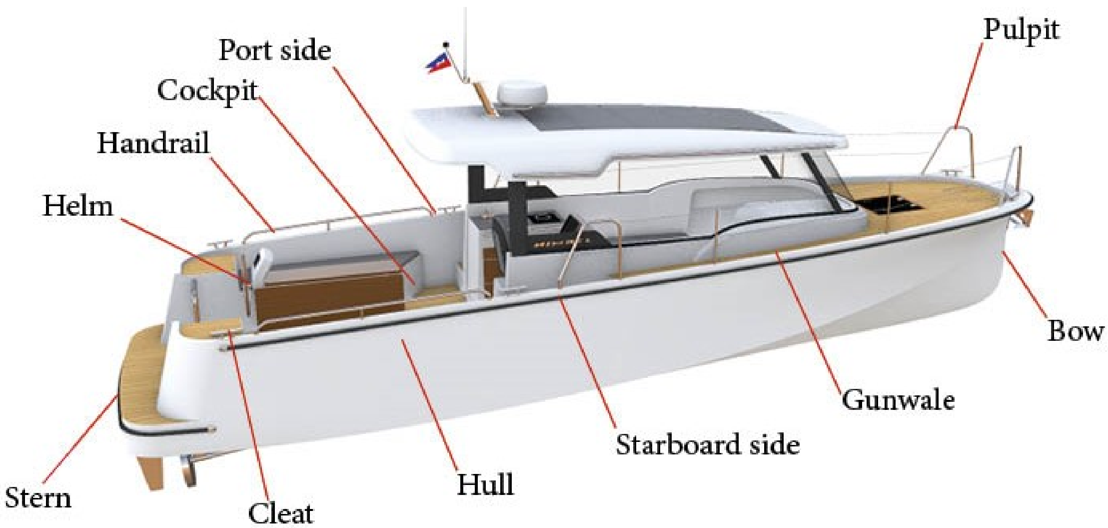


Figure 2.1: Picture explaining some boat terminology visually

Following is a list with all terminology presented in the report that needs explanation.

Bow	Forward part of a boat.
Cleat	A fixture to attach mooring lines to.
Cockpit	A space on deck that is often in form of a open well, from were the boat is controlled.
Deck	Sits on top of hull, a platform which you walk on.
Foredeck	Deck at the forward part of the boat.
Gunwale	The upper edge of a hull.
Handrail	Rails placed around the boat to provide support.
Helm	Position from which boat is operated.
Hull	Main body off a boat.
Port side	Left side of a boat.
Pulpit	The railing at the bow of a boat.
Starboard side	Right side of a boat.
Stern	The back of a boat.

2.2 Hull types

This section describes some common hull types that exists. Apart from the hull types mentioned below there are variations of these where all of the following hull types can be either a monohull or a multihull. Monohull is a boat with a single hull, a multihull has two or more hulls combined.

2.2.1 Displacement hull

The displacement hull is displacing water as it moves, meaning that the hull lies in the water and slices through it instead of running on top of the water. It is characterized by slow speed since the speed is limited to the “hull speed” which has a relation to the water length, a longer displacement hull can travel at greater speeds. The displacement hull is often very efficient which makes it a popular choice for many electric boats where the speed is not a focus (Rudow, 2021).

2.2.2 Planing hull

The planing hull seen in figure 2.2 is a hull that is supported by a vertical pressure force that lifts the hull at high speeds (Larsson et al., 2022). The hull is considered to be planing if its is mainly supported by the hydrodynamic pressure. Planing hulls are commonly V-shaped to enhance seakeeping qualities, the V-shape is also refereed to as a deadrise. Greater deadrise angles reduces the lift, to maintain the lift, spray rails can be added along the hull. The spray rails force the water flowing sidewards down to generate lift, as seen in figure 2.3. Another way to improve the performance of a planing hull is to add steps at the bottom of the hull which generate more lift due to a small length to beam ratio for each step (Larsson et al., 2022), the steps can be seen in figure 2.2.

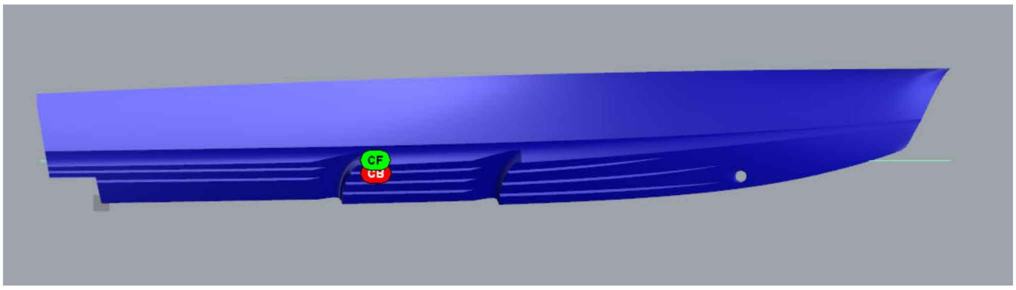


Figure 2.2: Picture showing the planing hull for Nimbus T11

Figure 2.3: Picture showing hull spray rails

2.2.3 Semi displacement hull

The semi displacement hull combines the characteristics of the planing hull and the displacement hull, with a v shaped bow that gradually softens towards the stern. The bow will efficiently cut the waves and the stern will generate lift. The result is a greater speed than for a displacement hull and better efficiency than a planing hull at intermediate speeds. The drawbacks with the semi displacement hull is that it is weight sensitive, and not as efficient as the planing hull in high speed (Torterat, 2017).

2.2.4 Crossover planing hull

A special hull was designed by Heyman Yachts to take powerboat hull designs further. The hull is designed for Nautus 7-50 and seen in figure 2.4. The idea was to create a hull that is efficient in slow displacement speeds, semi planing speeds and planing speeds. The hull is a planing hull but with a sharper bow to reduce slamming, the efficiency of the hull allows for a low fuel consummation of between 0,4 - 0,45 liter diesel per NM in most speeds (Heyman, 2022).

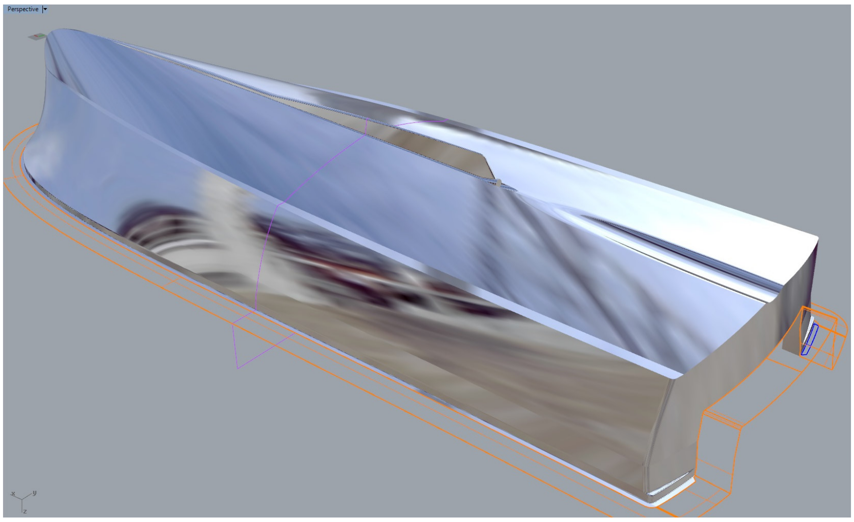


Figure 2.4: Picture showing the hull of Nautus 7-50

2.2.5 Foiling hull

A foiling boat has submerged hydrofoils that generates lift so that the hull of the boat fly above the water, this reduces the hydrodynamic hull resistance to zero (Larsson et al., 2022). There are different variations of foil concepts and foils can either be fully submerged as T-foil or surface piercing as V-foil both seen in figure 2.5. The surface piercing V-foils has the advantage of height adjustment automatically since the submerged part of the foil generates just the required lift to carry the weight of the boat, as the speed increases less of the foil are submerged. The submerged T-foil requires an active control system since the lifting surface of the foil are the same for all ride heights. When reaching high speeds the submerged T-foil can pierce the surface which results in loss in lift of the foil and might lead to the boat crashing to the surface. This can be avoided with the active control system maintaining the correct ride height (Larsson et al., 2022).

Figure 2.5: Picture showing V- and T-foil

2.3 Common day boat types

In this section some common boat types for day boating are described. Note that all day boat types existing are not included, only the ones which are common and fits into Nimbus Groups profile.

2.3.1 Centre console and Walk around

Centre console and walk around boats have a centered console were the helm of the boat is located. There are possibilities to pass between bow and stern on each side of the boat. This is a benefit especially when docking the boat and access to both sides are required to attach fenders and mooring lines. Centre console boats are usually open as seen in figure 2.6, and larger boats might offer a toilet compartment under the console. The difference between a centre console boat and a walk around boat are that the walk around layout offers a cabin with sleeping possibilities while the centre console are open at the bow.

Figure 2.6: Picture showing centre console boat

The centre console boat seen in figure 2.6 is well suited for day trips because it has large and practical spaces for bringing items and it offers excellent ability to move around on the boat (Nordkapp boats, 2020b). Centre console boats are great for fishing or as a transport boat to summer houses located on islands. The drawback with centre console boats is that passengers sitting in the aft couch are more exposed to weather and wind since the windscreen often only gives protection for the people sitting right behind the console. The walk around boat seen in figure 2.7 has similar benefits with the addition that you can sleep aboard. However a drawback is that the foredeck is raised and the sidewalks often is a bit narrower compared to the centre console (National Marine Manufacturers Association, 2022).

Figure 2.7: Picture showing walk around boat

2.3.2 Side walk

A sidewalk boat has an asymmetric layout with a wide side deck on one side to provide generous space for moving between bow and stern, as seen in figure 2.8. At the same time it gives more volume to the cockpit or interior space (Nimbus Group, 2022b). The drawback for the sidewalk layout is that one side becomes narrow and some time access to both side are required when docking in certain harbours, someone might have to move around the narrow side to attach fenders and mooring lines.

Figure 2.8: Picture showing Nimbus W9 sidewalk

2.3.3 Bowrider

The bowrider as seen in figure 2.9 has a full width windscreen with a door to pass between bow and stern (Nordkapp boats, 2020a). It provides shelter from the wind when sitting in the cockpit, and there is often possibility to sit at the bow. Bowriders are often described as ideal family day boats since it provides plenty of seating for friends and family. It offers plenty of storage space and is usually great for water sports (Glastron, 2021).

Figure 2.9: Picture showing a bowrider

2.3.4 Daycruiser

A daycruiser which can be seen in figure 2.10 has a large cockpit behind a full width windscreen and a cabin in the bow section. It provides good shelter from wind and weather (Flipper Marine, 2022). Common for modern daycruisers is to have a windscreen with a door in the center to access the foredeck or cockpit, some day cruiser models have narrow gunwales on each side to pass from the foredeck to the cockpit. Daycruisers are popular since they provide plenty of shelter and many like to have the possibility to spend a few nights in the small cabin (Nordkapp boats, 2020c). The drawbacks with the daycruiser is the limited ability to move around at the foredeck which often lack proper grab rails which make it a balance hazard.

Figure 2.10: Picture showing Flipper 640 daycruiser

2.3.5 Sloop

A sloop is a boat type with a displacement hull for slow cruising (Atlantica, 2016) as seen in figure 2.11. Often it has an open layout but can also have a cabin to allow for overnight stays. The benefit of the sloop is the peace it offers in slow cruising and social environment were you spend time on the water with family and friends. The drawback is that it is limited to the hull speed since it is a displacement boat (Atlantica, 2016). It is a common boat type at the inland waterways around Holland but can also be seen frequently along the Swedish coast.

Figure 2.11: Picture showing a traditional sloop

2.3.6 Pilothouse and Cabin boats

Pilothouse boats, also referred to as cabin boats depending on region, have an enclosed pilothouse that can be completely sealed of from the elements as seen in figure 2.12. This makes a pilothouse great for all year use since it can be used in a wide variety of weathers. A pilothouse can be fitted to all of the above mentioned layout types. The drawbacks with a pilothouse is that it limits the outdoor space of the boat which is sometimes desired in warm summer days (Discover Boating, 2022).

Figure 2.12: Picture showing a boat with pilothouse

2.4 Propulsion types for boats

There are different variations for delivering propulsion to a boat. In this section some common variants are described. Other variants exists but are not mentioned here since they are not a part of the results.

2.4.1 Inboard with shaft drive

Inboard engines with shaft drive are mounted inside an engine room often located at the midsection of the hull. The drive shaft extends out from the engine and runs through the bottom of the hull. At the end of the shaft the propeller delivers the propulsion and a ruder is located behind the propeller for steering the boat (Maritimo, 2020).

2.4.2 Inboard with sterndrive

Inboard engines with a stern drive are located at the stern with a drive unit attached to the transom. The drive unit provides steering since it can be rotated to generate thrust in the direction you want to go. It can also be tilted up and down to change the trim angle of the hull for more efficient cruising. The tilting function also allows for entering shallow waters, however it is limited and can never be fully tilted out of the water which is the case for an outboard. The drawbacks with the sterndrive compared to a shaft boat is that there are more moving components and more exposed components which can lead to damage and corrosion (Tom George Yacht Group, 2019).

2.4.3 Outboard

Outboard engines are mounted to the transom located at the stern of the vessel. The outboard is a self-contained unit including the engine, gearbox and propeller (Tom George Yacht Group, 2019). The boat is steered by rotating the engine to push the boat in the direction you want to go. Similar to the sterndrive the outboard can be tilted to find the most efficient trim angle for efficient cruising. It can be tilted completely out of the water which is a benefit when entering shallow bays or for preventing growth of marine organisms on the submerged parts when standing still for long periods, which can have a large impact on the performance of the boat (Andreae, 2014). It is also easy to maintain or change since access are unlimited because it is mounted on the outside.

2.4.4 Steerable pod drives

Steerable pod drives are mounted at the bottom of the hull usually with forward facing propellers. The steerable pod drives generates excellent manoeuvrability together with other benefits such as increased fuel economy, performance and more usable space onboard. When comparing Volvo Pentas IPS system using steerable forward facing pods it is seen that it has a 30% reduction in fuel consummation and 20% higher top speed compared to a shaft driven boat (Volvo Penta, 2022). Driving a boat with steerable pods using a joystick enables precise and controlled harbour manoeuvres. The drawbacks with pod drives is the maintenance and price (Fortey, 2021).

2.4.5 Thruster bow and stern

A bow or stern thruster is a device to enable sideways movement or rotating a boat to increase the maneuverability in a harbour. The bow thruster is often located in a tunnel at the bow and the stern thruster is usually located at the stern transom (Lanier, 2014).

2.5 Electric propulsion

2.5.1 Electric engine

The electric marine engines available to the market are of both AC (alternating current) and DC (direct current) types (DiQuinzio, 2015). The benefits with the DC motors is that they offer a high torque capability in relation to the weight and size and can be controlled electronically. Downsides with the DC motor is that it has brushes that from time to time has to be replaced. The AC motor has no brushes but it requires sophisticated controllers to invert DC into AC (DiQuinzio, 2015).

2.5.2 Battery

Lithium-ion batteries are the main battery technology used for powering electric boats right now. Compared to other battery technologies such as lead-acid the lithium-ion batteries have higher energy density than any other battery technology today while being almost 20% more efficient (Dragonfly Energy, 2021). The disadvantages with the lithium-ion batteries is that they have a tendency to overheat, can loose capacity due to ageing and are costly. Compared to gasoline the lithium-ion batteries are hundred time less energy dense (Clean Energy Institute, 2020).

Battery capacity is limited by the depth of discharge (DOD) which refers to the amount of capacity that has been drained. If draining a battery of 80% of its capacity the DOD is 80% and 20% of the battery capacity remains. If batteries have less than 20% of the capacity remaining it might run out of electricity, therefore 80% DOD is seen as a maximum (Crown Battery, 2018).

2.6 Materials used in Nimbus boats

Fibre-reinforced plastic (FRP) is a common material for building boat hulls and decks and is used for Nimbus boats. One advantage of FRP is the possibility to tailor the strength properties which lead to light and strong structures (Larsson et al., 2022). The main parameters that decides the strength are what type of reinforcement that are being used and the fibre content. The glass reinforcement that is most common to use is a chopped strand mat, consisting of short fibres that are between 4 to 5 cm long which are distributed evenly and held together by a binder (Larsson et al., 2022).

Wood veneer is a material that uses a thin layer of natural hardwood that is bonded with a core material. This results in less exotic wood such as teak or mahogany being used. The core material depends on the indented application of the wood veneer but usually it is of plywood (CHI, 2022).

Teak is a wood material commonly used for decks on boats. Since natural teak decks contributes to the deforestation of rainforest it is not good from an sustainable perspective. Alternatives of teak decking exists that simulated natural teak and most common is the synthetic teak PVC decks. The PVC decks have a textured surface to simulate the grains of wood (Holmes, 2020).

2.7 DFMA

Design for Manufacturing and Assembly (DFMA) is a methodology within engineering that focus on creating products that are efficient to produce which lead to a reduced time-to-market and at the same time lowered production costs. The best stage to ensure low manufacturing and assembly costs are at the design stage, which makes it important to consult with experts within manufacturing throughout the design process (Siemens, 2022).

2.7.1 Nimbus boats manufacturing process

Following paragraphs describes the manufacturing process for Nimbus boats and information is gathered through an interview with M. Jacobsson (personal communication, 22 Mars 2022)

When a new boat model is being prepared for manufacturing the first step is to send the 3D-files generated in CAD (Computer Aided Design) to a CNC milling machine to create a mold plug. A base for the plug is created in plywood and then a coat of foam is applied to the plywood base. The foam is then milled to the desired shape. Next step is to add a paste of polyurethane or epoxy, were the epoxy paste is considered to generate a better finish but requires more from the occupational health and safety. To create a smooth product the plug are then ground manually using a long-board or sanded by hand and then a surface layer of topcoat are applied to generate a glossy surface. Then the plug are used to create the mold which are laminated in vinyl ester. Frames are integrated to the mold for handling. When the boat are being produced in the molds the mold first have to be waxed. This is done to reduce the grip to enable the product to be removed from the mold.

There are two main techniques that are used when laminating boats, hand lay-up and vacuum infused lay-up. Hand lay-up is done by placing pieces of glass fibre in the mold that later is saturated with either epoxy resin, polyester or vinyl ester. Nimbus group mainly use vacuum infusion in its production but some parts are made with hand lay-up. The process of vacuum infusion at Nimbus begins with adding a layer of gelcoat followed by a layer of vinyl ester based barrier coat in the mold. Then the glass fibre peaces are pre-cut and placed dry in a specific lay-up to achieve both strength and good surface finish which can be seen in figure 2.13. If a sandwich structure is used for the part being made the core material of divinycell is placed between the layers of glass fibre. Sandwich structure are mainly used in parts which require strength such as a hull or a deck as seen in figure 2.14. Divinycell is a light weight PVC foam core material that enable building boats strong while keeping weight down (Diab Group, 2022).

Figure 2.13: Picture showing how glass fibers are laid up by hand

Figure 2.14: Picture showing the sandwich construction with divinycell

When the lay up of glass fibre and core material are completed everything are covered in a bag which are put to vacuum, as seen in figure 2.15. The bag is connected with tubes to allow polyester to enter. It takes around one hour to fill a hull with polyester and after another 40 minutes it starts to harden. After the polyester has hardened for 3 hours the bag is removed and the hull structure is completed.

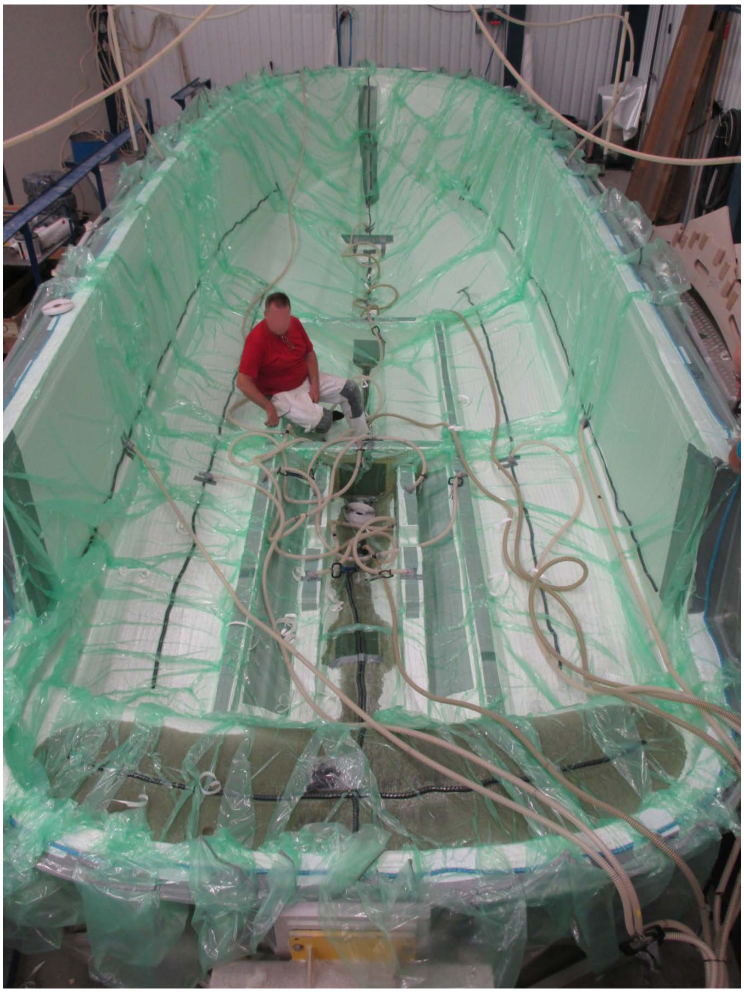


Figure 2.15: Picture showing hull covered in bag

Next step is to add the reinforcing beams to the hull as seen in figure 2.16 which are done within 4 hours of the completion of the hull in order for the laminate to be chemically active to get chemical bonding between the hull laminate and beams. Then the hull is left in the mold over the night and the day after it is removed from the mold. The process is similar when creating other vacuum infused parts.

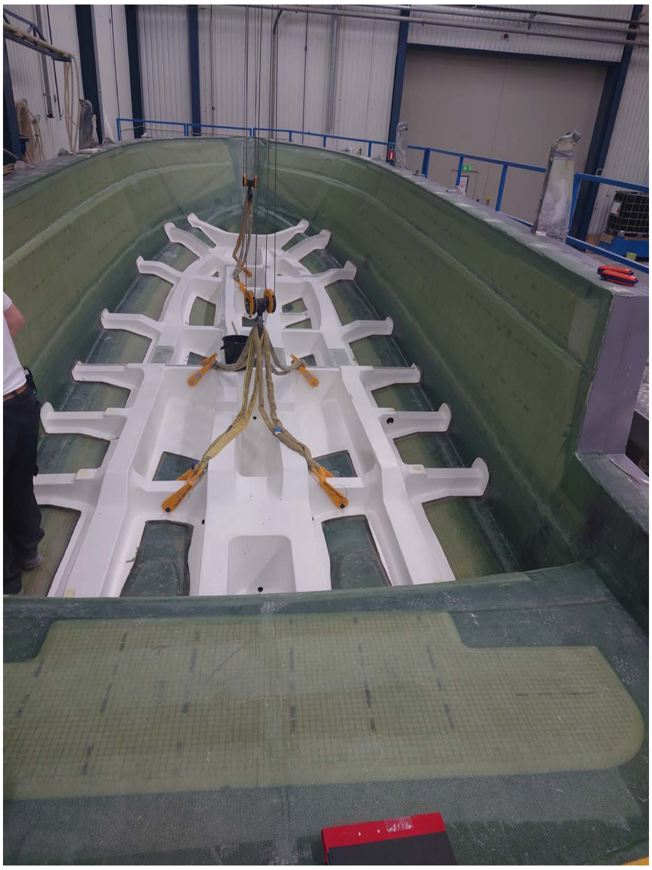


Figure 2.16: Picture showing hull beams laying inside the hull

It is made sure that all cutting and drilling in the laminate are done prior to moving into the mounting phase. There are three mounting stations for each production line, one for the hull, one for the deck, and one for putting the deck and hull together. It is made sure to mount as much as possible before the deck is put on the hull as seen in figure 2.17. It allows for easier mounting of parts since space inside the boat get more cramped when the deck is added. Much of the furniture are also mounted as ready modules. For example the toilet comes as a complete module which can be seen in figure 2.18 that just have to be connected with piping and such.

Figure 2.17: Picture showing assembly of systems before decking

Figure 2.18: Picture showing toilet module

When the boat is ready to be decked the deck is lifted and hull is placed underneath. A deck that is almost ready for being lifted and placed on a hull is seen in figure 2.19 First it is tested if the hull and deck fits together before they are glued together. Then the deck is lifted again and glue is applied around the edges and then hull and deck is pressed together. The hull and deck are also bolted together as seen in figure 2.20. Then all the electrical systems and piping between the hull and deck are connected and some furniture mounted that can’t be mounted before the hull and deck is put together.

Figure 2.19: Picture showing station for decking

Figure 2.20: Picture showing the hull and deck bolted together

The last station is the test station where all the systems are tested in a pool as seen in figure 2.21. Different areas of the boat are also checked for leakage. A final inspection is made to check that everything that the customer has ordered are included and then the boat is packed for delivery.

Figure 2.21: Picture showing boat being tested in test tank

2.7.2 Nimbus approach to DFMA

Following paragraphs describe some of the aspects Nimbus Group consider when designing for manufacturing and assembly. The information is gathered through and interview with M.Jacobsson and J.Gustavsson (personal communication, 17 May 2022).

When designing a boat for efficient manufacturing it is important to not add too much details since many detail increase the complexity and cost. The number of molds should be minimized since it is a logistic problem to have many molds, the more molds that are needed the more complex it makes the assembly and result in higher prices. The molds also requires a lot of space when they are not in use. It is desired to add functions in the laminate without increasing the cost, features that impacts the complexity and cost is for example elevations, immersions and creases.

It is important that there are draft angles on surfaces so that parts can be removed from the mold. One design rule Nimbus follow is that the draft angles should be minimum 1.5 degrees for shiny surfaces and if the surface is rougher larger draft angles is required. It is also important to take the aspect of removing the laminate from the mold into account. It should be possible to lift the laminate out of the mold vertically with a traverse. Narrow laminate details should be designed after the criteria that something that has a certain height should have a width of a third of the height. By keeping this criteria in mind it facilitates the access of tools when laminating the surfaces.

Critical meetings between different laminate details which require tolerances should be minimized. If it is possible to build in self fixation for different modules it is a way to minimize complex meetings. One example is when the deck is put on the hull and everything has to fit together.

It is desired to build furniture as modules outside the boat and then lift and place it inside the hull. Wood details should be using same thickness for wooden plates to improve the logistics.

2.8 Emission data for electric and diesel propulsion

Theoretical background for the data used in emissions calculations are presented in this section.

2.8.1 Battery manufacturing emissions

A mean value for battery manufacturing emissions was estimated to be 75 kg CO2eq/kWh during 2020 (Hoekstra, 2020). It is also seen that GHG emissions from battery manufacturing decreases since battery production is becoming more efficient and the use of renewable energy is increasing in the production of batteries (Hoekstra, 2020).

2.8.2 Electricity mix over the lifetime of a vehicle

In the study by Hoekstra (2020) it is brought up that the electricity mix used over the years a vehicle is driven should be used for calculating driving emissions. Furthermore the upstream emissions, trading and losses are added to the emissions. It is estimated that the electric emissions at the charger is 0,25g CO2eq/kWh over the lifetime of a vehicle sold during 2020 (Hoekstra, 2020).

2.8.3 Fossil fuel production and consummation emissions

It is stated by Hoekstra (2020) that 24% should be added to the tailpipe emissions for the production of diesel. The tail pipe emission for 1 kg of diesel from an marine engine is around 3.15 kg CO2eq. One liter of diesel weighs 0.87kg (Zang et al., 2021) which result in a tail pipe emission of 2.74 kg C02eq per liter. The total emissions per liter are thus 3.4

kg C02eq for running a marine engine on diesel when adding the 24% for fuel production (Hoekstra, 2020).

3
Methodology

In this chapter the methodological approach and methods used are described.

3.1 Methodological Approach

The methodological approach used to generate a concept is based on two different methodologies to generate products. The first methodology by Ulrich and Eppinger (2020) is focusing on methods for general product development. The second methodology by Larsson et al. (2022) is focusing on the development and design of a boat. The two methodologies have been merged and adapted to suit this specific project. In figure 3.1 a process flow chart is seen showing the stages of concept development.

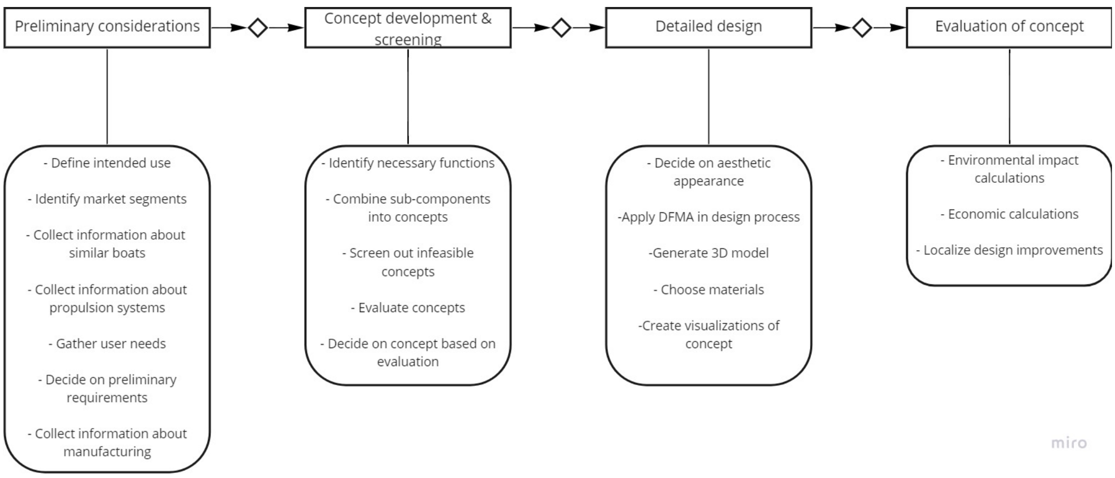


Figure 3.1: Flow chart showing the development process

3.2 Market research

Market trend research was performed to understand how the market for day boats looks like around the world and to identify electric boat manufacturers currently on the market. Search engines was used to identify electric boat manufacturers which was concluded in a list comparing technical data of each boat, including size, performance, propulsion system and price. From the list of electric boat data some graphs where created to serve as a visual aid when comparing the existing electric boats performance against each other.

Market segmentation was conducted to identify potential markets and how markets differ depending on location. It was done through interviews of sales persons representing Nimbus Group from different locations. Furthermore a customer survey was used to identify usage patterns from different locations.

3.3 User needs study

One-to-one interviews were held with different distributors of Nimbus Group boats around Europe to understand what users are demanding from their day boats, and how the boats are used in the region. Nimbus Group has markets on other places around the world but since the chosen interview objects from different locations cover most of the different usage patterns of day boating there was little need to interview distributors from more locations.

An online survey was created to identify usage patterns and user demands on day boats. It also included questions related to electric boat interest and environmental aspects. The survey was targeted at the end user of boats. To reach out to users from different locations the survey was spread on different online platforms such as Facebook groups, LinkedIn and web-based boating forums. To achieve a statistical representative sampling a target of 500 respondents was aimed for.

The gathered data from the interviews together with complementary customer need statements based in personal boating experience as well as input from the development team at Nimbus was used to form a customer needs list. The customer need statements was translated into a list with needs formulated to be as general as possible.

3.4 Technical study

Following sub chapters cover the technical study that was conducted.

3.4.1 Literature study

Literature were used to support the development process. The literature study cover principles of yacht design, boat building materials and design for manufacturing and assembly (DFMA). The book Principles of Yacht Design (Larsson et al., 2022) will cover the basics of yacht design as well as boat building materials, other relevant sources might also be used. Other literature used was found using search engines like Google scholar.

3.4.2 Marine electric propulsion and steering systems

A study of existing marine electric propulsion systems was conducted to find out which subcontractors of propulsion systems that was suitable for the generated concepts. The propulsion system in this case was focused on engine, battery, drive type and steering. The research was done using search engines to identify potential propulsion systems and batteries. Interviews was held with some of the identified subcontractors to gather more information.

3.4.3 Boat manufacturing at Nimbus Group

A visit to the Nimbus factory was made to gather insight in the boat building process and to understand how the boat should be designed to fit into Nimbus Groups manufacturing strategy. During the visit a walk trough tour was given showing all the stages of the manufacturing process. The visit to the factory was complemented with a interview of the CTO of Nimbus Group further explaining each process of the boat building process.

3.5 Requirement specification

Based on the information gathered during the user needs and technical study an initial requirement specification was created that was updated as the project proceeded. The requirement specification was used as a basis for criterions in the concept screening phase.

A requirement specification describes what a product has to do in precise and measurable detail (Ulrich and Eppinger, 2020). In the case of a boat this can for example be "minimum range at full speed greater than 20 nautical miles", this can be divided into a metric and a value. The metric in the example is "minimum range at full speed" and the value is "greater than 20 nautical miles".

3.6 Functional decomposition

A functional decomposition was conducted to identify all the necessary functions that might be included in a boat, and how these functions should be solved. A functions-means tree was used to decompose the functions related to boat use. It is a method based on Hubka´s law where functions and means have a relation and where they are connected on different levels. It is possible to use the function means tree to show possible solutions (Robotham, 2001).

3.7 Concept development and screening

The concept development phase was in the beginning divided in two parallel concept generations, one focused on performance and the other on functionality. The performance concept generation included different hull types based on references gathered from the market study, propulsion types and battery packs. The functionality concept generation included layouts, weather protection and different types of enclosure.

3.7.1 Concept combination

For both the performance and function concepts a concept combination table was used to combine the different components into concepts. It is a method that enables a systematic consideration of combining solution fragments (Ulrich and Eppinger, 2020). Each column in the table corresponds to a solution for a subproblem. Usually one fragment from each column are combined to form concepts, in this project there where some subproblems that enabled more than one fragment from the same column to be combined. Depending of the size of the table a large amount of combinations can be generated. However some considerations where taken when combining concepts not to create unreasonable combinations. This is done to keep the number of concept combinations down to a minimum. It is also recommended to keep the columns in the table down to 4 to minimize the number of combinations that has to be considered, otherwise the table might lose its usefulness (Ulrich and Eppinger, 2020). Because of that the concept combination was split in two parallel phases where combinations could be evaluated separately.

The performance concepts that had been generated through the concept combination table was then evaluated by roughly calculating the range in cruising speed and maximum speed, where speeds where estimated based on the references from the market research. The calculations for the battery performance was done using a 80% depth of discharge. The calculation for maximum speed was done trough dividing the full battery capacity in kWh with the full engine power in kW to get how many hours that can be run with full engine power. If you travel in 1 knot you reach a distance of one nautical mile during one hour, and if you travel in 10 knots for one hour you reach 10 nautical miles. Then it is possible to calculate how many hours you reach with the approximated maximum speed. To determine the cruising speed range you need to know how much power that is required to maintain cruising speed. This was determined by approximation based on the references from the market research and by asking the propulsion suppliers for guidance. The range in cruising speed is then calculated in the same way as for the maximum speed.

3.7.2 Concept elimination

The performance concepts was later screened out using an elimination matrix to eliminate the concepts that doesn't fulfill the requirements on performance. The elimination table has different criterions for each column and each concept on separate rows. The concepts are given a (+) if they fulfill the criterion or a (-) if they doesn't fulfill it. If it is unsure it can receive a ? for further evaluation.

The function concepts where not taken through an elimination matrix since there where no specific requirements at that stage that could be used as a basis for elimination.

3.7.3 Concept screening using Pugh Matrix

For the function concepts and the remaining performance concepts a Pugh matrix was used to further narrow down the amount of concepts. The Pugh matrix was introduced in the 1980s by Stuart Pugh and is often refereed to as Pugh concept selection (Ulrich and Eppinger, 2020). The inputs in the matrix are different criterions on the rows and different concepts in each Column. A reference are chosen which all the concepts are rated against. The reference could be both a concept developed from the project, or a product existing on the market. In this case already existing electrical boats was use as reference, and three references where used for both the performance concept screening and the function concept screening. The reason why three references instead of one where used is because it is likely to generate a more robust outcome.

The Pugh matrix was done separately with different criterions for the performance concepts and function concepts. The criterions used to screen out performance concepts was similar to those used in the elimination matrix, with some more added such as maneuverability. For the function concepts the criterions where based on the customer needs list and the functional decomposition.

The concepts are rated against the reference and are given either a (+) for "better than", a (0) for "same as", and a (-) for "worse than". The rating of the performance matrix was done by rating the estimated performance for the performance concepts against the actual performance of the reference boats, this was done by the master thesis student alone. For the function concepts rating was done together with representatives from Nimbus Group to reach objectiveness. The amounts of (+), (0) and (-) are summarized in the bottom of the matrix. Then a score are calculated by subtracting the number of (+) with the numbers of (-). After a score have been calculated for each concept the concepts are ranked based on its score, where the ones with a higher score are ranked higher (Ulrich and Eppinger, 2020). Since three references were used it required that three matrices had to be done for both the performance screening and the function screening. For each concept there where three different ranks depending on which reference had been used. The total ranking score where summarized and the concepts where then ranked again based on the total ranking score, where the one with the lowest summarized rank where the ones receiving highest rank.

After the Pugh matrix had been performed separately for the performance concepts and function concepts some concepts with higher score where chosen to be taken in to next step where the performance and function concepts where combined. Before the combination was done clusters were formed of concepts having close similarity, this was done to avoid too many concepts being generated when combining the performance concepts with the function concepts in a concept combination table.

The combined performance concepts and function concepts were then further developed to test if the layouts fitted with the hull types and propulsion placement. This was done through using 3D modeling in Rhino 3D to block up the basic surfaces including hull, deck, superstructure and propulsion including batteries and engine. The reason why quick and rough 3D modeling where used for evaluating was because it gives a better perspective for the available space than doing it in 2D.

3.7.4 Concept screening using Kesselring matrix

Kesselring matrix is a tool for screening concepts using criterions that are weighted. The concepts are receiving a score that have been determined by the creation of a grading scale such as 1 to 5. The value representing a grade can either be numeric or subjective. Numeric values are used for criterions related to performance or other measurable variables such as size and weight. Short range would receive a grade of (1) and long range would receive a grade of (5). Subjective values are used for qualitative criterions such as comfort or appearance, were for example "very bad" receive a score of (1) and "very good" receive a score of (5).

The purpose of having weighted criterions is because some criterions have a higher importance than others. The weighted criterions were in this project generated using a matrix that have each criterion both vertical and horizontal in the same following order. Then the centred diagonal was grayed out where the criterions was the same both vertically and horizontally. The criterions was given a score for each comparing criterion, score (1) for "more important", (0.5) for "same importance" and (0) for "less important". The scoring was made together with two representatives from Nimbus Group to avoid personally biased scoring that might be the case if grading activities are made single handed. The scores for each criterion was then summarized horizontally and then divided by the total sum of all summarized scores to generate the weight number.

The Kesselring matrix was done together with Nimbus Group representatives to reach a more objective evaluation of the concepts when deciding grading scores for each criteria. The grading scores (v) are multiplied with the weighted importance (t) for the criterions and then summarized (T) in the bottom of the matrix. The summarized (T) are then divided by the maximum (Tmax) to generate a percentage of total value. The maximum (Tmax) are determined by implementing an fictive ideal concept which receive grading score 5 for each criterion. The last step is to rank the concepts based on the (T) score.

3.7.5 Concept selection for further development

To make a decision of which concept to further develop for this specific project it was decided to put the concepts in a graph based on the percentage of total value for each concept and an estimated price for each concept. The price was roughly estimated by using Nimbus Group references with similarities with the concepts. Then the combustion driveline where subtracted from the price and the price of the electric driveline were added, which gave a rough estimate of what would be the cost of each concept. The graph served as a tool to aid the selection of a concept.

3.8 Detailed concept design

Detailed concept design were done by sketching and 3D modeling to generate renderings and a 3D model for how to manufacture and assembling the boat.

3.8.1 Sketching

After a concept has been chosen further development the detailed design process took place. The first step was to develop hand sketches of the exterior and the interior based on the chosen layout. The sketches was both in profile and perspective.

3.8.2 3D modeling and rendering

The sketches served as guidance when creating the 3D model of the boat. The 3D model was created using the Rhinoceros 7 software, which is a common software for marine design projects. The 3D model will be used to visualize the final concept through the creation of realistic renderings (McNeel, 2022). Renderings were created using Enscape, a plug in software for Rhino.

3.8.3 DFMA

The information gathered from DFMA research and the visit to Nimbus Group manufacturing plant served as a basis for designing the concept for manufacturing and assembly. There was an exploded view of the 3D model created in Rhino to show how the boat are to be divided into sub assemblies.

3.9 Evaluation of remaining concept

Evaluation of the remaining concept was done by environmental and economic calculations. Design evaluation was done using Virtual Reality.

3.9.1 Comparing GHG emissions of electric and combustion boat

A comparative environmental evaluation of the generated concept was conducted by calculating the greenhouse gas emissions (GHG) for the electric concept boat and for an equal boat equipped with a diesel engine. By doing this it is possible to identify if and when the electric propulsion has environmental benefits compared to diesel propulsion.

A study made to compare the lifetime GHG emissions from electric cars with the emissions from cars using gasoline or diesel was used as a reference for the calculations (Hoekstra, 2020). To adapt the calculations to marine vessels the distance in kilometers used in the formula by (Hoekstra, 2020) was changed for nautical miles as seen in equation 3.1.

$$emissions\ per\ NM = \frac{manufacturing\ emissions + driving\ emissions}{NM\ driven} \tag{3.1}$$

Regarding the manufacturing emissions the original formula summarize the emissions from battery, drivetrain and vechicle manufacturing (Hoekstra, 2020). Since the boat being evaluated is the same for electric and combustion propulsion the manufacturing emissions for the boat is excluded from the calculations. To further simplify the calculations the manufacturing emissions from the drivetrain is excluded because of difficulties in finding emission data of all drive train components.

The formula for calculating driving emissions per nautical mile is seen in equation 3.2

$$driving\ emissions = boat\ energy\ use\ in\ \frac{kWh}{NM} \cdot electricity\ emissions\ per\ kWh \tag{3.2}$$

To calculate the emissions for the diesel engine same formula seen in equation 3.1 is used. Since the driveline and boat is excluded from the manufacturing emissions in this case, it results in emissions per NM only being dependent on driving emissions and distance travelled. Driving emissions from the diesel driven boat are calculated with the formula seen in equation 3.3

$$driving\ emissions = boat\ energy\ use\ in\ \frac{liter}{NM} \cdot electricity\ emissions\ per\ liter \quad (3.3)$$

3.9.2 Economic analysis

The economic analysis and comparison was done by simple calculations based on the initial price of the concept boat and initial price for boats being compared. Then the running costs are calculated by finding out the price at the charger for electricity and price at the pump for diesel. The yearly service costs from the electric engines is not included since service is minimal for electric propulsion. The yearly service cost for diesel propulsion is found out by finding prices for standard service of diesel engines. The usage of the boat is based on average day boat users.

3.9.3 Design analysis through virtual reality

The concept design was tested in virtual reality by using the 3D model of the concept boat as an environment. The software used for renderings has a built in VR capability that together with VR googles the test person is wearing allows the test person to experience the model almost as in reality. This gives an awareness for the available space, ergonomics and the available vision from for example a helm station.

4

Results

This chapter contains the results from the methods used in the project. It includes the results from the market research and customer needs study, the concept development stage and finally a presentation and evaluation of the chosen concept.

4.1 Study of electric boats on the market

In this section some electrical boats currently in the market will be presented, together with graphs to compare performance among the competitors.

4.1.1 Electric boat competitors

Several electric boats have been identified that already exists on the market or are in development right now. A complete list including some technical data for the identified boats can be found in Appendix A. The list is excluding electric boats that are out of the scope for the project, such as electric boats not targeted at day use and low performing or expensive high performance boats. Technical data has been found both in boat brand web-pages and from articles in boating magazines.

The boats included in the list can be categorised in following categories depending on the cruising speed:

- Slow cruising semi-displacement boats
- Intermediate cruising semi-displacement boats
- Fast cruising planing boats
- Fast cruising hydrofoil boats

To give examples from each category the slow cruising boats have a cruising speed of around 5 to 7 knots and might reach top speeds of around 10 knots, slightly above the hull speed. In this category Nimbus Groups electric Bella Zero 6.3 is found together with other sloop like boats of similar character.

Among the boats with an intermediate cruising speed of between 8 to 15 knots and maximum speeds under 20 knots boats such as Strana by Orust E-boats seen in figure 4.1, Pogo Loxo 32 4.2 and the Domani E32 4.3 are found. Common for all this boats are an efficient hull that enable maintaining different speeds without facing a distinctive planing threshold.

The fast cruising planing boats have a cruising speed of above 15 knots and can reach top speeds of above 30 knots. In this category the X Shore Eelex 8000 is found, seen in figure 4.4. Common for all the boats in this category are that they use a traditional deep V hull which allow them to cruise efficiently at higher cruising speeds but is limited by the planing threshold which makes it inefficient to cruise at intermediate speeds.

The last category of hydrofoil boats can maintain cruising speeds of around 20 to 25 knots and reach maximum speeds of around 30 knots. Among the hydrofoil electric leisure boats Candela, seen in figure 4.5 is the only established brand, but are accompanied by some start ups. The hydrofoil boats are characterized by efficiency with little power required to reach higher speeds.

4.1.2 Reference boats described

In this section some reference boats found through the competitor research are further described. The reference boats are used both as references for hull design and as references for concept evaluation.

4.1.2.1 Strana

Strana sen in figure 4.1 is a 7m open boat with a semi displacement hull. It is driven by either a 7.5kW or a 15kW Sea drive steerable pod engine and has a battery capacity of 28.8 kWh (Strana boats, 2022).

Figure 4.1: Picture showing Strana

4.1.2.2 Pogo Loxo 32

Pogo Loxo 32 seen in figure 4.2 is a sailboat inspired motorboat with a semi displacement hull and a walk around deck house layout. It is mainly sold with combustion engines but has the option of full electric drivetrain. The electric version is driven by twin Oceanvolt 15 kW engines and a 53 kWh battery pack (Oceanvolt, 2022).

Figure 4.2: Picture showing Pogo Loxo 32

4.1.2.3 Domani E32

Domani E32 seen in figure 4.3 has a semi displacement hull and a day cruiser layout. It has a 50kW engine on shaft and a 75kWh battery pack (**Domani**).

Figure 4.3: Picture showing Domani E32

4.1.2.4 X Shore Eelex 8000

X Shore Eelex 8000 seen in figure 4.4 has a planing hull and a centre console layout. It is driven by a 225kW electric inboard engine on shaft and a 126kW battery pack (X Shore, 2022).

Figure 4.4: Picture showing X shore Eelex 8000

4.1.2.5 Candela

Candela C-7 seen in figure 4.5 is a hydrofoil boat with active control system of the foils. it has a 55kW engine mounted on the aft foil and a 40kWh battery pack (Candela, 2022).

Figure 4.5: Picture showing Candela C7

4.1.3 Performance of competitors compared

The electric boats found are here presented in different graphs to visualize and compare the boats against each other. For some boats there are no technical data available which means some boats from the list is not included in the graphs. The boats are also divided by color representing the four cruising speed categories mentioned above. Yellow is representing the slow cruising semi-displacement boats, green is representing the Intermediate cruising semi-displacement boats, orange is representing the fast cruising planing boats and turquoise are representing the hydrofoil boats.

The first graph presented in figure 4.6 is presenting the range in cruising speed against the cruising speed. Here it is seen that higher cruising speeds which is the case for the fast planing boats results in lower range of around 25 nautical miles when maintaining speeds between 20 to 25 knots. It is seen that the hydrofoil boat reach double the distance in same cruising speed.

When looking at cruising speed and range it is also of interest to compare cruising speed range with the available battery capacity which is presented in figure 4.7. It is seen that the fast planing boats have relatively large battery packs in relation to the cruising range. The hydrofoil boats in comparison have half the amount of battery capacity but has a range of around twice as long as the planing boats. The intermediate cruising semi-displacement boats both have small and large battery packs and the larger boats in this category with battery packs above 75 kWh can reach ranges above 90 nautical miles in cruising speed.

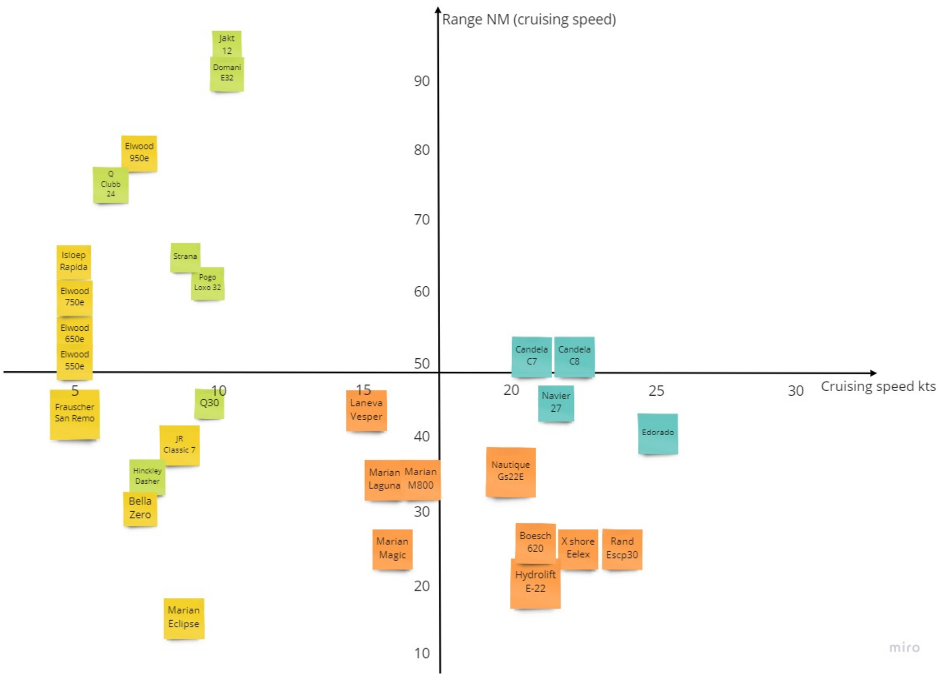


Figure 4.6: Graph showing cruising speed range against cruising speed in kts

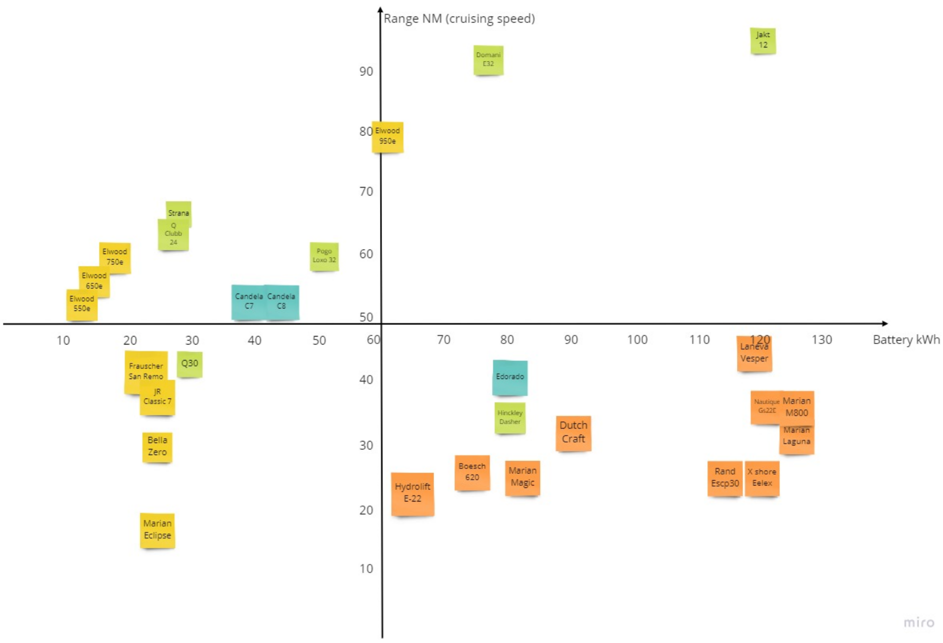


Figure 4.7: Graph showing crusing range against battery capacity

Another interesting comparison to make is the relation between battery pack size and the cost of the boat. In figure 4.8 it is seen that the cost of some of the fast planing boats are same as for the hydrofoil boats. The battery pack for the foiling boats are a third of the size compared to some of the fast planing boats. The reason for the price being similar for the hydrofoil boats even though less battery is used, is driven by other factors such as light weight expensive materials being used and technology related to the hydrofoils. The prize are also driven by size of boat and what type of propulsion that are used.

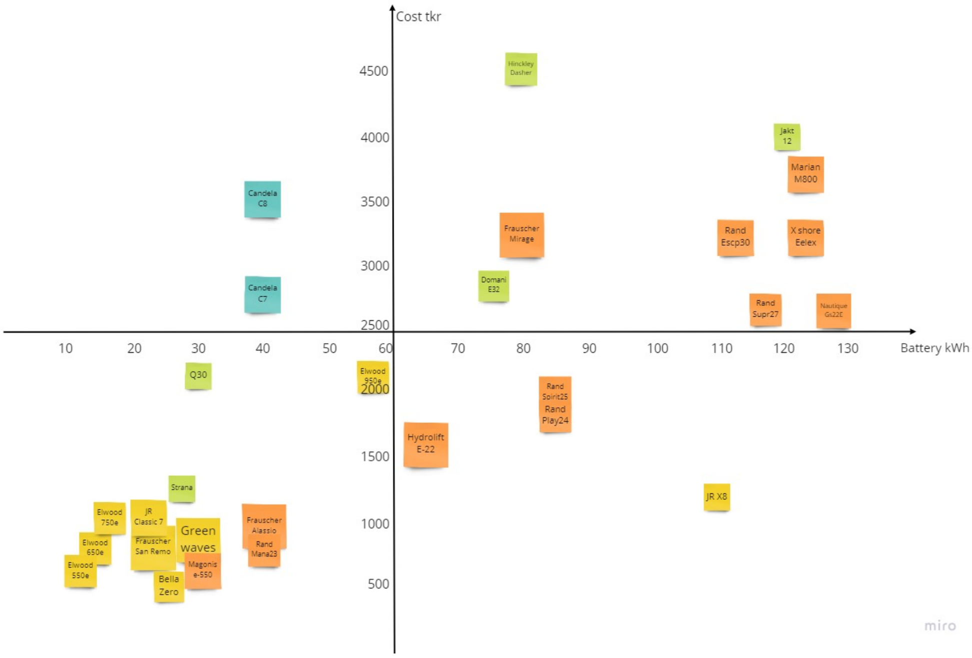


Figure 4.8: Graph showing cost in SEK (tkr) against battery capacity

The last graph seen in figure 4.9 show the range in maximum speed against the maximum speed.

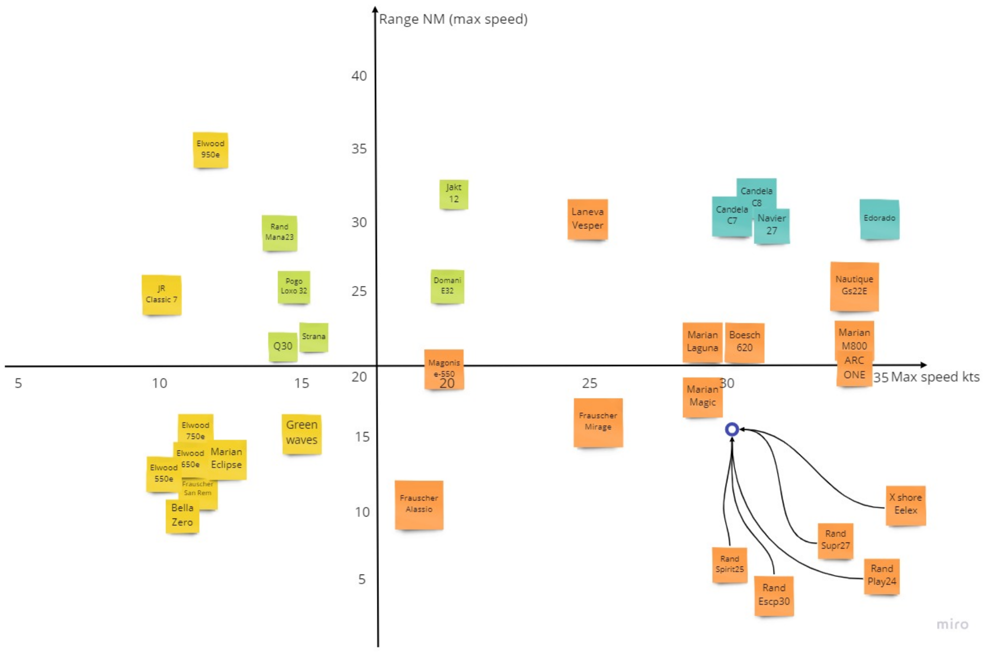


Figure 4.9: Graph showing maximum speed range against maximum speed in kts

4.2 Electric engine suppliers

A research of electric engine and battery suppliers were conducted to identify potential drivelines that could be used for the generation of concepts. This section will present the different engine and battery suppliers that were found relevant for the project. All of the engine suppliers presented below were interviewed to gather information about their different solutions. A conclusion from each interview are presented below and questions asked in the interviews are found in Appendix B.

4.2.1 Evoy

Evoy is a Norweigan developer and manufacturer of electric marine engines for both leisure and commercial boats. They deliver plug-and-play systems that should minimize the work for the boat builders trough easy instalment. Evoy has both outboard and inboard engines. The outboard engine that is available right now is a 90kW, but the are plans to release outboards of 150, 225 and 300kW in the future. The inboard engines available right now is either 300kW or 90kw, there will be a 150kW and a 225kW inboard engine released in the future. The inboard engines can be connected to either a shaft, sterndrive or water jet. The batteries Evoy use for their systems are 63kWh Kreisel batteries that can be connected to allow battery packs ranging from 63 to 378kWh.

Evoy is striving to be the market leader when it come to deliver user friendly systems. The systems are connected through software that deliver important information to the user both trough screens on the dashboard or directly to a smart phone trough an app. The system is key less and the boat is started through typing a code on the screen that is decided by the owner.

To ensure customers receive excellent service all the propulsion systems that are installed in boats and used are connected to Evoy head quarters and can be diagnosed remotely. If it is impossible to fix the problem remotely Evoy sends service people to fix it.

4.2.2 Oceanvolt

Oceanvolt is an electric marine engine developer and manufacturer from Finland. Oceanvolt deliver 48V systems to ensure a safe product since the low voltage will not cause any severe harm if an accident would occur. The main market for Oceanvolt is slow going boats and sailboats but they have systems for semi fast boats as well. The AXC shaft drive system is a modular system in four different power configurations ranging from 10 to 40kW. The AXC system, due to its direct drive offers low noise and vibration levels. Less space is required for the engine compared to traditional diesel engines. The systems are plug-and play which allows for easy installment for the boat manufacturers.

Oceanvolt offers an robust software system to ensure user friendly products. Displays provide the user with information regarding battery capacity, the available range and other important information. The boat is easily started with either a digital switch, telephone or a traditional key.

The driveline from Oceanvolt requires minimal service and the systems are connected to enable remote software service. The engines can be used for approximately 4000 hours before service is required. Only small service such as changing glycol is required once in a while.

4.2.3 SeaDrive

SeaDrive is a Norwegian developer an manufacturer that provides electrical propulsion systems in form of pods that is either steerable or fixed. Since the engine is mounted inside the pod the system required little space in the hull of the boat. There are three different size of pods, the smallest is a 7.5 kW engine with a 48V system. The middle size is a 15kW engine with a 96V system and lastly a 30kW engine with a 400V system.

The system is started throguh a main switch, traditional key or through an app. To ensure a good user experience the information is provided through screens showing battery capacity and performance and the information can also be provided directly to your phone trough the SeaDrive app. The propulsion system requires little maintenance and the pod can be drive for 3000 hours before the oil needs to be changed.

4.2.4 Stream propulsion

Stream propulsion is a Swedish developer and manufacturer of electric outboard engines. The goal for Stream propulsion is to deliver electrical engines at a reasonable price and do so by utilizing standard outboard components to decrease the price. Stream propulsion deliver electric engines to a cost that are 30 to 50% lower than for the competitors. Stream offers the complete driveline as a plug an play system were everything is included. Currently it is only possible to have a single 26kWh battery, but it is planed to release a modular system that allows for batteries to be connected in series.

The simplicity of the system makes it easy to use. A display provides the user with information regarding battery capacity and performance. It show the available time that you can drive in relation to the battery consummation.

4.2.5 Torqeedo

Torqeedo is the most established developer and manufacturer of electric marine engines for leisure boats and was founded in Germany 2005. They provide propulsion system for both the recreational and professional market. The products offered are small outboards and pods and more powerful engines offered as inboard or outboard. The high-power system known as Deep Blue comes in outboard and inboard configuration as either 50 or 100kW. The battery used in Torqeedos system is a 40kWh BMW i3 battery that has been converted by Torqeedo for marine use. There is possibility to have multiple batteries depending on the required need.

Torqeedo has developed a user friendly interface based on screens that show performance and battery capacity. The system is modular to meet all the different requirements. A global service network ensure that the customers receive good service. The propulsion systems are connected remotely to enable remote service and upgrades. The system requires little maintenance and it is enough to do a yearly check which is easily done by the owner.

4.2.6 Vision Marine

Vision marine is a Canadian developer and manufacturer of electric marine outboards and other related technologies. Vision offers an electric outboard called E-motion which is a 134kW engine, currently the most powerful outboard on the market. The system is plug-and-play which enables easy installment for the boat manufacturers.

Information about the system is received by the user on a display on the dashboard that shows battery capacity and range. The propulsion system is started with a button and the display is turned on separately. Vision marine are planing to have a call centre that are available any time for trouble shooting remotely.

4.3 Customer needs study

Here are the result from the sales interviews and survey, regarding customer needs is presented together under categories. The gathered needs from the interview and survey are presented in a customer needs list. The survey questions is seen in Appendix C.

4.3.1 Survey demographics

The survey reached out to 733 respondents from all around the world. The respondents are mainly from the northern Europe region which is seen in figure 4.10. In figure 4.11 it is seen that the largest group of respondent are between 45-54 years old followed by the group of 55-64 and 35-44 years old. There are less respondents in the groups 25-34 years old and 65+ and few in the ages 18 to 24 years old.

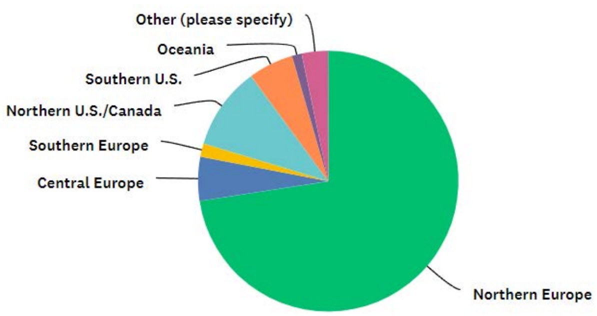


Figure 4.10: Graph showing the geographic distribution of respondents

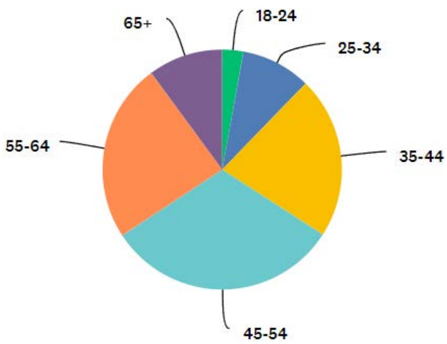


Figure 4.11: Graph showing the age distribution of respondents

In figure 4.12 the distribution of previous boat experience and from what types of boats is shown. It is seen that most of the respondents have experience from fossil fuel driven motor boats, 30% have experience from sailing, 6% of electric boats and 4% of other boat types such as a kayak or other means of water transportation. It is only 3 of the respondents (0,5%) that have never used a boat.

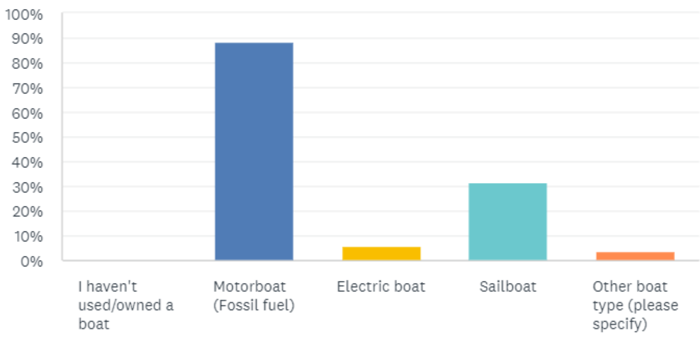


Figure 4.12: Graph showing the distribution of previous boat experience

4.3.2 Day boat usage

A common denominator for day boating is the focus on pleasure. To identify what main activities that are taking place when day boating, questions where asked both in the interviews and in the survey. In question 9 seen in Apeendix C it shows that 85% of the respondents see their boating activities as a way of relaxation and 15% see their boat as a means of transportation from point A to point B. The most common activity that is identified for day boating is going out in nice weather with some food and beverage brought and then either just cruise around peacefully or finding a nice spot to anchor at. Then you take a swim and enjoy the sun. Figure 4.13 show the result from the question "What activities do you do with/on your day boat? around 70% use their day boat for sun bathing and swimming activities very often or often. It is seen that 60% use their boat for dining and 50% for cooking very often or often. Commuting, fishing and water sports each is done around 30% very often or often. The answers varies a bit depending on location and will be covered further down in the market segmentation section.

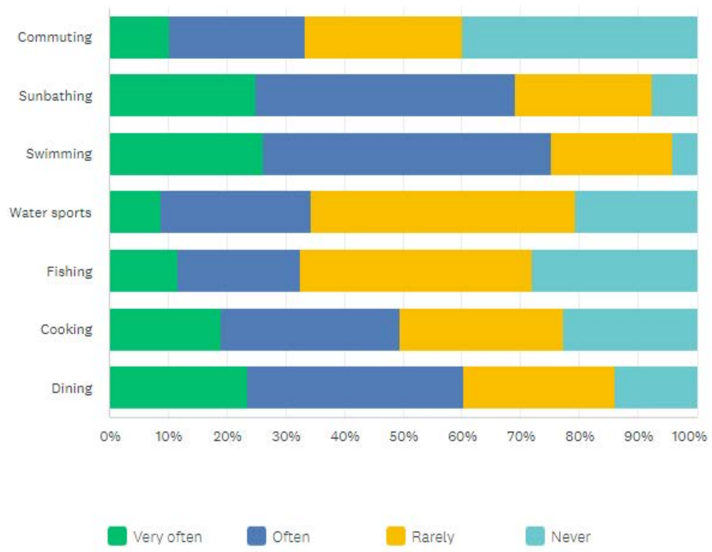


Figure 4.13: Graph showing day boat activities

4.3.3 Day boat types and desired size

It is of interest to identify what boat types that are the most desired for day boating and how it varies depending on location. The demographic differences of day boat types are covered in the market segmentation section. The respondents are asked to choose which boat type that best suit their day boating needs and choose between six different common day boat types illustrated with pictures, each boat type are described in the theory chapter. In figure 4.14 it is seen that the cabin boat is the most desired at 32% followed by day cruisers at 28%. Walk around and centre console boats have 15% of the answers and sidewalk and bowrider each have around 10%. The least desired boat type globally is the slow speed sloop.

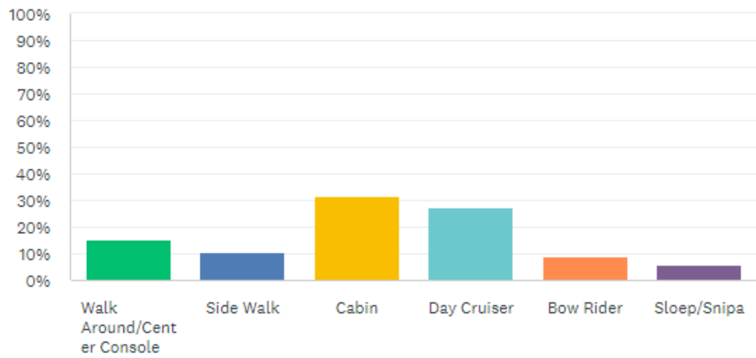


Figure 4.14: Graph showing desired day boat types

The desired size of day boats is seen in figure 4.15 where it is found that boats between 6-7m and 7-8m each got 25% of the answers, boats between 8-9m got 16% and the rest got 10% each.

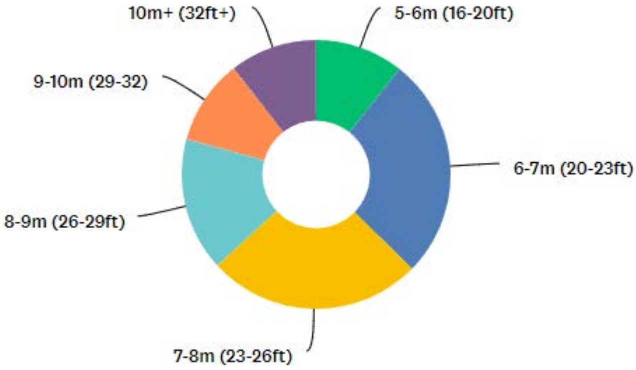


Figure 4.15: Graph showing desired size of day boats

4.3.4 Performance demands of day boats

Through the interviews of sales persons of Nimbus Group brands it was found that a common denominator for the different locations is that speed is of importance for day boating. In the survey there are two questions related to speed, the first one focus on the desired cruising speed and the second focus on the desired maximum speed for day boats. It is seen in figure 4.16 that 29% desires a cruising speed of 20-25 kts, which is a common cruising speed for planing boats. A cruising speed between 15-20 knots is desired by 20% and 18% desires a cruising speed of more than 25 kts. It is 14% desiring a speed of 10-15 kts, 13% a speed of 7-10 kts and 7% desires a cruising speed of 4-7 kts. A similar distribution is seen in the desired maximum speed graph presented in figure 4.17.

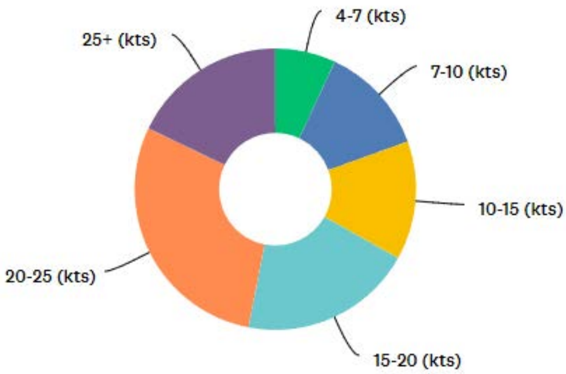


Figure 4.16: Graph showing desired crusing speed for day boats

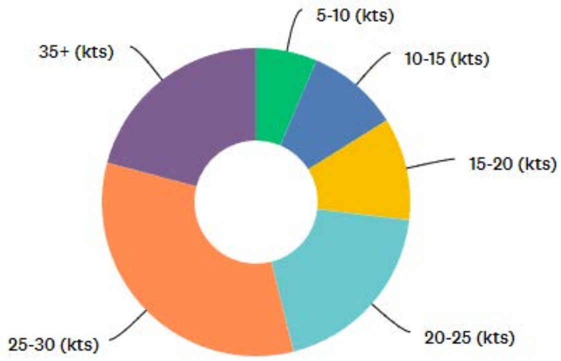


Figure 4.17: Graph showing desired maximum speed for day boats

The desired range for one day of boating is seen in figure 4.18. The question was formulated so that the respondents were to consider one day of use without charging for an electric boat. It is seen that 26% demands a range of 30-40 NM, 24% a range of 40-50 NM and 21% a range of 20-30 NM. In the long range register it is seen that 14% demands a range of 50-75 NM and 12% a range of 75-100 NM. It is 4% that desires shorter range of 10-20 NM. From the interview of different sales persons representing different locations the most frequent answer is that motorboat is usually driven around 20 NM during a day trip.

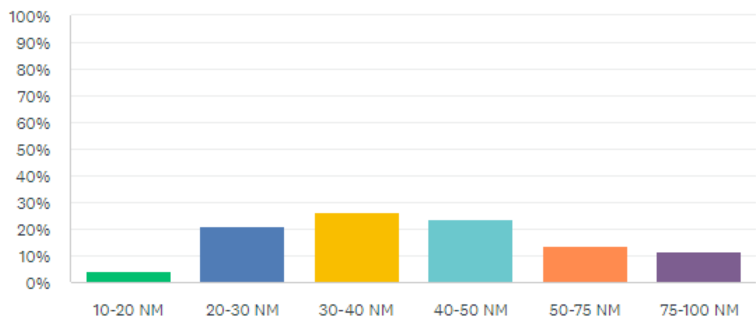


Figure 4.18: Graph showing desired range for one day of boating

4.3.5 Needs of amenities

It is of interest to find out what amenities customers desires on their day boats. In the survey there is a question whether respondents find some common boat amenities very important, important or not important which is seen in figure 4.19. Since it is difficult to distinguish between important or very important it is chosen to read (very important) and (important) together when looking at the results. It is seen that 67% find sleeping possibility necessary for their day boating needs. It was also brought up in the the sales interviews that many desires sleeping possibility even though it is rarely used for that. When it comes to weather protection is is seen that 90% think it is important or very important and 75% think sun shading is of importance. A sun bed is of importance for 50% of the respondents. 10% finds it important with an air conditioner. A toilet, fridge and water tank is of importance for around 65% of the respondents. A wet bar which is a small counter equipped with a sink with running water is desired by 36% of the respondents. A shower located at the stern transom is of importance for 39%, it is often used to wash salt of the body after a swim. Anchor windlass at either bow or stern or both is of importance for around 45% of the respondents.

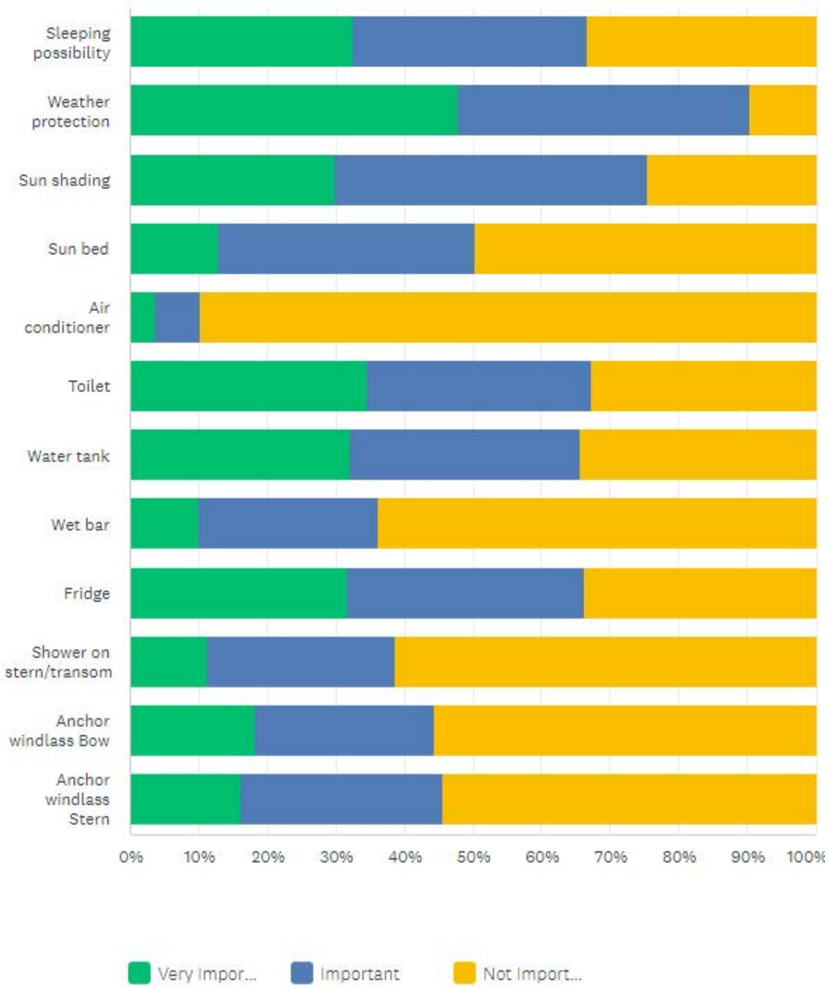
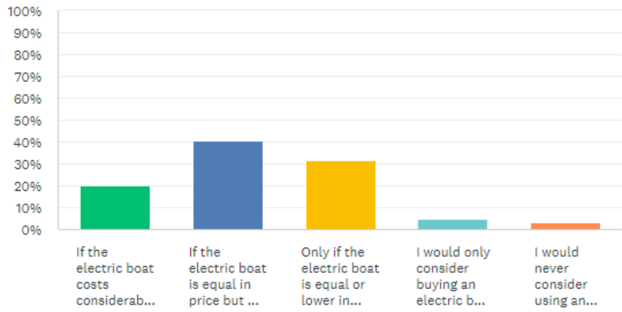


Figure 4.19: Graph showing desired amenities for a day boat

4.3.6 Interest of electric boats

In both the interviews of sales persons and in the survey questions the interest of electric boats have been asked. The sales persons where asked to describe what they see as key factors for electric boats to succeed on the market. Common for most of the interviewees is that charging infrastructure has to improve around marinas. Another factor the interviewees brought up is the high price of electric boats that need to become cheaper to reach a broader market. Other important aspects that is brought up in the interviews to succeed with electric boats are the performance, sound levels, and reduced maintenance.

The questions in the survey are first asking what it takes to choose an electric boat in front of a combustion engine boat, were the answers are presented in figure 4.20. It is seen that 41% are willing to compromise on performance if the price of the electric boat is equal to the one of a combustion engine boat. 32% will only buy an electric boat if it is equal or lower in price and has same or better performance compared to the combustion engine boat. It is seen that 20% are willing to pay a higher amount of money to achieve decent performance and decrease running costs. 5% would only buy a electric boat if forced by regulations and 3% would never consider using an electric boat.



If the electric boat costs considerably more and has decent performance but running costs are less.	20 %
If the electric boat is equal in price but I have to compromise on performance.	41 %
Only if the electric boat is equal or lower in price and has same or better performance.	32 %
I would only consider buying an electric boat if forced by regulation.	5 %
I would never consider using an electric boat.	3 %

Figure 4.20: Graph showing what it take to choose an electric boat instead of a combustion engine boat

Next question asked with the purpose to identify the interest of electric boats is which reasons that describes why one would consider to buy an electric boat, were the answers are presented in figure 4.21. The respondents could fill in multiple reasons. It is seen that 62% would buy an electric boat to protect the environment, 55% because of the low running costs, 49% for reduced fuel costs and 53% because they like to travel in silence. 29% would buy an electric boat because they want to use the latest technology and a few didn't see any of the presented reasons as a reason to consider buying an electric boat.

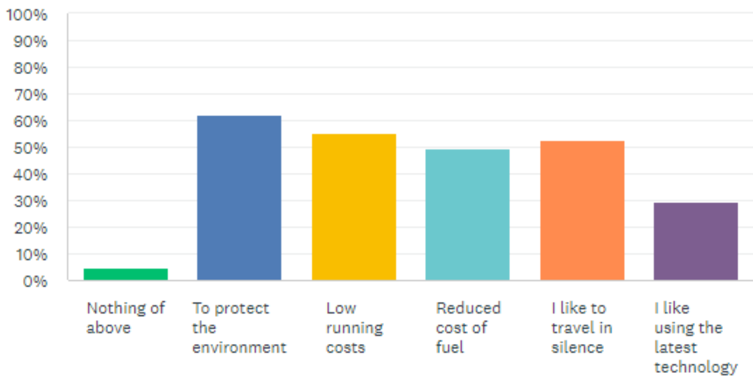


Figure 4.21: Graph showing why people would consider buying an electric boat

A similar question was asked but instead focused on reasons that describes why one would not consider to buy an electric boat which is seen in figure 4.22. Here it is seen that 66% of the respondents would not consider buying an electric boat if there is not enough charging infrastructure and 35% if the charging time is to long. 66% wouldn't buy an electric boat if the range is to short. 56% would not buy an electric boat if the initial cost is higher and 28% if the performance in terms of speed are too slow.

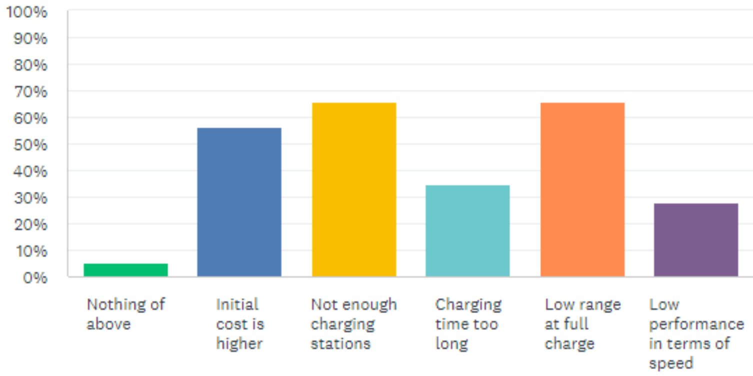


Figure 4.22: Graph showing why people would not consider buying an electric boat

4.3.7 Environmental awareness

The last question asked is a general environment awareness question to identify what environmental aspects the customers sees as important or not important when buying a boat. Because of the difficulty to distinguish between important or very important it is chosen to read (very important) and (important) together when looking at the results. The statements are following and presented in the same order as in figure 4.23, including how many of the total respondents in % that find that statement of importance.

- Boat is built in sustainable materials. (71%)
- Boat has low impact on water environment. (86%)
- Low production emissions from boat manufacturing. (75%)
- The brand of the boat has a high environmental profile. (47%)
- Material waste are limited and recycled in the production process. (73%)
- Renewable energy is used in the manufacturing process.(64%)

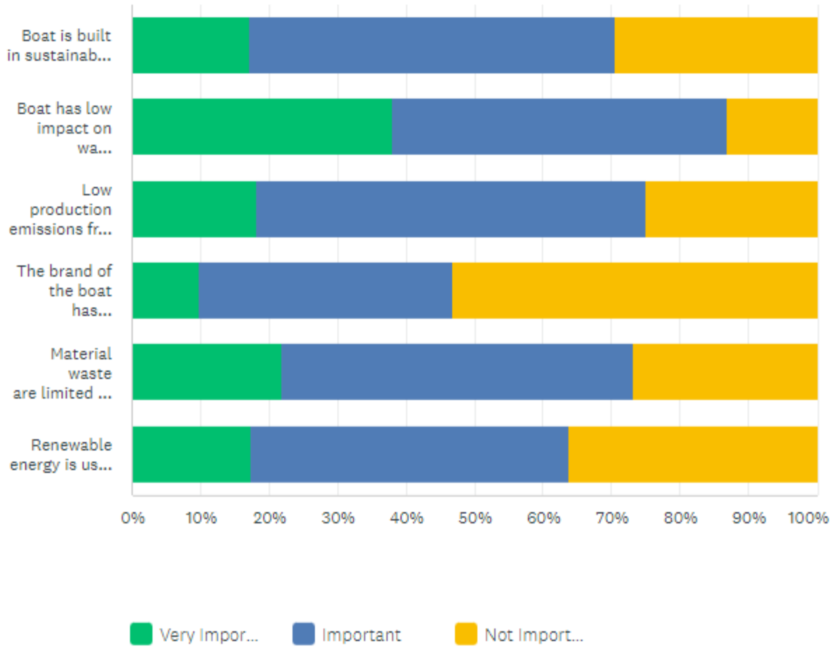


Figure 4.23: Graph showing the importance of some environmental statements

4.3.8 Customer needs list

The identified customer need statements from the interviews and complementary statements gathered, is concluded in a customer needs list seen in table 4.1. The list is divided into performance needs, general needs and usage needs.

Table 4.1: Customer needs list

No.		Need	imp.
		Performance needs	
1	The boat	is equipped with an efficient hull which require less power to allow higher speeds if needed.	4
2	The boat	can handle challenging weather conditions	4
3	The boat	is an appealing and social environment where the user wants to spend time in lower speeds.	5
4	The boat	provides enough battery capacity for a normal day use.	5
		General needs	
5	The boat	is equipped with a propulsion system which requires minimal maintenance.	4
6	The boat	provides easy access to maintenance of propulsion system	3
7	The boat	are equipped with a propulsion system that emits minimal sound levels.	5
8	The boat	has fast charging possibility	3
9	The boat	is built in materials with an minimal environmental impact.	4
10	The boat	has a market price low enough to provide economical benefits if the boat is used during a long time.	4
11	The boat	The boat has an design that is modern and unique and last through time.	5
		Usage needs	
12	The boat	is intuitive to use and requires minimal effort to start.	5
13	The boat	has a propulsion system which allows excellent maneuverability.	3
14	The boat	has a layout which allows for easy and safe movement.	4
15	The boat	provides enough space for several people to comfortably join the ride.	4
16	The boat	provides several spaces for storage of both large and small items.	3
17	The boat	has a space that can be used for sleeping or storage.	4
18	The boat	provides the possibility to shelter people from weather and wind.	5
19	The boat	has either a solid sun cover or a flexible sun cover that can be deployed if needed.	4
20	The boat	has a sunbed that enables sunbathing.	3
21	The boat	has the possibility to install an air conditioner or heater	3
22	The boat	has a swim platform, which is easily accessible and equipped with a ladder.	4
23	The boat	is equipped with a towing hook and have a stern platform which are suited for watersports.	2
24	The boat	has clean spaces along the sides where it is possible to stand while fishing.	2
25	The boat	has a fresh water tank.	4
26	The boat	is equipped with a toilet which provides privacy for the user.	4
27	The boat	allows for a shower with freshwater to be quipped at the stern.	2
28	The boat	has an inbuilt fridge or a space to store a mobile fridge	4
29	The boat	has a table which is large enough to dine around	4
30	The boat	provides the possibility to heat food.	2

4.4 Market segmentation

The market segmentation describes the differences of day boating both geographically and demographically. The information for the segmentation has been gathered through interviews with sales offices from different regions and from applying filters to the customer survey to determine demographic and geographic differences.

4.4.1 Day boating usage categories

Following usage categories for day boating have been identified and can roughly be divided into following.

- Island hopping
- Coastal cruising
- Channel and inland waterway cruising
- Lake cruising

Island hopping is a common way of boating in areas that has an archipelago, which most of the Swedish coast have. A usual day boat trip is then to go from your home harbour to some island in the archipelago. It can be either a natural harbour were the boat is moored at a beach or to the cliffs, or a guest harbour on an island. Plenty of summer houses exists on the islands in Sweden and therefore many use their boats for commuting. It is common to bring some food and picnic to enjoy at the destination and many guest harbours have restaurants. The waters are often sheltered by the islands which enables smaller day boats to be used.

Coastal cruising is different in that there are no islands to shelter from weather and wind. Destinations when coastal cruising is usually bays along the coast or guest harbours. This type of boating is common in the Mediterranean. Day boats are usually also bigger in such areas with open coasts to deal with larger waves. Similar to island hopping food and beverages are often brought on the day trips. You drop the anchor in a bay and take a swim and enjoy a nice day in the sun.

Lake cruising can have elements of both island hopping and coastal cruising depending om which lake you are boating on and the size of it. Channel and inland waterway cruising is different in that it is often limited to slow speed. Central Europe has plenty of inland waterway cruising on the rivers. Another example is Amsterdam with its channel system where boats peacefully cruise around in slow speeds.

4.4.2 Geographic segmentation

In figure 4.10 the geographic distribution of respondents is shown. The usage categories presented above is represented in either all or some of the locations. Northern Europe is mostly focused on island hopping in archipelagos but there are also several big lakes in Sweden and Finland were boating takes place. There are also plenty of unprotected coast line which represent the coastal cruising category. Channel and inland waterway cruising is also found in northern Europe for example in Göta Canal that stretches from coast to coast through Sweden. Central Europe has coast line along the Baltic sea in northern Germany and Poland which mostly is unprotected with a few exceptions of archipelago like areas. In central Europe the categories of lake cruising and channel and inland waterway cruising is very popular. Southern Europe is mostly focused on coastal cruising but also have elements of island hopping in areas such as Croatia and Greece. There are also elements of inland waterway cruising and lake cruising in southern Europe. In both southern and northern US, and Canada all of the usage categories are found.

4.4.3 Survey answer differences depending on location

From the survey it is possible to compare the answers based on locations. It is chosen to only compare the locations which generated more than 40 respondents to get a somewhat statistical significance on the comparison. Furthermore it is chosen to only show the questions where clear location differences can be found even though a comparison of all questions and locations have been made.

In figure 4.24 the desired cruising speed per location is presented. Here two distinctive differences are showing compared to the graph presented in figure 4.16 showing the combined responses of all regions. The first difference is a spike in cruising speed for central Europe were 30% desires a cruising speed of 7-10 kts compared to 13% which is the case for the combined responses of all regions. It is also seen that more people desire cruising speeds of 25+ kts in the northern American region compared to other regions.

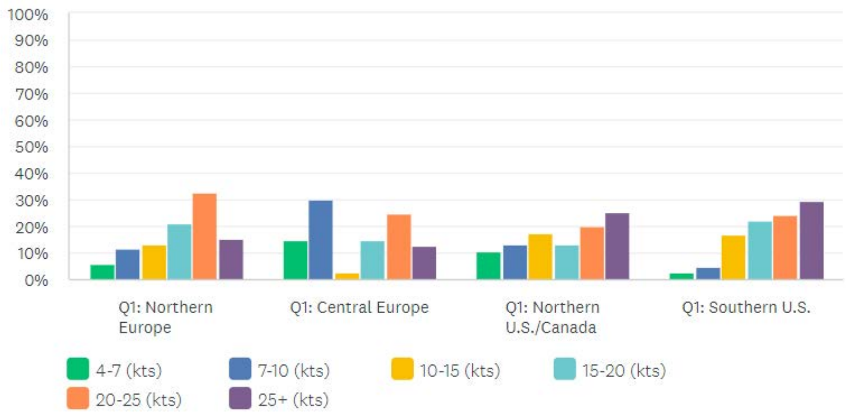


Figure 4.24: Graph showing the desired cruising speed per location

When looking at which activities that are done with day boats depending on location it is found that the occurrence of activities are very similar for all regions but with a clear difference in the occurrence of fishing from your day boat in northern U.S./Canada and Southern U.S. compared to the other regions, Which is seen in figure 4.25.

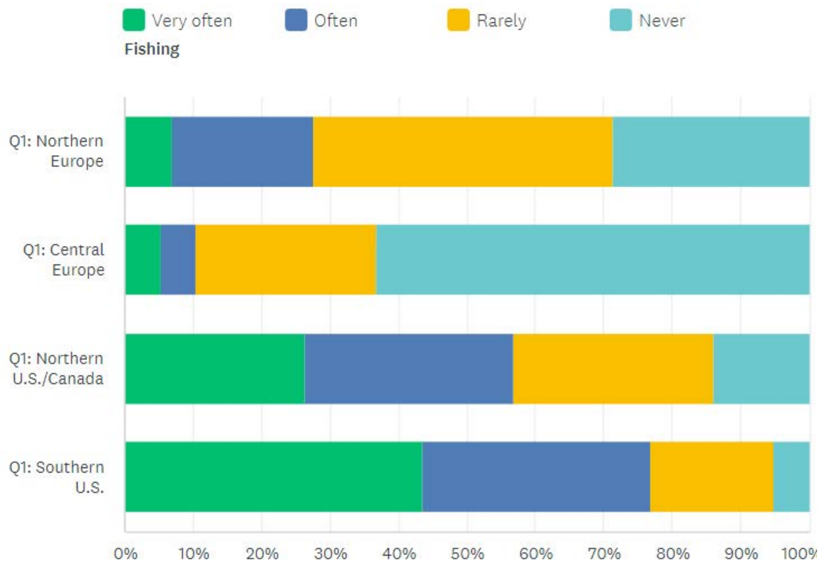


Figure 4.25: Graph showing the occurrence of fishing per location

The importance of some amenities required on day boats differ between regions. It is seen in figure 4.26 that 80% see sleeping possibility as of importance in central Europe, 70% in northern Europe, 55% in northern U.S./Canada and 34% in southern U.S..

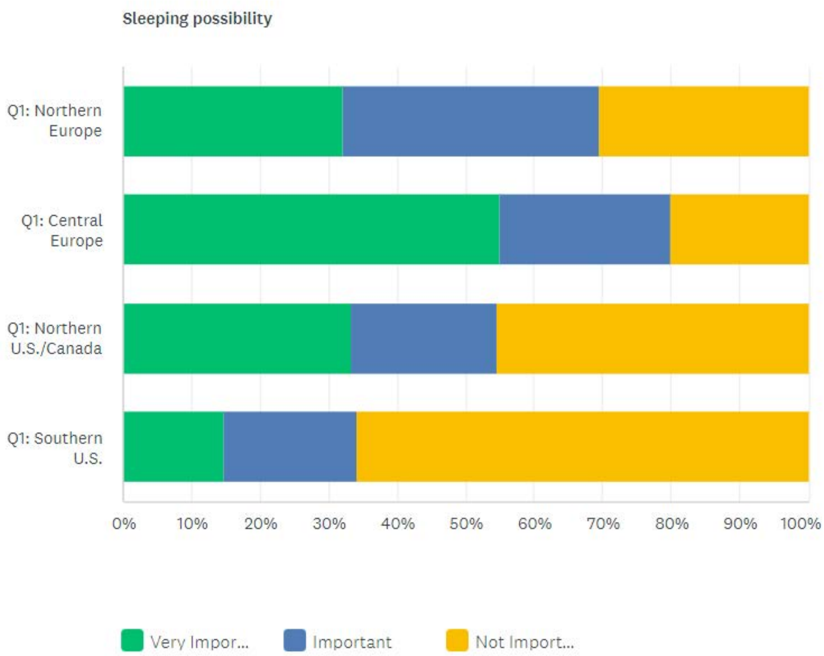


Figure 4.26: Graph showing the importance of sleeping possibility per location

Looking at figure 4.27 air condition is seen as of importance for 5% of the northern European respondents. Looking at southern U.S. with a warmer climate, 30% see air condition as of importance.

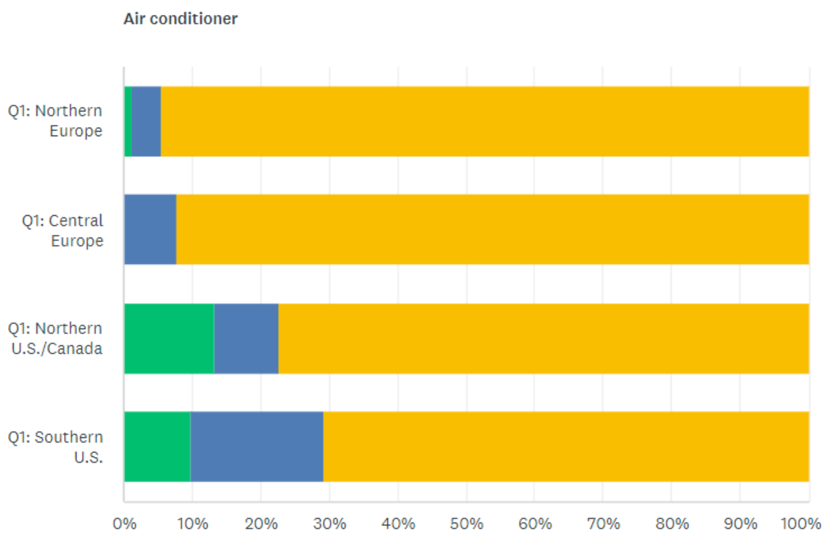


Figure 4.27: Graph showing the importance of air conditioner per location

Fridge is seen to be of higher importance in Europe than in northern America as seen in figure 4.28

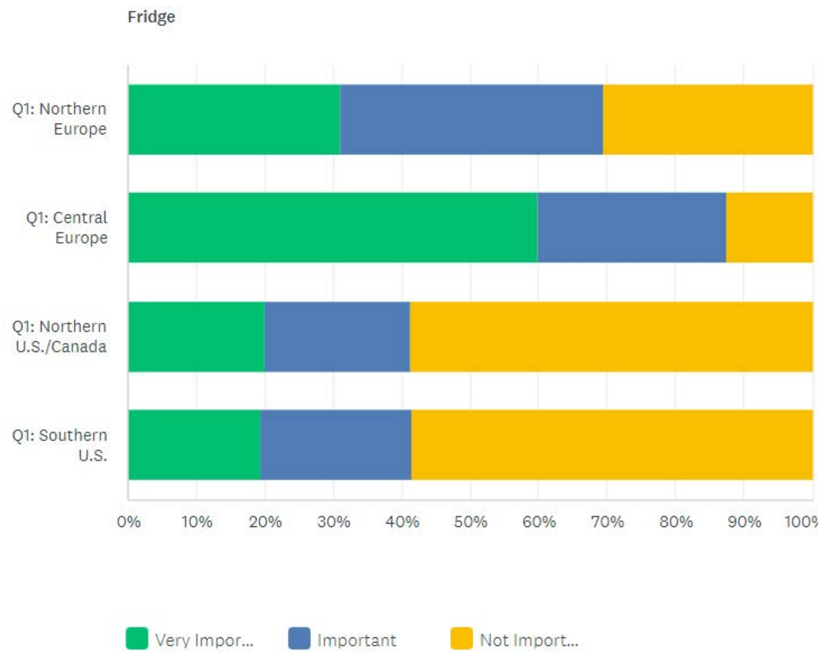


Figure 4.28: Graph showing the importance of fridge per location

When it comes to anchor windlass at either bow or stern or both it is seen that northern Europe differs from the rest in that they rather have an anchor windlass at the stern instead of at the bow as seen in figure 4.29 and figure 4.30.

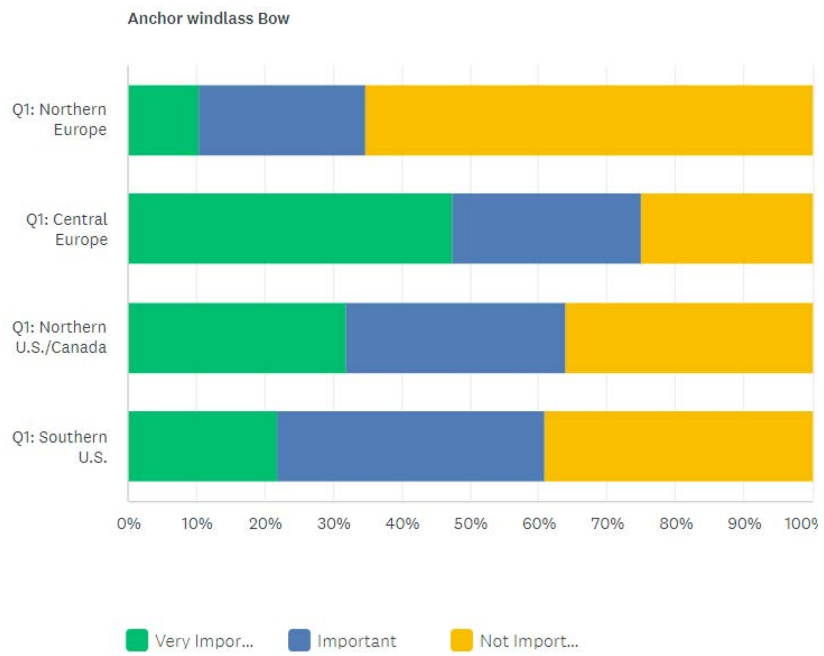


Figure 4.29: Graph showing the importance of anchor windlass at bow per location

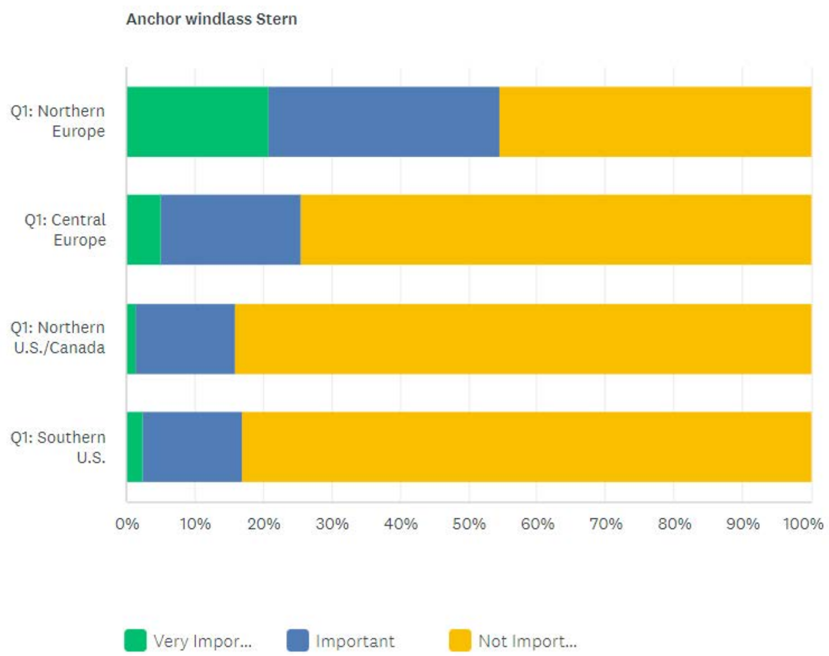


Figure 4.30: Graph showing the importance of anchor windlass at stern per location

4.5 Initial requirement specification

The initial requirement specification of technical data seen in table 4.2 includes data that will be used in the concept elimination and screening phase. The input data of the requirement specification is based in the competitor study and customer needs study.

Table 4.2: Initial requirement specification

	Document type	Requirement Specification					
	Project	Electric boat concept					
Issued by		*Created:* 2022-02-21					
Jesper Rönnebrand		*Modified: 2022-04-25*					
	Criterias	*Specified value*	*Type of Requirement*	*Demand /wish*	*Imp.*	*Verification method*	*Justification*
	Function(s)						
1.	**Performance**						
1.1	Cruising speed	≥ 8 kts	Performance	D			
1.2	Maximum speed	≥ 15 kts	Performance	W			
1.3	Range at slow cruising (~4kts)	≥ 80 NM	Performance	W			
1.4	Range at cruising speed	≥ 40 NM	Performance	D			
1.5	Range at maximum speed	≥ 20 NM	Performance	D			
2.	**Technical**						
2.1	Boat lenght	6 ≤ m ≤ 12	Technical	D			
2.5	Battery capacity	< 130 kW	Technical	W			
2.8	Design category	C	Technical	D			
2.9	Number of people	6 ≤ ppl ≤ 12	Technical	D			
3.	**Usability**						
3.1	People to operate	1 person	Functional	D			
4.	**Economics**						
4.1	Initial Cost for customer	<4000 tkr	Financial	D			

4.6 Functional decomposition

The functional decomposition of the usage of a motor boat is shown in a function-means tree. The many functions of a boat is divided into smaller subgroups to easier understand

and analyse the functions of a boat as a whole. The subgroups included in the function-means tree are seen in the list below, and an example from one of the subgroups is seen in figure 4.31. The rest of the subgroups can be found in Appendix D.

- Generate buoyancy
- Maneuver boat
- Start boat
- Enter boat
- Provide shelter
- Provide comfort
- Provide storage
- Provide facilities
- Provide entertainment

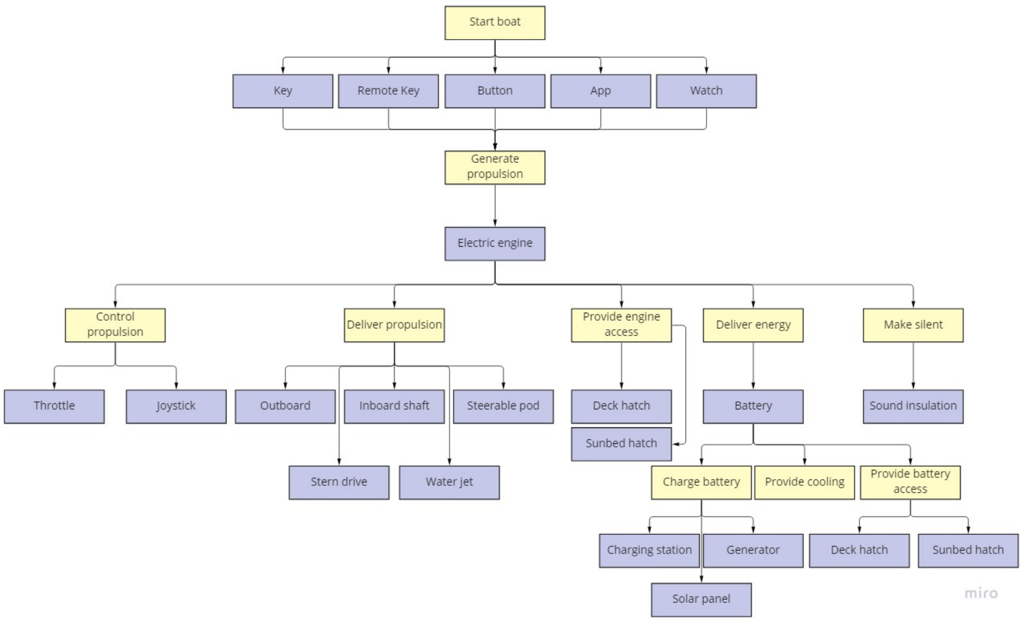


Figure 4.31: Function-means tree from subgroup of "Start boat"

4.7 Concept generation, evaluation and selection

The initial concept generation phase is divided into two parallel generation groups, the performance concepts consisting of driveline and hull type and the functionality concepts consisting of layout, weather protection and different types of enclosure.

4.7.1 Systematic generation of performance concepts

The performance concepts is generated trough the morphological matrix seen in figure 4.32 by creating combinations of hull types, engines and battery packs.

Figure 4.32: Morphological matrix for performance concepts

In column A hull types are placed starting with the semi displacement hull at position A1 using Strana by Orust E-boats as a reference. Next hull at position A2 is a long and narrow semi displacement hull using the Loxo 32 by Pogo structures as a reference. At position A3 is the efficient planing hull using Nautus 7-50 as a reference. Position A5 is a stepped planing hull for higher speed performance using Nimbus T8 as a reference. Lastly there is the hydro foiling hull at position A5 using Candela boats as a reference.

In column B the outboard engines are placed starting with Stream propulsion at position B1 (22.5kW) and B2 (33kW). At position B3, Torqeedo's 50 kW outboard engine is placed. Followed by Evoy's 90 and 150 kW engines at position B4 and B5. Lastly Vision Marines 134 kW engine is placed at position B6.

Column C are representing the steerable pod engines. Position C1 to C4 displays different variations of Sea drives 15 and 30 kW pod in either singe or twin configuration. Position C5 is a hydrofoil steerable pod using the Candela's C-pod as a reference.

In column D the inboard engines on shaft are located. At position D1 to position D5 Oceanvolt's modular AXC engine is placed in different configurations either as single or twin installation. Torqeedo's 50 and 100kW engine is found at position D6 and D7. At position D8 and D9 Evoy's 90 and 150 kW engines are found. The Evoy inboard engines are also compatible with stern drives and is found at position E1 and E2.

The battery packs are found in column F starting with the 26 kW Stream propulsion battery at position F1. From position F2 to position F4 MG energy systems modular LFP battery pack of 7.2 kW each are found in different configurations. Torqeedo's 40 kW

BMW i3 converted battery pack is found at position F5 and as twin battery pack of 80 kW at position F6. At position F7 Kreisel electrics 63 kW battery is found and as twin pack of 126kW at position F8. Lastly Vision Marine's battery pack of three 33kW batteries is located on F9.

4.7.1.1 Generated performance concepts

A total of 19 performance concept combinations were generated through the morphological matrix. A concluding list with combinations and performance estimations is seen in table 4.3. The estimated performance is based on the references performance and some simple calculations from energy output and battery capacity and the relation between speed in kts and range in NM, were you reach 1Nm in 1 hour if traveling in 1kts.

Table 4.3: Combination table for performance concepts

Performance concept	Combination	Cruising speed kts	Cruising range NM	Maximum speed kts	Maximum speed range NM
1	(A1:B1:F1)	8	24	15	14
2	(A1:D1:F3)	8	40	15	26
3	(A1:C1:F2)	8	26	15	23
4	(A1:C1:F3)	8	40	15	35
5	(A1:C3:F7)	8	57	20	30
6	(A2:C2:F4)	8	60	15	25
7	(A2:D3:F4)	8	60	15	25
8	(A2:D6:F6	8	96	20	26
9	(A2:C4:F8)	10	100	20	33
10	(A2:D8:F8)	10	100	28	31
11	(A2:B4:F8)	10	100	28	31
12	(A3:B3:F5)	16	34	25	16
13	(A3:B4:F7)	16	53	30	17
14	(A3:D5:F4)	16	50	25	29
15	(A3:D5:F3)	16	37	25	21
16	(A4:B4:F8)	25	37	30	30
17	(A4:B6:F9)	20	? <40	30	17
18	(A4:D9:F8)	21	28	32	21
19	(A5:C3:F5)	22	50	30	32

4.7.2 Elimination of performance concepts

An elimination matrix is used to eliminate the concepts that is not fulfilling the performance requirements from the initial requirement specification. The elimination matrix is seen in figure 4.4. All concepts marked with green are concepts that is fulfilling the requirements and concepts marked with yellow are concepts that is very close to fulfilling the requirements.

Table 4.4: Elimination matrix for performance concepts

Elimination matrix							
Performance Concept	Cruising speed	Max speed	Cruising range	Max speed range	Cost	Comment	Decision
1	+	+	-			Limited cruising range	-
2	+	+	+	+	+		+
3	+	+	-			Limited cruising range	-
4	+	+	+	+	+		+
5	+	+	+	+	+		+
6	+	+	+	+	+		+
7	+	+	+	+	+		+
8	+	+	+	+	+		+
9	+	+	+	+	+		+
10	+	+	+	+	+		+
11	+	+	+	+	+		+
12	+	+	-			Limited cruising range	-
13	+	+	+	-		Limited max speed range	-
14	+	+	+	+	+		+
15	+	+	?	+	+	Cruising range just under limit	?
16	+	+	?	+	+	Cruising range just under limit	?
17	+	+	-			Limited cruising range	-
18	+	+	-			Limited cruising range	-
19	+	+	+	+	+		+

4.7.3 Functional concepts

Similar to the performance concepts the functional concepts are generated through the use of a Morphological matrix seen in table 4.33 to combine components into concepts. The layouts in column A are rough with the purpose to analyse movement in the boat which is illustrated with red arrows. In column B different types of windscreens are located ranging from a soft sprayhood and small windscreens to fully enclosed cabins. In column C different variations of T-top's are located. Canvas solutions to provide both sun protection and weather protection are located in column D. A total of 22 functional concepts was generated were combinations can be seen in table 4.5 together with a short description.

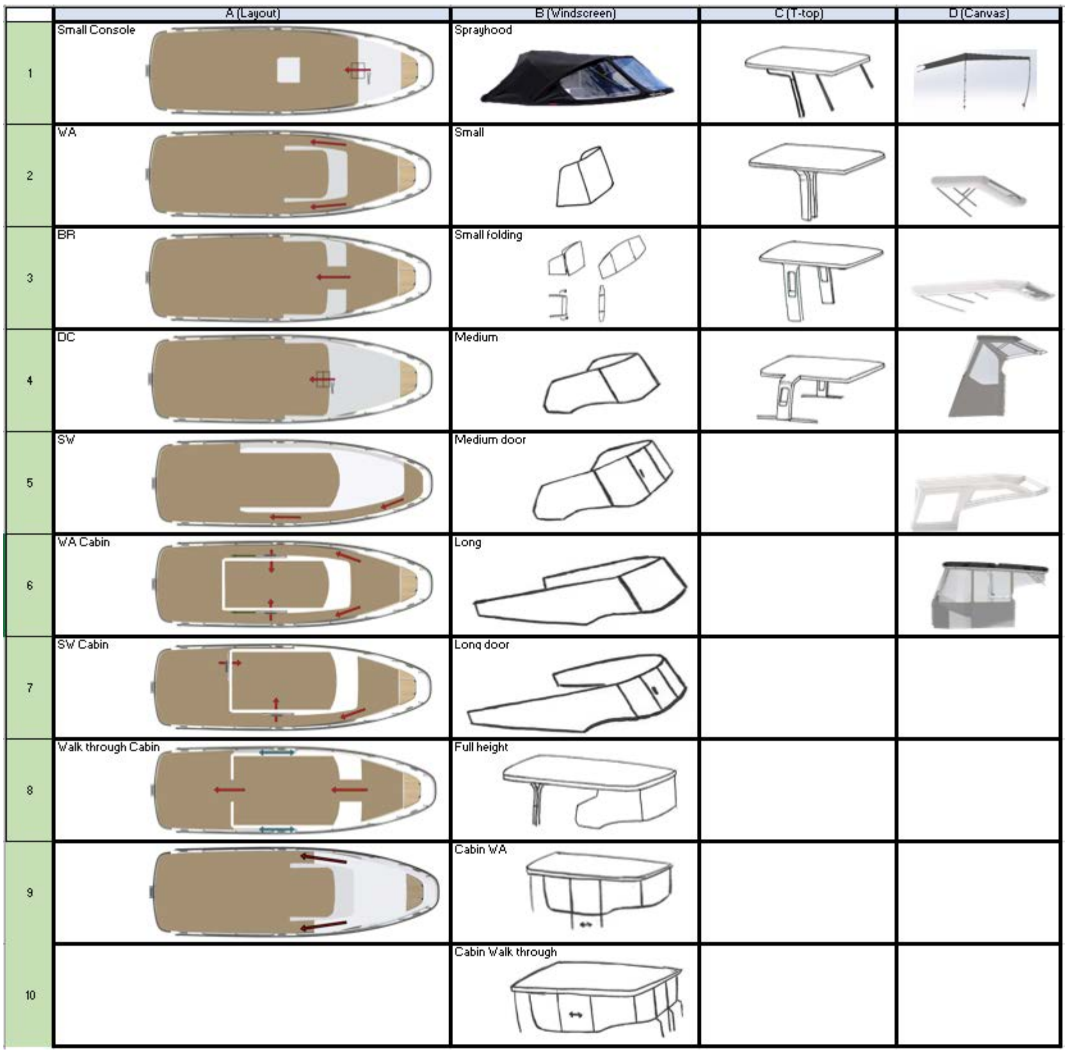


Figure 4.33: Morphological matrix for function concepts

Table 4.5: Combination table for function concepts

Function Concept	Combination	Comment
1	(A1:B1:D1)	Open layout with canvas spray hood. Possibility to mount sun shaders.
2	(A1:B2:B1)	Open layout with a small windscreen for the driver console and a sprayhood for the bow area.
3	(A1:B2:D2:D4)	Open layout with a small windscreen for the driver console with the option for bimini or full enclosure.
4	(A1:B2:C3:D6)	Open layout with small windscreen for the driver console and a T-top for sun shade with the possibility to enclose with canvas.
5	(A1:B2:C2:D&)	Open layout with small windscreen for the driver console and a T-top for sun shade with the possibility to enclose with canvas.
6	(A1:B5:D2:D5)	Open layout with a windscreen with door and a bimini sun shade with the possibility to enclose with canvas.
7	(A1:B5:C1:D6)	Open layout with a short windscreen and a door in the midle. T-top to provide sun shading and possibility to enclose with a canvas.
8	(A3:B5:D3:D5)	Bowrider layout and windscreen with door. Full canvas cover with option to remvoe parts of it to create a bimini sun shade.
9	(A3:B5:C4:D6)	Bowrider layout and windscreen with door. T-top to provide sun shading with possibility to enclose with canvas.
10	(A3:B7:C1:D6)	Bowrider layout and windscreen with door. T-top to provide sun shading with possibility to enclose with canvas.
11	(A2:B4:C3:D6)	Walk around layout with a windscreen. T-top to provide sun shading, possibility to enclose with canvas.
12	(A2:B2:C1:D7)	Walk around layout with a windscreen and a T-top, with possibility for full enclosure.
13	(A2:B2:C8:E6)	Walk around layout and full height windscreen. T-top to provide sun shading with possibility to enclose with canvas.
14	(A9:B8:C2:D6)	Walk around daycruiser layout and a full height windscreen. T-top for sun shading and possibility to enclose fully.
15	(A4:B6:D3:D5)	Daycruiser layout and a long windscreen with door in the middle. Bimini top for sun shading and possibility to enclose fully.
16	(A4:B5:D2:D5)	Daycruiser layout, windscreen with a door and possibility for bimini top or full enclosure.
17	(A4:B6:C4:D6)	Daycruiser layout and a long windscreen. T-top for sun shading and possibility to enclose fully.
18	(A5:B6:D3:D5)	Sidewalk layout and a long wind screen. Bimini top for sun shading and possibility to enclose fully.
19	(A5:B8:C3:D6)	Sidewalk layout and a full height wind screen. T-top for sun shading and possibility to enclose fully.
20	(A7:B9)	Sidewalk cabin layout.
21	(A8:B10)	Walk through cabin layout. Windows on the side that can slide and give access to mooring and air flow.
22	(A6:B9)	Walk around cabin layout. Doors on the side that can slide and give an open feeling.

4.7.4 Pugh matrix of performance concepts

A Pugh matrix is used to evaluate and screen out the remaining performance concepts. The matrix is iterated three times with different datum's (references) that the generated concepts are evaluated against. The first datum is the semi-displacement Strana by Orust E-boats were the matrix and results is seen in table 4.6. The second datum is the long semi-displacement Domani E32 were the matrix is seen in table 4.7. The last datum is the hydrofoil Candela C7 with matrix seen in table 4.8. The ranking of concepts from the three iterations are summarized and a final ranking generated which is seen in table 4.9.

Table 4.6: Pugh matrix for performance concepts (Strana as Datum)

Performace concept	Pugh Matrix													
Concepts → Criterias ↓	Strana	PC2	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC14	PC15	PC16	PC19
Cruising speed		0	0	0	0	0	+	+	+	+	+	+	+	+
Maximum speed		0	0	+	0	0	+	+	+	+	+	+	+	+
Crusising speed range		+	+	+	+	+	+	+	+	+	+	+	+	+
Maximum speed range		+	+	+	+	+	+	+	+	+	+	+	+	+
Seaworthiness	D	0	0	0	+	+	+	+	+	+	0	0	+	0
Manuoverability	a	-	0	0	+	-	-	+	-	-	-	-	-	-
Enyoyment	t	0	0	0	+	+	+	+	+	+	0	0	-	-
Thrill	u	0	0	+	0	0	+	+	+	+	+	+	+	+
Maintenance	m	+	0	0	-	-	-	-	-	-	+	+	0	-
∑+		3	2	4	5	4	7	8	7	7	6	6	6	5
∑-		1	0	0	1	2	2	1	2	2	1	1	2	3
∑S		2	2	4	4	2	5	7	5	5	5	5	4	2
Ranking		4	4	3	3	4	2	1	2	2	2	2	3	4

Table 4.7: Pugh matrix for performance concepts (Domani E32 as Datum)

Peformace concept	Pugh Matrix													
Concepts → Criterias ↓	Domani E32	PC2	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC14	PC15	PC16	PC19
Cruising speed		0	0	0	0	0	0	+	+	+	+	+	+	+
Maximum speed		-	-	0	-	-	0	0	+	+	+	+	+	+
Crusising speed range		-	-	-	-	-	0	+	+	+	-	-	-	-
Maximum speed range		+	+	+	+	+	+	+	+	+	+	-	+	+
Seaworthiness	D	-	-	-	0	0	0	0	0	0	-	-	-	-
Manuoverability	a	0	+	+	+	0	0	+	0	0	0	0	+	0
Enyoyment	t	-	-	-	0	0	0	0	0	0	-	-	-	-
Thrill	u	0	0	+	-	-	0	+	+	+	+	+	+	+
Maintenance	m	+	0	0	0	+	0	-	0	0	+	+	0	-
∑+		2	2	3	2	2	1	5	5	5	5	4	5	4
∑-		4	4	3	3	3	0	1	0	0	3	4	3	4
∑S		-2	-2	0	-1	-1	1	4	5	5	2	0	2	0
Ranking		7	7	5	6	6	4	2	1	1	3	5	3	5

Table 4.8: Pugh matrix for performance concepts (Candela as Datum)

Performace concept	Pugh Matrix													
Concepts → Criterias ↓	Candela	PC2	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC14	PC15	PC16	PC19
Cruising speed		-	-	-	-	-	-	-	-	-	-	-	+	0
Maximum speed		-	-	-	-	-	-	-	-	-	-	-	0	0
Crusising speed range		-	-	+	+	+	+	+	+	+	0	-	-	0
Maximum speed range		-	+	-	-	-	-	+	+	+	+	+	-	0
Seaworthiness	D	0	0	0	+	+	+	+	+	+	0	0	0	0
Manuoverability	a	0	+	+	+	0	0	+	0	0	0	0	+	0
Enyoyment	t	+	+	+	+	+	+	+	+	+	0	0	0	0
Thrill	u	-	-	-	-	-	-	-	-	-	-	-	-	0
Maintenance	m	+	+	+	0	+	+	+	+	+	+	+	+	0
∑+		2	4	4	4	4	4	6	5	5	2	2	3	0
∑-		5	4	4	4	4	4	3	3	3	3	4	3	0
∑S		-3	0	0	0	0	0	3	2	2	-1	-2	0	0
Ranking		6	3	3	3	3	3	1	2	2	4	5	3	3

Table 4.9: Total ranking of Pugh iterations for performance concepts

Concepts →		PC2	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC14	PC15	PC16	PC19
Tot ranking sum		17	14	11	12	13	9	4	5	5	9	12	9	12
Tot ranking		8	7	4	5	6	3	1	2	2	3	5	3	5

The concepts marked with green in table 4.9 are the performance concepts chosen for further development. Even though performance concept 16 received a total ranking of 3 it was chosen afterwards not to take it any further since it was deemed to be a bit unrealistic to achieve the estimated performance after some further evaluation and internal discussion with Nimbus group representatives.

4.7.5 Pugh matrix of function concepts

An initial screening and elimination of the functional concepts was conducted using the Pugh matrix instead of priorly using the elimination matrix since none of the initial requirements could be used as a basis for elimination in the elimination matrix.
The function concepts were also compared to three different datum's, were the first one is Nimbus Groups Bella Zero 6.3 shown in table 4.10, the second is X shore Eelex 8000 shown in table 4.11 and the last one is the Pogo Loxo 32 seen in table 4.12. Similar to the performance Pugh matrix the ranking of the three Pugh iterations are summarized to generate a total Pugh ranking.

Table 4.10: Pugh matrix for function concepts (Bella Zero as Datum)

Function concept	Pugh Matrix																						
Concepts → Criterias ↓	Bella Zero	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	LC9	LC10	LC11	LC12	LC13	LC14	LC15	LC16	LC17	LC18	LC19	LC20	LC21	LC22
Entering boat		-	-	0	0	0	-	-	0	0	0	+	+	+	+	-	-	-	+	+	+	-	+
Moving onboard		0	0	+	+	+	0	0	-	-	-	+	+	+	+	-	-	-	+	+	+	-	+
Weather protection		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sun protection		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ease of putting up canvas		+	+	+	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Enyoyment	D	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0
Nature connection	a	0	0	0	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sleeping possibility	t	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	-	+
Toilet space	u	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Storage	m	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+
Safety		0	0	0	+	+	-	0	-	-	-	+	+	+	-	-	-	-	0	0	-	-	-
∑+		4	4	6	6	6	5	4	5	5	5	10	10	10	9	7	7	7	9	9	8	5	8
∑-		1	1	0	1	1	2	2	3	3	3	1	1	1	2	4	4	4	1	1	2	5	2
∑S		3	3	6	5	5	3	2	2	2	2	9	9	9	7	3	3	3	8	8	6	0	6
Ranking		6	6	4	5	5	6	7	7	7	7	1	1	1	3	6	6	6	2	2	4	8	4

Table 4.11: Pugh matrix for function concepts (X Shore Eelex as Datum)

Function concept	Pugh Matrix																						
Concepts → Criterias ↓	X shore	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	LC9	LC10	LC11	LC12	LC13	LC14	LC15	LC16	LC17	LC18	LC19	LC20	LC21	LC22
Entering boat		-	-	-	-	-	-	-	-	-	-	0	0	0	-	-	-	-	-	-	-	-	0
Moving onboard		-	-	-	-	-	-	-	-	-	-	0	0	0	-	-	-	-	-	-	-	-	-
Weather protection		0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sun protection		-	-	-	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+
Ease of putting up canvas		-	-	-	0	0	-	0	-	-	-	0	0	0	+	0	0	0	0	0	+	+	+
Enyoyment	D	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0
Nature connection	a	+	+	+	0	0	0	0	-	-	-	0	0	0	-	-	-	-	-	-	-	-	-
Sleeping possibility	t	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+
Toilet space	u	+	+	+	+	+	+	+	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+
Storage	m	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Safety		0	-	-	0	0	-	0	-	0	0	0	0	0	-	-	-	-	-	-	-	-	-
∑+		3	3	5	4	4	4	4	3	3	3	5	5	5	6	5	5	5	5	5	6	6	6
∑-		4	5	5	2	2	5	2	5	4	4	0	0	0	4	4	4	4	4	4	4	4	3
∑S		-1	-2	0	2	2	-1	2	-2	-1	-1	5	5	5	2	1	1	1	1	1	2	2	3
Ranking		6	7	5	3	3	6	3	7	6	6	1	1	1	3	4	4	4	4	4	3	3	2

Table 4.12: Pugh matrix for function concepts (Pogo Loxo 32 as Datum)

Function concept	Pugh Matrix																						
Concepts → Criterias ↓	Pogo Loxo	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	LC9	LC10	LC11	LC12	LC13	LC14	LC15	LC16	LC17	LC18	LC19	LC20	LC21	LC22
Entering boat		+	+	+	+	+	+	+	+	+	+	+	+	+	0	-	-	-	+	+	+	-	+
Moving onboard		+	+	+	+	+	+	+	-	-	-	0	0	0	0	-	-	-	-	-	-	-	0
Weather protection		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Sun protection		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Ease of putting up canvas		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Enyoyment	D	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nature connection	a	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	-	-	-
Sleeping possibility	t	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Toilet space	u	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Storage	m	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Safety		+	+	+	+	+	+	+	-	-	-	0	0	0	0	-	-	-	-	-	-	-	0
∑+		4	4	4	4	4	4	4	2	2	2	2	2	2	1	0	0	0	1	1	1	0	1
∑-		7	7	7	6	6	6	6	8	8	8	3	3	3	3	6	6	6	5	5	3	4	1
∑S		-3	-3	-3	-2	-2	-2	-2	-6	-6	-6	-1	-1	-1	-2	-6	-6	-6	-4	-4	-2	-4	0
Ranking		4	4	4	3	3	3	3	6	6	6	2	2	2	3	6	6	6	5	5	3	5	1

Table 4.13: Total ranking of Pugh iterations for function concepts

Concepts →		LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	LC9	LC10	LC11	LC12	LC13	LC14	LC15	LC16	LC17	LC18	LC19	LC20	LC21	LC22
Tot ranking sum		16	17	13	11	11	15	13	20	19	19	4	4	4	9	16	16	16	11	11	10	16	7
Tot ranking		8	9	6	5	5	7	6	11	10	10	1	1	1	3	8	8	8	5	5	4	8	2

The function concepts marked in green in table 4.13 are the concepts that are chosen to take further in the concept generation process. The concepts marked in yellow received a similar ranking score as some of the green marked concepts, however it was chosen not to take these any further since there were similar concepts with walk around layout that received a higher rank. The reason Concept 4 and 5 are chosen for further development even though they received a rank of 5 are because some of the open layout concepts had to be brought into the next phase, for pairing with performance concepts. Concept 4 and 5 were the open layout concepts which reached the highest rank.

4.7.6 Combination of remaining performance and layout concepts

The remaining performance and function concepts are combined using a Morphological matrix seen in figure 4.34. To keep the amount of generations down to a manageable number the concepts with close similarity from the performance and function concepts are clustered.

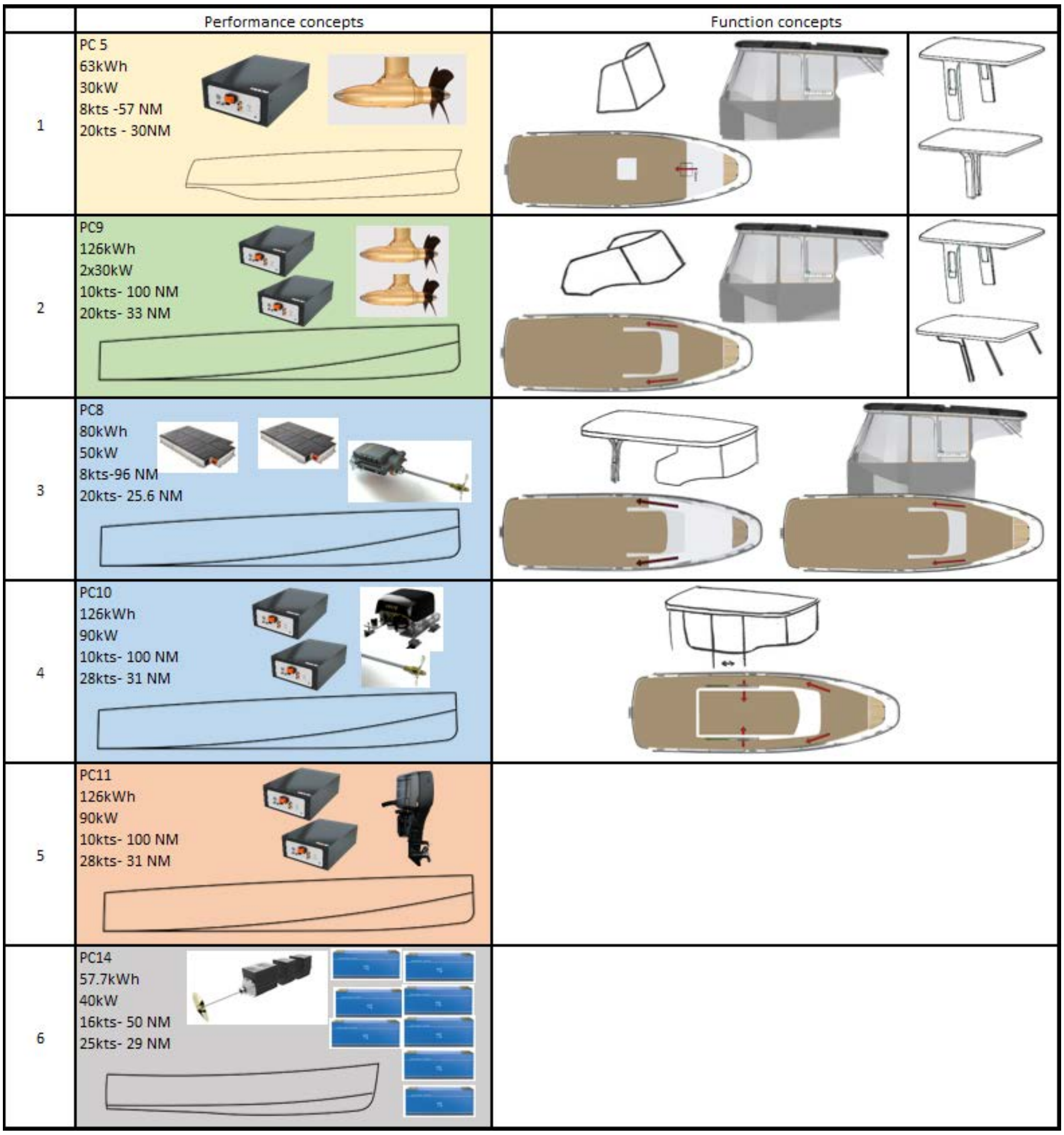


Figure 4.34: Morphological matrix of combined performance and function concepts

The result of the combination are 14 concepts refereed to as combined concepts which can be seen as combinations in table 4.14.

Table 4.14: Table showing combined performance and function concepts

Combined concept	Combination
1	Performance 1 / Function 1
2	Performance 2 / Function 2
3	Performance 3 / Function 2
4	Performance 5 / Function 2
5	Performance 2 / Function 3
6	Performance 3 / Function 3
7	Performance 5 / Function 3
8	Performance 2 / Function 4
9	Performance 3 / Function 4
10	Performance 5 / Function 4
11	Performance 6 / Function 1
12	Performance 6 / Function 2
13	Performance 6 / Function 3
14	Performance 6 / Function 4

4.7.7 Further development of remaining concepts

A further development of the combined concepts was done to determine whether the concepts are reasonable and to distinguish them more from one and another. It is done by the creation of 3D drawings of the combined concepts. Hull surfaces are created using the existing reference boats for creating hull shapes. Then a boxy layout is created to identify if the layout works on the designated hull or size of boat. Furthermore batteries and engines are placed inside the hull to determine if the drive line is compatible for the concept. From the further development of the combined concepts it resulted in 10 refined basic concepts trough merging concepts with close similarity.

Basic concept 1 seen in figure 4.35 has the semi-displacement hull using Strana by Orust E-boats as reference, with a 30 kW Sea drive steerable pod and a 63 kWh battery from Kreisel. The layout is open with a small windscreen for the driver console. A T-top provides sun shading and also enables full enclosure. The estimated performance is a cruising speed of 8 knots enabling a range of 57 NM and a maximum speed of 20 kts that can be maintained for 30 NM.

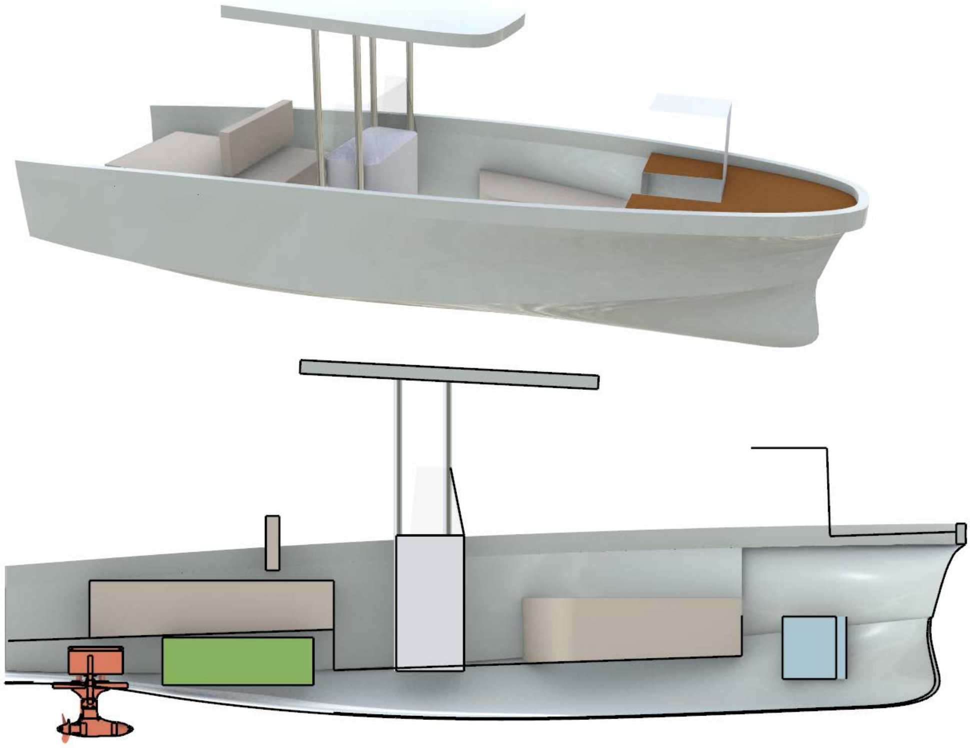


Figure 4.35: Basic concept 1

Basic concept 2 seen in figure 4.36 has the long semi-displacement hull using Pogo Loxo 32 as a reference, with a 50 kW Torqeedo inboard engine on shaft and a 80 kWh BMW i3 Torqeedo battery pack. It has a walk around layout with a sunbed astern were the batteries are placed underneath. There are room for a bed and a toilet compartment under the foredeck. A T-top provides shading from the sun and enables full enclosure. Estimated performance is a cruising speed of 8 knots were a range of 96 NM can be reached. Maximum speed is estimated to be 20 kts and enables a range of 25 NM.

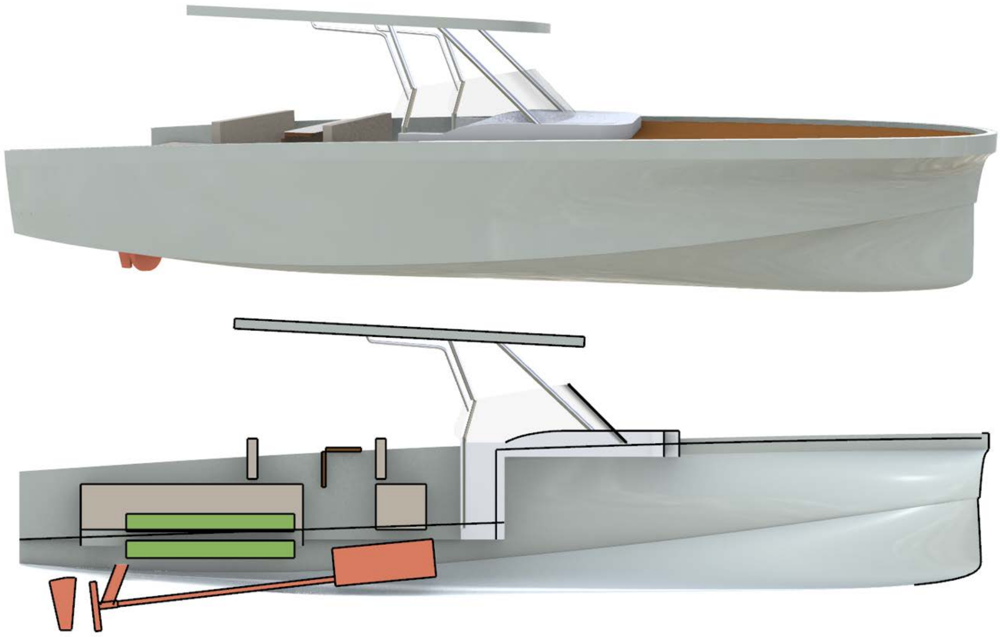


Figure 4.36: Basic concept 2

Basic concept 3 is seen in figure 4.37 and has same hull, layout and functions as basic concept 2. The difference is the driveline were basic concept 3 has an outboard 90 kW engine from Evoy together with a 126 kWh battery pack from Kreisel. The performance is estimated to be 10 kts in cruising speed with a range of 100 NM and a maximum speed of 28 ktsd and a range of 31 NM.

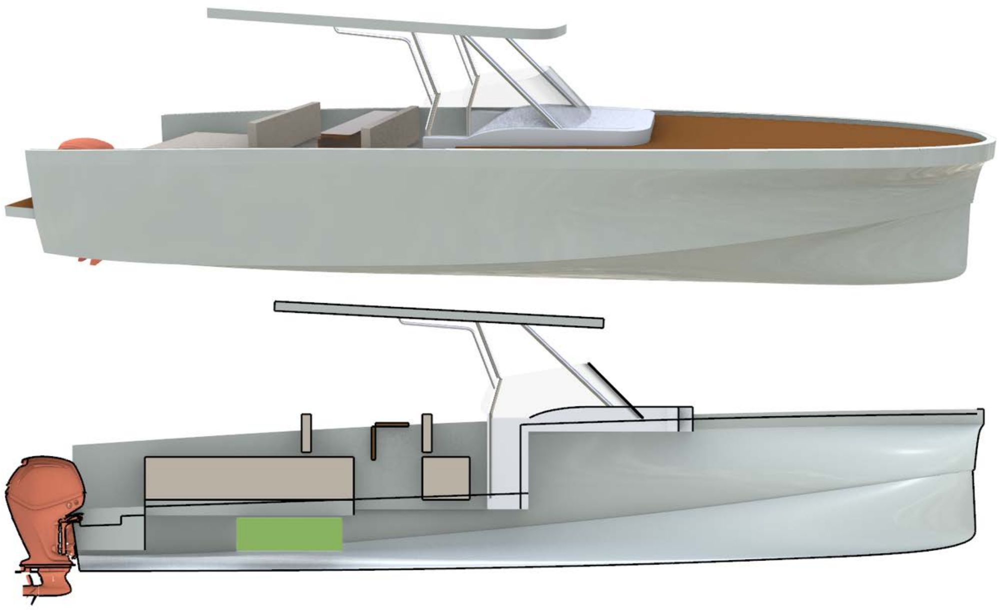


Figure 4.37: Basic concept 3

Basic concept 4 seen in figure 4.38 has same hull, layout and driveline as basic concept

3. The difference is the windscreen and T-top were the windscreen is full height up to the T-top. A full canvas enclosure can close of the outdoor space for weather protected cruising.

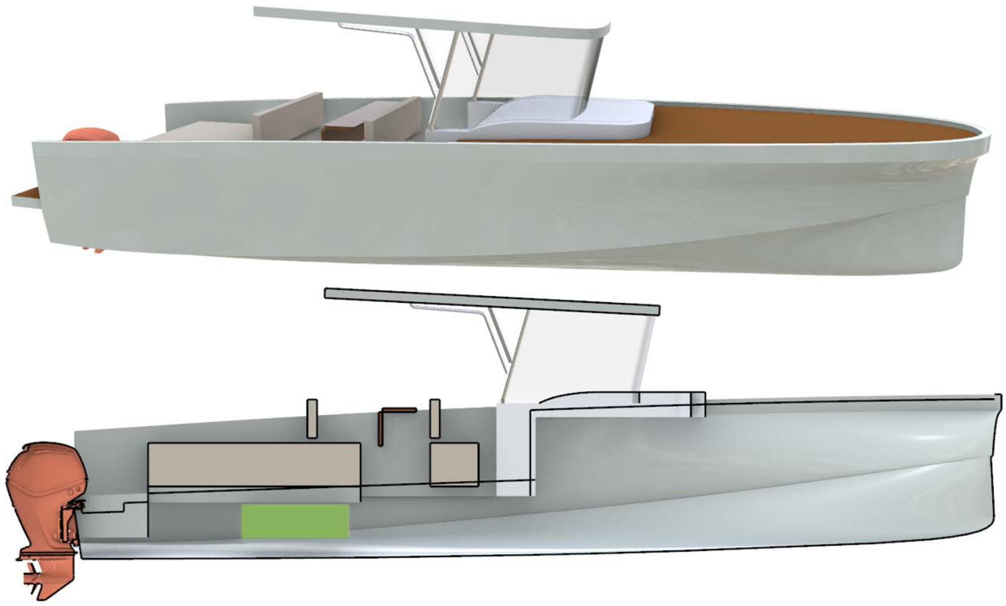


Figure 4.38: Basic concept 4

Basic concept 5 seen in figure 4.39 are same as basic concept 4 apart from the driveline. It has twin Sea drive 30 kW steerable pods and a 126 kWh battery pack from Kreisel. The performance at cruising speed is estimated to be 10 kts reaching 100 NM and a maximum speed of 20 kts reaching 33 NM.

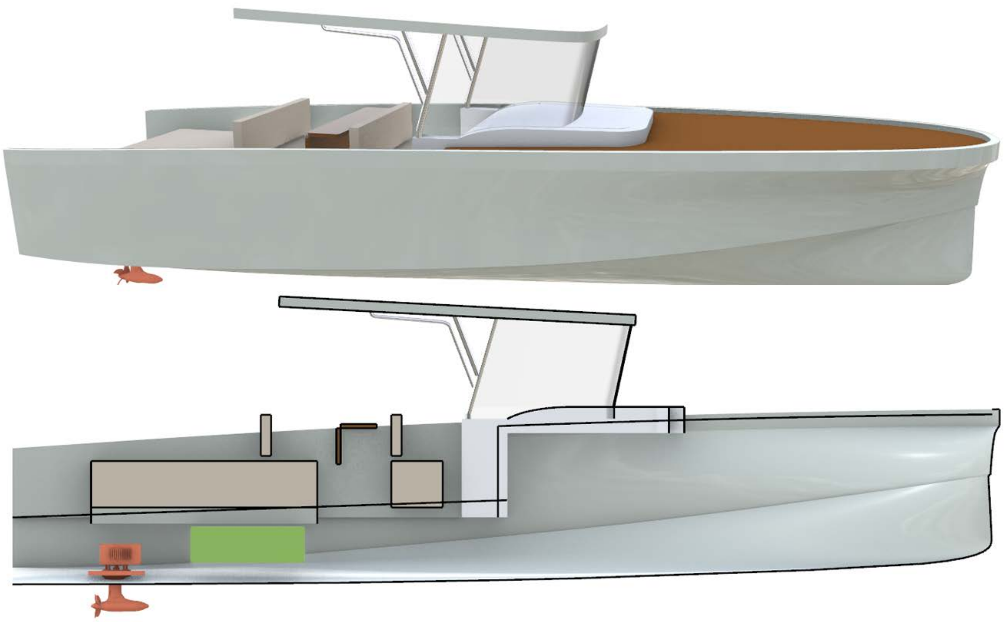


Figure 4.39: Basic concept 5

Basic concept 6 seen in figure 4.40 has the long semi-displacement hull and a walk around cabin layout wind sliding doors on the sides. It has twin Sea drive 30 kW steerable pods and a 126 kWh battery pack from Kreisel. The performance at cruising speed is estimated to be 10 kts reaching 100 NM and a maximum speed of 20 kts reaching 33 NM.

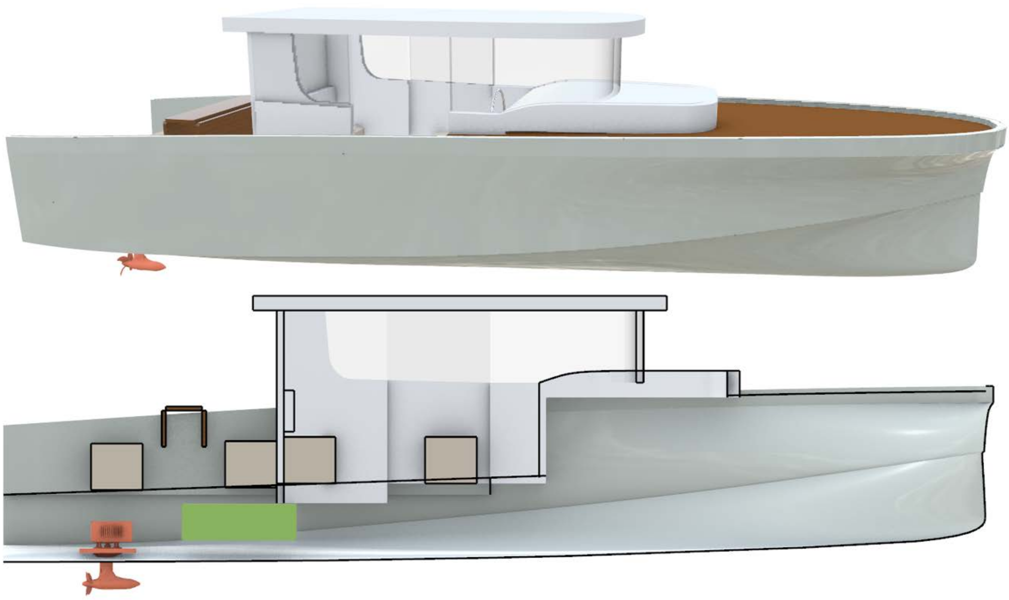


Figure 4.40: Basic concept 6

Basic concept 7 seen in figure 4.41 has the same hull and driveline as basic concept 6. The layout is a walk around cabin layout with the cabin open to the back. Inside the cabin there are sofas on both sides and the helm is located furthest back to enable a social driver experience so that the driver is facing the passengers when driving the boat. A pantry is located on the opposite side of the helm an enables food preparation and food storage. Under the foredeck there is space for a bed and a toilet compartment.

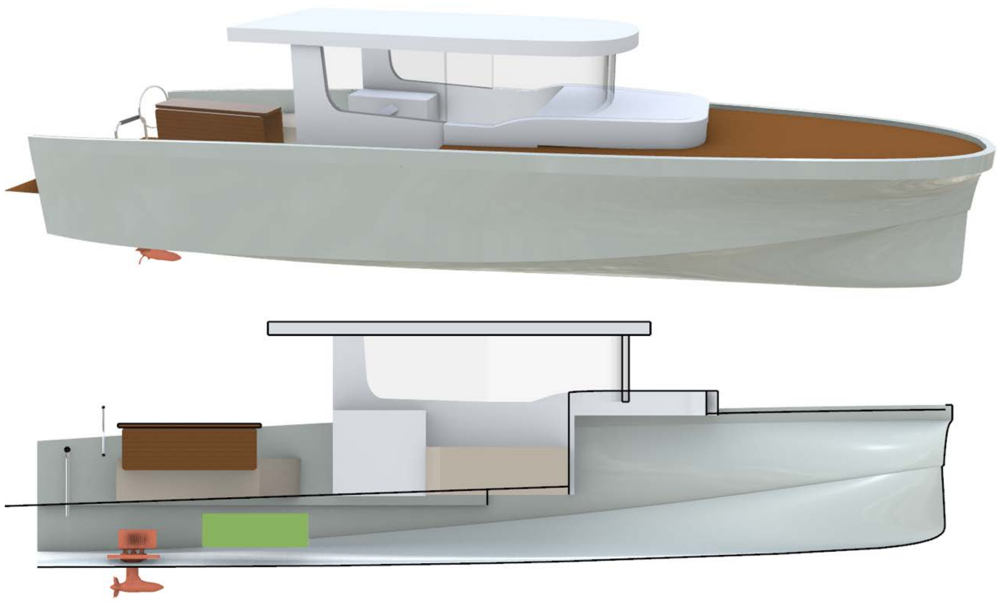


Figure 4.41: Basic concept 7

Basic concept 8 seen in figure 4.42 has the efficient planing hull using Nautus 7-50 as a reference. The layout is open with a centre console were a windscreen provides some wind protection. A T-top provides sun shading and a full enclosure canvas can be mounted for full weather protection. In the bow a toilet is placed under a hatch that when open provides full sitting height. It has a Oceanvolt AXC 40kW engine and a 60kWh battery pack from MG Energy Systems. The estimated performance were also refined and the cruising speed set to 12 kts with a range of 40NM and a maximum speed of 18 knots and a range of 22 NM.

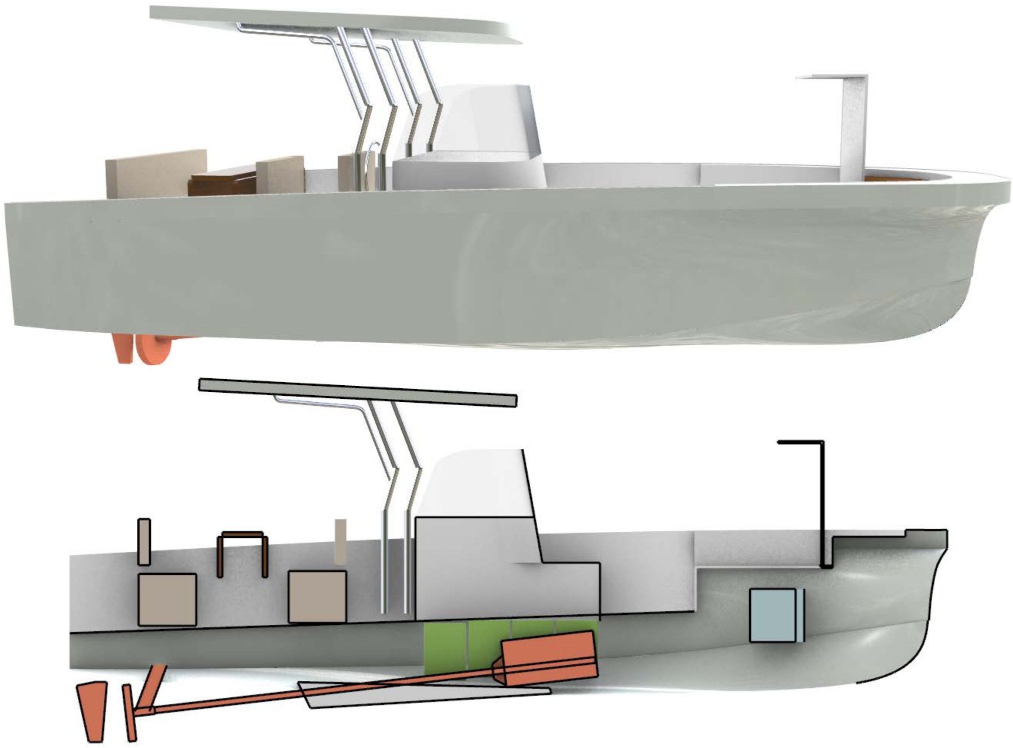


Figure 4.42: Basic concept 8

Basic concept 9 has the same hull, layout and functions as basic concept 8. The driveline is different using twin Oceanvolt AXC 30kW engines with a 75kWh battery pack. The performance is estimated to be 12 kts at cruising speed with a range of 40NM and a maximum speed of 22kts with a range of 22NM

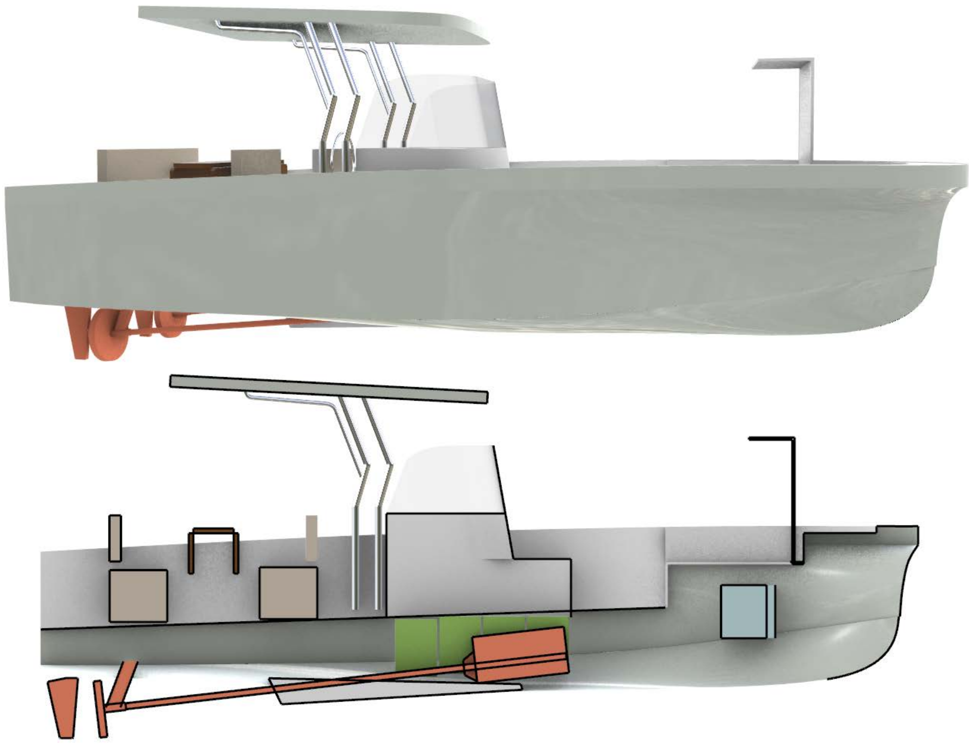


Figure 4.43: Basic concept 9

Basic concept 10 has the same hull, driveline and performance as basic concept 9. The layout is similar but has differences at the foredeck were the foredeck is raised to allow for sleeping possibility. The toilet is placed under the centre console. You enter the forepeak and toilet compartment from a hatch at the bow.

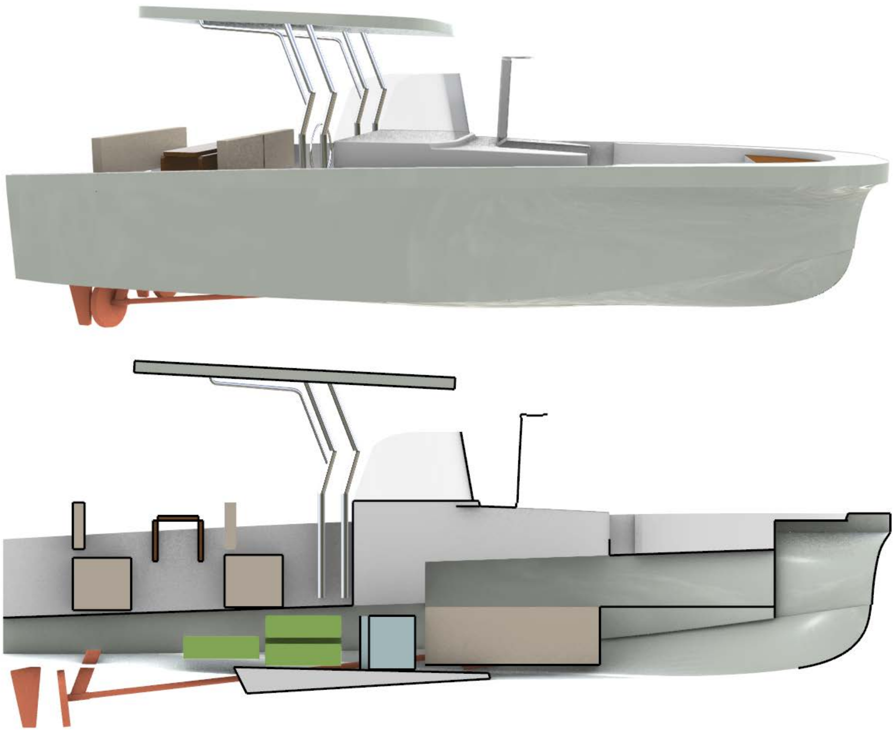


Figure 4.44: Basic concept 10

4.7.8 Concept evaluation using Kesselring matrix

A Kesselring matrix is used to further evaluate the basic concepts. In difference from the previous used evaluation and screening methods the Kesselring matrix introduces weighted criterions.

4.7.8.1 Weighting requirements

In table 4.15 the results of the weighting of criterions is seen. The participants apart from the master thesis student were representatives from Nimbus group. The marked green and yellow field has been added as an example of how the table is to be read. For the cruising speed criteria that is evaluated in the first row it is seen that cruising speed has been grayed out in the first column. That is because the same criteria can't be compared against each other. In the second column cruising speed is seen as more important than maximum speed and therefore receive a 1 which is more important (green field). At the same time maximum speed receive a 0 against cruising speed (yellow filed). The sum for each row are divided by the total sum to receive the weight of each criteria.

It is seen that safety has the highest importance among the criterions with a weight score of 0.094 and that range in maximum speed has the lowest importance with a weight score of 0.0048.

Table 4.15: Criterion weighting table

Criteria	Cruising speed	Maximum speed	Range (Cruising speed)	Range (Maximum speed)	Sea-worthiness	Manouvre-ability	Thrill	Enjoyment	Nature connection	Entering boat	Moving aboard	Weather protection	Sun protection	Ease of putting up canvas	Sitting space	Sleeping comfort	Cold food/ beverages storage	Food preparation	Toilet space	Storage space	Safety	Sum	Weight
Cruising speed		1	0,5	0	0.5	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	0	16	0,077108434
Maximum speed	0		0	0	0	0	0,5	0	0	0	0	0	0,5	0,5	0,5	1	1	1	1	0	0	6	0,028915663
Range (Cruising speed)	0,5	1		1	0	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	0	17	0,081927711
Range (Maximum speed)	1	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0,004819277
Seaworthiness	0,5	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,5	19	0,091566265
Manouverability	0	1	0	1	0		1	1	1	0,5	0,5	1	1	1	1	1	1	1	1	1	0	15	0,072289157
Thrill	0	0,5	0	1	0	0		0,5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0,009638554
Enyoyment	0,5	1	0,5	1	0	0	0,5		0,5	1	1	1	1	1	1	1	1	1	1	1	0	15	0,072289157
Nature connection	0	1	0	1	0	0	1	0,5		0,5	0,5	0,5	0,5	0,5	0	1	1	1	1	0,5	0	10,5	0,05060241
Entering boat	0	1	0	1	0	0,5	1	0	0,5		1	1	1	1	0,5	1	1	1	1	1	0	13,5	0,065060241
Moving aboard	0	1	0	1	0	0,5	1	0	0,5	0		1	1	1	0,5	1	1	1	1	0,5	0	12	0,057831325
Weather protection	0	1	0	1	0	0		0	0,5	0	0		1	1	1	1	1	1	1	0,5	0	10	0,048192771
Sun protection	0	0,5	0	1	0	0	1	0	0,5	0	0	0		1	0	0,5	0	1	0,5	0	0	6	0,028915663
Ease of putting up canvas	0	0,5	0	1	0	0	1	0	0,5	0	0	0	0		0	1	1	1	1	0,5	0	7,5	0,036144578
Sitting space	0	0,5	0	1	0	0	1	0	1	0,5	0,5	0	1	1		1	1	1	1	1	0	11,5	0,055421687
Sleeping comfort	0	0	0	1	0	0	1	0	0	0	0	0	0,5	0	0		0,5	1	0	0	0	4	0,019277108
Cold food/bevarages storage	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0,5		1	1	0	0	5,5	0,026506024
Food preparation	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0		0	0	0	2	0,009638554
Toilet space	0	0	0	1	0	0	1	0	0	0	0	0	0,5	0	0	1		1		0	0	4,5	0,021686747
Storage space	0	1	0	1	0	0	1	0	0,5	0	0,5	0,5	1	0,5	0	1	1	1	1		0	10	0,048192771
Safety	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		19,5	0,093975904
1 = more important / 0.5 = same importance / 0 = less important																				Tot sum		207,5	

4.7.8.2 Grading scales of criterions

In figure 4.45 the grading scales used for the Kesselring evaluation are seen. Each criterion are divided into grades from 1 to 5 based on either numeric values such as knots or subjective values ranging from very bad to very nice.

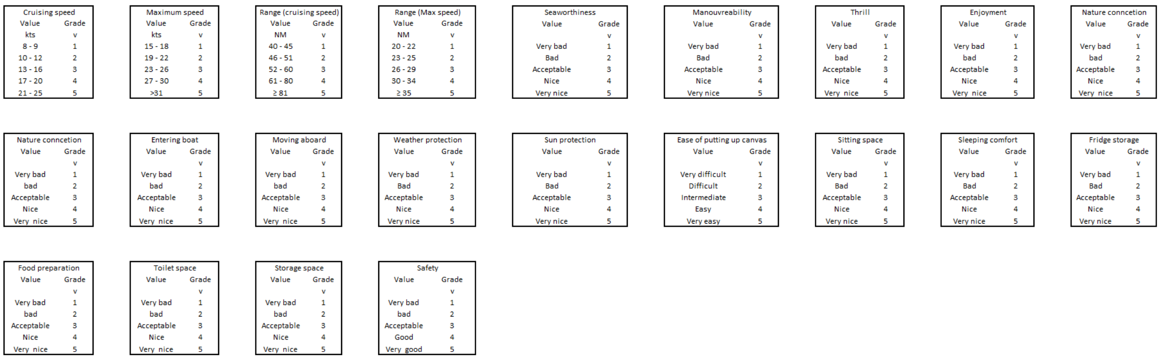


Figure 4.45: Grading scales of criterions

4.7.8.3 Evaluation of concepts using Kesselring matrix

The evaluation of basic concepts using Kesselring matrix is seen in table 4.16. The weighted criterion score are displayed next to the criterions under (w). The concept named Ideal is a reference that receives the highest score. Each concept are receiving a grading (v) for each criteria that is multiplied with the weighted criterion (w) to generate (t). In the bottom of the table the scores are summarized were (V) is the sum of the grading scores, (T) is the sum of the weighted grading scores and (T/Tmax) is how much in percentage the concept corresponds to the ideal. Lastly to concepts are ranked based on the (T) and (T/Tmax) scores.

Table 4.16: Kesselring matrix

Electric boat concept		Kesselring Matrix																					
Variant →		Ideal		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6		Concept 7		Concept 8		Concept 9		Concept 10	
Criterias ↓	w	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t
Cruising speed	0,0771	5	0,3855	1	0,0771	1	0,0771	2	0,1542	2	0,1542	2	0,1542	2	0,1542	2	0,1542	2	0,1542	2	0,1542	2	0,1542
Maximum speed	0,0289	5	0,1445	2	0,0578	2	0,0578	4	0,1156	4	0,1156	2	0,0578	2	0,0578	2	0,0578	1	0,0289	2	0,0578	2	0,0578
Range (Cruising speed)	0,0819	5	0,4095	3	0,2457	5	0,4095	5	0,4095	5	0,4095	5	0,4095	5	0,4095	5	0,4095	1	0,0819	1	0,0819	1	0,0819
Range (Maximum speed)	0,0048	5	0,024	4	0,0192	2	0,0096	4	0,0192	4	0,0192	4	0,0192	4	0,0192	4	0,0192	1	0,0048	1	0,0048	1	0,0048
Seaworthiness	0,0916	5	0,458	3	0,2748	4	0,3664	4	0,3664	4	0,3664	4	0,3664	4	0,3664	4	0,3664	3	0,2748	3	0,2748	3	0,2748
Manouverability	0,0723	5	0,3615	4	0,2892	3	0,2169	4	0,2892	4	0,2892	5	0,3615	5	0,3615	5	0,3615	4	0,2892	5	0,3615	5	0,3615
Thrill	0,0096	5	0,048	3	0,0288	3	0,0288	5	0,048	5	0,048	3	0,0288	2	0,0192	2	0,0192	2	0,0192	4	0,0384	4	0,0384
Enjoyment	0,0723	5	0,3615	3	0,2169	3	0,2169	3	0,2169	4	0,2892	4	0,2892	3	0,2169	5	0,3615	3	0,2169	3	0,2169	3	0,2169
Nature connection	0,0506	5	0,253	4	0,2024	3	0,1518	3	0,1518	3	0,1518	3	0,1518	2	0,1012	3	0,1518	4	0,2024	4	0,2024	4	0,2024
Entering boat	0,0651	5	0,3255	3	0,1953	4	0,2604	4	0,2604	4	0,2604	4	0,2604	4	0,2604	4	0,2604	5	0,3255	5	0,3255	5	0,3255
Moving aboard	0,0578	5	0,289	4	0,2312	5	0,289	5	0,289	5	0,289	5	0,289	4	0,2312	4	0,2312	5	0,289	5	0,289	5	0,289
Weather protection	0,0482	5	0,241	2	0,0964	3	0,1446	3	0,1446	3	0,1446	3	0,1446	5	0,241	4	0,1928	3	0,1446	3	0,1446	3	0,1446
Sun protection	0,0289	5	0,1445	3	0,0867	4	0,1156	4	0,1156	4	0,1156	4	0,1156	5	0,1445	5	0,1445	4	0,1156	4	0,1156	4	0,1156
Ease of putting up canvas	0,0361	5	0,1805	1	0,0361	3	0,1083	3	0,1083	4	0,1444	4	0,1444	5	0,1805	5	0,1805	3	0,1083	3	0,1083	3	0,1083
Sitting space	0,0554	5	0,277	3	0,1662	3	0,1662	3	0,1662	3	0,1662	3	0,1662	5	0,277	5	0,277	4	0,2216	4	0,2216	3	0,1662
Sleeping comfort	0,0193	5	0,0965	1	0,0193	4	0,0772	4	0,0772	4	0,0772	4	0,0772	4	0,0772	4	0,0772	1	0,0193	1	0,0193	4	0,0772
Fridge storage	0,0265	5	0,1325	3	0,0795	4	0,106	4	0,106	4	0,106	4	0,106	4	0,106	5	0,1325	5	0,1325	5	0,1325	5	0,1325
Food preparation	0,0096	5	0,048	2	0,0192	3	0,0288	3	0,0288	3	0,0288	3	0,0288	3	0,0288	4	0,0384	4	0,0384	4	0,0384	4	0,0384
Toilet space	0,0217	5	0,1085	3	0,0651	4	0,0868	4	0,0868	4	0,0868	4	0,0868	4	0,0868	4	0,0868	3	0,0651	3	0,0651	4	0,0868
Storage space	0,0482	5	0,241	2	0,0964	4	0,1928	4	0,1928	4	0,1928	4	0,1928	5	0,241	5	0,241	3	0,1446	3	0,1446	5	0,241
Safety	0,094	5	0,47	4	0,376	4	0,376	4	0,376	4	0,376	4	0,376	3	0,282	3	0,282	5	0,47	5	0,47	5	0,47
V=∑vi			105		58		71		79		81		78		80		84		66		70		75
T=∑ti			5		2,8793		3,4865		3,7225		3,8309		3,8262		3,8623		4,0454		3,3468		3,4672		3,5878
T/Tmax			1		0,57586		0,6973		0,7445		0,76618		0,76524		0,77246		0,80908		0,66936		0,69344		0,71756
Ranking		-			10		7		5		3		4		2		1		9		8		6

4.7.9 Plotting Kesselring results against cost

Plotting Kesselring scores on a graph against cost is giving a sense for how much value for the money an user receives for each concept. In figure 4.46 the concepts numbers are placed in a position corresponding to its (T/Tmax) score and an roughly estimated cost based on reference boats already in the market.

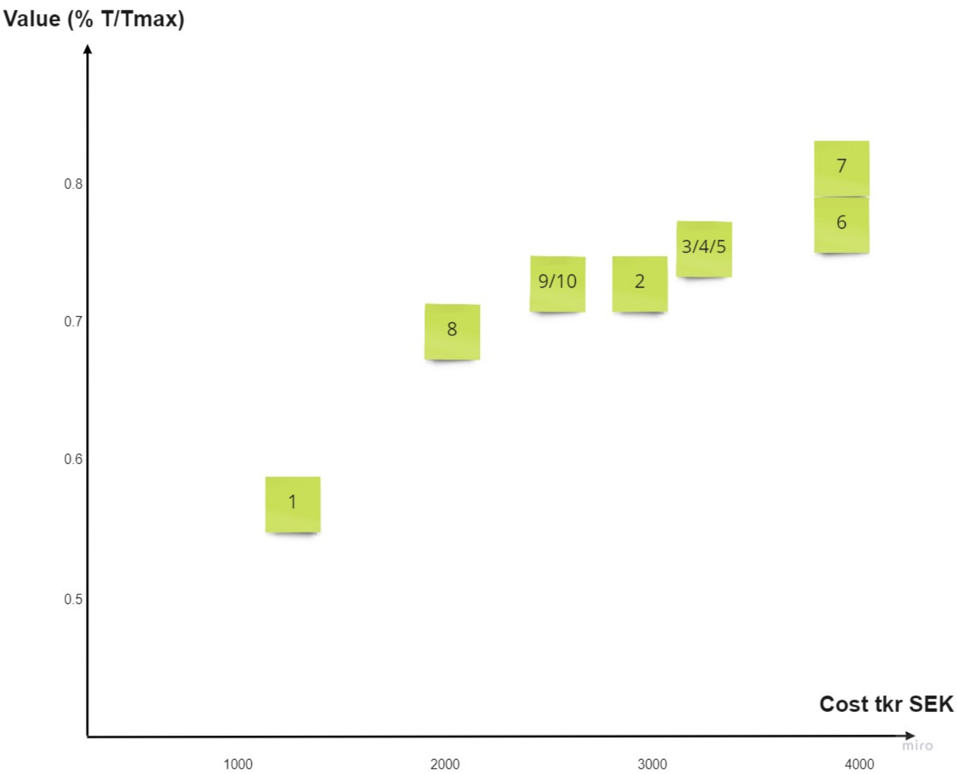


Figure 4.46: Graph showing value for money

4.7.10 Choosing concept for further development

It is seen in figure 4.46 that concept 1 delivers most value for the money based on the criterions and weight of criterions that was set for this project. Even though concept 1 delivers most value for the money, the other concepts are still valid concepts that can not be eliminated on the single basis of cost. All the concepts have the potential to fulfill different market needs and could be further developed. To decide which of the 10 concepts to further develop for this specific project the master thesis student together with Nimbus Group representatives took other aspects in to account such as product novelty and survey results to guide the decision.

It was then decided to take concept 7 into further development since it is the concept that received the highest score in the Kesselring evaluation but also the concept that has the highest product novelty among the 10 concepts. The product novelty is found in the layout that combines elements of sailboats with a walk around cabin layout. It also fulfills most of the customer needs seen as important from the market study. The concept is flexible, providing both good and social exterior and interior environments and the possibility to operate the boat from both exterior and interior. Sleeping possibility together with a pantry and toilet compartment enables comfortable longer stays if desired.

Furthermore it was decided to use the driveline from concept 9 and 10 with an increased battery capacity of 100 kWh and combine it with concept 7. This decision was based in creating a cheaper solution that has close to same maneuverability as twin pod drives. It is because a twin shaft installation combined with a bow thruster and smart software can achieve similar sideways and rotating maneuvers when connecting it to joystick steering.

4.8 Detailed concept design

To further develop concept 7 a detailed design phase was conducted by sketching ideas on paper and creating a 3D model. Furthermore design for manufacturing were brought in to the design process to create a concept boat that is realistic from the point of manufacturing.

4.8.1 Concept hull design

First step was to adjust the hull design that was created in the earlier steps of the basic concept evaluation using 3D. The final design of the hull is seen in figure 4.47. The hull can hydrodynamically be seen as a combination of the hull design used on Pogo Loxo 32 and the design used for Nautus 7-50. To extend the waterline length the hull is extending to the end of the stern swimming platform. The bow is narrow at the waterline and has a flare on the upper part to deflect water spray as seen in figure 4.48. The hull gradually flattens out towards the stern to generate lift.

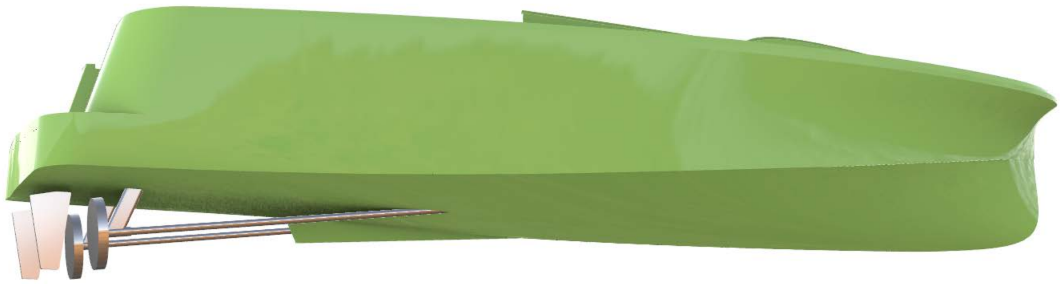


Figure 4.47: Finalized concept design of hull in 3D (side view)

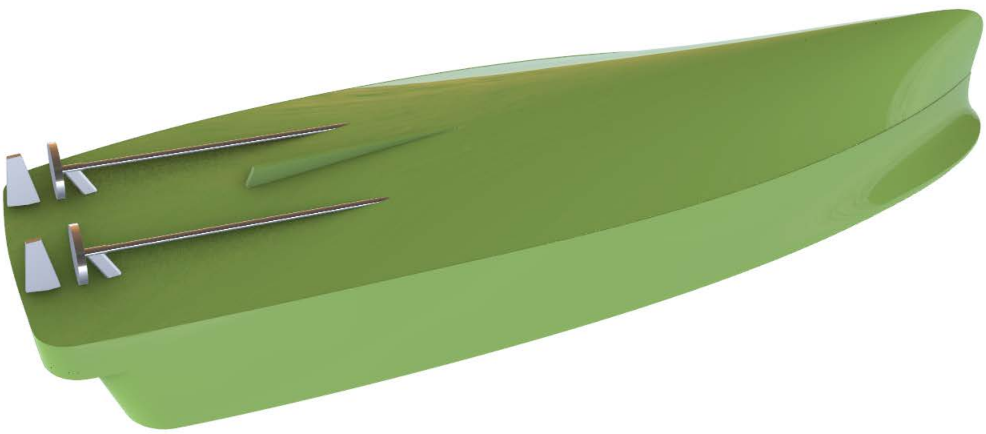


Figure 4.48: Finalized concept design of hull in 3D (bottom view)

4.8.2 Propulsion of concept

The propulsion consists of twin Oceanvolt AXC 30 kW engines on shafts. The engines are placed centralized in the hull under the side couches in the cabin . The engines can be reached from both hatches in the couch and from a deck hatch, allowing for easy maintenance if required. The battery pack of 14, 7.2 kWh batteries are placed under the aft deck at the sides and can be reached trough deck hatches for maintenance. Apart from the main propulsion a bow thruster will be integrated at the bow to enable efficient harbour maneuvers.

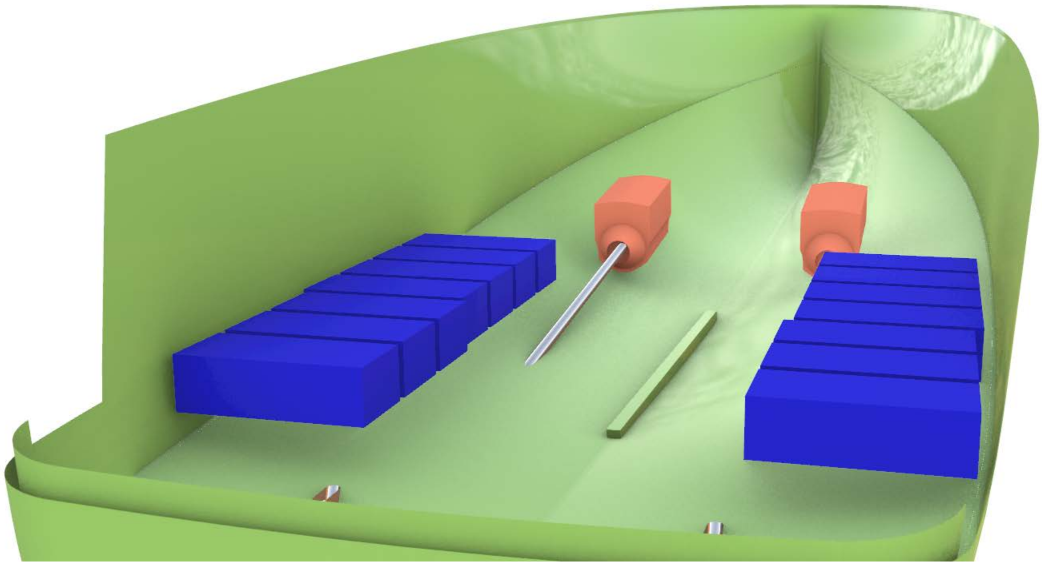


Figure 4.49: Placement of driveline components (Red showing engine placement and blue showing battery placement)

4.8.3 Determining the aesthetic design

To decide shapes and aesthetic design of the concept some sketches were generated. The first decision was about the cabin design were some example were created with different wind screen designs. In figure 4.50 a design with an angled windscreen is seen, the benefit with this design is that it allows for an more airy interior and contributes to a more sleek look. In figure 4.51 another cabin design example is seen with a vertical windscreen, this design is similar to Nimbus commuter models and provide a more powerful work boat look.

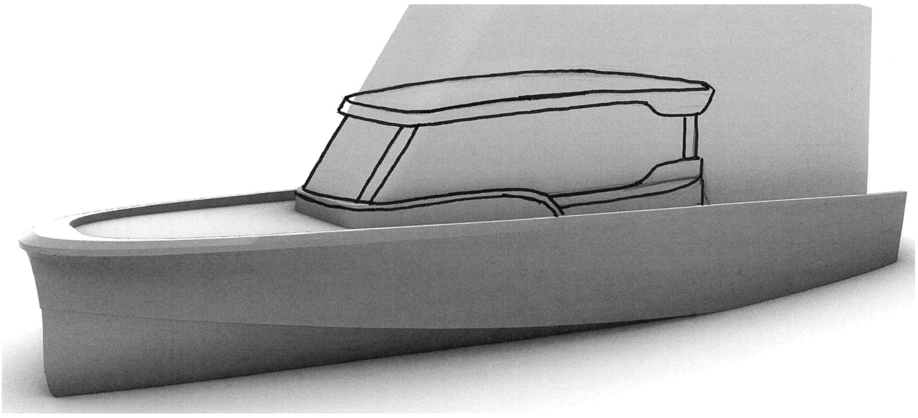


Figure 4.50: Sketch showing a design suggestion for cabin design with angled windscreen

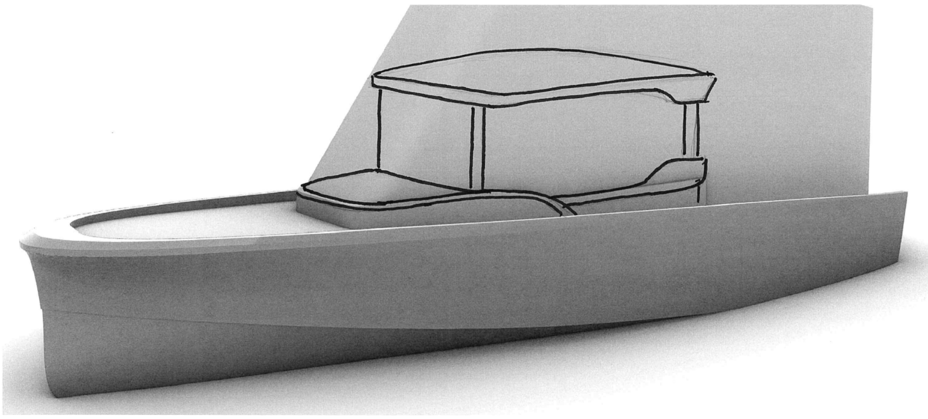


Figure 4.51: Sketch showing a design suggestion for cabin design with vertical windscreen

It was decided to go for the sleek look with an angled windscreen since it provided more interior volume and also suited the sleek hull better. In figure 4.52 a developed design of the cabin is seen together with the finalised concept hull design. Furthermore a developed sketch of the roof was created seen in figure 4.53.

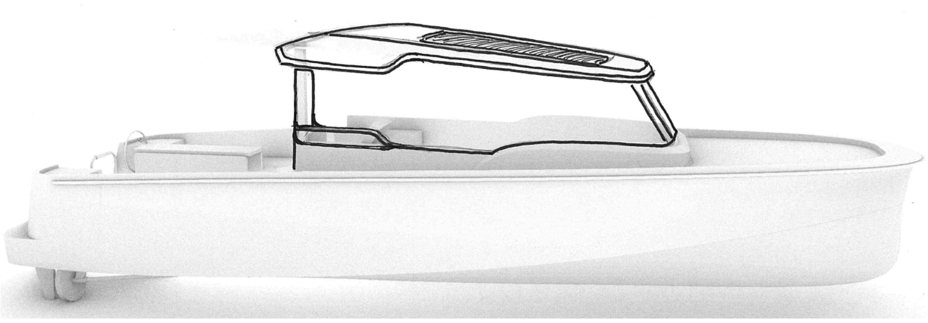


Figure 4.52: Sketch showing a developed design for a cabin with angled windscreen

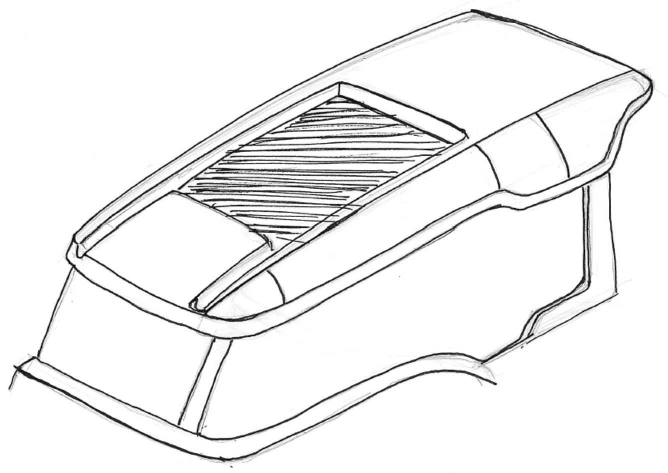


Figure 4.53: Sketch showing roof design

A sketch was also made for the design of the primary helm station located in the cabin which is seen in figure 4.54. It includes the dashboard and the positioning of the chart plotter joystick and throttle. The primary helm is further explained in the section of final concept design.

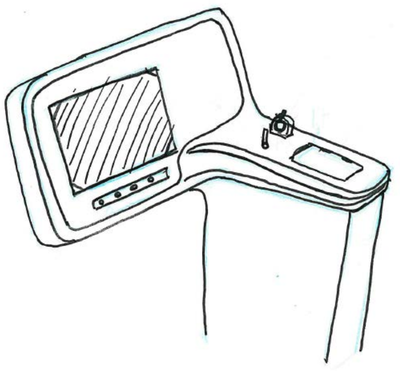


Figure 4.54: Sketch showing the dashboard for the primary helm

The other items designed was created directly in CAD and some design elements were brought directly from Nimbus existing models such as the radar mast, helm seat, anchor windlass and pantry components.

4.9 Final design of concept

The idea was to create a design seen in figure 4.55 that can be identified and recognized as a Nimbus while at the same time bringing some new design elements in. The bow can be recognized by the flare and wider bow deck to enable spacious access to the bow. The bow angle is straighter compared to current Nimbus models and this is made to achieve a greater waterline length. An anchor windlass integrated in the bow comes as an option depending on the customers desires. The foredeck is raised to achieve greater headroom for the accommodations. To ensure a safe passage between the bow and stern the boat is equipped with a generous railing along the foredeck as seen in figure 4.56. Hand rails can also be found along the roof of the cabin.

Figure 4.55: Render showing design of concept

Figure 4.56: Render showing a woman standing at the foredeck

The exterior cockpit seen in figure 4.57 is heavily inspired by sail boat cockpits with benches along the side that offers plenty of storage and a centralized table enabling outdoor dining for up to 6 persons. There is a secondary helm located furthest aft of the cockpit so that the skipper have the possibility to choose to maneuver the boat from the exterior or from the interior. Having the secondary helm position located aft of the passengers enables interaction between skipper and passengers. Even though the skipper is standing at the aft and driving and have the cabin in front, the field of vision is adequate for a secondary driver position as seen in figure 4.58.

Figure 4.57: Render showing exterior cockpit

Figure 4.58: Render showing view from exterior helm position

The cabin which is open to the back and easily closed of with a canvas has room for 6 persons sitting in the couches along the sides as seen in figure 4.59. The roof can be opened up to provide ventilation since the canvas can be retracted. A pantry equipped with running fresh water, a small stove, fridge and some storage is located on the port side. Further down is the bed that has room for two adults and the toilet compartment located to starboard as seen in figure 4.60.

Figure 4.59: Render showing full cabin interior

Figure 4.60: Render showing inner cabin interior

On the starboard side the primary helm is located seen in figure 4.61. Similar to the exterior helm the primary helm is located aft of the passengers sitting inside the cabin to enable a social environment. From this helm the boat is only steered with a joystick. When cruising the speed is controlled with a throttle and the joystick is used for steering simultaneously with the autopilot. When changing the course the joystick is pushed towards the desired direction and when release the autopilot keep the set course. For precision maneuvering in slow speed the joystick control both the engines rudders and bow thruster through a system to act simultaneously and cooperate to move the boat in any desired direction. This allows for a clean dashboard since there are no need for a dual throttle, bow thruster control or steering wheel at the primary helm.

Figure 4.61: Render showing primary helm position

4.10 Initial idea about concept manufacturing

This section covers the main materials used in the concept and how the structure is divided into molds.

4.10.1 Materials used in concept

A delimitation was made early on in the project that the boat should fit into Nimbus Groups manufacturing and assembly processes. Nimbus Group creates boats in both fibreglass and aluminium. Since a visit only was made to the Nimbus brand factory which creates fibreglass boats and the generated concept was decided to suit better under the Nimbus brand it was decided to design the boat using fibreglass for the structure.

Apart from the main structure there are other materials like stainless steel for grab rails and other details. The idea is that the deck should be covered by synthetic teak in favor of natural teak to limit the impact of deforestation. Wood panels are of teak veneer instead of solid teak for the same reason.

4.10.2 Dividing concept into molds

Throughout the design process the aspects of manufacturability were considered. Since the design is at a concept stage the idea is to show how the different main structure components are divided into molds and how they are connected. The components can be seen in figure 4.62 and have different colors which are explained in the list below.

- Green - Hull
- Gray - Main Deck
- Red - Hull Liner
- Purple - Deck liner
- Beige - Cabin deck
- Black - Pillars
- Turquoise - Roof

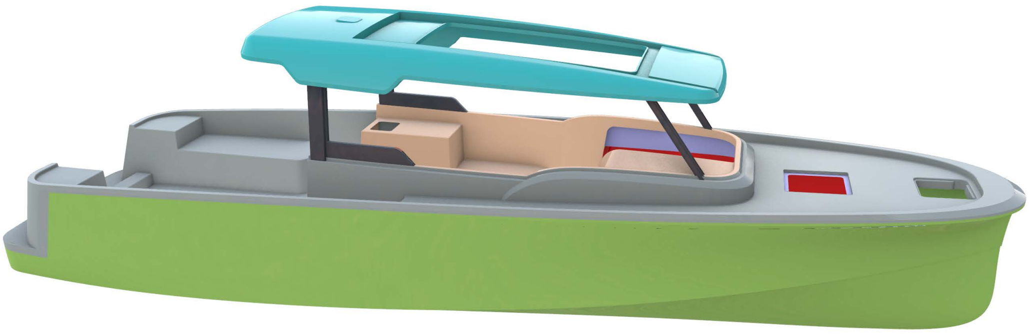


Figure 4.62: 3D model of boat with colors showing how it is divided into components

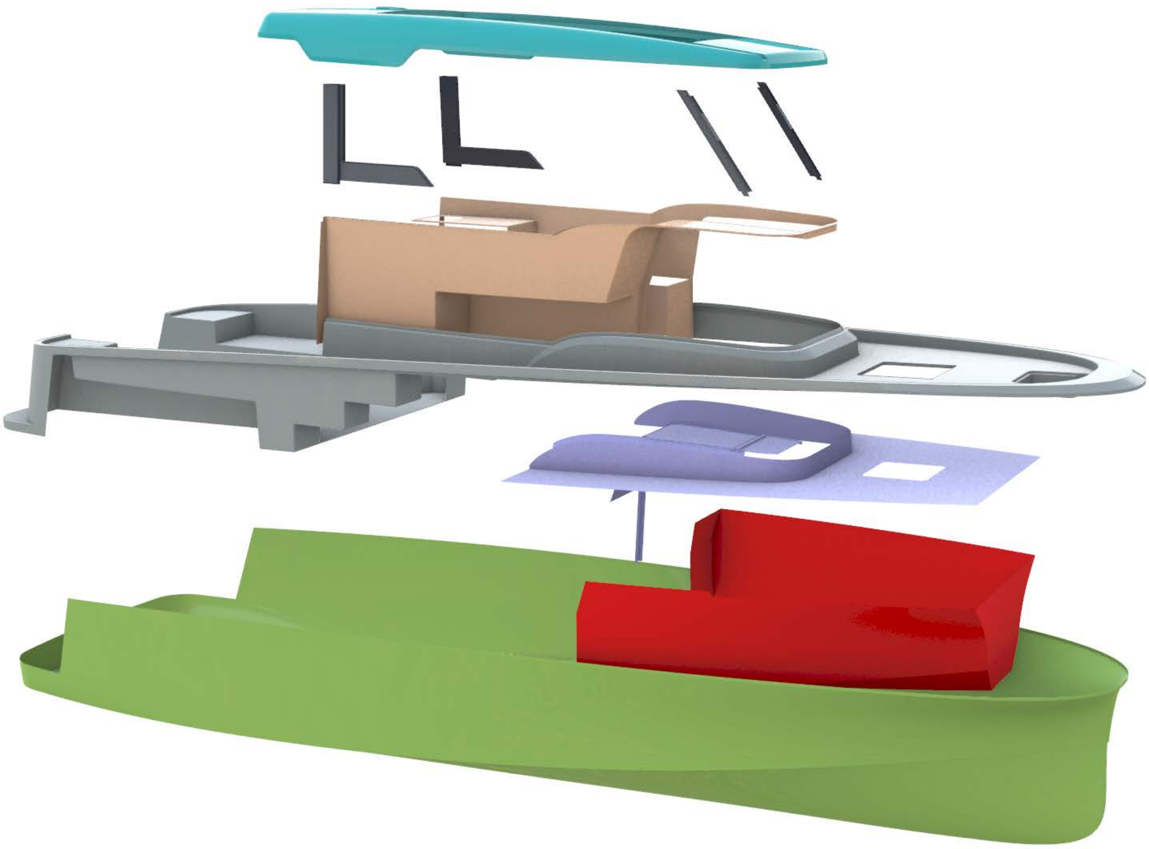


Figure 4.63: Exploded view of main components

An exploded view of the components can be seen in figure 4.63. Firstly the hull liner are mounted to the hull and then the deck liner and cabin deck is mounted to the main deck. Before assembling the hull and deck, installations of drive line, tanks and other items which can be mounted before decking are done. Then the pillars are mounted and lastly the roof.

4.11 Evaluation of concept

Some basic evaluations of the final concept has been conducted to identify if the electric boat is a viable option both environmentally and economically for someone desiring a boat for day use. Furthermore it is interesting to identify improvement areas in the design.

4.11.1 Environmental evaluation and comparison between electric and combustion propulsion

The environmental calculations performed are based on the example by Hoekstra (2020) for comparing the lifetime green house gas (GHG) emissions of electric vehicles with an equal gasoline or diesel vehicle. The formula has been adapted for boats and some variables has been excluded because of lack of data.

The main formula seen in equation 4.1 show how the emissions per nautical mile are calculated. Manufacturing emissions in this case relates to battery manufacturing were it is found that the production generates 75kg CO2eq per kWh. The boat is excluded from the calculations since it is the same boat being compared with either electric or diesel driveline. Because of unavailable information about emissions from driveline manufacturing the driveline has also been excluded from the calculations.

$$emissions\ per\ NM = \frac{manufacturing\ emissions + driving\ emissions}{NM\ driven} \tag{4.1}$$

The driving emissions for the electric propulsion are calculated with the formula seen in equation 4.2. The emissions per kWh at the charger are found in Hoekstra (2020), which is 0,25kg CO2eq per kWh.

$$driving\ emissions = boat\ energy\ use\ in\ \frac{kWh}{NM} \cdot electricity\ emissions\ per\ kWh \tag{4.2}$$

The energy in kWh required per NM is found by using the electric Pogo Loxo 32 as reference were it is known that it has a battery capacity of 53,2 kWh and a range of 28NM in 12 kts. The battery should have a depth of discharge at 80% meaning that the actual available battery capacity is 42,56 kWh. Then it is possible to calculate the required energy per nautical mile which is $\frac{42.56\ kWh}{28\ NM}$ that equals 1,52 kWh per NM. Driving emissions for the electric boat are then calculated to bee 0,38 kg CO2 per NM as seen in equation 4.3

$$driving\ emissions = 1,52 \cdot 0,25 = 0,38\ kg\ CO2\ per\ NM \tag{4.3}$$

The generated concept has a battery pack of 100 kWh which generates manufacturing emissions of 7500 kg C02eq which is added to the driving emissions for the first year of use for the electric concept boat.

The driving emissions for the diesel propulsion is calculated using formula 4.4. The fuel consummation for the reference boat, a Pogo Loxo 32 driving at 12 kts using diesel propulsion is 0,5 liters per hour. Once liter of diesel consumed in a marine engine generates approximately a total of 3.4 kg CO2eq. The driving emissions calculated in equation 4.5 thus equals 1.7 kg CO2eq per NM for the diesel propulsion.

$$driving\ emissions = boat\ energy\ use\ in\ \frac{liter}{NM} \cdot electricity\ emissions\ per\ liter \tag{4.4}$$

$$driving\ emissions = 0.5 \cdot 3.4 = 1,7\ kg\ CO2\ per\ NM \tag{4.5}$$

The distance driven for a common day boater is around 20 NM per day. A average amount of days a day boat is used in Sweden is 23,4 days per year based on a survey from the Swedish transport administration (Lagerqvist, 2020). The lifetime of a boat is difficult to determine so it is chosen to look at a 20 year period. Based on this data it is calculated that a average boat driver would drive 468 NM per year and during a 20 year period would drive 9360 NM. This is a very rough estimation since both the distance and amount of days were the boat is used varies for a real case.

The amount of propulsion related GHG emissions that has been emitted for the electric concept and the same concept using diesel propulsion is presented in table 4.17. The battery manufacturing emissions are displayed as abbreviation (BME), driving emissions as (DE).

Table 4.17: Table comparing GHG emissions for electric and diesel concept

Propulsion type →		Electric ↓	Diesel ↓
BME (kg CO2eq) →		7500	-
DE per NM (kg CO2eq) →		0,38	1,7
Year ↓	NM ↓	kg CO2eq	kg CO2eq
1	468	7677,84	795,6
2	936	7855,68	1591,2
3	1404	8033,52	2386,8
4	1872	8211,36	3182,4
5	2340	8389,2	3978
6	2808	8567,04	4773,6
7	3276	8744,88	5569,2
8	3744	8922,72	6364,8
9	4212	9100,56	7160,4
10	4680	9278,4	7956
11	5148	9456,24	8751,6
12	5616	9634,08	9547,2
13	6084	9811,92	10342,8
14	6552	9989,76	11138,4
15	7020	10167,6	11934
16	7488	10345,44	12729,6
17	7956	10523,28	13525,2
18	8424	10701,12	14320,8
19	8892	10878,96	15116,4
20	9360	11056,8	15912

From table 4.17 it is seen that the battery manufacturing emissions for a 100kW battery pack has a big impact on the emissions from the first years of use. For an average day boat user it will take 13 years for the electric boat to generate less GHG emissions compared to the same boat but with a diesel engine using 0,5 liters per NM.

4.11.2 Comparing GHG emissions for the concept and existing boats

To evaluate the GHG emissions from the concept against existing boats, calculations using equation 4.1 were conducted on three existing boats representing different categories. The boats included in the comparison seen in table 4.18 are the foiling Candela C8, planing X Shore Eelex 8000 and Bella Zero 6.1 which also is a planing boat but with a smaller battery. A diesel boat consuming 1,5 liter per NM is also included since it represents a planing boat with cruising speed around 25 kts.

Since the cruising range and battery capacity is known for the existing boats, were data can be seen in Appendix A, it is possible to calculate the required kWh per NM in cruising speed for the different boats and put it into equation 4.2 to generate the driving emissions (DE). The battery manufacturing emissions (BME) are calculated from the known battery capacities and the known value of 75kg CO2eq per kWh.

Table 4.18: Table comparing GHG emissions for concept and existing boats

Boat type →		Concept ↓	Candela C8↓	X Shore↓	Bella Zero 6.1	Diesel 0,5l/NM ↓	Diesel 1,5l/NM ↓
BME (kg CO2eq) →		7500	3300	9450	1950	-	-
DE per NM (kg CO2eq) →		0,38	0,176	0,83	0,495	1,7	5,1
Year ↓	NM ↓	kg CO2eq	kg CO2eq	kg CO2eq	kg CO2eq	kg CO2eq	kg CO2eq
1	468	7677,84	3382,368	9838,44	2181,66	795,6	2386,8
2	936	7855,68	3464,736	10226,88	2413,32	1591,2	4773,6
3	1404	8033,52	3547,104	10615,32	2644,98	2386,8	7160,4
4	1872	8211,36	3629,472	11003,76	2876,64	3182,4	9547,2
5	2340	8389,2	3711,84	11392,2	3108,3	3978	11934
6	2808	8567,04	3794,208	11780,64	3339,96	4773,6	14320,8
7	3276	8744,88	3876,576	12169,08	3571,62	5569,2	16707,6
8	3744	8922,72	3958,944	12557,52	3803,28	6364,8	19094,4
9	4212	9100,56	4041,312	12945,96	4034,94	7160,4	21481,2
10	4680	9278,4	4123,68	13334,4	4266,6	7956	23868
11	5148	9456,24	4206,048	13722,84	4498,26	8751,6	26254,8
12	5616	9634,08	4288,416	14111,28	4729,92	9547,2	28641,6
13	6084	9811,92	4370,784	14499,72	4961,58	10342,8	31028,4
14	6552	9989,76	4453,152	14888,16	5193,24	11138,4	33415,2
15	7020	10167,6	4535,52	15276,6	5424,9	11934	35802
16	7488	10345,44	4617,888	15665,04	5656,56	12729,6	38188,8
17	7956	10523,28	4700,256	16053,48	5888,22	13525,2	40575,6
18	8424	10701,12	4782,624	16441,92	6119,88	14320,8	42962,4
19	8892	10878,96	4864,992	16830,36	6351,54	15116,4	45349,2
20	9360	11056,8	4947,36	17218,8	6583,2	15912	47736

The concept boat and Bella Zero 6.1 is best compared to the diesel boat consuming 0,5 liter diesel per NM and X Shore and Candela is best compared to the diesel boat consuming 1,5 liter diesel per NM, if comparing from the perspective of cruising speed. As above the concept boat has a GHG emission pay off time of 13 years and Bella Zero a pay off time of 4 years compared to the diesel consuming 0,5 liter per NM. X Shore has a pay off time of 5 years and Candela a pay off time of 2 years compared to the diesel consuming 1,5 liter per NM. It is also seen that an effective diesel powered hull with a consummation of 0,5 liter per NM which is the case for the Pogo Loxo 32 has lower GHG emissions over the 20 year period than the X Shore. The foiling Candela which require a low kWh per nautical mile in cruising speed together with a moderate size battery has the lowest GHG emissions of all the boats compared.

4.11.3 Economic evaluation and comparison between electric and combustion propulsion

The economic evaluation is done to identify when and if it pays off economically for an average day boat user to own an electric boat, a table with the results is seen in table 4.19. The evaluation is done on the concept boat were a price has been estimated and then it is compared to an equal boat using diesel propulsion. Furthermore the same existing boats being compared in the GHG emission evaluation are compared from the economic perspective, the arbitrary high performing diesel boat in the GHG emission evaluation is replaced with a Nimbus W9 with a diesel consuming 1,2 liter per NM in cruising speed since an initial price for the boat is required. The assumed amount of average nautical miles driven per year are based on the same data as for the GHG emission evaluation, resulting in a yearly driven distance of 468 NM. The consummation in kWh per NM and liter per NM are based on the consummation at cruising speed. Yearly service costs for the diesel engine is included were the prices is based on standard service fee from a local marine engine service. Since the service cost of electric engines are nearly zero it is not included in the calculations.

Table 4.19: Table comparing costs over a 20 year period for electric and diesel driven boats

Boat type →		Concept ↓	Candela C8↓	X Shore↓	Bella Zero 6.1	Concept with diesel 0,5l/NM ↓ Volvo Penta D2-75	Nimbus W9 1,2l/NM ↓ Mercury Diesel 3.0L
Initial cost		2800000	3700000	3200000	600000	1800000	1800000
Yeraly servcie cost		-	-	-	-	6753	10000
Consumtion (kWh/NM) and (l/NM)		1,52	0,704	3,33	0,495	0,5	1,2
Cost (kWh/NM) and (l/NM)		1,5	1,5	1,5	1,5	24	24
Year ↓	NM ↓	kr (SEK)	kr (SEK)	kr (SEK)	kr (SEK)	kr (SEK)	kr (SEK)
1	468	2801067,04	3700494,208	3202337,66	600347,49	1812369	1823478,4
2	936	2802134,08	3700988,416	3204675,32	600694,98	1824738	1846956,8
3	1404	2803201,12	3701482,624	3207012,98	601042,47	1837107	1870435,2
4	1872	2804268,16	3701976,832	3209350,64	601389,96	1849476	1893913,6
5	2340	2805335,2	3702471,04	3211688,3	601737,45	1861845	1917392
6	2808	2806402,24	3702965,248	3214025,96	602084,94	1874214	1940870,4
7	3276	2807469,28	3703459,456	3216363,62	602432,43	1886583	1964348,8
8	3744	2808536,32	3703953,664	3218701,28	602779,92	1898952	1987827,2
9	4212	2809603,36	3704447,872	3221038,94	603127,41	1911321	2011305,6
10	4680	2810670,4	3704942,08	3223376,6	603474,9	1923690	2034784
11	5148	2811737,44	3705436,288	3225714,26	603822,39	1936059	2058262,4
12	5616	2812804,48	3705930,496	3228051,92	604169,88	1948428	2081740,8
13	6084	2813871,52	3706424,704	3230389,58	604517,37	1960797	2105219,2
14	6552	2814938,56	3706918,912	3232727,24	604864,86	1973166	2128697,6
15	7020	2816005,6	3707413,12	3235064,9	605212,35	1985535	2152176
16	7488	2817072,64	3707907,328	3237402,56	605559,84	1997904	2175654,4
17	7956	2818139,68	3708401,536	3239740,22	605907,33	2010273	2199132,8
18	8424	2819206,72	3708895,744	3242077,88	606254,82	2022642	2222611,2
19	8892	2820273,76	3709389,952	3244415,54	606602,31	2035011	2246089,6
20	9360	2821340,8	3709884,16	3246753,2	606949,8	2047380	2269568

It is seen in table 4.19 that neither of the electric boats pays off economically if taking the initial cost of the boat into account, for the average day boat user. The concept electric boat is compared to the same concept boat with a diesel consuming 0,5 liter. Over the 20 year period the electric concept boat's running costs are 21 340 kr compared to the diesel boat with a total running and service cost of 247 380 kr. If comparing the X Shore Eelex against the Nimbus W9 the X Shore has a running cost of 46 753 kr and the Nimbus W9 a running and service cost of 469 568. Even though the running costs of the Nimbus W9 is 10 times higher the total cost of the boat plus running the boat is less than the initial price of a X Shore Eelex 8000.

4.11.4 Design evaluation using virtual reality

Design evaluation using virtual reality was done in the 3D model with rendered materials. Using VR googles, it is possible to get an understanding for how the concept feel in reality since you get a perception of the available space. Through the VR environment it is possible to walk around in the model with a 360 view as you rotate your head. The areas that was evaluated are seen in the list below.

- Walk around the boat to test passages.
- Test the driver helm position for filed of vision and reachability.
- Sitting in couches and laying in bed

The areas that has been identified for improvements are that there is room to create more sleeping space if extending the bed under the couch on the port side. By doing this it should be possible for three adults or two adults and two children to sleep aboard.

The aft support for the railing can be moved forward to generate more space for the hips when acceding and descending the stairs from the sidewalk to the cockpit. It also generates an improved possibility to enter the boat from the side since the height difference will be reduced.

5
Discussion

This chapter brings up reflections about the development process, the methods used and reflection of the results and evaluations.

5.1 Market study

The market study done on existing boats are based on data found in news articles and data from the manufacturers. Some of the data might be theoretical approximations and some data might not represent the true performance of the boat. The list with data comparing performance of electric boats in appendix X should therefore not be seen as a 100% truthful representation when it comes to performance.

The customer needs survey was open for world wide respondents. However it was mostly northern Europeans that responded on the survey, consisting of 73% of the total respondents. This lead to the global view of day boating and electric boats being skewed to a northern European point of view. Southern Europe only had 12 respondents out of 733 and this might be due to the platforms used to reach out with the survey were more targeted at northern Europeans.

The most desired day boat type according to the survey is the Cabin boat. If looking at Sweden specifically cabin boats is not the most common day boat type from my personal experiences of boating at both the Swedish east and west coast. It is more common with open console boats, daycruisers and bowriders for day boating. One reason for the cabin boat being the most desired might be that the survey took place in February when it is winter in northern Europe, if it would have been summer and nice weather the result could have turned out differently.

It was found that 70% of the day boat users in northern Europe desired day boats with sleeping possibility. However sleeping aboard is something which in reality rarely takes place on a day boat. Many boat users with day boats that have sleeping possibility instead use the sleeping compartment for storage. The user think they want to sleep and therefore buy a boat with sleeping possibility, when in most cases in reality they go out for short day trips and then go back to sleep comfortably at home.

5.2 Development process

In the concept development and selection process some sessions were held to evaluate and rank concepts based on criterions, and also ranking the criterions. This was done in a group consisting of myself and three representatives from Nimbus Group, the CTO, chief designer and a project manager. The reason for this was to take more objective decisions in the process. However it is important to bring up that the representatives are all within Nimbus Group and likely have principles of what makes good boats based in Nimbus principles. To reach an even more objective decision it would have been better to include independent persons with different experiences of what makes a good boat. Furthermore everyone involved in the evaluation process were men, which also might have an impact on the decisions.

The detailed design process after the basic concept had been chosen differs from the early concept development process using combination matrices and tables for evaluation to make decisions. Instead a quicker process were used were one or a few sketches were made and then directly created in the 3D model after either a quick single handed decision or after brief discussion with someone from Nimbus. In theory the same process as for the early concept stage could have been used for some elements like the design of the helm station or roof but that would have been very time consuming. In a project were you are only focusing on for example creating the helm station a process using morphological matrices and evaluation tables could have generated a helm station with higher inventiveness. Furthermore more design iterations of different design elements could have been created to explore potential better forms. However the emphasis is not on creating the best looking final design of a boat, it is more about showing the concept idea and the functionality.

The selection of the final concept could have been further supported by GHG emission calculations if these would have been conducted prior to the choosing of a single concept for further development. If calculations had been made for each of the 10 basic concepts it might have turned out with another choice since it was later identified that bigger batteries has a large impact on the environmental pay off time. Choosing concept with the environment as the highest priority would instead have resulted in either basic concept 1 or basic concept 8, each with around 60kWh battery. However this only concerns the environmental perspective, even though the environmental aspect is being of high importance there are many other aspects that speaks for the chosen concept.

5.3 Reflections about final concept

The idea with the concept was to create a boat that users see as something more than a transportation from point A to point B. Inspirations have been taken from sail boats were passengers sits along the sides and the helm position is located aft. In this case there are two helm positions, one inside and one outside, both located aft of the passengers position to enable a social environment. The focus is then moved away from the driving itself to enjoying the time spent onboard. This is likely to generate a less need for driving boats in high speeds, which is not optimal when having a limited amount of battery capacity. The internal helm position has no wheel and the boat is only steered from here with a joystick. Many traditional boaters might find that they will miss the steering wheel. However a big steering wheel is included at the aft outdoor helm position to enhance the feeling of driving a sailboat.

The layout should provide flexibility to enjoy the boat in any weather. The cabin open to the back generates an indoor-outdoor feeling and is quickly enclosed with canvas if cruising in rough weather or perhaps a cold autumn day. During nice hot summer days the roof can be opened up for ventilation.

5.4 Environmental and economic evaluation

The environmental evaluation were GHG emissions were calculated for electric and diesel boats showed that the electric boats pay off for the environment in the long term if comparing to equal diesel driven boats. It also shows that the manufacturing of the batteries has a big impact of the overall GHG emissions caused by an electric boat over its lifetime. The smaller battery, the quicker the environmental pay off for the electric boat compared to diesel propulsion.

It is seen that a diesel driven boat that is efficient and consumes around 0,5 liter per NM in cruising speed emits less green house gas than an electric planing performance boat in cruising speed with a big battery pack and high energy consummation. This shows that going electric does not necessarily mean going more environmentally friendly than diesel propulsion, if diesel propulsion is used on efficient hulls with slower cruising speeds. This assumption is based on the average day boat user driving around 468 NM per year and would have a different outcome benefiting the electric performance boat for a user that drive longer distances and more often.

It is also seen that the foiling boat has the lowest GHG emissions of all the boats being compared. This show that limiting battery size and required energy need to maintain cruising speed is highly beneficial from an environmental perspective.

The generated concept boat has a GHG emission pay off time of 13 years for an average day boat user, compared to the equal boat with diesel propulsion consuming 0,5 liter per NM. This is a rather long environmental pay off time for the initial buyer. This could be lowered by decreasing the battery size to decrease the manufacturing emissions from the battery. If decreasing the battery pack to 60 kWh the environmental pay of time would be 7 years instead.

All the calculations are done assuming a boat usage of 20 NM per day and that day boats is used in average 23,4 days per year in Sweden. It is also assumed that the boats are constantly maintaining a cruising speed. This assumptions are not a realistic representation of how boats actually are used, the speed often varies a lot as well as distances traveled. Furthermore it is a simplified formula that is not including the manufacturing emissions of boat and driveline, apart from the manufacturing emissions for the battery. Therefore the results should not be seen as a definite amount of emissions since the result will differ a bit when everything is taken into account.

The economic calculations show that for an average day boat user it is not beneficial to buy an electric boat if you want the long time pay off of cheap running cost to compensate for the higher initial price. However, a boat being used for work related services such as a taxi boat is being used considerably more than an average day boat and are likely to generate economic benefits over the lifetime.

6
Conclusion and further work

In this chapter some summarizing conclusions from this project are presented, followed by recommendations for further work.

6.1 Conclusions

The generated concept design is based on well tested hull designs that has good performance at most speed registers. Using these as references and further developing them should result in a hydrodynamically efficient hull without any distinctive planing threshold that meets the demand on both speed and range. Furthermore the social layout should invite the users to spend more time one the boat and see the boat ride as more than just a transportation from point A to point B. This are likely to lead to peaceful cruising in slower speeds resulting in greater distances being reached.

For an average day boat user it is found that an electric boat is not benefiting economically over the lifetime due to the high initial price of the driveline. Even though the running costs are considerably lower the low amount of boat usage for the average day boat user is not enough to break even with the lower initial price and higher running costs of the combustion boats. For an electric boat to pay off economically over the life time it should be driven often and longer distances.

It is found that all electric boats are benefiting the environment compared to equal combustion engine boats. The biggest environmental impact from the electric boat comes from the battery manufacturing, which shows that small batteries and low energy consummation are preferable instead of large battery packs to compensate for the low energy density compared to fossil fuel. It was also found that for the average boat user, a diesel boat with low fuel consummation around 0,5 liters per NM emits less green house gas over the lifetime compared to a boat with a large battery pack of over 100kWh. This also show that the amount of usage has an impact on when to reach the break even point of when the electric boat is better for the environment.

6.2 Further work

The project is developed at a concept level and should serve as a guidance to Nimbus Group to suggest how to further approach the electric boat market. To further develop the concept hydrodynamic calculations and tests should be performed to verify and adapt the hull design. A full scale mockup of the suggested design should be built to test the space and ergonomics. If bringing the boat into production it needs to be engineered on a detailed level. The material choices should be further evaluated to make sure that sustainable materials are chosen.

The concept had a long environmental pay off time due to the large battery pack of 100kWh, compared to the efficient hull only consuming 0,5 liter diesel per NM in cruising speed. Therefore it is recommended to decrease the battery size for an average day boat user to around 60kW since it would still be enough for their day boating needs. A boat owner that use the boat often and for long distances might still desire the bigger battery pack since the environmental pay of time is decreased as a result of increased use. Therefore it might be interesting to offer the boat with two different sizes of battery pack, since the system is modular and could be configured differently depending on the user needs.

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A

Appendix: List of data of electric boats

The following pages present the list of data of electric boats

Boat	Price	Lenght	Width	Draft (lowest)	Weight (with driveline	Hull type	Cruising speed	Max speed	Low speed range	Cruising speed range	Max speed range	Engine model	Engine Capacity	Battery model	Battery Capacity
Model name	tkr	m	m	m	kg	-	kts	kts	NM	NM	NM	-	kW	-	kWh
Alfastreet marine															
21 open		6,3													
23 Cabin EVO		6,93	7,8		2100								30		
28 open		9,84	2,97		4300								36		
Aquawatt															
aquawatt 717 classic sport		7,17	2,25	0,5		Semi displacement	6	15		50			25		
aquawatt 848		8,5	2,5	0,5	1700	Semi displacement		22					80	Lithium Ion	
ARC boats															
ARC ONE	2711	7,3	2,6			Planing		35			20		350		200
Boesch															
Boesch 620		6,5	2,15	0,55	1250	Planing	21	31		27	23	Piktronik	100	Lithium Ion	75
Candela															
Candela C-7	2500	7,7	2,4	0,7	1300	Foiling	22	30		50	32		55	Lithium ion BMWi3	40
Candela C-8	3700	8,5	2,5	0,5	1605	Foiling	24	30		50		Candela C-pod	50		44
Dutch craft															
DC25		8	2,4	0,4			6	30		31			100		89
Edorado															
Edorado 8s		8,4	2,5	0,45	1905	Foiling	25	38		40	30		100		80
Elwood															
550e	600	5,5	1,5	0,6	740	Semiplaning	5	10		50	14	Oceanvolt	8		11,4
650e	840	6,5	1,65	0,65	1200	Semiplaning	5	11		55	14,6	Oceanvolt	10		13,3
750e	1100	7,5	1,8	0,7	1600	Semiplaning	5	12		60	15,8	Oceanvolt	13		17,1
950e	2000	9,5	2,3	0,7	2170	Semiplaning	7	13		80	35	Oceanvolt	20		57,6
Frauscher															
610 San Remo	625	6,1	1,8		750	Semi displacement	5	11		43	12,4		15	Lithium Ion	22
650 Alassio	975	6,5	2,17		950	Semi displacement		18	42		10	Torqeedo	60	Lithium ion BMWi3	40
740 Mirage	3400	7,47	2,5		1900	Planing		26	60		17	Torqeedo	110	2x Lithhium Ion BMWi3	80
Ganz boats															
Ovation 6.8E		6,8	2,35		1600	Planing				21			150	Lithium Polymer	100
Ovattion 7.6E		7,65	2,5		1600	Planing		32					200		150
Green waves															
GW 630X	722	6,3	2	0,5	900	Semi displacement		15					30		30
Hinckley yachts															
Dasher electric	4500	8,7	2,6	0,6		Semi displacement	7	23,5		35				Lithium ion BMWi3	80
Hydrolift															
Hydrolift E-22	1600	6,68	2,3		1500	Planing	23	40	35	23		Evoy	111		65

Boat	Price	Lenght	Width	Draft (lowest)	Weight (with driveline	Hull type	Cruising speed	Max speed	Low speed range	Cruising speed range	Max speed range	Engine model	Engine Capacity	Battery model	Battery Capacity
JR yachts															
Domani E32	2820	9,5	2,7		2000	Semi displacement	8	20	108	96	24		50		75
Classic 7	908	7,5	2,5		800	Semi displacement		10	75	38	25		8		23
Jr X8	1252								170				36		110
Isloep															
Rapida 777		7,77	2,35	0,55	1450	Semi displacement	5	17	80	65					
Laneva															
Laneva Vesper		8	2,5	0,73		Semi displacement	15	25		45	30	Laneva	90	2x60	120
Magonis															
Magonis Wave e-550	750	5,5	2	0,3				22				MAG Power 30 RL	30		28,65
Marian															
Eclipse 580		6,15	1,8		750	Semi displacement	8	12	55	16	12,4		20	Lithium Ionen	25,7
Magic 640		6,4	2,2		1000	Planing	16	28	164	26	17,3	Piktonik	100	Lithium Ionen	83,7
Laguna 760		7,6	2,3		1200	Planing	16	28	270	36	22	Piktronik	125	Lithium Ionen	125
M 800	3700	7,9	2,5		1300	Planing	16	34	270	36	21	Piktronik	150	Lithium Ionen	125
Merione															
Merione 22		6,8	2,25			Semi displacement	6	20		35	20	Torqeedo Deep blue 80	50	Lithium BWM	32
MY Electroboat															
MY-Elegance S		7,1	2,34	0,7	1100	Planing							100		
Nautique															
Supreme Air Nautique Gs22E	2800	7,35	2,54		2976	Planing	20	37,5	124	35	30	Ingenity	150		124
Navier boat															
Navier 27	2500	8,2	2,6			Foiling	18	30	75				100		
Nimbus Group															
Bella Zero	500	6,3	2,45	0,5	1250	Semi displacement	6	11	55	30	8	Stream propulsion	33		25,9
Orust Eboats															
Strana	1500	7	2,25			Semi displacement	8	15	200	67	23	SeaDrive	15	MG	28,8
Pixii															
Pixii SP800															
Q-yachts															
Q-30	2350	9,3	2,2	0,6	1600	Semi displacement	9	14	60	42	17	2x Torqeedo Cruise po	20	Lithium ion	30
Clubb 24		7,2				Displacment	6			78					27
Rand boats															
Mana 23	750	7,2	6,3	0,25		Semi displacement	7	15			30	E-drive	15	Lithium ion	40
Play 24	1870	7,4	2,5	0,3		Planing	10	32			15	E-drive	180	Lithium ion	86
Spirit 25	2023	7,5	2,55	0,37	1250	Planing	20	36	80		17	E-drive	180	Lithium ion	86
Supreme 27	2500	8,44	2,6	0,35	1550	Planing	21	35	100		16	E-drive	250	Lithium ion	117
Escape 30	3075	9,95	2,89	0,53	3000	Planing	26	35	60	25	15	E-drive	230	Lithium ion	113
Twin vee															
240 Electric		7,3	2,6			Catamaran	20	40	70				320		140
Vision Marine															
Bruce 22	1900	6,7	2,08	0,45	1000	Planing						E-motion	134	Lithium ion	72
Vita yachts															
Vita Lion		10,5				Planing	22	35				Vita Power	440		
X Shore															
Eelex 8000	3200	8	2,5	0,8	2600	Planing	20	30+	100	30	16	Brusa	225	2x Kreisel Lithium ion	120
Pogo															
Loxo 32		9,5	2,55		1800	Semi displacement	8	14		60	25	Ocean Volt SD15	30	Lithium ion	53
Jakt 12 Electric (theoretical)	3500	12	2,85	0,6	2000	Semi displacement	15	20	100+	70	34		60	Lithium ion	120

B

Appendix: Interview questions for electric propulsion suppliers

The following page present the questions asked in the interview of electric propulsion suppliers.

Interview questions template (Sales)

Company name:

Interviewee name:

Question 1: Give a short introduction to the company

Answer:

Question 2: What do you offer (engine, complete drive line system)

Answer:

Question 3: What components are included in your system?

Answer:

Question 4: Is it possible to use other batteries than the ones you have as a standard with your system?

Answer:

Question 5: How do you ensure user friendly products. Describe how your user interface works?

Answer:

Question 6: How does the process of starting the boat look like?

Answer:

Question 7: What do you offer in term of service?

Answer:

Question 8: Are your system compatible with fast charging?

Answer:

Question 9: How does the price model look for a boat manufacturer that would series production boats with your driveline?

Answer

Question 10: Is the system CE certified?

Answer

Question 11: Imagine a scenario where I'm a customer that are considering buying a new engine, and are considering whether to buy a combustion engine or electric engine, can you give me some reasons why I should buy an electric engine, and why I should choose (Name of company).

Answer:

C
Appendix: Customer survey

The following pages present the customer survey.

NIMBUS GROUP

ALUKIN AQUADOR BELLA FALCON FLIPPER NIMBUS PARAGON YACHTS

Customer study for an electric day boat

Survey information

Following customer study is a part of a Master thesis project between Nimbus Group and Chalmers University of Technology, aimed at developing a concept for an electric day boat.

Definitions:
Dayboat: A boat used for cruising a few hours, up to a day.
Cruising speed: The speed which is comfortable and economical

* 1. Choose your location

- ○ Northern Europe
- ○ Central Europe
- ○ Southern Europe
- ○ Northern U.S./Canada
- ○ Southern U.S.
- ○ Oceania
- ○ Other (please specify)

* 2. Chose your age interval

- ○ 18-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65+

* 3. Do you use/own, or have previously used/owned a boat?

- ○ Yes
- ○ No

* 4. What type of boats do you use/own, or have previously used/owned?

- [ ] Motorboat (Fossil fuel)
- [ ] Electric boat
- [ ] Sailboat
- [ ] Other boat type (please specify)
- [ ] I haven't used/owned a boat

* 5. What is for you a desired size of day boat

- 5-6m (16-20ft)
- 6-7m (20-23ft)
- 7-8m (23-26ft)
- 8-9m (26-29ft)
- 9-10m (29-32)
- 10m+ (32ft+)

* 6. What is for you a desired cruising speed for a day boat

- 4-7 (kts)
- 7-10 (kts)
- 10-15 (kts)
- 15-20 (kts)
- 20-25 (kts)
- 25+ (kts)

* 7. What do you see as a decent maximum speed for your day boating needs?

- 5-10 (kts)
- 10-15 (kts)
- 15-20 (kts)
- 20-25 (kts)
- 25-30 (kts)
- 35+ (kts)

* 8. What is a required range (Nautical Miles) for your day boating needs? (Consider an electric boat with a whole day of use without charging)

- 10-20 NM
- 20-30 NM
- 30-40 NM
- 40-50 NM
- 50-75 NM
- 75-100 NM

* 9. Choose one of the following statements that best fit your way of boating

- ◯ I mainly see boating as a mean of transportation and like going fast from point A to point B
- ◯ I mainly see boating as a way of relaxation and like spending time on the boat

10. What activities do you do with/on your day boat

	Very often	Often	Rarely	Never
Commuting	◯	◯	◯	◯
Sunbathing	◯	◯	◯	◯
Swimming	◯	◯	◯	◯
Water sports	◯	◯	◯	◯
Fishing	◯	◯	◯	◯
Cooking	◯	◯	◯	◯
Dining	◯	◯	◯	◯

* 11. Choose which boat type that would suit your day boating needs the best. (Notice that the focus is on boat type, and not the boat on the picture itself)

Walk Around/Center Console

Side Walk

Cabin

Day Cruiser

Bow Rider

Sloep/Snipa

* 12. Answer whether the following is very important, important or not important for your day boat.

	Very Important	Important	Not Important
Sleeping possibility	◯	◯	◯
Weather protection	◯	◯	◯
Sun shading	◯	◯	◯
Sun bed	◯	◯	◯
Air conditioner	◯	◯	◯
Toilet	◯	◯	◯
Water tank	◯	◯	◯
Wet bar	◯	◯	◯
Fridge	◯	◯	◯
Shower on stern/transom	◯	◯	◯
Anchor windlass Bow	◯	◯	◯
Anchor windlass Stern	◯	◯	◯

* 13. In which case would you consider buying/using an electric boat instead of a fossil fuel driven boat?

◯ If the electric boat costs considerably more and has decent performance but running costs are less.

◯ If the electric boat is equal in price but I have to compromise on performance.

◯ Only if the electric boat is equal or lower in price and has same or better performance.

◯ I would only consider buying an electric boat if forced by regulation.

◯ I would never consider using an electric boat.

* 14. Which, if any, of the following reasons describe why you would consider buying an electric boat?

☐ To protect the environment

☐ Low running costs

☐ Reduced cost of fuel

☐ I like to travel in silence

☐ I like using the latest technology

☐ Nothing of above

* 15. Which, if any, of the following reasons describe why you would not consider buying/using an electric boat?

- [ ] Initial cost is higher
- [ ] Not enough charging stations
- [ ] Charging time too long
- [ ] Low range at full charge
- [ ] Low performance in terms of speed
- [ ] Nothing of above

16. What importance do you see the following statements have when choosing a boat.

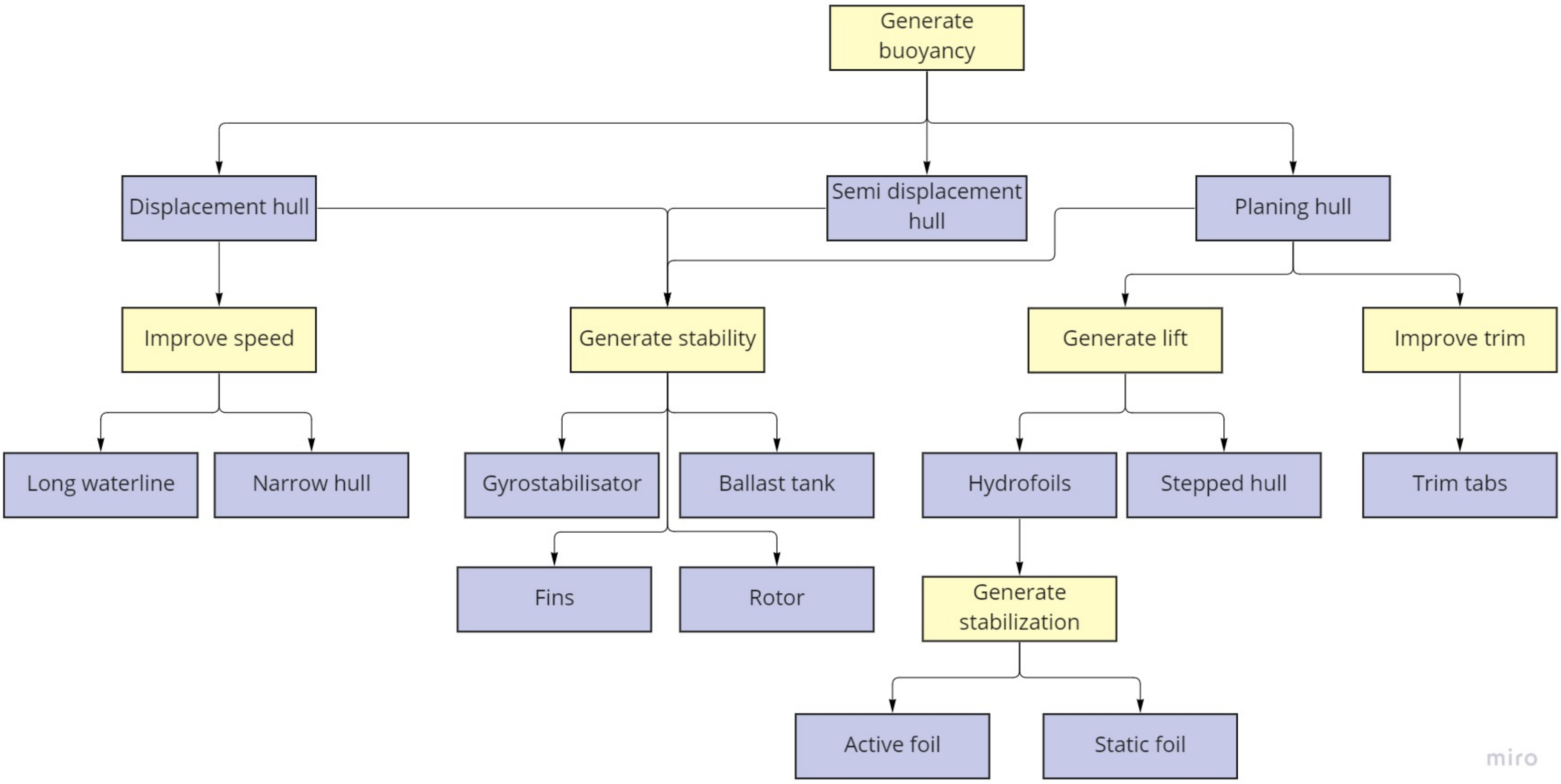
	Very Important	Important	Not Important
Boat is built in sustainable materials.	○	○	○
Boat has low impact on water environment.	○	○	○
Low production emissions from boat manufacturing.	○	○	○
The brand of the boat has a high environmental profile.	○	○	○
Material waste are limited and recycled in the production process.	○	○	○
Renewable energy is used in the manufacturing process.	○	○	○

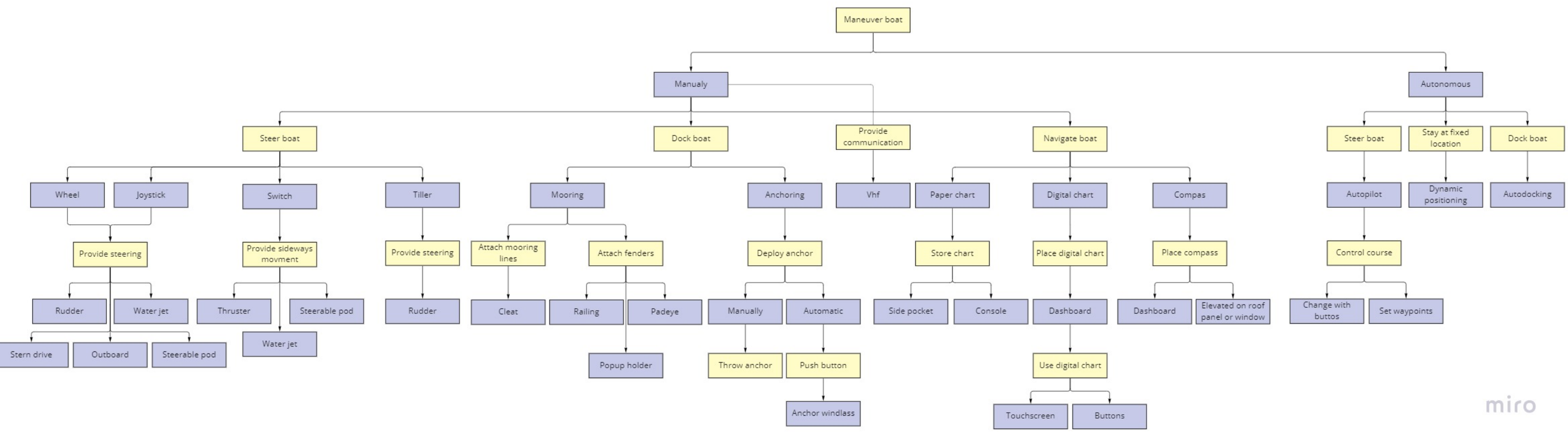
Thank you for your time!

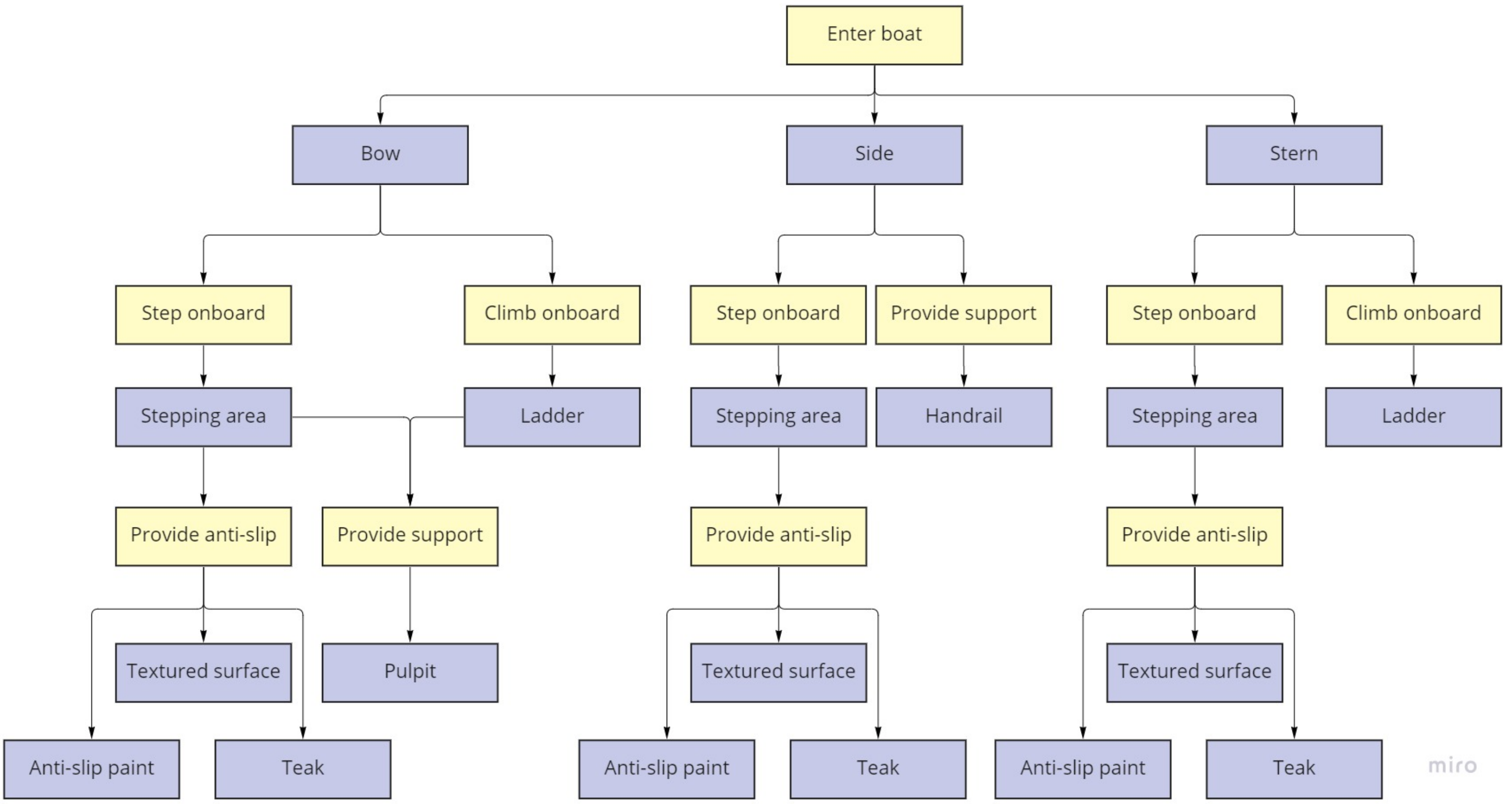
D

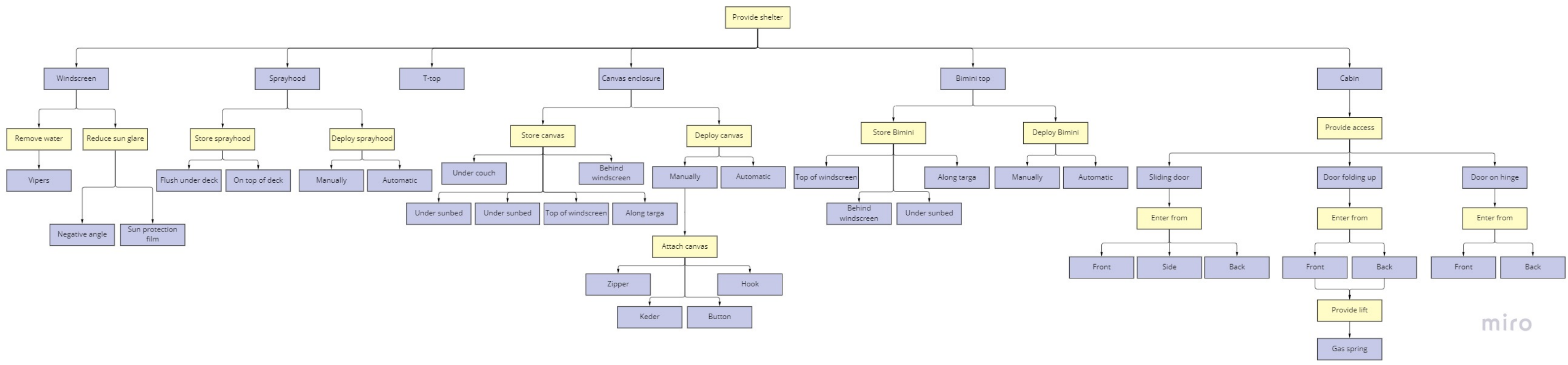
Appendix: Function means tree

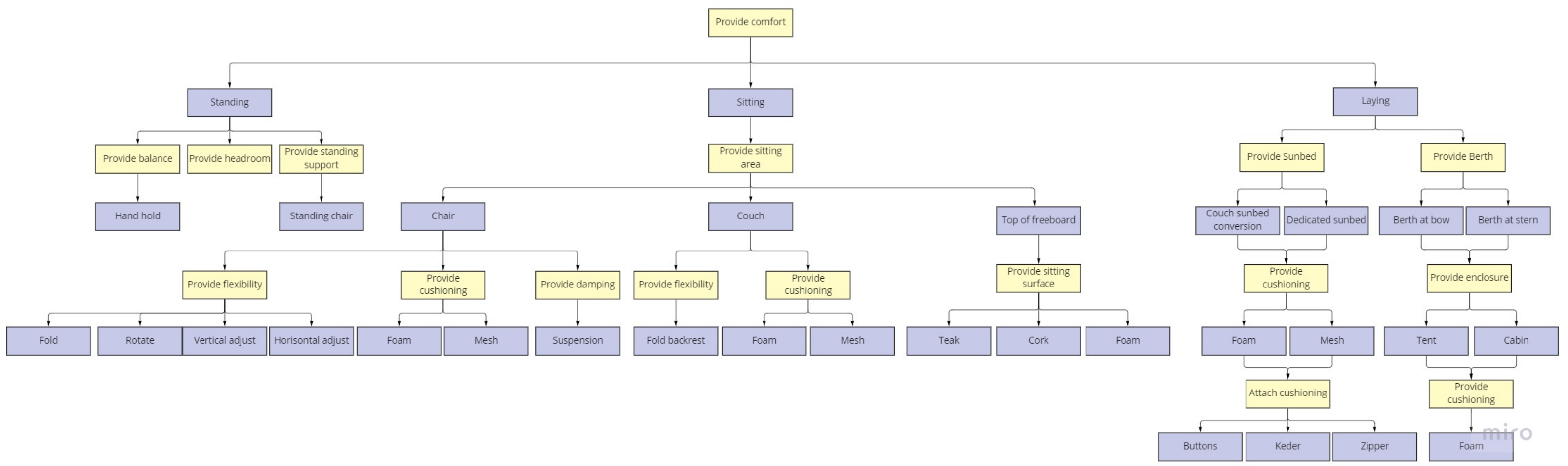
The following pages present the function mean sub-trees

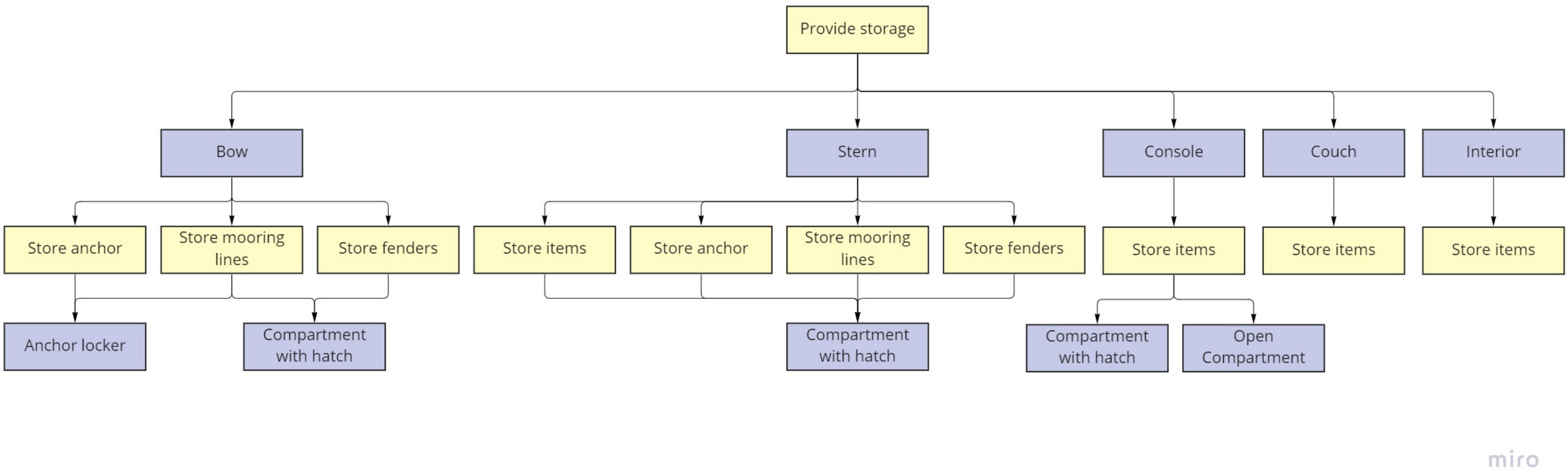


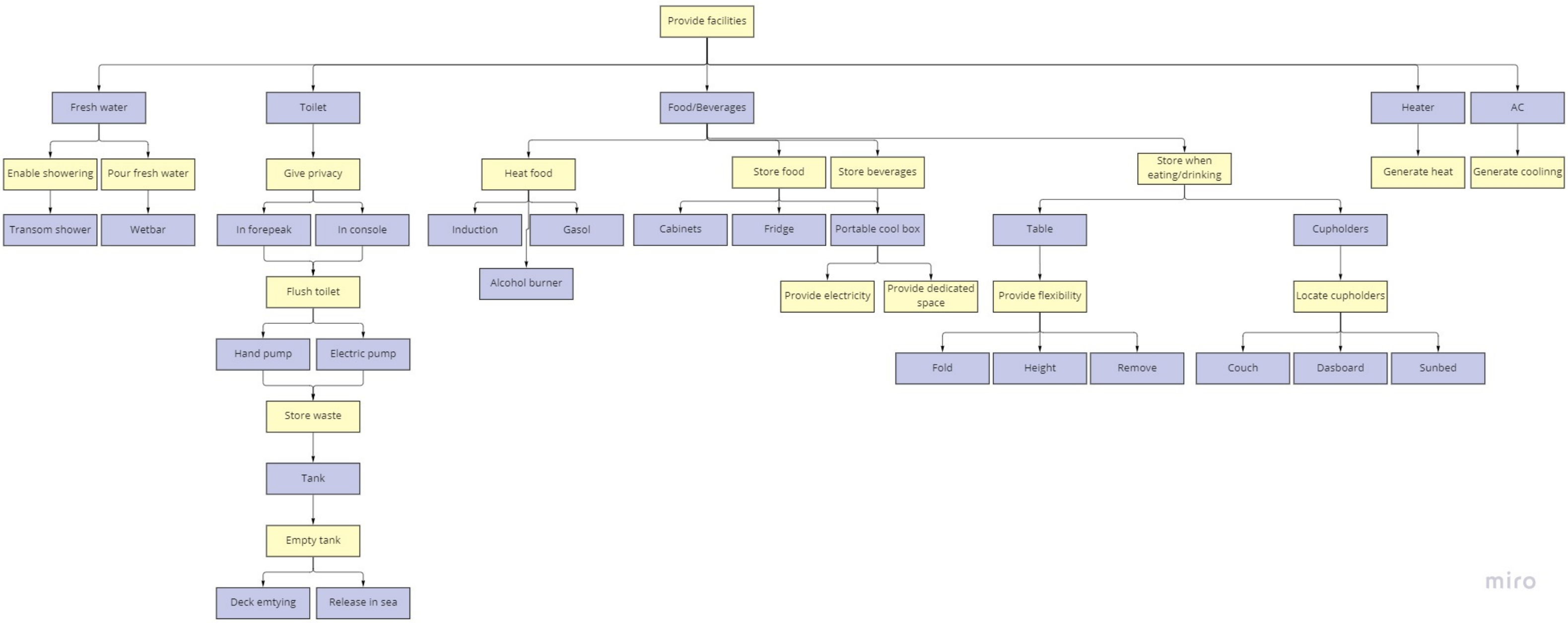


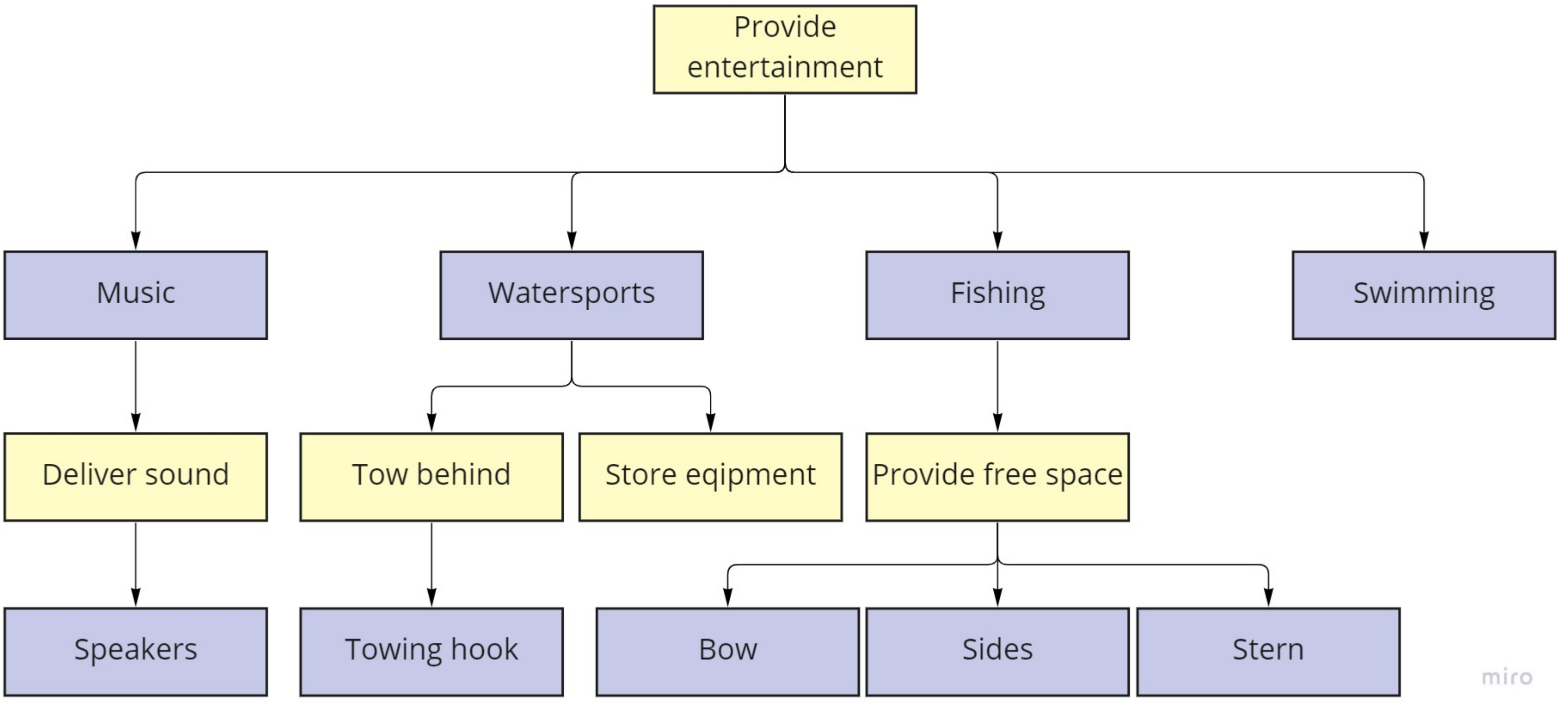

Enter boat
Bow
Side
Stern
Step onboard
Climb onboard
Step onboard
Provide support
Step onboard
Climb onboard
Stepping area
Ladder
Stepping area
Handrail
Stepping area
Ladder
Provide anti-slip
Provide support
Provide anti-slip
Provide anti-slip
Textured surface
Pulpit
Textured surface
Textured surface
Anti-slip paint
Teak
Anti-slip paint
Teak
Anti-slip paint
Teak


Provide shelter
Windscreen
Sprayhood
T-top
Canvas enclosure
Bimini top
Cabin
Remove water
Reduce sun glare
Store sprayhood
Deploy sprayhood
Store canvas
Deploy canvas
Store Bimini
Deploy Bimini
Provide access
Vipers
Flush under deck
On top of deck
Manually
Automatic
Under couch
Behind windscreen
Manually
Automatic
Top of windscreen
Along targa
Manually
Automatic
Sliding door
Door folding up
Door on hinge
Under sunbed
Under sunbed
Top of windscreen
Along targa
Behind windscreen
Under sunbed
Enter from
Enter from
Enter from
Negative angle
Sun protection film
Attach canvas
Front
Side
Back
Front
Back
Front
Back
Zipper
Hook
Keder
Button
Provide lift
Gas spring


Provide comfort
Standing
Sitting
Laying
Provide balance
Provide headroom
Provide standing support
Provide sitting area
Provide Sunbed
Provide Berth
Hand hold
Standing chair
Chair
Couch
Top of freeboard
Couch sunbed conversion
Dedicated sunbed
Berth at bow
Berth at stern
Provide flexibility
Provide cushioning
Provide damping
Provide flexibility
Provide cushioning
Provide sitting surface
Provide cushioning
Provide enclosure
Fold
Rotate
Vertical adjust
Horisontal adjust
Foam
Mesh
Suspension
Fold backrest
Foam
Mesh
Teak
Cork
Foam
Foam
Mesh
Tent
Cabin
Attach cushioning
Provide cushioning
Buttons
Keder
Zipper
Foam


Provide storage
Bow
Stern
Console
Couch
Interior
Store anchor
Store mooring lines
Store fenders
Store items
Store anchor
Store mooring lines
Store fenders
Store items
Store items
Store items
Anchor locker
Compartment with hatch
Compartment with hatch
Compartment with hatch
Open Compartment
miro


Provide facilities
Fresh water
Toilet
Food/Beverages
Heater
AC
Enable showering
Pour fresh water
Give privacy
Heat food
Store food
Store beverages
Store when eating/drinking
Generate heat
Generate cooling
Transom shower
Wetbar
In forepeak
In console
Induction
Gasol
Cabinets
Fridge
Portable cool box
Table
Cupholders
Alcohol burner
Flush toilet
Provide electricity
Provide dedicated space
Provide flexibility
Locate cupholders
Hand pump
Electric pump
Fold
Height
Remove
Couch
Dasboard
Sunbed
Store waste
Tank
Empty tank
Deck emtying
Release in sea
miro


Provide entertainment
Music
Watersports
Fishing
Swimming
Deliver sound
Tow behind
Store eqipment
Provide free space
Speakers
Towing hook
Bow
Sides
Stern
miro

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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