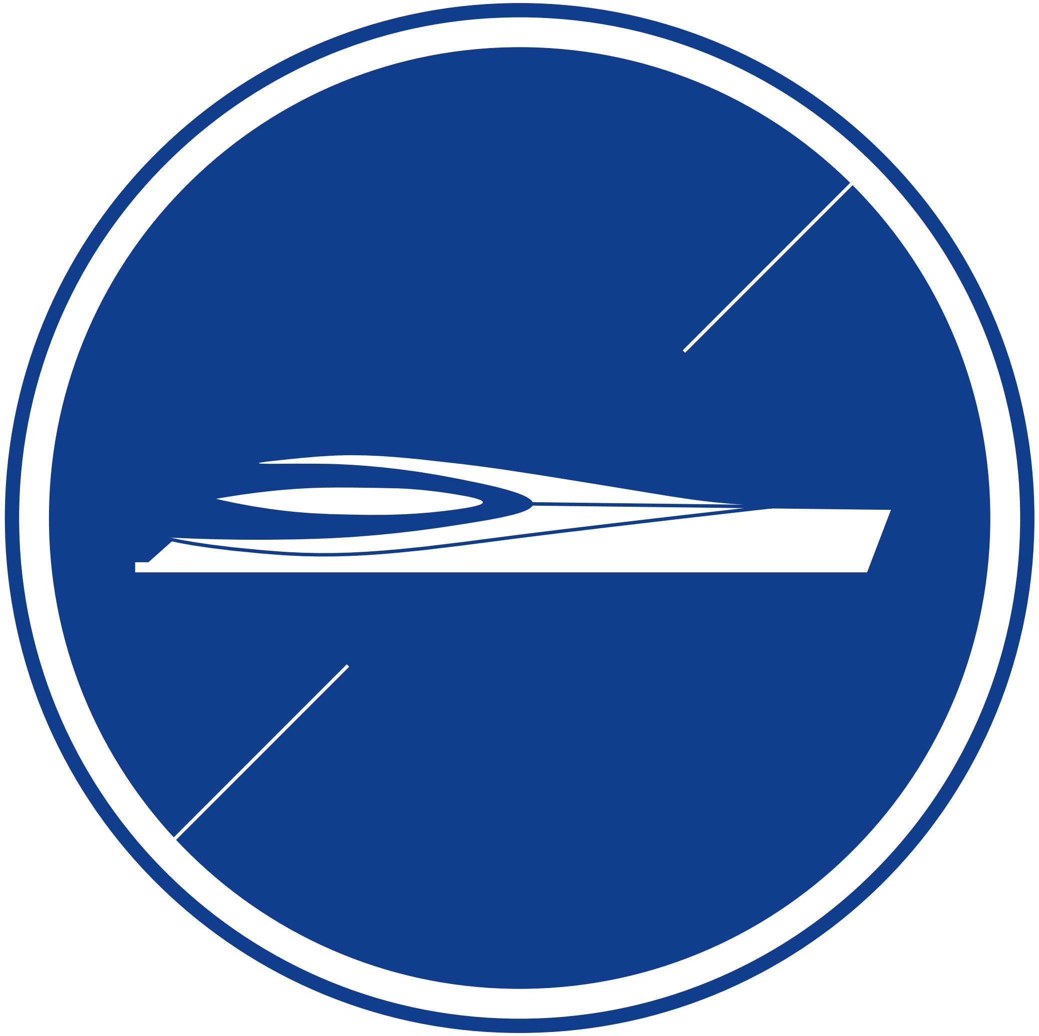
design of a

FULLY ELECTRIC SUPER YACHT



FEADSHIP ROYAL DUTCH SHIPYARDS / TU Delft / DE VOOGT NAVAL ARCHITECTS /

Rob Akershoek

TABLE OF CONTENTS

PREFACE

Before you lies the dissertation "Designing a Fully Electric Super Yacht", which is an "research by design" study into the viability, feasibility and desirability of a fully electric super yacht leading to a final concept.

Coming from a background of Automotive Design both at the TU Delft and Coventry University, mobility has always interested me. My goal as a designer is to shape the future and this connected well with the challenge Feadship and I discussed; "designing a Fully Electric Super Yacht".

This project was undertaken at "de Voogt Naval Architects" in Haarlem, which is the creative and technical center of Feadship and I have been working in the design department of the company on this project for the last half year.

This thesis lies the basis for the development of a fully electric super yacht. It is a extension of the preparation work done by Feadship in this field and should advise them in future development.

I would like to thank my supervisors from both the TU Delft and Feadship for their guidance and support during the process. It has been very stimulating to work from within the design department of de Voogt Naval Architects and being able to get feedback from my supervisors in the Industrial Design Engineering facility when I was in Delft.

I hope you enjoy reading this thesis,

Rob Akershoek

Delft, September 17th, 2018

Faculteit: Industrial Design Engineering

TU Delft chair: Dr. ir. Jansen, A.J.

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SUMMARY

The aim of this thesis is to analyze if a fully electric super yacht is feasible, desirable and viable. This is done using a "research by design" approach using the current (and future) drivers, enablers and barriers to design a concept.

First, a vision is developed using the ViP (Vision in Product design) method, in order to create a clear raison d'être (reason of being) for the concept to be successful.

Context and Technology analysis lead to the formulation of a design brief, which was used for the Ideation. A main idea is selected to be developed into a concept, which is used to answer the research questions.

The design of the final concept showed the possibilities for fully electric yachting within the boundaries as set in the design brief. A fully electric super yacht will be less flexible in usage and is potentially only suitable for a selected clientele. The main barriers are technical and related to the infrastructure and usage.

INTRODUCTION

PROBLEM DEFINITION

Although Feadship claims that a fully electric yacht is feasible, desirable and viable (Feadship, 2017), it is unclear what the current (and future) drivers, enablers and barriers are. The analysis of these aspects will lead to the formulation of design opportunities such as aesthetics, business model and user experience.

How do these design opportunities link to the customer demands and what is the 'raison d'être' (reason of being) for this concept to be successful? Fully electric yachts will be used and experienced in a different way. The challenge is therefore designing a concept that emphasizes this (figure 1).

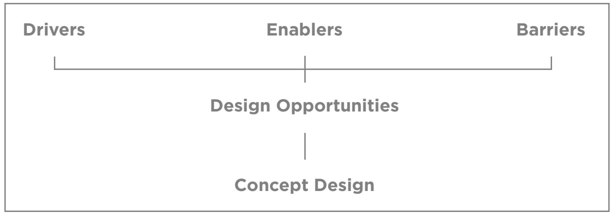


Fig 1. Problem Definition

DESIGN/RESEARCH PROCESS

A vision will be developed for a fully electric super yacht by exploring the context, user experience and technology (ViP). Combined with an analysis into current (and future) drivers, enablers and barriers, this vision will be used to develop a design concept for a fully electric yacht that supports (or denies) the claim made by Feadship. Applicable research will be conducted (research-by-design) in order to find possible design consequences for a fully electric yacht. The process is visualized in figure 2.

The result of this project will be a fully electric super yacht concept, which will support (or deny) the claim made by Feadship that a fully electric yacht is feasible, desirable and viable. Furthermore, it should project a vision on the usage and design of a fully electric yacht in the near future.

The goal is to end up with a concept where a potential client can sign for (say yes to further development). This means that the yacht and the infrastructure will have to be thought out and analyzed, but not yet fully detailed. The focus is on the concept idea and the exterior design.

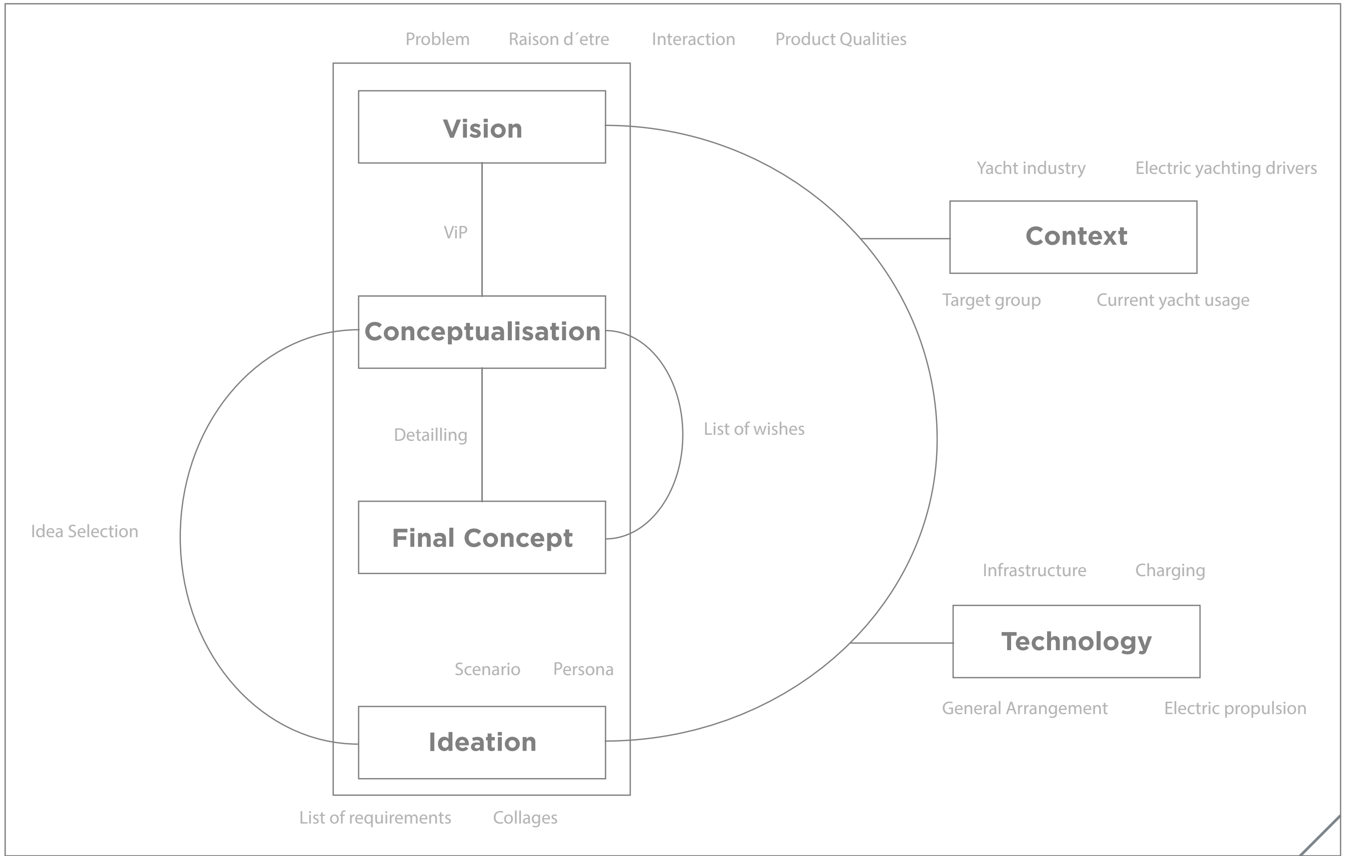


Fig 2. Design/Research Process

RESEARCH QUESTIONS

In order to structure the design of a fully electric super yacht concept, the following main research questions have been developed:

Main Research Question

What are the current (and future) drivers, enablers and barriers of a fully electric yacht?

ViP

What should a fully electric yacht look and feel like?

Context

What does the current super yacht market look like (in terms of design) and where are opportunities for a fully electric super yacht to stand out?

What are the drivers for clients to want to buy a fully electric super yacht?

What is the potential target group for a fully electric super yacht? And what are their characteristics?

What is the current usage of Feadship super yachts?

Technology

What infrastructure is required to enable fully electric yachting?

What kind of energy system is optimal and how does this influence the design?

How can a fully electric yacht fit the future vision?

The conclusions from these research questions will be developed into a final concept design that will be used to convince Feadship and other stakeholders of the potential viability, desirability and feasibility of a fully electric yacht.

VISION IN PRODUCT DESIGN

INTRODUCTION

What should a fully electric yacht look and feel like?

The challenge is especially to develop a clear raison d'être (reason of being), in order for the concept to be successful. Fully electric yachts will have to be designed and used in a different way compared to regular yachts and therefore require a design (and infrastructure) that emphasizes this. For example, Feadship already mentioned that batteries offer a better weight distribution, allowing for new form options. The main focus is therefore on designing something that will not be bought for just being the first electric super yacht, but also for the advantages and/or different user experience it offers.

The process chosen to achieve this is the ViP process, since it focuses on the vision first, rather than the actual product (Hekkert, 2017). The vision will help design the fully electric super yacht for the near future.

The ViP design approach is grounded on three basic principles (Hekkert, 2017);

1. A designers job is to look for possibilities and possible futures instead of simply solve present-day problems.

2. Products are means to accomplish or develop appropriate interactions.

3. The appropriateness of any interaction is determined by the context.

The ViP process starts with analyzing the meaning of the current product on three different aspects; product, interaction and context (figure 3). The next phase shapes the future vision for the product and consists of the selected domain, context factors, statement definition, human-product interaction and finally product qualities (Hekkert, 2017).

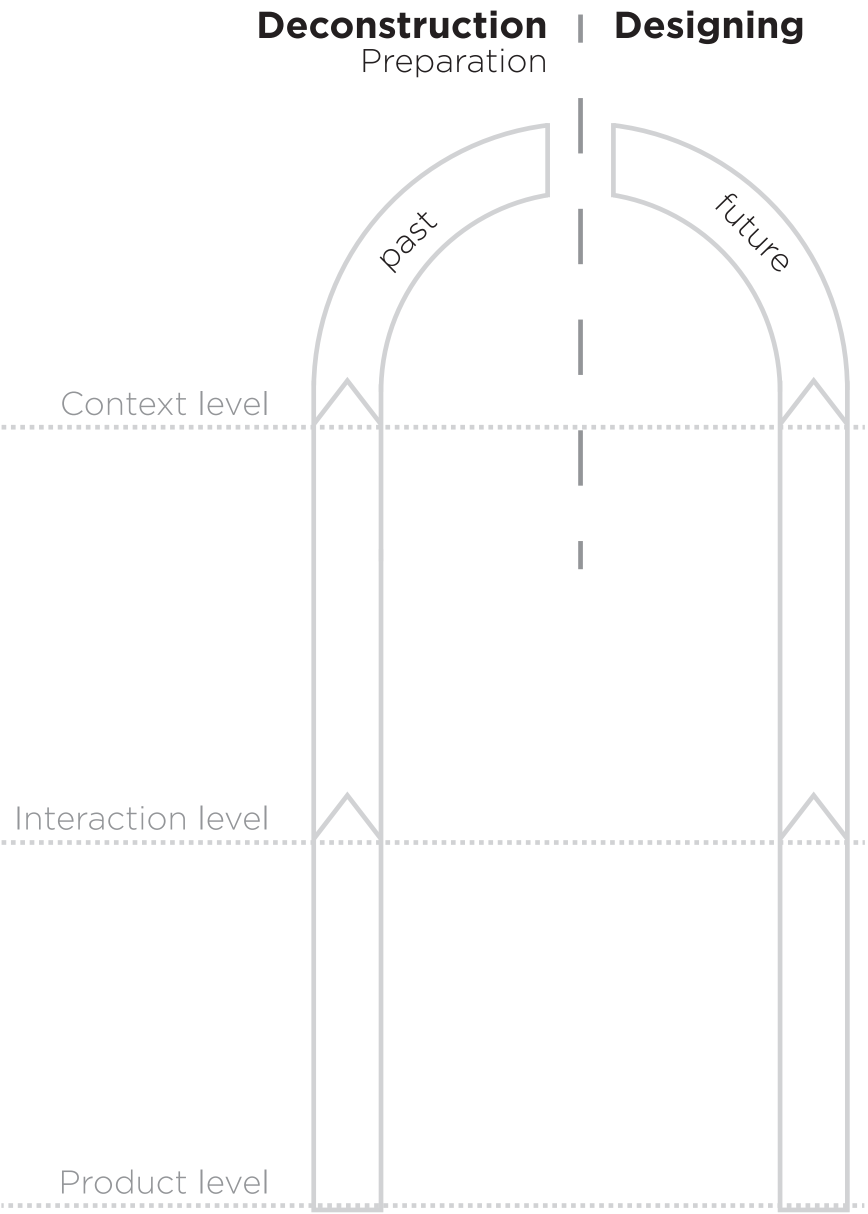


Fig 3. ViP Process

DECONSTRUCTION PHASE

Product

First of all, the current product will be deconstructed. The Feadship Savannah (figure 4) has been chosen, because it is the first hybrid diesel-electric super yacht and has won several industry awards, therefore setting the benchmark for modern yacht design. The entire product will be described by its main features on product level.

Super yacht Savannah:

- Length: 83.50m
- Diesel-Electric propulsion
- Metal body + large glass panels
- First hybrid super yacht
- Recreational area's (pool, cinema, etc.), underwater (nemo) lounge, gym and wellness center.
- 6 Staterooms, 12 guests, 22-26 crew members
- 2x 9m tenders + 1x 4.60m tender + "toys" (jet-skis, kayaks, etc.)
- Max. Speed of 17 kn & cruising speed of 14 kn
- 6.500nm range

What does the current product express?

The ViP process is about creating a vision using your own designer expertise and using trends and developments to shape it (Hekkert, 2017). In the deconstructing phase, the product will be analyzed using only the personal views of the designer.

- Freedom & Independence
- Timelessness
- Luxury
- Status
- Sleek
- Wealth & Prestige
- Modernity
- Solitude
- Relaxation

Interaction

How do you see people interacting with the product? The interaction can be characterized by:

- Amusement
- Glamour
- Introversion / Private
- Isolation
- Charming
- Laid back
- Pride
- Serenity
- Coordination
- In charge
- Sophistication
- Posh
- Demand Respect

Fig 4. Feadship Savannah

Context

What were the design factors? Why does this product exists (in this form)? Considerations that make the interaction qualities meaningful:

- Escapism: influential and important clients have the need to escape from their busy life and want to relax without distractions
- Experience > (appearance) of pursuing experiences
- Privacy > retreating away to not be disturbed by other people, not even by the crew
- Pioneering > the desire to own the latest tech
- Personalization > adapting completely to the users wants and needs (unique)
- Elitism > show your importance to the world, be part of the upper class
- Wealth > increasing number of ultra-high-net-worth individuals

DESIGNING PHASE

Domain

Next the domain of the assignment is determined, which should fit the strategic goals, mission and the client. The level of abstractness should be defined too. How far in the future will the concept be?

Fully electric yacht; a yacht for the near future that embraces the unique opportunities of electronic mobility and revolutionizes the use of these new yachts.

Context Factors

Using the different themes from the ViP method; trends, developments and principles have been searched for that relate to the domain (appendix 1). These trends have grouped into the different categories as advised by the ViP method (Hekkert, 2017).

The context factors from1. help shape the focus of the assignment and determine the scope. They have been structured into different themes, which will be used to create a statement, human-product interaction and product qualities.

Immersive Experience

Desire to escape reality (trend)

Augmented (Virtual-) reality > increasing immersion (trend)

Seamless integration > discreet way of hiding technology (trend)

Gamifying > the spread of gaming to new audiences and new activities (trend)

Immersive Layered Entertainment > multiple environments > maximizing moments (trend)

Biomimicry > imitation of nature > solve complex human problems and inspire design (trend)

The more choice a person has, the less likely it is that he or she will make a decision (principle)

Digital centralization (IoT) > convenient way to manage everything from as few devices and locations as possible (development)

Authentic Experience

Desire for local, embodied presence > setting roots > local culture (trend)

Authenticity matters > sentimentality that comes from having purchased a genuine luxury good is part of the reason we seek authenticity (principle)

Exposure to the same stimuli for extended periods of time triggers boredom (principle)

Aiming to be unique > be interesting (principle)

Personalization > be different from the rest (development)

Sense of adventure > choosing unfamiliar options > sampling the unknown (principle)

People go on vacation for novelty and education (next to 7 other socio-psychological motives) (state)

Buying an Identity

Attaining status > achievement (principle)

Desire to accumulate wealth and possessions > especially true for highly ambitious and competitive people (trend)

Yachts, like cars, are an expression of identity (trend)

Importance of how other people perceive you > bragging > self-promotion (principle)

Successful pioneering (setting an example) helps the widespread use of a new technology/product (principle)

High Quality of Life

Upgrading health > rich people (development)

Spending more money on education > rich people especially (development)

Need for being > sensing connection with something larger than ourselves (principle)

Experiences make people happier than possessions (feel alive) > become accustomed to an object (principle)

Pursuit for wellness > especially for millennials (trend)

Swimming reduces mental tension and anxiety, caused by everyday stress (principle)

Spending money on experiences or to regain time increases happiness > which we share with others (principle)

Young adult geographic mobility is at its lowest level in 50 years (development)

Sharing is Caring

Urge to share information about one's life > same sensations in the brain synonymous with eating food (principle)

DESIGNING PHASE

Informality > more openness (development)

Shift from privacy demands > millennials not worried about privacy (development)

Community focused lifestyle > connect with others > move from individualism to collectivism (trend)

Need to belong to a certain social group (principle)

Wealthier people tend to give a smaller percentage of their income to charity > yet the more generous people were, the happy they reported feeling (principle)

Wealth makes you distance yourself from others > value independence more and social connectedness less (principle)

Taking Responsibility

Cultural norm that we should all work towards a sustainable future (state)

Sustainability & environmental awareness > consumers are more and more interested in sustainable and ethical products (trend)

Full lifecycle sustainability > focus is not just on the product anymore, also recycling and usage for example (trend)

Energy generating systems on board and/or portable (development)

Statement Definition

Using the most inspiring context factors, a statement definition has been formulated;

Authenticity > Immersive usage > accentuate the difference between a regular yacht > sell an authentic and unique experience

Need for being > Healthy & sustainable lifestyle > ZEN > Biomimicry

“Feadship wants to give millionaires an authentic and immersive experience that fits their high quality of life and supports their “need for being” using principles of Zen and biomimicry.”

DESIGNING PHASE

Human-product interaction

Experience the future > pioneering > be different > authentic experiences

Joy in (premium) sustainability > sensing connecting with something larger than ourselves > philanthropy > biomimicry

Pure relaxation > balanced lifestyle > ZEN experience

Extension of yourself > Reflecting your personality and values

Product qualities

- Seamless
- Natural
- Subtle
- Refreshing
- Futuristic
- Premium
- Balanced
- Dynamic
- Organic

These aspects will be integrated into the design of the fully electric super yacht and will help shape the direction of the ideation phase. The product qualities will be translated into collages that will be used for inspiration during the ideation phase. They will also be used to compare ideas with each other to determine the best direction.

To summarize the values from the ViP method, a design mood board (figure 5) has been developed. It reflects the vision and the different trends and will be used as inspiration for the ideation phase.

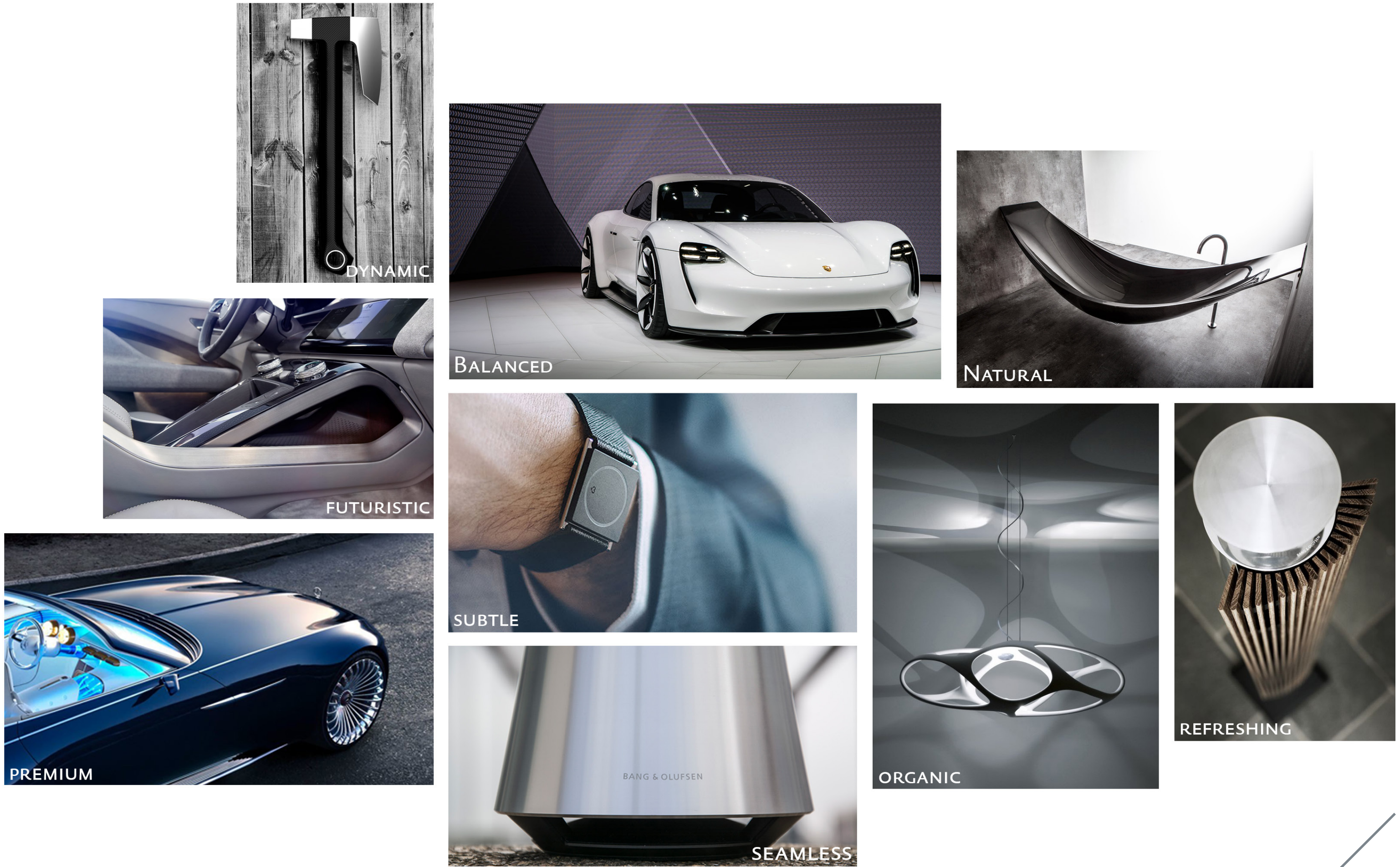


Fig 5. Product Qualities

DESIGNING PHASE

Zen design

The ViP analysis lead to a vision that had some similarities with the Zen philosophy. Since this fits in well with the principles of electric mobility, healthy living and being more connected (need for being), Zen has been analyzed too.

- Zen design is based around 7 principles (Reynolds, 2009):
- Kanso: Simplicity or elimination of clutter
- Fukinsei: Asymmetrical balance > dynamic
- Shibui: Beautiful by being understated > direct and simple > without being flashy
- Shizen: Naturalness: no artificiality > full creative intent unforced > spontaneous
- Yugen: Suggestion rather than revelation > showing more by showing less
- Datsuzoku: Freedom from habit or formula > transcending the conventional > surprises
- Seijaku: Tranquility or energized calm > solitude

These 7 principles have been translated in a design mood board (figure 6) to serve as inspiration during the design process.

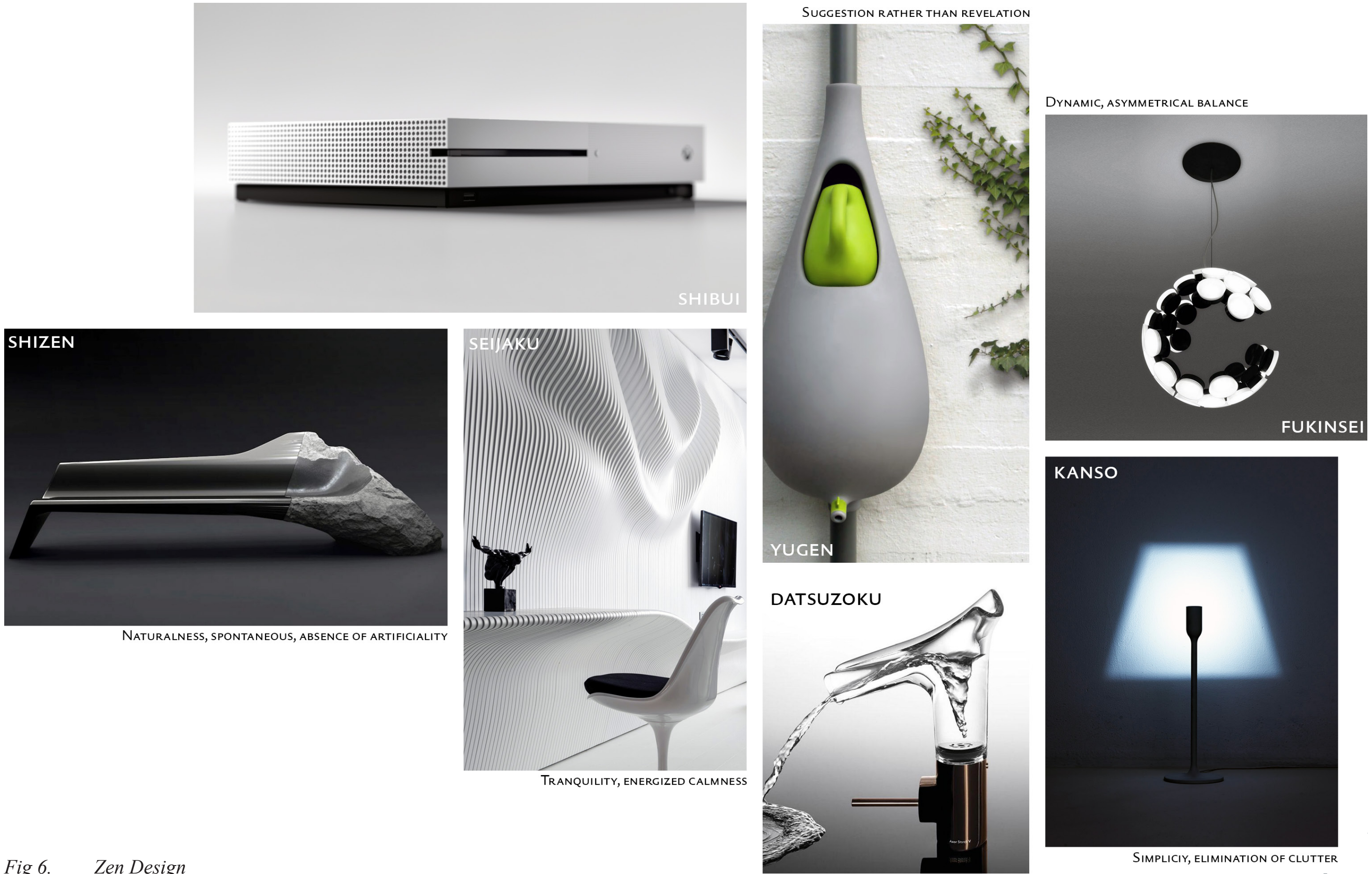


Fig 6. Zen Design

DESIGNING PHASE

In order to get a better grip on the ViP process, a concept has been selected to be analyzed that is a good example of memetic design and fits the ViP trends that have been selected. The selected concept is the Oceanco Tuhura (figure 7).

This concept has been highlighted since it is a good example of memetic design and fits selected ViP trends like biomimicry and authenticity. Because of this, it is quite an extraordinary design, different from most super yachts. The shape mimics the early canoes, while the stripes and color remind of the rare white whales. The concept itself evokes a feeling of actually "being on the water" and experiencing nature in a relaxing way.

The ViP method will provide the input required to create a memes as well as a emotive collage. A memetic collage describes the 'look' and 'memes' of the design (forms, colors, materials, textures, details, etc.) (figure 9). An emotive collage describes the feel and ambiance of the product (figure 8). These collages will be used as inspiration during the design phase. For these collages, biomimicry and authenticity and need of being (Zen) have been used as main context factors from the ViP process.

- Biomimicry
- Authenticity
- Need for being (Zen)

This leads to the following statement:

The statement that follows is a combination of the main context factors as well as the product qualities. The main goal of this statement is to be input for the emotive collage.

- Experience the future > pioneering > be different > authentic experiences
-
- Joy in (premium) sustainability > sensing connecting with something larger than ourselves > philanthropy > biomimicry
-
- Pure relaxation > balanced lifestyle > ZEN experience
-
- Extension of yourself > Reflecting your personality and values

Fig 7. *Oceanco Tuhura*

DESIGNING PHASE

Emotive collage

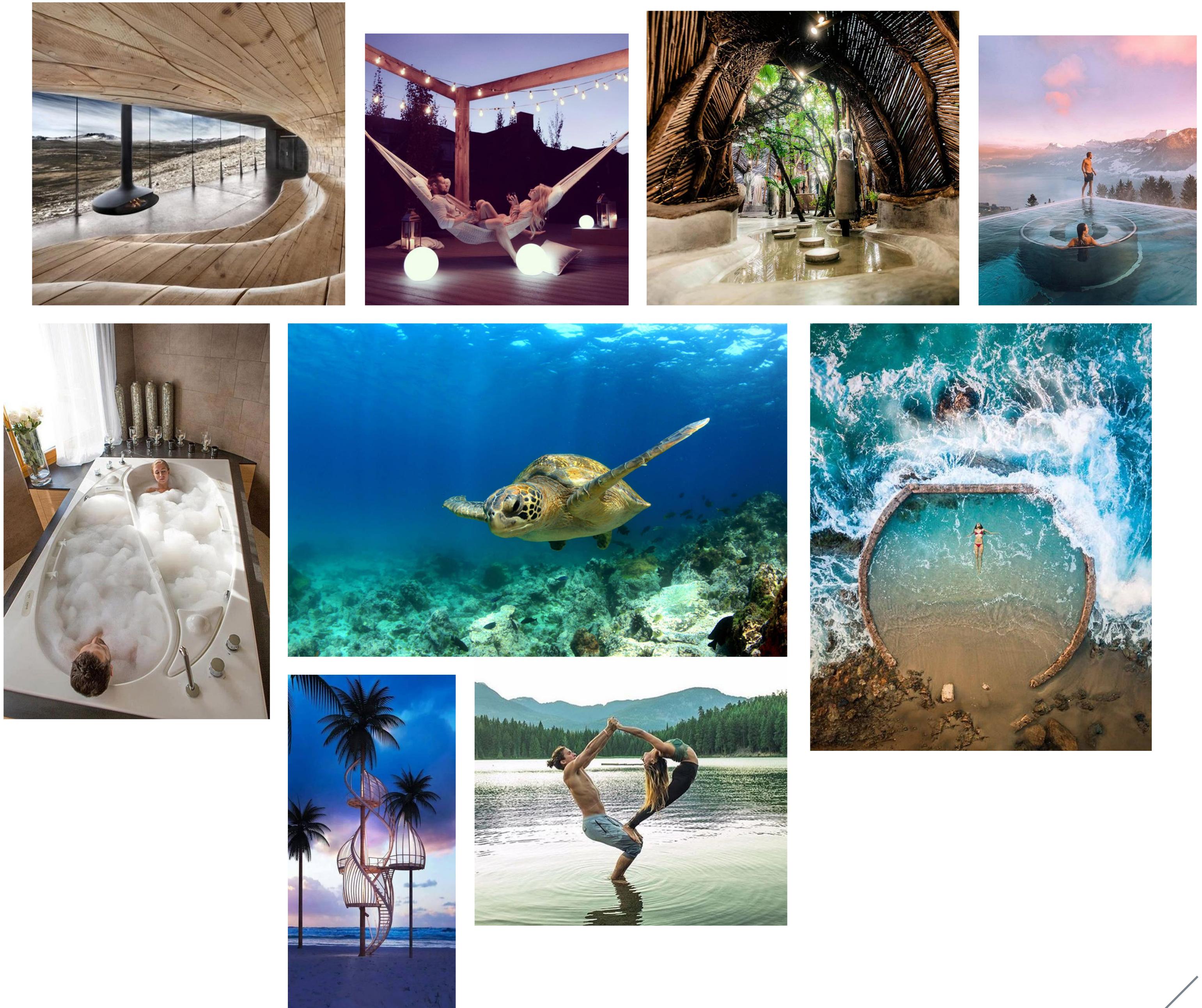


Fig 8. Emotive Collage

DESIGNING PHASE

Memetic collage

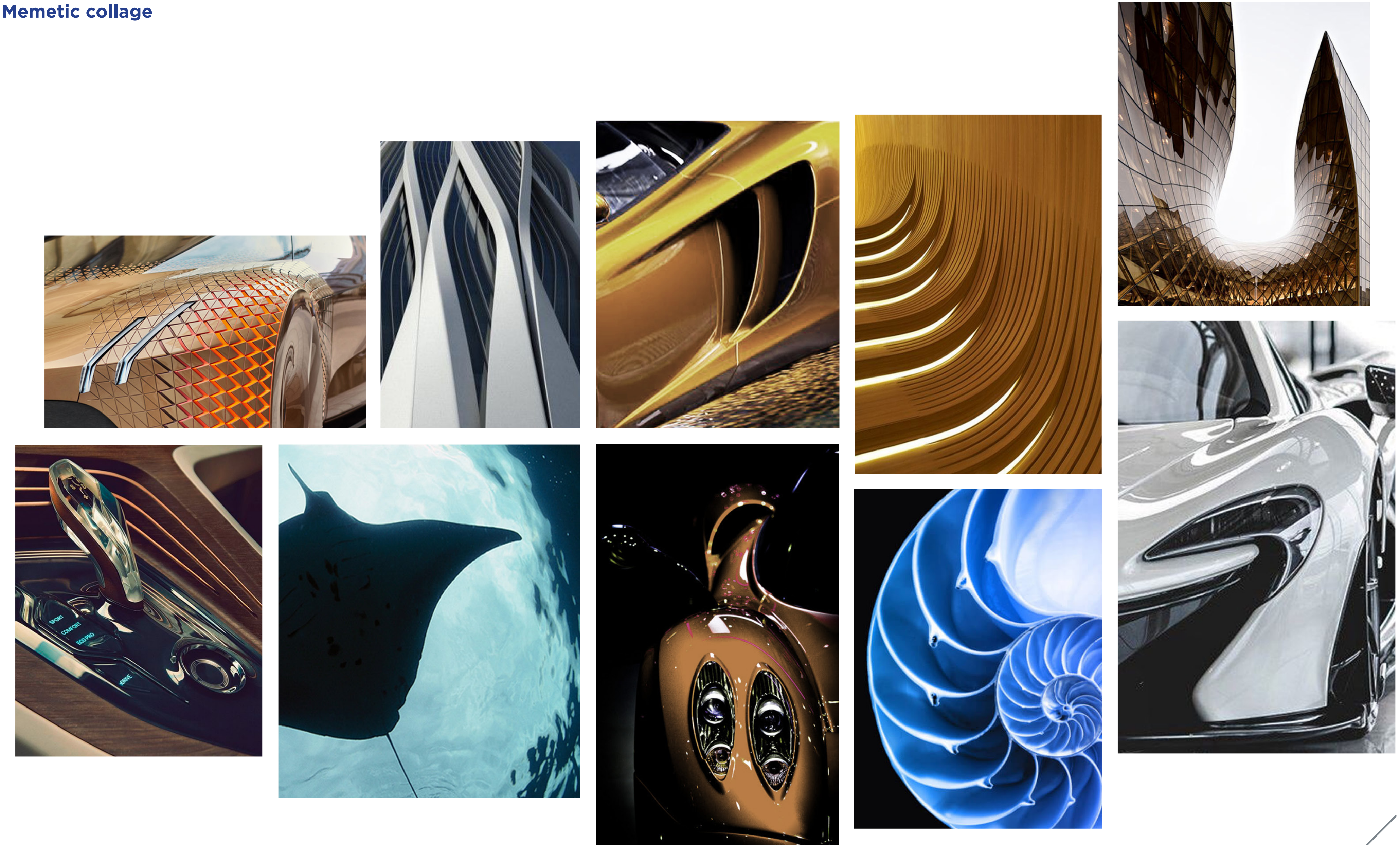


Fig 9. *Memetic Collage*

CONTEXT

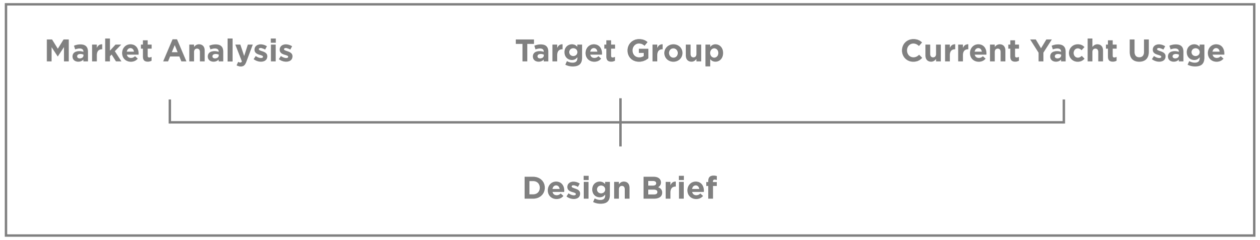


Fig 10. Context

MARKET EXPERIMENT

How can a yacht design be unique in the current superyacht market?

As discussed in the ViP process, the uniqueness (authenticity) of the concept and the idea behind the concept (raison d'etre) is very important. Therefore to verify the product qualities as analyzed in the ViP process, a market experiment has been set up. The goal of this research is to investigate current super yacht designs on the market and where the new super yacht concept would fit in the current market. Several descriptive words have been used that are in correlation with the ViP process analysis and the yachts will be ranked based on these words.

The product qualities were formed to the following combinations:

- Modern versus Classic
- Organic versus Geometric
- Dynamic versus Static
- Simplistic versus Complex

Participants will receive pictures of several yachts, which have been carefully selected to represent the top tier of the super yacht market. They consist of recent Feadships as well as Super yacht Award winning ships from the last 4 years. They are then asked to rank these yachts based on a scale of 2 words, such as Classic versus Modern. The scores range from 1-5, with 1 for example being very classical and 5 being very modern (3 being the middle of the matrix and 1 and 5 the corners of the matrix). Next to this number they are required to place them in a certain order, for example 2 yachts can be ranked between 3 and 4, however one can be more leaning towards 4 than the other. This research has been conducted with me and coworkers from DVNA, 3 from Design and 3 from other disciplines.

The first part of the research focused on the combinations of Modern versus Classic and Organic versus Geometric (figure 11). The opportunities can be found in the upper side of the grid of Organic and Modern design and this aligns with the ViP vision as well. The combination of pure Organic and Classic design also has opportunities, however this does not fit the vision.

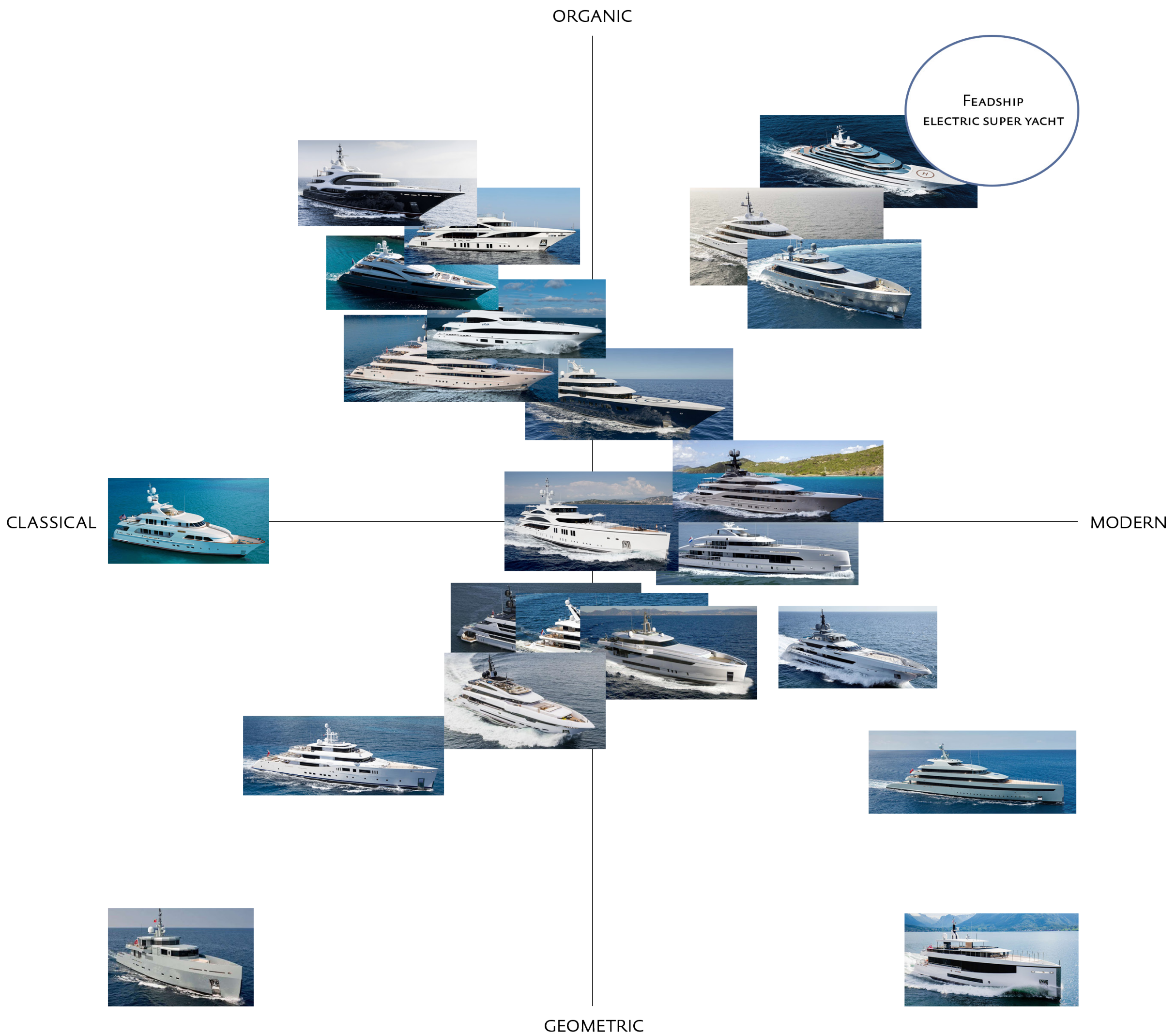


Fig 11. Market Experiment (Organic/Geometric vs. Modern/Classic)

MARKET EXPERIMENT

Furthermore, aligning with the ViP method the combinations of Dynamic versus Static and Complex versus Simplistic have been researched (figure 12). It can be seen that opportunities can be found in both Dynamic and Simplistic designs as well as in Complex and Static designs. The Dynamic and Simplistic combination fits the product qualities from the ViP method well, while Complex and Static does not.

Both of these matrices verify the aim for uniqueness of the design. Furthermore, the matrix shows that the most unique yachts, the yachts that really attract attention, are the ones in the corners of the matrix.

For example the Feadship Kamino (in the Modern versus Geometric corner in figure 11, is a very distinctive yacht because of these extreme values.

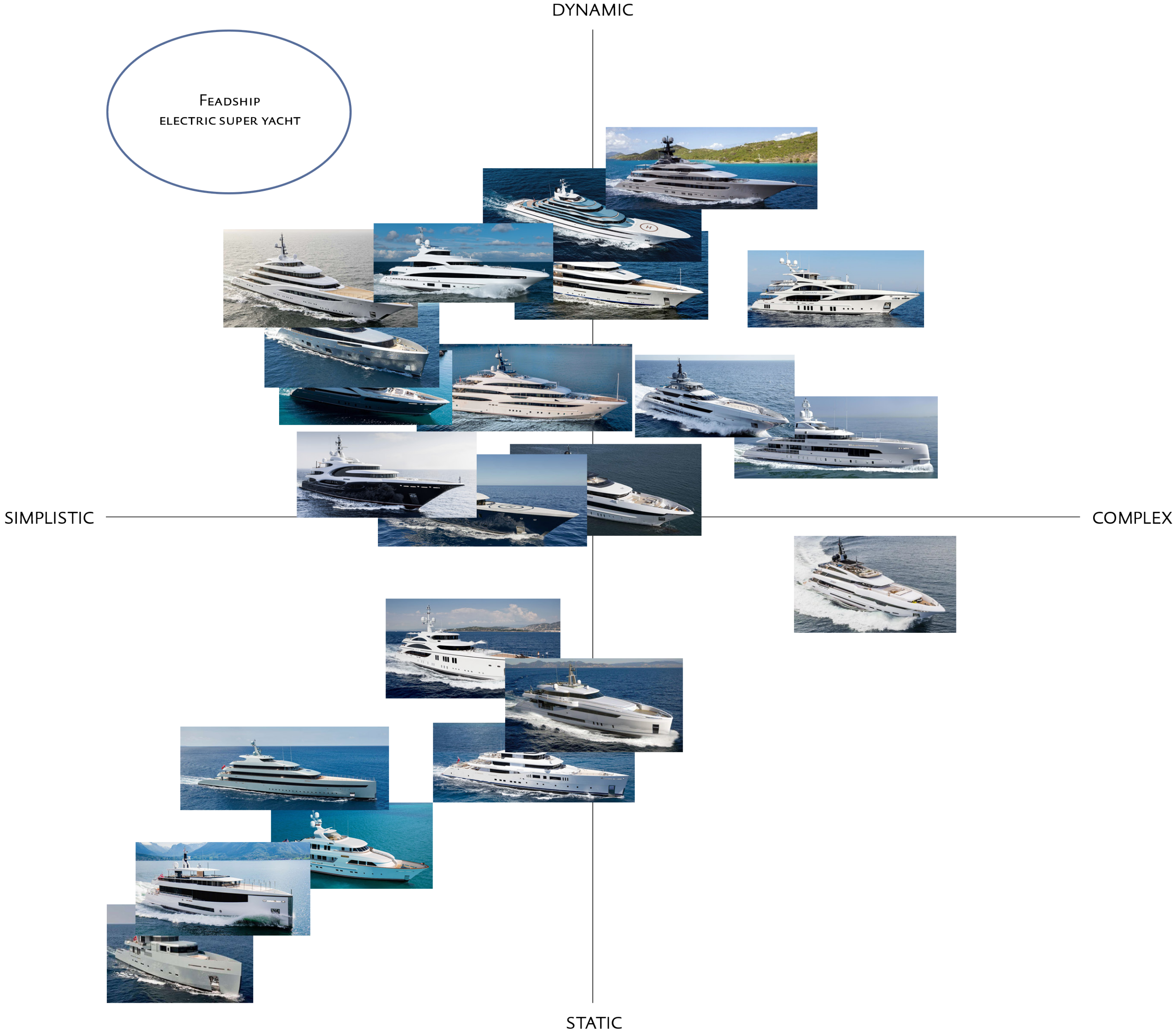


Fig 12. Market Experiment (Simplistic/Complex vs. Dynamic/Static)

TARGET GROUP

Electric transportation

What are the drivers for clients to be interested in electric yachting?

The idea of electric propulsion is appealing to clients in the super yacht market, as Feadship confirmed that clients have expressed interest in owning an electric super yacht. The presumed advantages are (Feadship, 2017):

- Emission less operation
- More comfort, due to the removal of moving generators
- Less maintenance
- Attractive identity

The main challenge, according to Feadship is achieving a satisfying range with limited charging times.

The super yacht market is currently very invested in impressing with large numbers (size, speed, range, etc.). This can be seen by the ever increasing yacht sizes that Feadship is building.

The question is, whether a fully electric super yacht should follow these trends, because it will have a presumed disadvantage in terms of range and speed, compared to a diesel yacht.

Electric yachting is new for the industry, while in the automotive industry for example it is already more settled. Yachts are different from cars in the way that they are not a practically useful mode of transportation, but rather a luxury product. Expensive cars can also be seen as luxury object however, and therefore it has been analyzed why people want to buy electric cars, in order to see if parallels can be drawn to the yachting industry (figure 13 & 14).

Why would people buy an electric yacht? Which of these reasons can be linked to the yachting industry?

- Costs aren't as important compared to cars, since it is a really different cliental in terms of wealth. Next to that, super yachts are in a completely different price range compared to even the most luxurious of cars.

- Tech desire and the environment drivers could be translated into the yachting industry as well, being the main drivers. These should be enhanced in the design and experience of the electric yacht.

- Energy dependence is an interesting driver as well, since electric energy could be generated sustainably on/off the yacht.

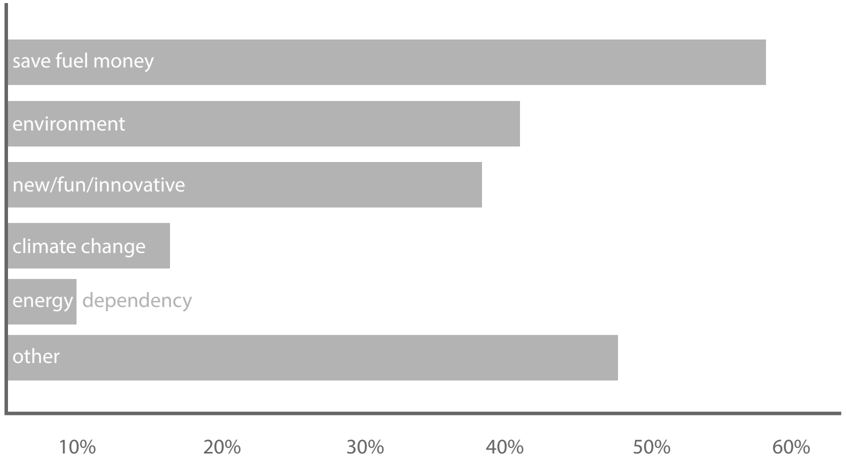


Fig 13. Why do people buy an electric car? (EVObsession, 2015)

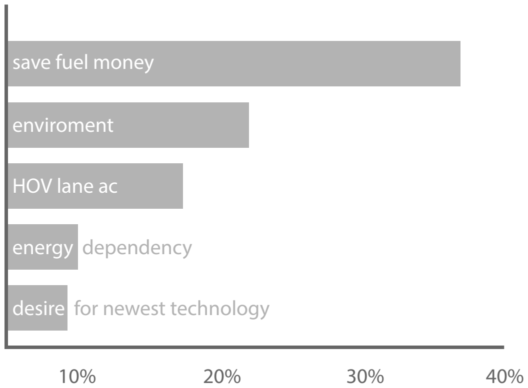


Fig 14. Reasons to aquire an EV (Clean Vehicle Rebate Project, 2018)

TARGET GROUP

With the battery cost declining and specific energy increasing over the past few years (The Economist, 2017), the future of electric yachting looks to be more viable each day. However we are not nearly at a state where batteries can juts replace diesel in yachts, since it does not have the required energy density yet.

According to these predictions the battery costs will decline by ~50% and the specific energy of batteries will increase by ~100% from 2014 to 2022 (figure 15).

The future predictions are based on the reports by GM and Tesla regarding the future of electric driving (The Economist, 2017). Therefore it must be questioned whether these are the aimed values, or predicted values.

The focus on the design should be on the tech desire , environment and energy dependency drivers of the clients. These should be reflected in the design and also complement the vision.

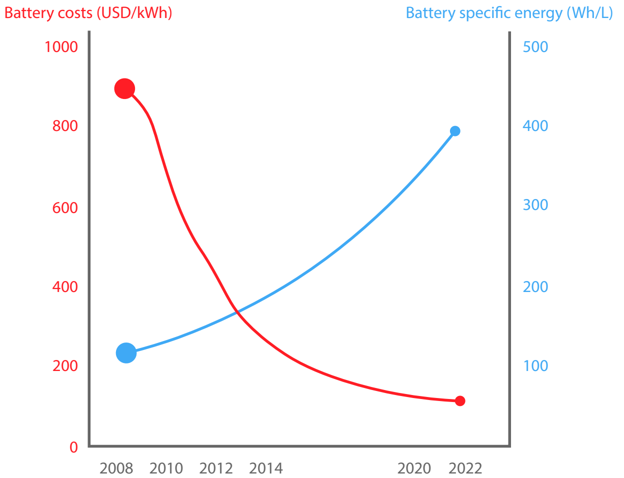


Fig 15. Battery Predictions (The Economist, 2017)

Luxury experiences

How can you achieve exclusive authentic luxury experiences in a yacht?

In the past, luxury stood for material quality, exclusivity and craftsmanship. Nowadays luxury is seen as engaging in exclusive tailor made experiences (Lewis, 2018). The main point here is the appearance of pursuing an experience, since only a few yachts in the worlds are really being used to explore the world (Lewis, 2018).

The exclusive lifestyle of the ultra-rich is usually highly visible and focused on projecting their status and commanding respect. Yachts are interesting luxury products, since unlike private jets, they are not a useful mode of transport and unlike art and property they are depreciate in value. “Yachts allow the ultra-rich to perform their wealth status” (Abrams, 2016). They are very prominent in how and where they are used and there is a certain tension between the privacy the yachts offer and the desire to see and be seen (Batty, 2016). This can be seen from how and where it is used; namely prominent places and ports close to renowned bars/restaurants (Abrams, 2016). Most clients have a yacht that is more expensive and more personalized than a home and they use it as a sort of floating personal hotel (Abrams, 2016).

The luxury experience focuses around time, privacy and personalization. Time is very valuable to the ultra-rich; therefore it is vital that no time is wasted. Next to that, privacy is important to seclude them from the world. Finally, personalization gives the ultra-rich that exclusive and unique feeling, reflecting the client (Lewis, 2018).

One of the current examples of these aspects is the vacation home of Mark Zuckerberg (owner of Facebook) he uses artificial intelligence to create a smart home, saving him time as well as workers. This increases not only his privacy and time but also his personalization since he can adjust his house in any way he would like.

For a new electric super yacht, the three main luxury aspects in combination with the vision, lead to a redefined sense of luxury. First of all, pioneering is important, since the ultra-rich want to stand out of the crowd (Yeoman, 2017). Secondly, the time aspect should be redefined from wasting no time, to relaxing and taking your time (Yeoman, 2017), to fit with the trends form the vision analysis. Finally, the privacy aspect is leaning towards personal image and how they appear to others (Yeoman, 2017). This defines who they are (or want to be) to the rest of the world and includes them in selective elite clubs.

TARGET GROUP

The ultra-rich

What is the potential target group for a fully electric super yacht? And what are their characteristics?

When spoken of ultra-rich, the UHNW (ultra high net worth) people are considered.

Net worth categories (in dollars): (the Guardian, 2015):
- 1-5 million – high net worth (HNW)
- 5-30 million – very high net worth (VHNW)
- >30 million – ultra high net worth (UHNW)

This is excluding residential properties and passion investments. The group UHNW consists of 0.003% of the world's population and has 13% of the world's total wealth (the Guardian, 2015).

Wealth-X (the main source of this analysis) uses a database on UHNW individuals, which is made by partnering with prestige brands across the world. The data is quoted on trusted media organizations, such as The Wall Street Journal, Business Insider and the BBC.

The age of millionaires is mostly between the lower 50s and higher 60s (Wealth-X, 2017). For multimillionaires this is slightly higher. However there is a trend of younger millionaires upcoming, who made their money in the tech industry, earning a lot of money in a short amount of time and being especially interested in buying new technology products. They are 51 years old on average, with over half of them below the age of 50 (Wealth-X, 2017).

For the ultra-rich, quality of life is how fully they feel living it. For millennials it is also important to share this with others, to express the freedom, authenticity and 'real' experiences they live. A few of their concerns in life are missing out on key experiences and sustainability issues (the Resident, 2016).

Almost 90% are male (88.2% in 2016), 66% are self-made (14.5% got rich in finance, banking and investment) and 11.7% solely inherited their wealth. 21.9% got rich from a combination of inheritance and self-made (Wealth-X, 2017).

They express a growing demand for 'experimental luxury' and embody a rising philanthropic engagement. This consists of a social engagement and a motivation for personal fulfillment (especially among the younger millionaires) (Wealth-X, 2017).

Another trait is the focus on personalized service and products. They are also avid early adopters, following trends such as smart home, VR (virtual reality) and AI (artificial intelligence) (Wealth-X, 2017).

The ultra-rich have been among the prime purchasers of electric vehicles; this can be partly explained by the (younger) generation that tends to be more socially and environmentally minded (Wealth-X, 2017).

The top interests of the ultra-rich are retrieved from interviews and evidence regarding the time spent per interest (figure 16).

With business at number one, philanthropy is the 2nd top interest of the ultra-rich. This can be attributed to a few factors; personal fulfillment, recent global coverage of charitable endeavors and recognition of widening wealth inequality, as well as an increasingly multi-generational billionaire population. Next to that, philanthropy was viewed as a fundamental responsibility, if not duty, at the very highest levels of wealth.

Rank	Hobby Name	% of all UHNW
1	Business	56.9%
2	Philanthropy	38.6%
3	Sports	33.0%
4	Finance	28.3%
5	Education	17.8%
6	Outdoors	17.3%
7	Public Speaking	15.2%
8	Technology	14.6%
9	Aviation	14.5%
10	Real Estate	14.4%
11	Politics	13.9%
12	Travel	13.8%
13	Family	13.2%
14	Art	9.2%
15	Music	8.9%
16	Health and Wellness	8.9%
17	Engineering	8.9%
18	Vehicles	8.6%
19	Writing	8.1%
20	Environment	7.6%
21	Food	7.2%
22	Economics	7.2%
23	Science	7.1%
24	Animals	7.0%
25	Reading	6.8%
26	Collectibles	6.8%
27	Boating	6.7%
28	Law	6.1%
29	Languages	5.0%
30	Religion	5.0%

Fig 16. Top 30 interests of UHNW (Wealth-X, 2017)

TARGET GROUP

The following charts show the difference in UHNW interests according to three age groups (figure 17).

Sport remains a top interest of the ultra-rich, regarding the age. Business and philanthropy are very important to all age categories as well. However technology is a top interest only for the relatively young ultra-rich (Wealth-X, 2017).

To summarize these findings a target group mood board has been developed (figure 18). It also includes my own vision as developed from the ViP method. The chosen type of ultra-rich, are the ones that made their money in the tech industry and are relatively young (millennials). The mood board shows the most important aspects of the target group.

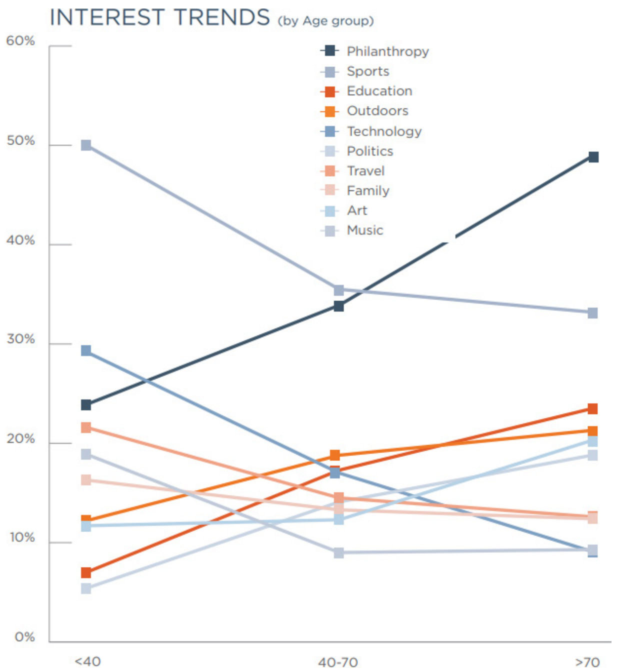


Fig 17. Interest Trends by Age Group (Wealth-X, 2017)

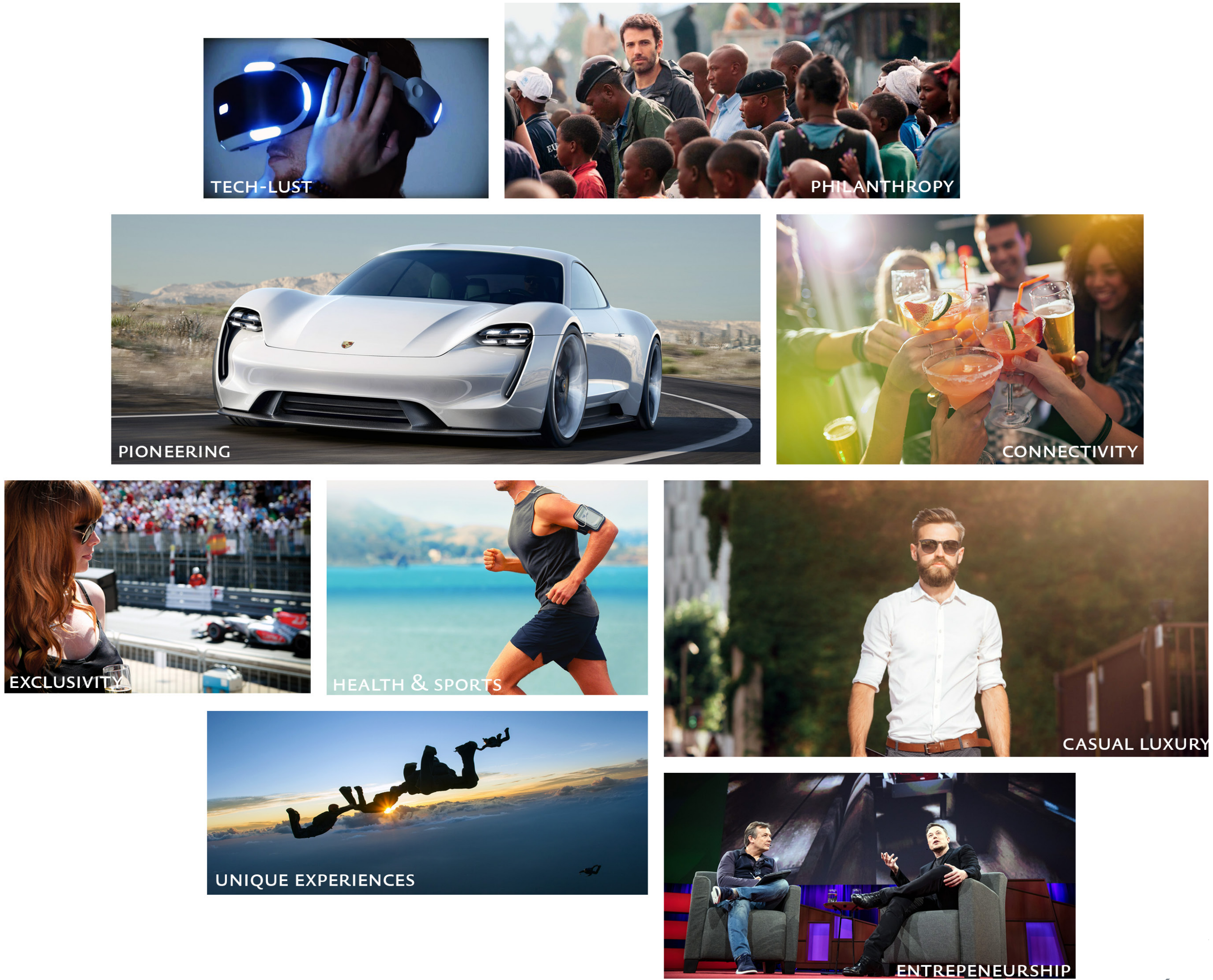


Fig 18. Target Group Mood Board

USAGE ANALYSIS

What is the current usage of super yachts?

In order to determine the whether a fully electric super yacht fits the current usage of a super yacht, the sailing profile of 35 Feadship yachts has been analyzed over a period of 5 years. This data lead to the formulation of 3 types of sailing profiles (A, B & C), where A resides around Europe, B goes from Europe to the Caribbean and vice versa and C travels around the world (Feadship, 2016). Size, age, range or other yacht parameters are not significant in the distinction between the profiles (Feadship, 2016).

The AIS-data (Automatic Identification System) consists of time stamps, GPS locations and speed, which shows where the yacht resides and for how long (Feadship, 2017). The sailed distance can be determined by the locations of the yacht. In coastal area's the interval between measurements is 4-5 minutes while on sea the interval can be 4-5 hours (Feadship, 2016).

Operational profile A

Operational profile A (figure 19) (12/35 Feadships) resides 90% of the time in the north Mediterranean Sea and 10% of the time in north Europe (Netherlands, South England & Nordic Fjords). The yachts are used for sailing 7% of the time and mostly from June to August. On average they sail 7000 nm per year (+/- 4000 nm). Finally the average speed ranges from 10-14 kn (figure 20), which is the range speed. Size does not have a significant influence (Feadship, 2016).

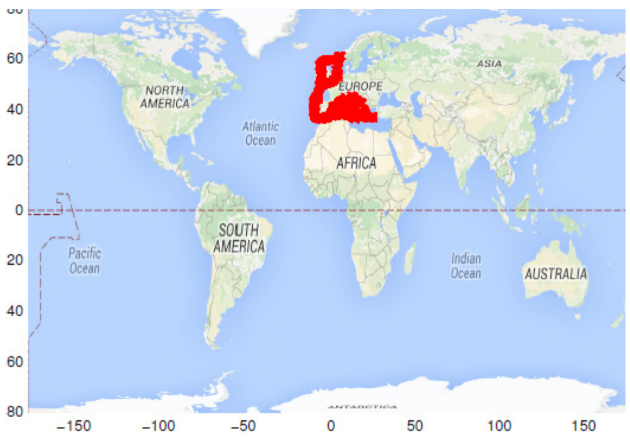


Fig 19. Operational Profile A

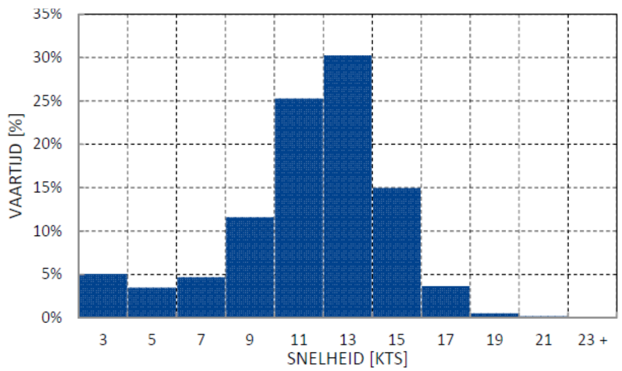


Fig 20. Generic Speed Profile A

Operational profile B

Operational profile B (figure 21) (12/35 Feadships) resides in the north Mediterranean Sea, cross the Atlantic Ocean twice a year and sail across the North American East Coast. 35% of the time they reside in the north Mediterranean Sea, 10% in north Europe, 20% in the Caribbean, 25% in Florida and 10% in the north coast of North America. The yachts are used for sailing 9% of the time (10% in the Caribbean). On average they sail 10.000 nm per year (+/- 3250 nm). The average speed ranges from 10-14 kn (figure 22). Finally 45% of all the distance sailed is in Europe, 15% is between Europe and America and 40% is in America and the Caribbean. The Trans-Atlantic trip happens twice a year on average and is in autumn from east to west using the south route via the Canary Islands, while in spring it is from west to east using the north route via Azoren (Feadship, 2016).

Fig 21. Operational Profile B

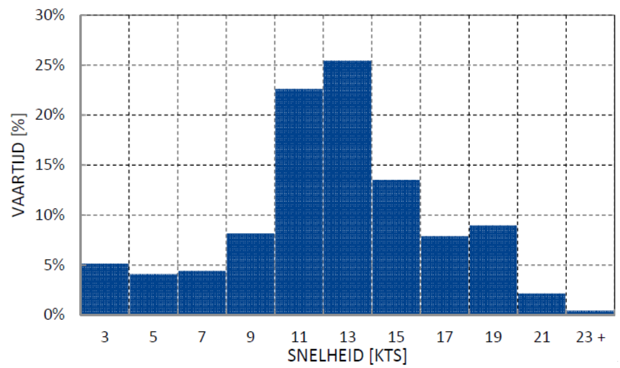


Fig 22. Generic Speed Profile B

USAGE ANALYSIS

Operational profile C

Operational Profile C (figure 23) (11/35 Feadships) sails across the entire globe. 35% of the time they reside in the north Mediterranean Sea, 5% in north Europe, 10% in the Caribbean, 5% in Florida, 10% north coast of North America and 35% in other locations worldwide. The yachts are used for sailing 10% of the time. On average they sail 11500 nm per year (+/- 2750 nm). The average speed ranges from 12-16 kn (Feadship, 2016) (figure 24).

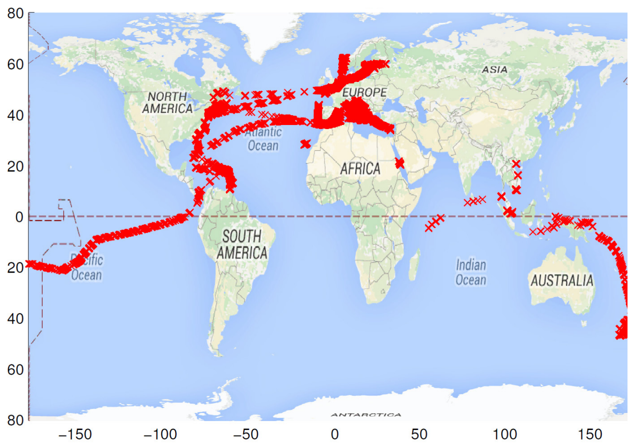


Fig 23.   Operational Profile C

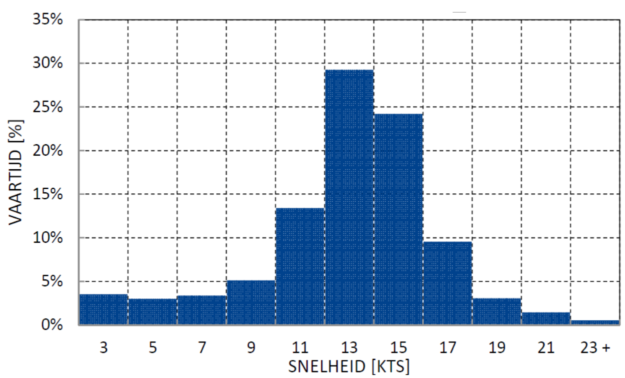


Fig 24.   Generic Speed Profile C

Next to these profiles, it is interesting to point out what distances are traveled (between harbors) and with what frequency, in order to determine a range for the concept. Using the same AIS data as used in the operational profile, the graph below (figure 25) has been set up. The dataset of AIS used for this analysis consisted of a range of distances traveled per 'trip', where a trip has been defined as the moment between sailing and being idle for a yacht. This has been used to assume the distance traveled to a potential harbor. The data is from 35 Feadship yachts and consists of around 750 trips (Feadship, 2017). For the statistics it has been chosen to ignore the small trips (0-5 nm) and focus on more realistic sailing distances between harbors (> 5 nm), increasing the chance that the selected trips are in fact from harbor to harbor.

Almost a third of the trips are less or equal to 50 nm (31.1%). With a range of 300 nm it is shown that 63.6% of the trips can be made. While for a range of 150 nm, 51.1% of the trips are possible. This shows that Feadship yachts are usually used for relatively short distances before docking. Especially since the trips between 0-5 nm, consisting of 12.3% of the total amount of trips, have been left out of the analysis (figure 26).

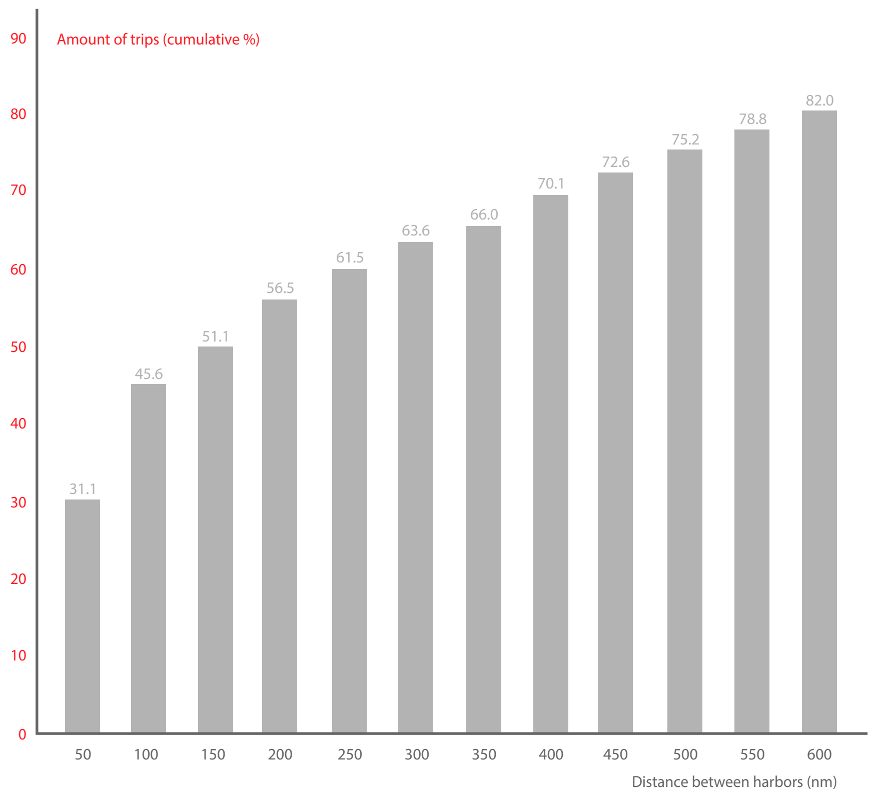


Fig 25.   Distance travelled between harbors (cumulative)

USAGE ANALYSIS

The data used in these graphs is based on AIS data from 35 Feadship yachts and consists of ~750 trips (between harbors) (Feadship, 2017). This data is very arbitrary though in the sense that it is hard to define what exactly has been a trip to a harbor (when it leaves and enters a harbor again?). Next to that it is hard to seclude potential non-harbor anchor spots from the data. However it helps in defining an image for the common usage of a Feadship yacht.

Conclusion

In terms of range, sailing profile A is the most suitable for a fully electric super yacht. It has been shown that large trans-Atlantic trips are rare and therefore left out of the scope of this project. The focus will be on the smaller trips between harbors in the Mediterranean Sea. This operational profile has an average distance sailed of 25% of the other profiles combined.

Profile A & B both have the potential to fit the limitations of fully electric yachting, while profile C would be too challenging. A & B both have the potential need for transits though, depending on the range of the fully electric super yacht. Profile A has a transit from the north Mediterranean Sea to the north of Europe, while profile B has a trans-Atlantic trip from the north Mediterranean Sea to the Caribbean.

The sailing speed will be further defined in the technology analysis, but from the scenario (profile A) it can be assumed that it should be between 10-14 kn.

Zooming in on the sailing data for operational profile A, the following statements can be made:

- 41% of all time the Feadships were in the area of profile A
- 1.8 million AIS points in this area between 2010-2014
- Preferred harbors indicated, size of marker indicate relative number of time spent
- 63.6% of all trips between harbors less than 300 nm (6.5% of the trips are between 300-600nm)

The graph in figure 28 is made from the perspective of 3 popular harbors (Monaco, Napels and Corfu), to analyses the range of a fully electric yacht within operational profile A. Based on 160 year of Feadship sailing data this map has been developed, incorporating 1.8 million AIS (Automatic Identification System) points in this area between 2010 and 2014 (Feadship, 2017). It can be concluded that 41% of all time, the Feadships were in this area. The red dots indicate the frequently visited ports; the size of the dot indicates the relative time spent there. The circles indicate an achievable range with an all-electric yacht, showing a range of 300 or 600 nm. 63.6% % of all trips between the harbors are less than 300 nm, while 6.5% of all trips between harbors are between 300 and 600nm. The grey lines indicate the sailing routes; the thickness of the lines indicates the relative amount of yachts that sailed this route.

Aiming for a range of at least 300 nm, allows the electric yacht to almost cover the entire Mediterranean Sea, using the 3 selected harbors to charge at. Next to that 63.6% of all trips are below 300 nm. This data will be used to make a scenario based on this range and envisioned usage of the super yacht.

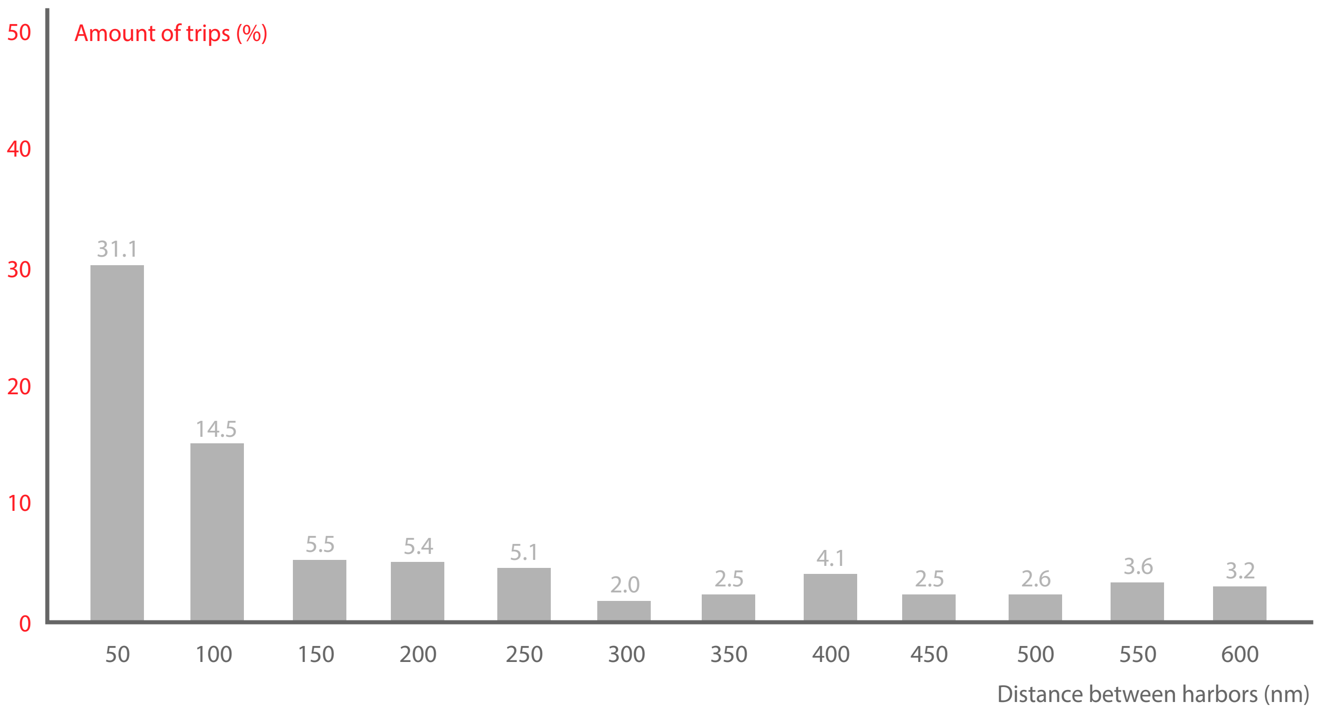


Fig 26. Distance travelled between harbors

USAGE ANALYSIS

Range map

Using the sailing profiles of several Feadships, a suitable range has been determined (at least 300 nm). However how does the usage of a similar yacht look like, in terms of sailing patterns and trips? This research helps to determine where potential charging points should be at, as well as options for the owner to invest in his own charging infrastructure.

The following picture has been made using the AIS-registrations from the Feadship Anna (67 m) (figure 27). This yacht has been used as example since the yacht fits the profile A (Mediterranean sea) and it is similar in size (Feadship, 2017).

According to Feadhip, it can be assumed that for the longer distances, the client is not actually on the yacht himself and it will be only the crew at those circumstances on board (Feadship, 2017). The shorter trips between harbors are usually made with the client on board as well as potential guests. Especially the islands between Greece and Turkey are widely visited.

The red points are AIS-registrations that are classified as “sailing”, black points are AIS-registrations that are classified as “idle”, the blue dots are harbors and the grey areas are anchor points.

Anchor points have been defined as points where the AIS-registrations are classified as “idle” are maximum 25 km apart.

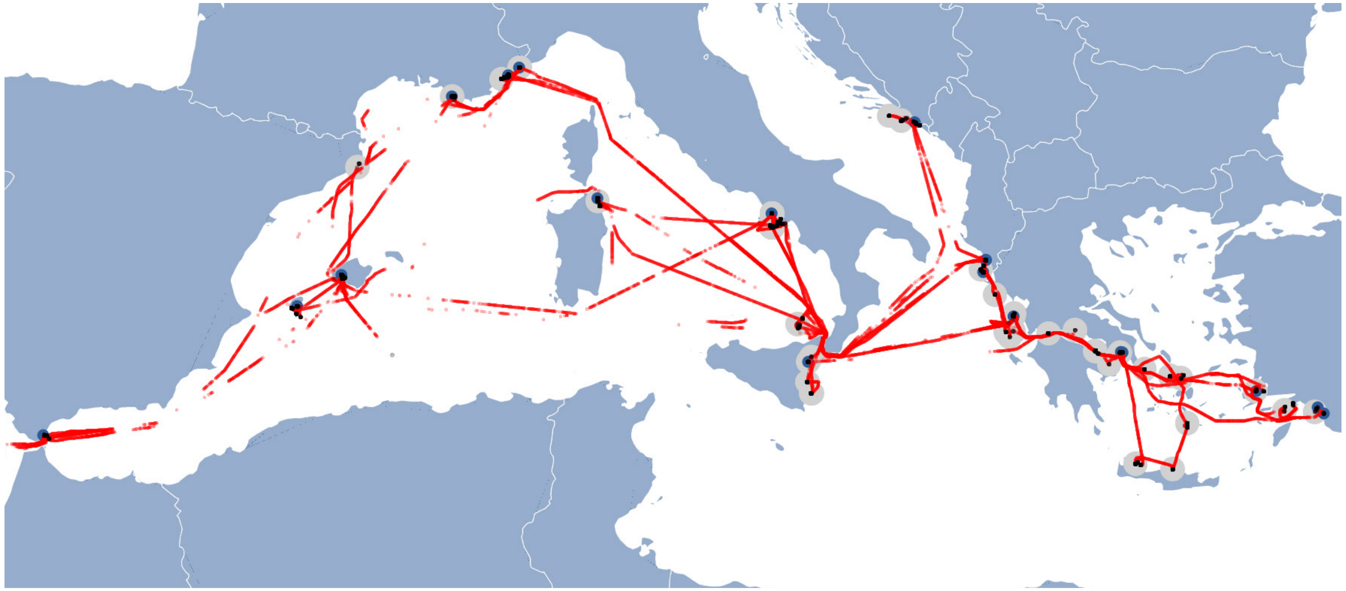


Fig 27. Feadship Anna Operational Profile

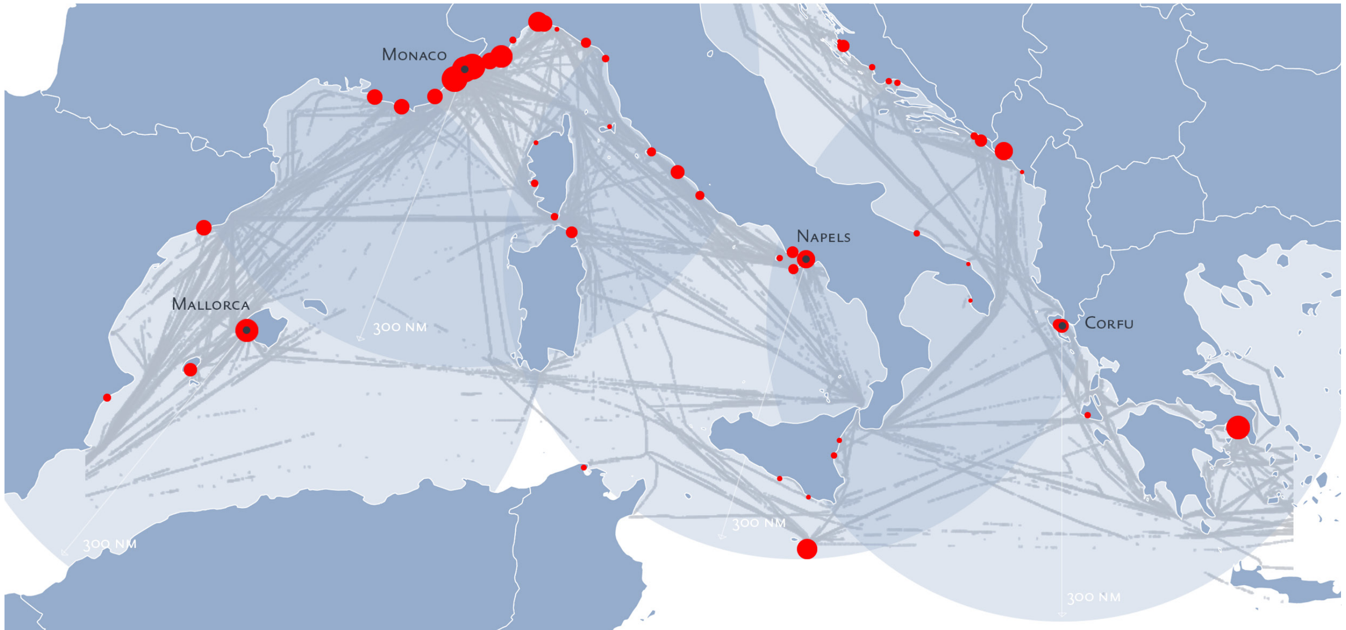


Fig 28. Range Analysis (300 nm)

USAGE ANALYSIS

It can be seen that most anchor points are around larger harbors, except the islands between Greece and Turkey. This shows the potentially charging options available for a fully electric super yacht. In the larger harbors, the charging infrastructure of the harbor itself can be used, while for smaller harbors or anchor points, the owner will have to use his own infrastructure or will be unable to charge his yacht at those points.

Charging options

What harbors are available for high speed charging, using just the infrastructure of the harbors itself? The harbors in Europe have been analyzed to find out where a fully electric super yacht potentially can be charged (Ecofys, 2015).

In this list (appendix 3) several ports in France, Italy and Spain are mentioned that are planning to build high speed chargers in the near future, showing the potential for high speed charging in the Mediterranean area (figure 29) (Ecofys, 2015).

Ports close to a housing or industrial area, medium voltage power (6.6-11 kV) may often be available close at hand or within a few kilometers (Ecofys, 2015). The high speed charging as mentioned before is mostly more than 1 MW, while that would suffice for a fully electric super yacht. Theref ore for the charging scenario, more ports can be taken into consideration to charge the super yacht.

Itinerary

How do the ultra-rich use their super yacht, in day-to-day usage? Detailed usage statistics are not available, which means that a suggested itinerary (appendix 4) will have to be developed based on the predicted use of the yacht. Since the concept of a fully electric yacht is new and requires an updated use and infrastructure, previous data regarding usage will only be used as guidelines.

Most charter cruises are about 7-14 days and mostly during the warm summer months (Feadship, 2017). This means there is a sunrise at 5:30-6:00 and a sunset at 20:30-21:00, this leads to long and active days and diners during sunset (Feadship, 2017).

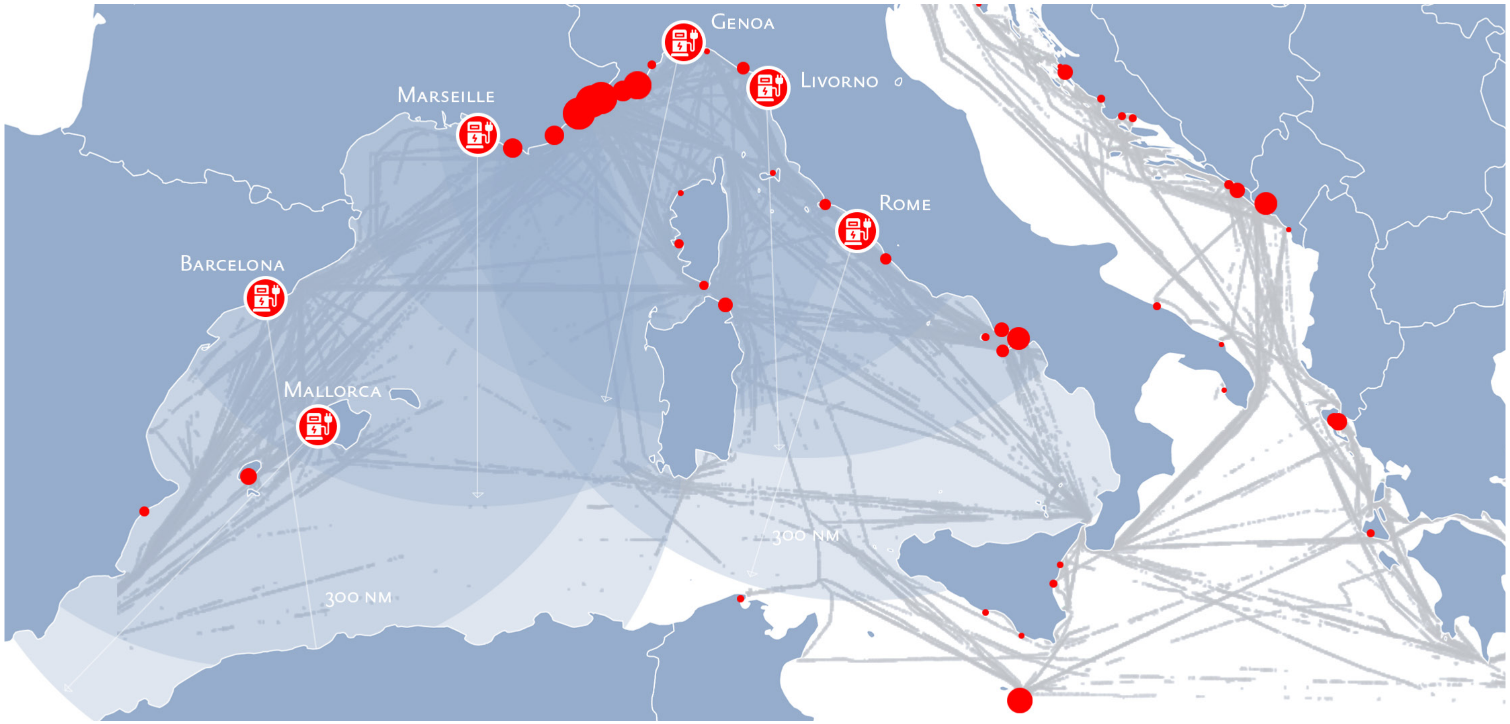


Fig 29. Map of High Speed Charging Options

TECHNOLOGY

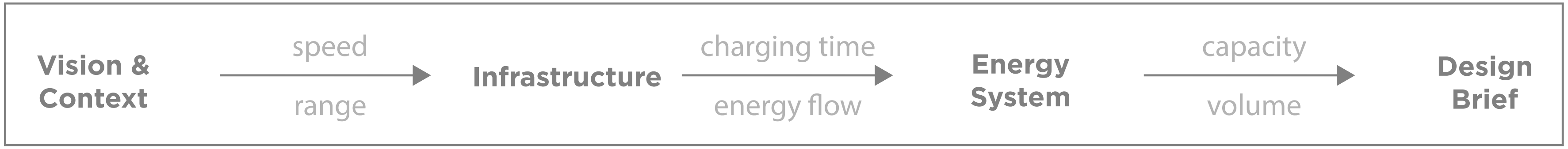


Fig 30. *Technology*

INFRASTRUCTURE

What infrastructure is required to enable fully electric yachting?

The primary users of this infrastructure will be the pioneers within this industry. As discussed earlier, high speeds charging options are only available in select harbors. This is why the focus on this analysis is on a flexible solution that could also enable charging in other harbors. A few options will be discussed after which the final infrastructure idea will be selected;

- Containerized supercharger units
- Charging buoys
- Electric support vessel

Containerized supercharger units

A system will be set-up for sharing and potentially leasing containerized super charger units. This system allows for more flexibility, since the customers will not be solely dependent on the harbor infrastructure, but will also have the chance to charge at smaller ports. These container units are modular and therefore easily extendable and replicated at other locations (Kokam, 2017) (figure 31).

- 5.5 MWh installed energy for a 40’ (12.2 m) container
- 5.5 MW max power

The main idea behind this infrastructure idea is flexibility. Most infrastructure ideas for electric charging require large investments and permanent solutions. Supercharger containers however do not require a change in the current infrastructure and have a lower threshold. In the future investments in the power grid could integrate these superchargers, but for the electric yachting pioneers, this will have to be done by themselves.

Clients can hire/lease or share these units in the harbors. When the clients sail to a different place, the containers

Fig 31. Total ESS Solution (Kokam, 2017)

Shore power buoys

An interesting option to charge outside of the port is the use of shore power buoys. These could potentially be attached to the harbor, to charge the electric yachts on renewable energy or energy from the harbor (GEPS techno, 2018) (figure 32).

They can be combined with supercharger containers and be scaled up accordingly. This adds even more flexibility to the infrastructure system and helps increase the range of electric yachts. The installation of these buoys would be more of an investment compared to only using the supercharger containers in the harbor, since these have to be built in several places in the Mediterranean Sea. They could either be charged using solar, wind or kinetic energy as well as by attaching them to a nearby harbor using long power cables (GEPS, techno, 2018).

Charging speed with normal shore power is relatively low and would require superchargers to go to high industrial charge rates (>1 MW) (GEPS, techno, 2018). These rates are currently available mostly in commercial harbors. Without radically changing the infrastructure in the harbor (normal power is 160 kW (Ecofys, 2015)), superchargers can be charged with the regular power grid (at normal speed) and then be used to charge the fully electric yachts in a faster way

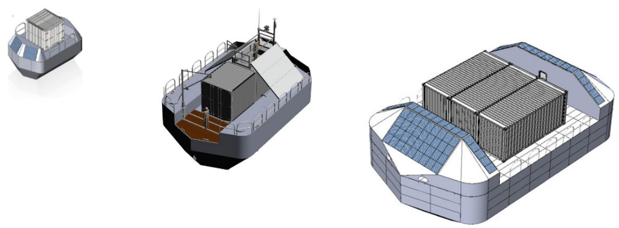


Fig 32. Shore Power Buoys (GEPS techno, 2018)

Electric support vessel

Another option for charging infrastructure is the addition of an electric support vessel that can sail towards the super yacht and provide the required energy. When in a hurry it could also be used as tugboat. In order to fit the sustainability picture, the support vessel would have to be fully electric as well. It has to carry enough energy to charge the super yacht, as well as propel itself to the required position. This would require a large support vessel full of batteries, however since it is a fully technical yacht, there are only a few crew rooms required.

Conclusion

The most suitable solution for the electric yachting concept will be the use of supercharger containers. Both the buoys and the support vessel are ideas that will only be developed if required to reach the desirable range, because otherwise they are more expensive and complex compared to the flexible supercharger containers. In the future investments in the harbors could integrate their own superchargers and back-up batteries in the grid, which would limit the use of portable superchargers to the smaller ports.

ENERGY SYSTEM

What kind of energy system is optimal and how does this influence the design?

Charging a yacht can currently be done in two ways. Either a conventional cable connection or induction charging will be used. Currently, as comparison, fully refueling the Feadship Como is done in 2 hours (Feadship, n.d.).

Induction charging

Induction charging is currently used for electric ferries in Norway due to the fast mooring it provides. The technology for this is called the Wartsila concept (figure 33).

One of the advantages of induction charging is the safety features. Since it is an automated system, compared to using regular cables, it is significantly safer. The Wartsila concept uses a quick charging system (1 MW charging power), by drawing power from a battery on the harbor that has been charged up earlier using the power network of the harbor (Sorfonn, 2016). This is possible because the power will be transferred from battery to battery rather than directly from the network. This can be combined with the super charger container units that were discussed earlier, since they could function as the battery on the harbor.

The reason induction charging was used for the electric ferry, was that the time at the charging point would only consist of a few minutes, before the ferry would set off again. Therefore this reduced the mooring time and allowed for larger charging times. For an electric super yacht however, this is not significant, as it will likely be moored for a couple of hours at least.

This system also reduces maintenance compared to regular cable connections, since there is no physical connection that could suffer from wear (Sorfonn, 2016). The efficiency is not as high as a traditional plug-connection system, but is still more than 95% (Sorfonn, 2016).

Plug-connection system

For charging with the supercharger containers, a charging speed of 5,5 MW will be used, however for charging at several ports, 1 MW can be used (Ecofys, 2015).

Currently there is an electric ferry (Tycho Brahe in Norway) using 10 MW charging, showing the possibilities of charging with higher power. This does however require larger transformers to lower the incoming voltage (Kane, 2016). There are multiple energy storage projects ongoing that are using high power charging, as can be seen in the table below (figure 34).

Fig 33. Wartsila Induction Charging (Sorfonn, 2016)

Large charging stations like this would drastically decrease charging times for super yachts and would also open up the possibility for potential larger yachts. However for this project the focus is on the near future and the proposed portable charging systems (on Tesla-trucks) in combination with charging in several ports that are investing in superchargers. In order to get high power charging stations, investments per harbor will have to be made to realize this kind of infrastructure. These high power charging stations will not be as portable as the Kokam superchargers.

The main reason to choose a plug connection over induction charging is that it is possible to use a power of up to 5.5 MW. This makes the concept more future-proof as it will be able to use superchargers in the harbors. For 5,5 MW power 13-15 three core cables weighing a total of 1,34-1,44 tons are required (appendix 5).

Five Largest Operational Lithium-ion Energy Storage Projects, by Energy Rating

Owner / Project	Power / Energy (Duration)	Technology	Location	Primary Function
State Grid Corporation of China / Zhangbei National Wind and Solar Energy Storage and Transmission Project	6 MW / 36 MWh (6 hour)	Lithium-ion-phosphate	Hebei, China	Renewable generation shifting
Southern California Edison / Tehachapi Wind Energy Storage Project	8 MW / 32 MWh (4 hour)	Lithium-ion	Tehachapi, CA	Renewable generation shifting
State Grid Corporation of China / Zhangbei National Wind and Solar Energy Storage and Transmission Project	4 MW / 16 MWh (4 hour)	Lithium-ion-phosphate	Hebei, China	Renewable generation shifting
Hawaii Renewable Partners / Hawi Wind Farm BESS	1 MW / 15 MWh (15 hour)	Lithium-ion	Hawaii	Renewables capacity firming
Invenergy / Grand Ridge Energy Storage	31.5 MW / 12.08 MWh (23 minute)	Lithium-ion-phosphate	Marseilles, IL	Frequency regulation

There are more than 45 lithium-ion projects with anticipated power ratings greater than 1 MW either planned or under construction, totaling 355 MW.[24]

Fig 34. Five Largest Lithiom-ion Energy Storage Projects (PSE IRP, 2015)

ENERGY SYSTEM

In ports without supercharger investments, the normal power is 160 kW (Ecofys, 2015).

Induction charging is also not as futuristic and fitting to the vision as it seems (figure 33), since the yacht and the supercharger still have to be connected. Next to that, the maximum amount of room between the charger and yacht is only 50 cm (Sorfonn, 2016).

This leads to the following energy flow diagram (figure 35), where the battery is either part of the grid (or replaced by the grid) in the port or part of the flexible supercharger.

Therefore the final infrastructure either uses the flexible superchargers with 5,5 MW power (mostly at remote locations) or the power grid of the few selected harbors with at least 1 MW power.

Batteries

The focus of the assignment is on a 50 m fully electric super yacht. A model has been developed by Feadship to calculate required energy for a reference trip (Feadship, 2017). The model is based upon the Feadship Como which has a length of 45 meters and a GT of 406 t. This has been scaled up in the calculations for a concept of 50m.

The model can be found in appendix 5. After analysis of the model, the HVAC (Heating Ventilation Air Cooling) was using extreme situations, but since the usage of this yacht is limited to the Mediterranean area, the capacity has been lowered to 23%. This leads to a hotelload of 2 MWh a day (appendix 5).

The calculations lead to a required battery capacity of 14 MWh. The scenario used has been a 3 day trip with 2 days of sailing 150 nm at a speed of 10 kn as well as spending 1 day idle (only hotelload), leading to a total range of 300 nm. When using the capacity of 14 MWh to sail directly and then charge afterwards, a total range of 440 nm is possible.

Using industrial battery standards that would lead to a required total battery space of 196 m3 and 67 m3 for the PCS (Power Conversion System) and the transformer (Kokam, 2017). The basic layout could be used using these values (based on the layout of the Como), as can be seen in figure 36.

Using the Kokam container batteries it is possible to fit them entirely in the bottom of the yacht without taking up any space on the lower deck for the owners, guests and/or crew. Since Kokam indicates on their site that their solutions are scalable, it is assumed that the batteries can be fit within the required space in the lower decks.

The technical area is assumed to remain similar, since opponents such as engine casings, generators, fuel systems and exhaust ducks will be replaced with a converter (Power Conversion System) and a transformer (Feadship, 2017). Meanwhile the diesel engines will be replaced by electric engines that are generally smaller (Feadship, 2017).

The size of this transformer and PCS has the same size as the 40' (67 m3) container. The total size of the technical area of the Como is 103.9 m3. A total of 36.9 m3 of the technical area on the yacht can be used for other applications. If analysis shows that more room for the technical area is required, then it might be necessary to remove one of the crew's rooms, since a fully electric yacht might require less technical crew members compared to a diesel yacht (Feadship, 2017).

Using the Feadship model, a 50 m yacht typically consists of 133 ton of diesel (including engines). For electric propulsion this would be 179 ton. Therefore the switch from diesel propulsion to electric propulsion leads to a 25% increase in weight. The diesel yachts usually have a range of ~5000 nm however.

The costs for a 14 MWh battery, using the price as calculated using industrial Tesla batteries, is 100 dollars per kWh; therefore 1.4 million dollars in total (Feadship, 2017).

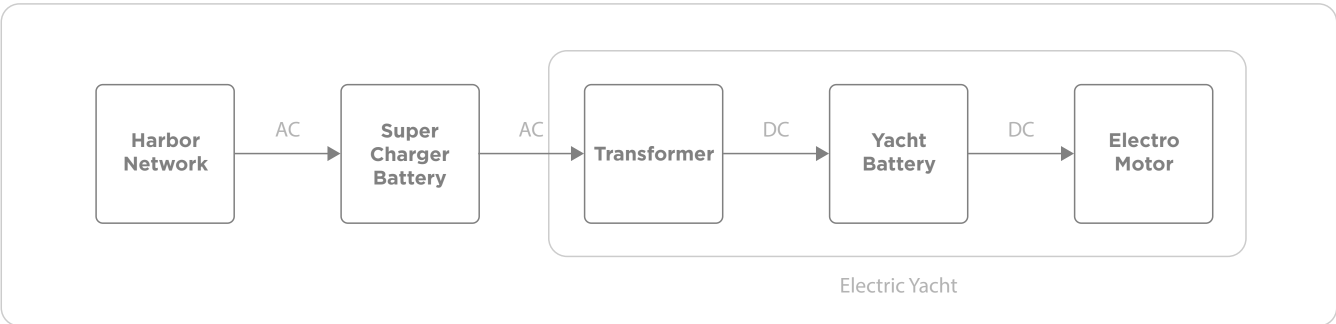


Fig 35. Electric Yacht Charging System

ENERGY SYSTEM

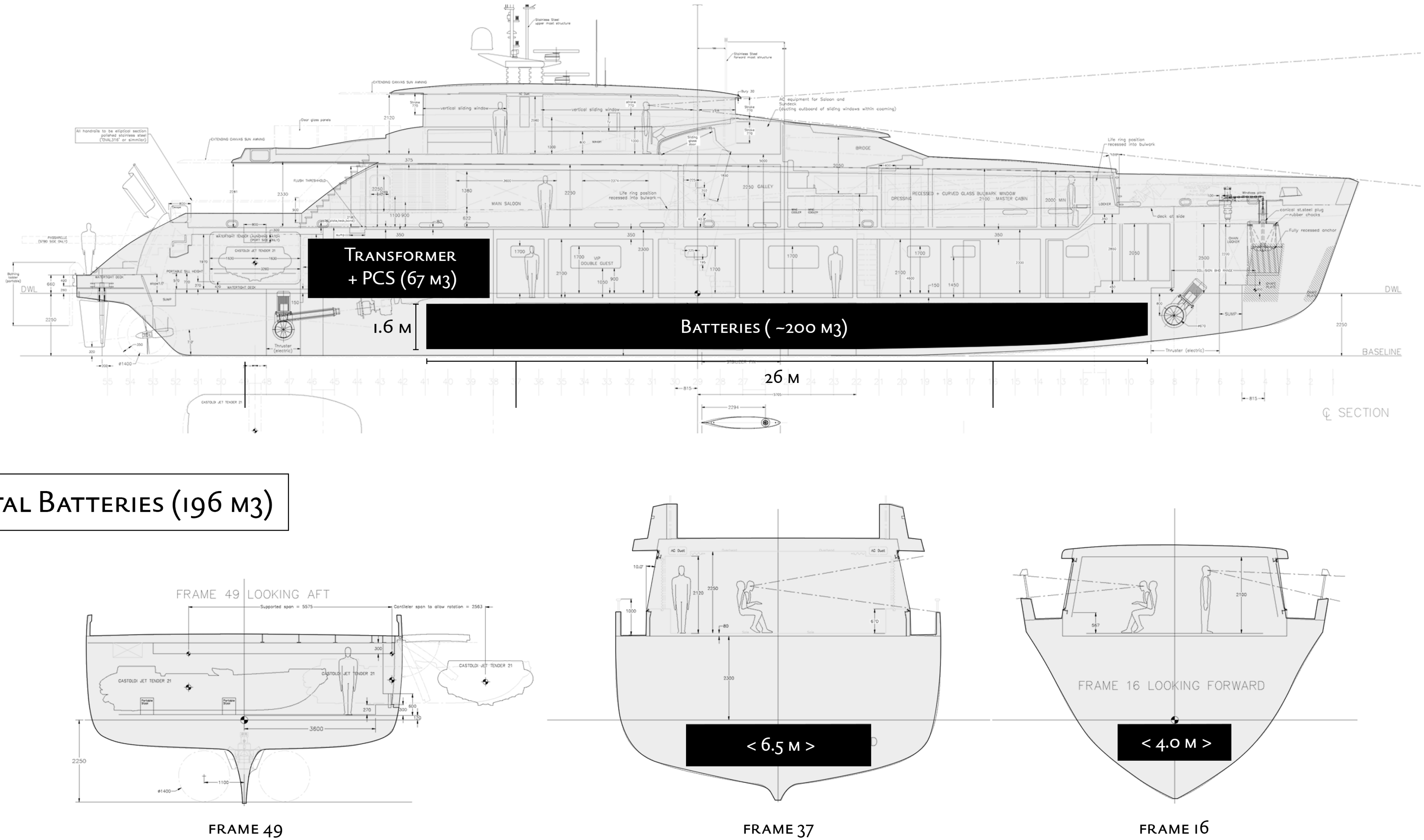


Fig 36. Potential Electric System Layout based on Feadship Como

SELF-SUFFICIENCY

How can a fully electric yacht fit the future vision?

Rather than using these sustainable energy generating methods on board, there is more potential for use off-board (appendix 3). Feadship had contact with a client who is interested in a fully electric super yacht. This client owns a private island in Greece, which can be used as a base for the energy generating system (Feadship, 2017).

This opens up possibilities for self-sufficiency, which fits the vision for the design very well. The client can generate his own green energy to charge his super yacht with, making sure that not just the super yacht itself is sustainable, but the energy supplied as well. Solar energy has been chosen because it is less intrusive to the island environment compared to windmills, besides that these clients are assumed to reside in the warmer areas of the Mediterranean Sea.

Solar energy = 1500 Kwh/m2/year on average in Greece = 4110 Wh/m2/day (RH Marine, 2018).

Panel efficiency = 18% = regular solar panel efficiency (RH Marine, 2018).

Energy generated = 740 Wh/m2/day
Required energy for a full charge = 15 MWh

2900 m2 (40% of a football field) to fully charge the super yacht in a week (figure 38).

Using solar panels with an area of at least 2900 m2 guarantees (on average) a fully charged 15 MWh storage battery in 7 days. This is assuming average solar power in Greece and a normal panel efficiency of 18%. This energy will be stored in a storage battery, which in turn will be used to charge the super yacht when it is docked in the harbor. Figure 38 shows the potential and the size required for the solar panel farm.

This self-sufficiency infrastructure (figure 37) allows the owner to be completely independent in a sustainable way. If he wants to sail further away from the island he will have to use the portable supercharger containers or use the infrastructure available in the harbors. This island and the analyzed technology will be used in the ideation phase to create a final scenario for the concept.

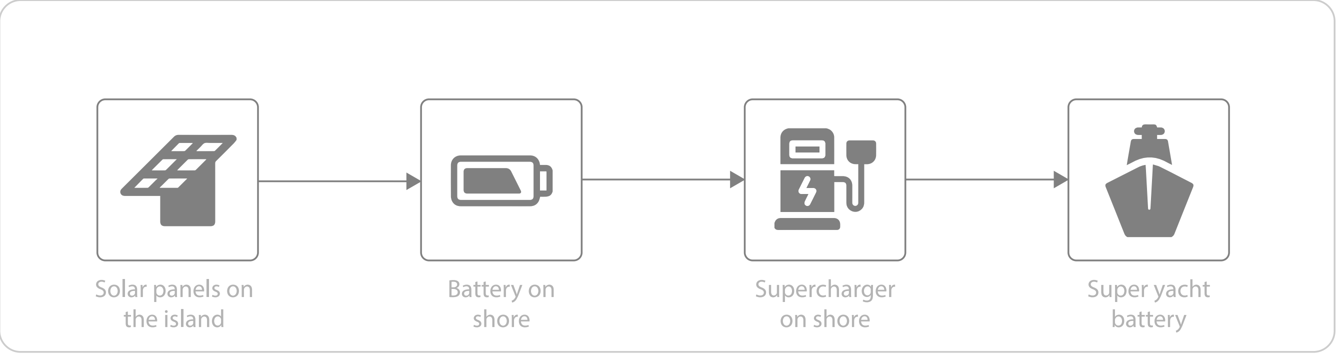


Fig 37. Self-Sufficient Infrastructure

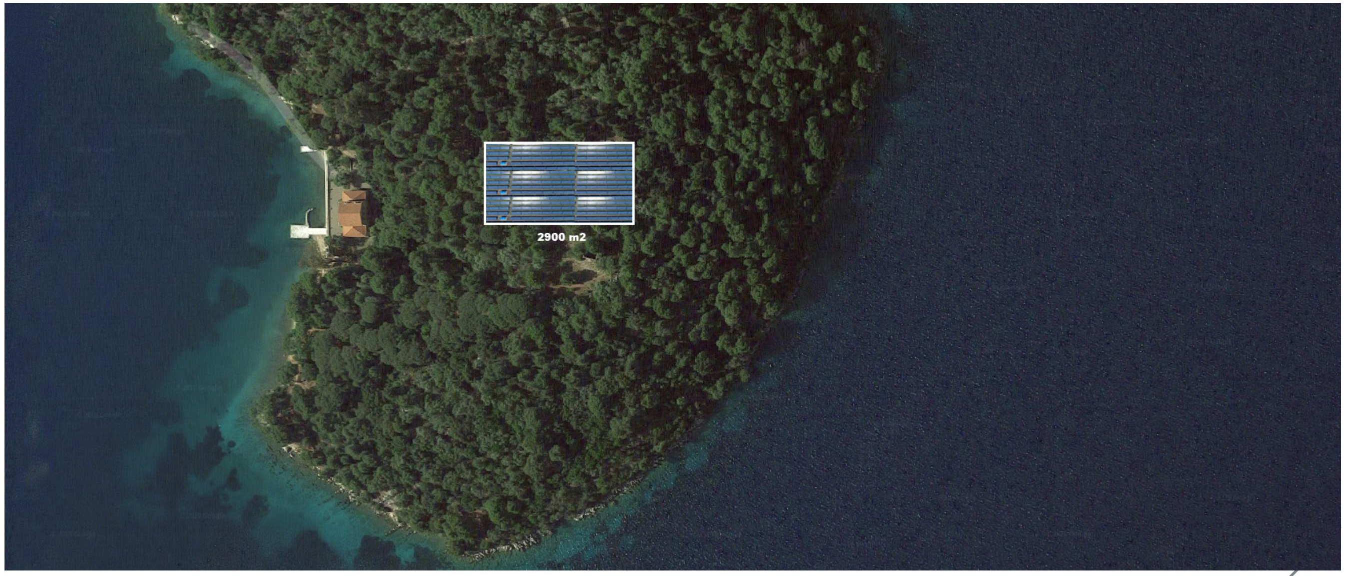


Fig 38. Island with Solar Pannels

DESIGN BRIEF

The main conclusions from the vision, context analysis and technology analysis will lead to the formulation of the design brief, to use as basis for the ideation phase. The ideas will have to meet these requirements in order for them to be successful.

Project Brief

- Length of the yacht: 50 m
- Fully electric propulsion
- 8 crew members
- 8 guests

Vision

- Product qualities: seamless, natural, subtle, refreshing, futuristic, premium, balanced, dynamic, organic

Context

- Organic/modern and dynamic/simplistic design
- Drivers: tech desire, energy independence & environment
- Luxury experience redefined: pioneering, time and personal image
- Target group: young UHNW millenials, with authenticity as main driver

Scenario

- Minimum range of 300 nm
- Cruising speed of 10 kn

Technology

- Infrastructure needs to be scalable, flexible and allow self-sufficiency options
- Energy system should fully charge the yacht in at least 1 day
- At least 196 m3 of batteries (14 MWh) and 67 m3 for the transformer and PCS is required

IDEATION

SKETCHES

IDEA SELECTION

SCENARIO DESIGN

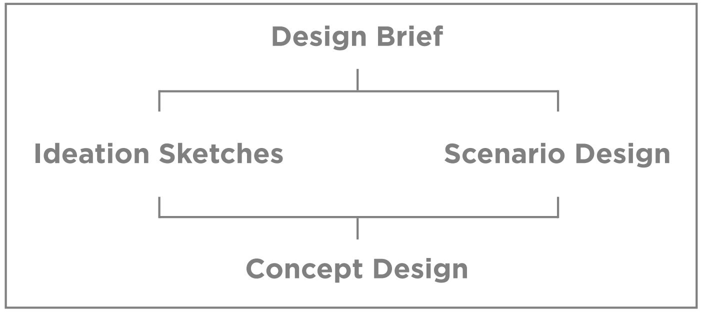


Fig 39. Ideation

IDEATION

SKETCHES

The ideation sketching is based mostly on the ViP process, focused on the styling of the yacht, while still taking into account the other research done in terms of context, scenario and technology.

The first step has been sketching side view profiles (figure 40) to determine interesting shapes and forms that fit the mood boards as developed during the ViP process. The Feadship Como has been used as underlay to ensure the proportions are realistic.

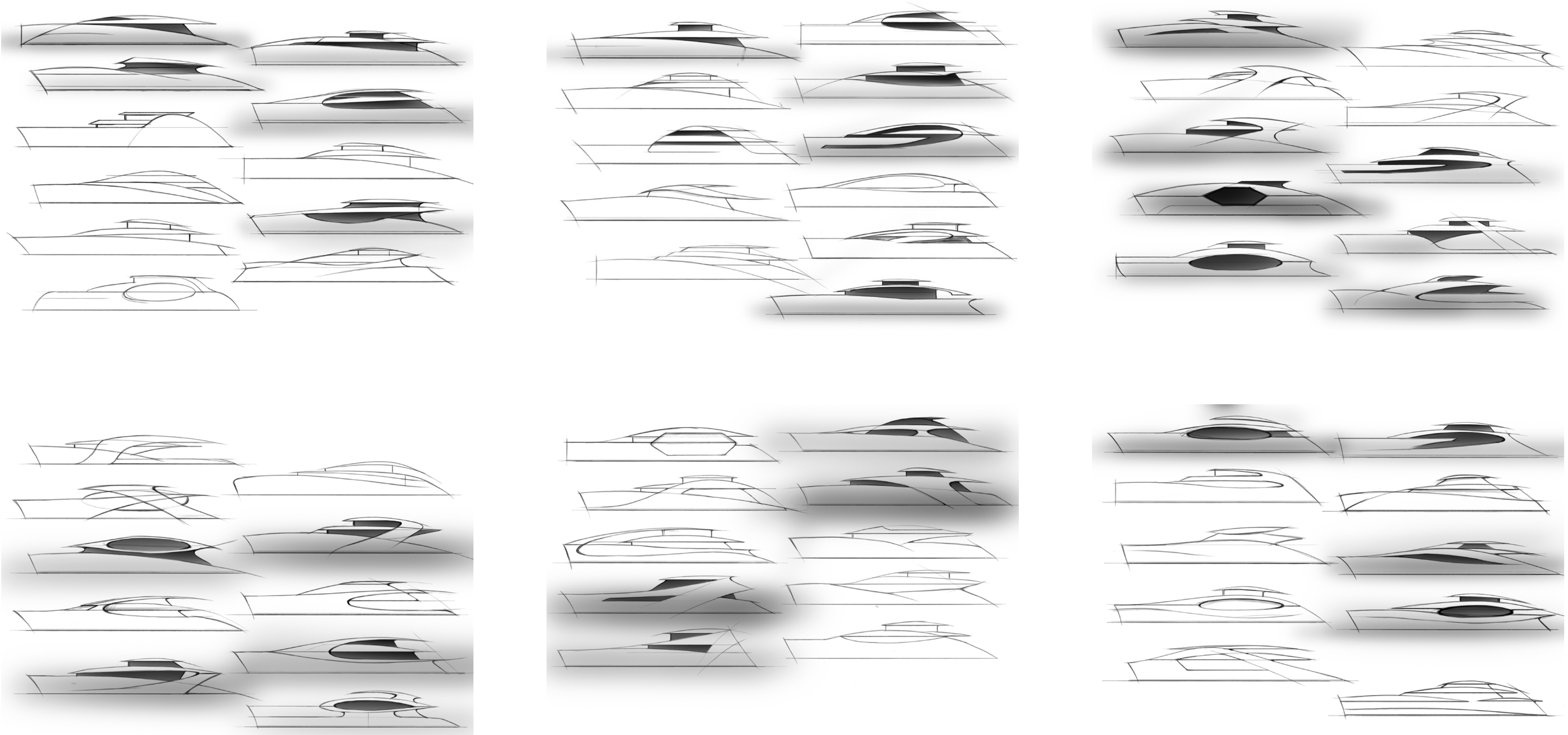
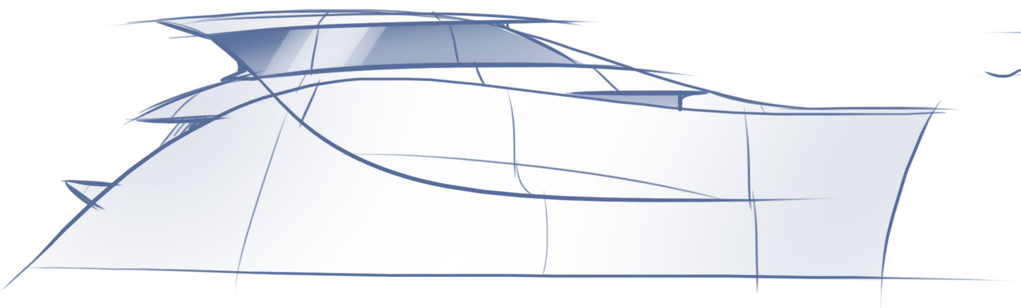


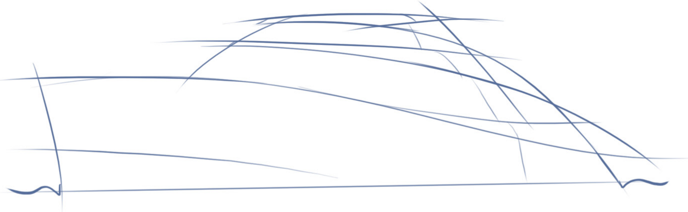
Fig 40. Ideation Sketches

SKETCHES

Based on this first ideation phase, selected ideas have been sketched in perspective, in order to make a decision for the styling of the yacht. Since the ideas are not fully developed yet they have been put into categories, in terms of similar looking design (figure 41-44).

Idea 1:





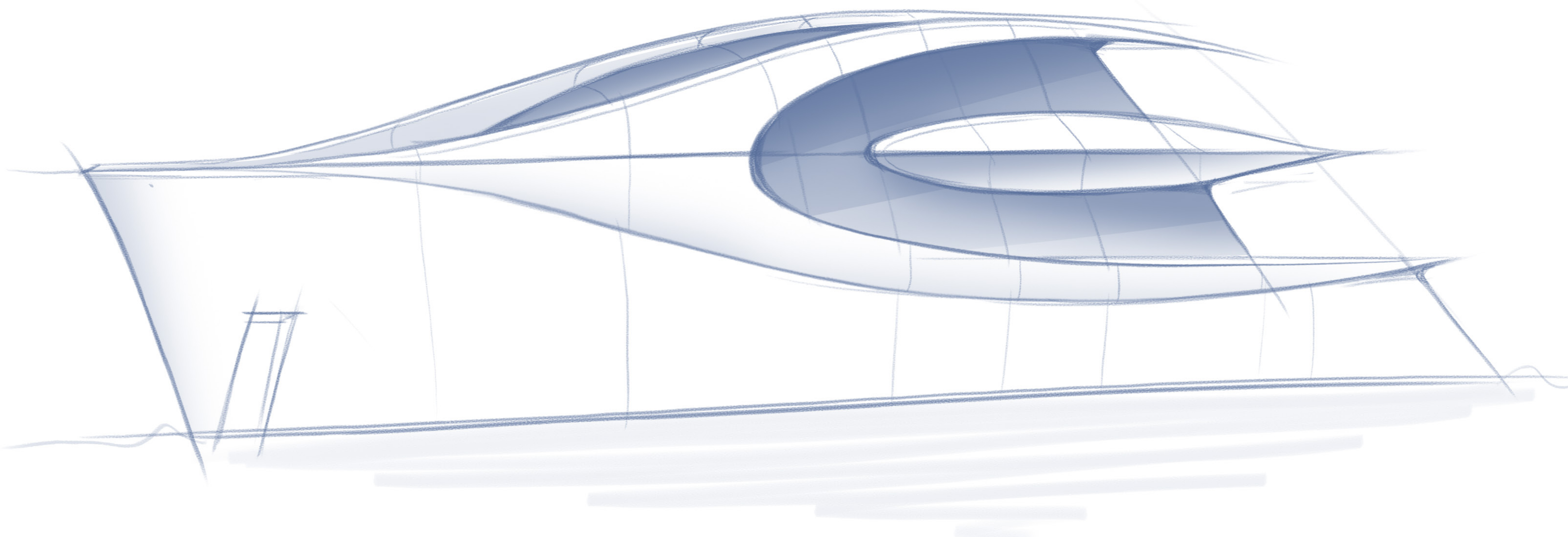


Fig 41. *Idea 1*

SKETCHES

Idea 2:

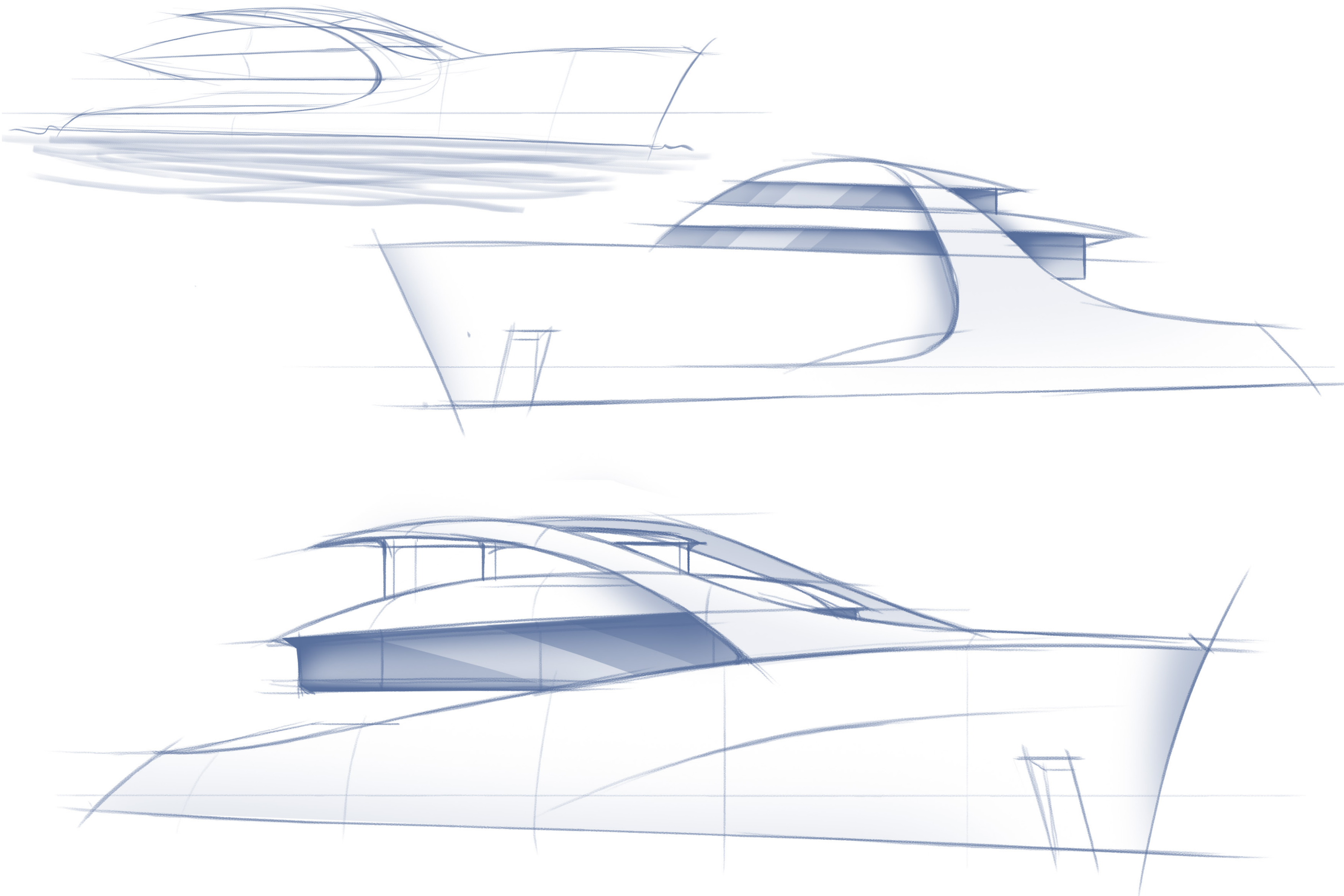


Fig 42. *Idea 2*

SKETCHES

Idea 3:

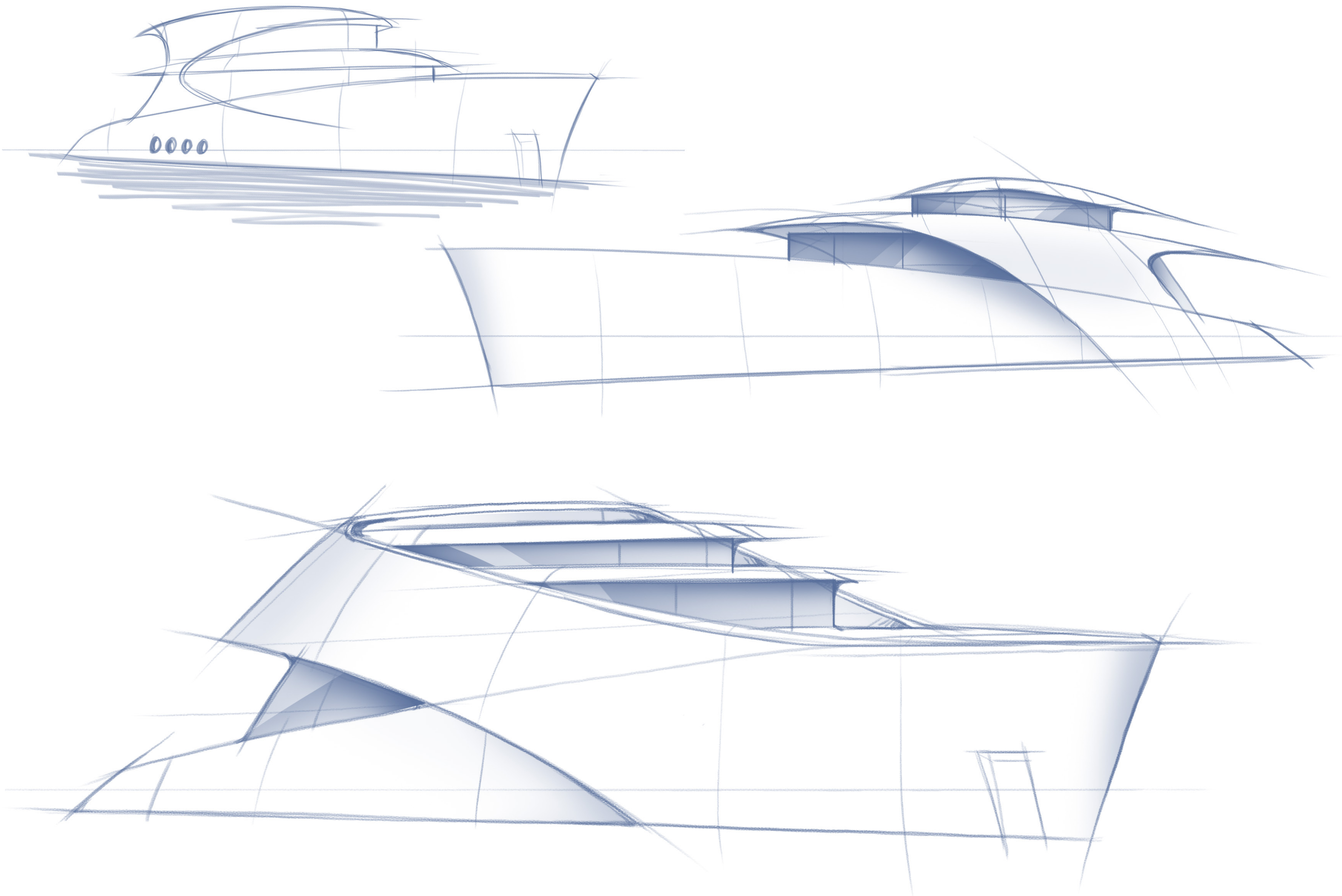


Fig 43. Idea 3

SKETCHES

Idea 4:

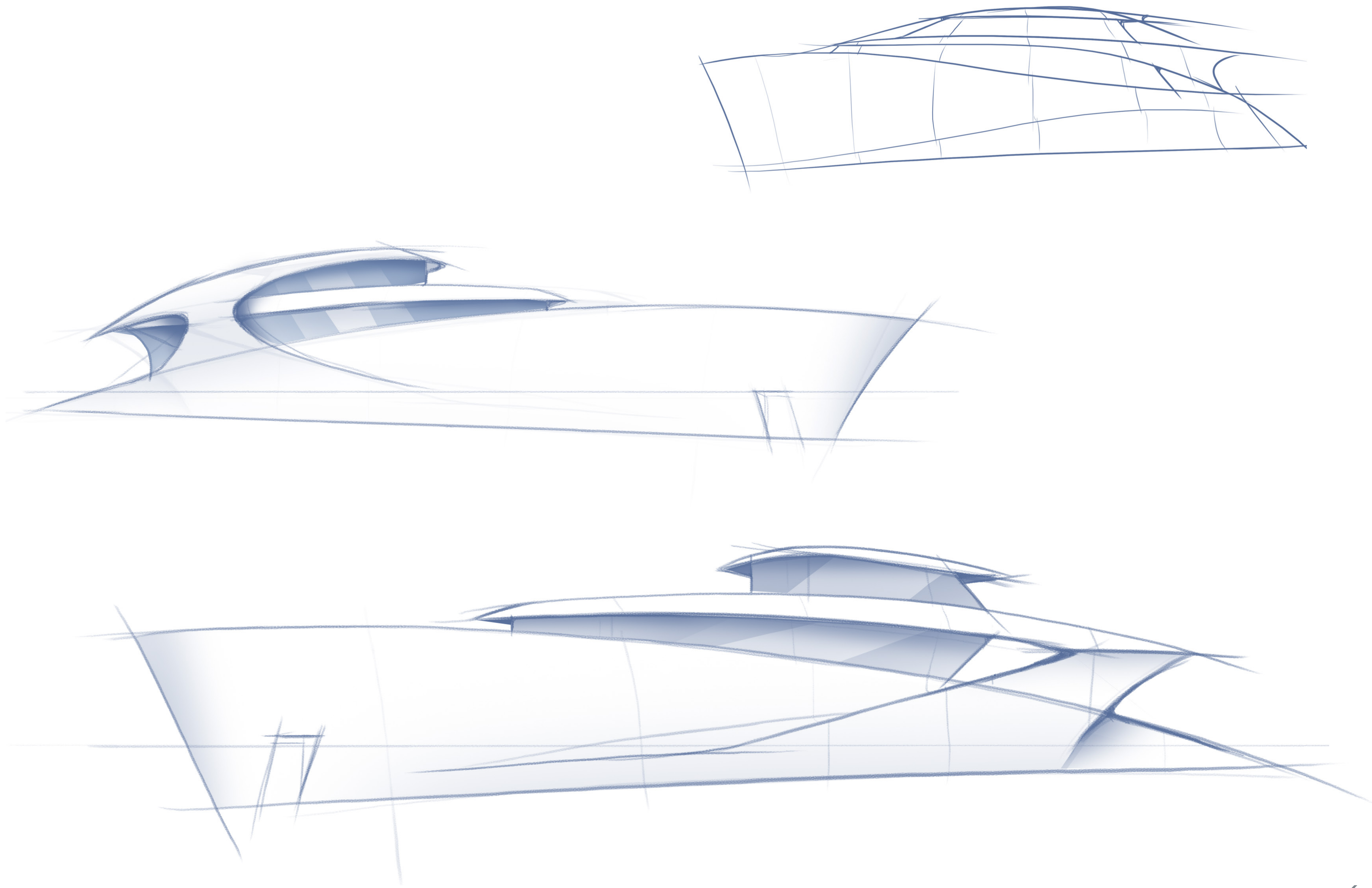


Fig 44. Idea 4

IDEA SELECTION

All of these ideas have been explored in different variants. In order to choose the design to go into the conceptualization phase with, they will all be compared to the product qualities as formulated during the ViP phase (figure 45).

Instead of developing three different concept, as is usually the case in IDE, it has been chosen to develop one concept, but with various variations. A fully electric super yacht is a very complex product, and since the main goal is to reach an overarching concept that will answer the research questions, it is more efficient to spend time on one concept and optimize this concept. In terms of ideation the first step is to select an idea for the overall styling of the yacht.

The product qualities from ViP were broken down into these 6 categories, that are used to determine the most suitable idea;

1. Seamless/Subtle
2. Natural/Organic
3. Refreshing/Futuristic
4. Premium
5. Dynamic
6. Balanced

Based on the ViP analysis, Idea 1 has the preference. It is also the most striking form of all the ideas, which is very important for a concept design. In the conceptualization phase, the design will be detailed and adapted to all the demands as researched in the analysis phase.

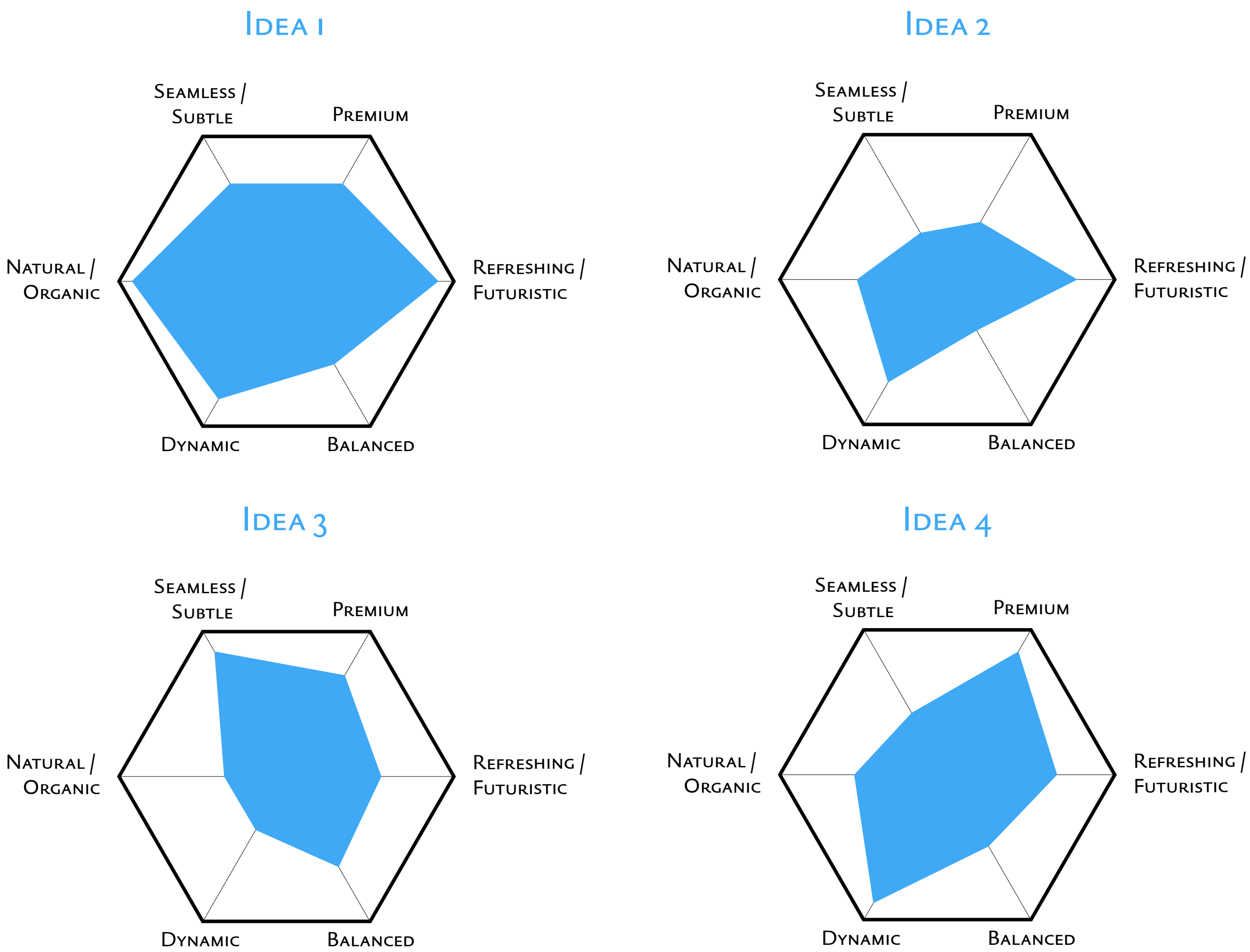


Fig 45. Idea Selection

SCENARIO DESIGN

Based on the research into the range and usage of current Feadships, a scenario has been developed that fits the target group and the use of a fully electric yacht. A few different trips have been considered and how the electric yacht should be used in that scenario, considering the range, speed and charging possibilities. The black spots in the scenario are references from anchor points from the Feadship Anna.

Scenario 1

For scenario 1 (figure 46), a client has been assumed that has a private island near Greece in the Mediterranean Sea. This profile is based upon an actual client that has shown interest in buying a fully electric yacht..

In this scenario the client sails first to Corfu to spend a day there, before moving on to the coast of Croatia. This trip takes 3 days in total where the client spends one full day nearby Corfu, not near any charging spots and 2 days sailing. The full distance sailed on this trip is ~300 nm, using ~15 MWh of energy (figure 47). He also has the possibility to bring his containerized supercharger with him using the Tesla trucks to further increase his range and/or to charge in Croatia for the return trip.

Fig 46. Scenario 1

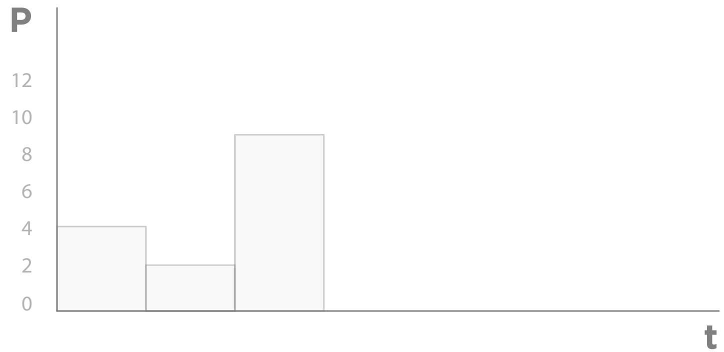


Fig 47. Scenario 1 Energy

SCENARIO DESIGN

Scenario 2

In this scenario the client sails from his personal island to the city of Athens, passing by a few small harbors (figure 48). The total distance sailed is ~225 nm, this has been done in trips of 45 nm per day. This leads to a total of 4 days with an energy use of ~15 MWh (figure 49). To increase the range and visit the ports near Athens, he can bring the supercharger truck to charge his yacht when anchored near Athens.

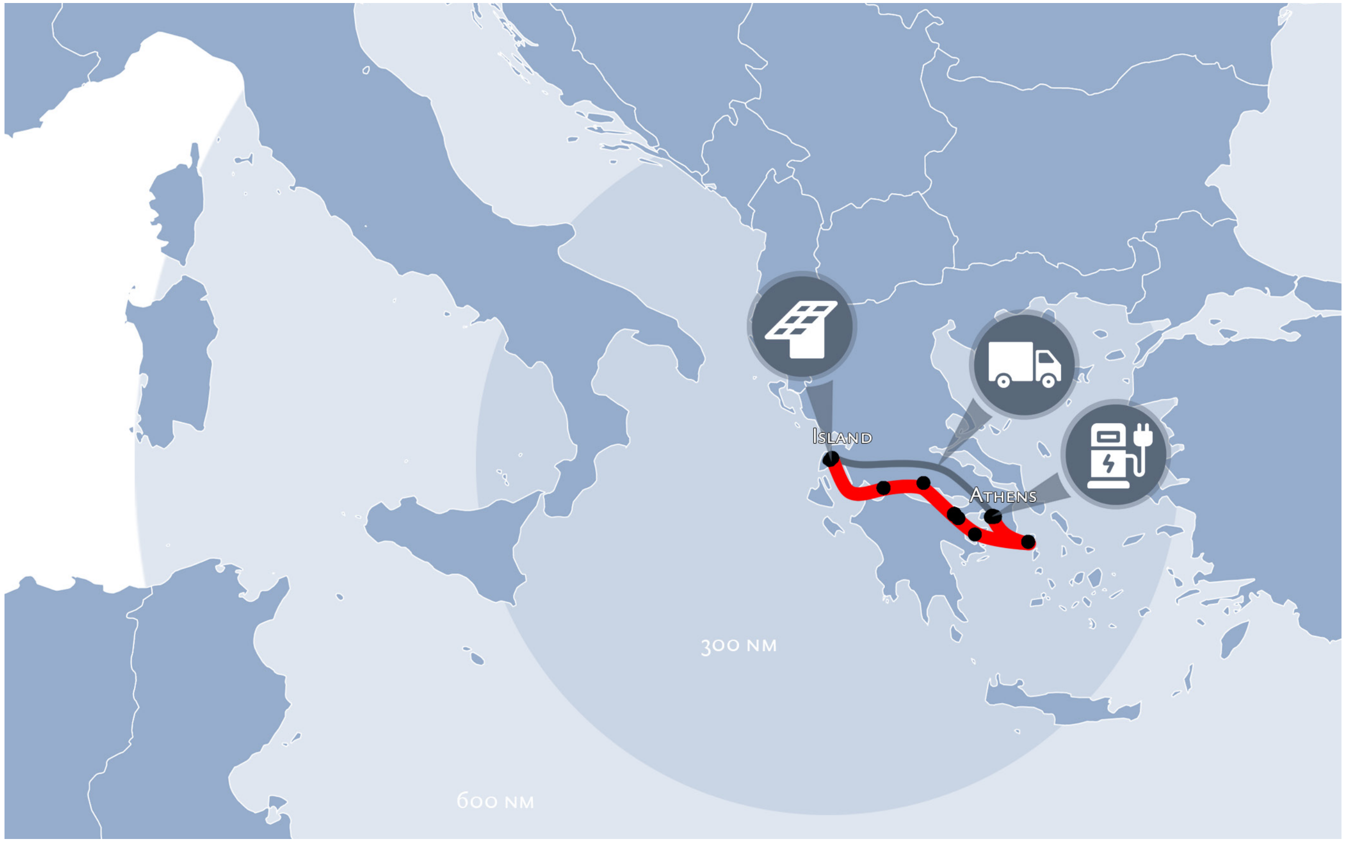


Fig 48. Scenario 2

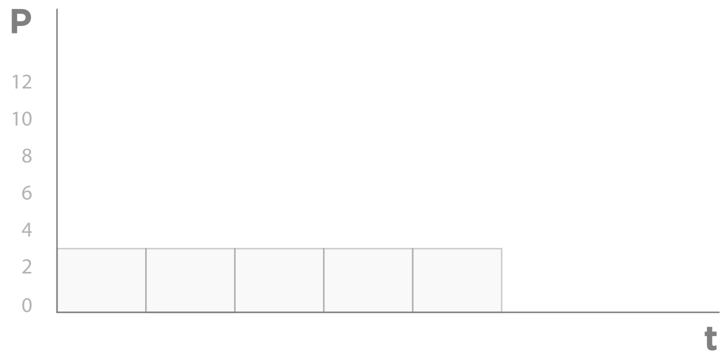


Fig 49. Scenario 2 Power

SCENARIO DESIGN

Scenario 3

This scenario starts after a transit from the personal island to Monaco (figure 50). For this transit the client himself is not on the yacht, but will get on board in Monaco. He will then sail to Marseille and spend some time in Saint-Tropez halfway during the trip (5 days in total). The total distance sailed is ~130 nm, with 3 days spending idle in Saint-Tropez, using a total of ~14 MWh (figure 51).

Fig 50. Scenario 3

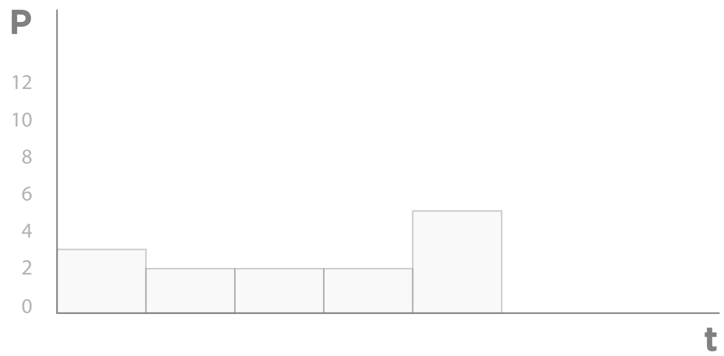


Fig 51. Scenario 3 Power

SCENARIO DESIGN

Scenario 4

In the final scenario the yacht will be in transit from the personal island to Mallorca where the owner gets on board (figure 52). He will first sail to Ibiza, where he will spend a few days before going back to Mallorca. The total distance sailed in this trip is ~180 nm (one day sailing to Ibiza, one day sailing back), while spending 3 days idle in Ibiza, consuming a total of ~15 MWh (figure 53).

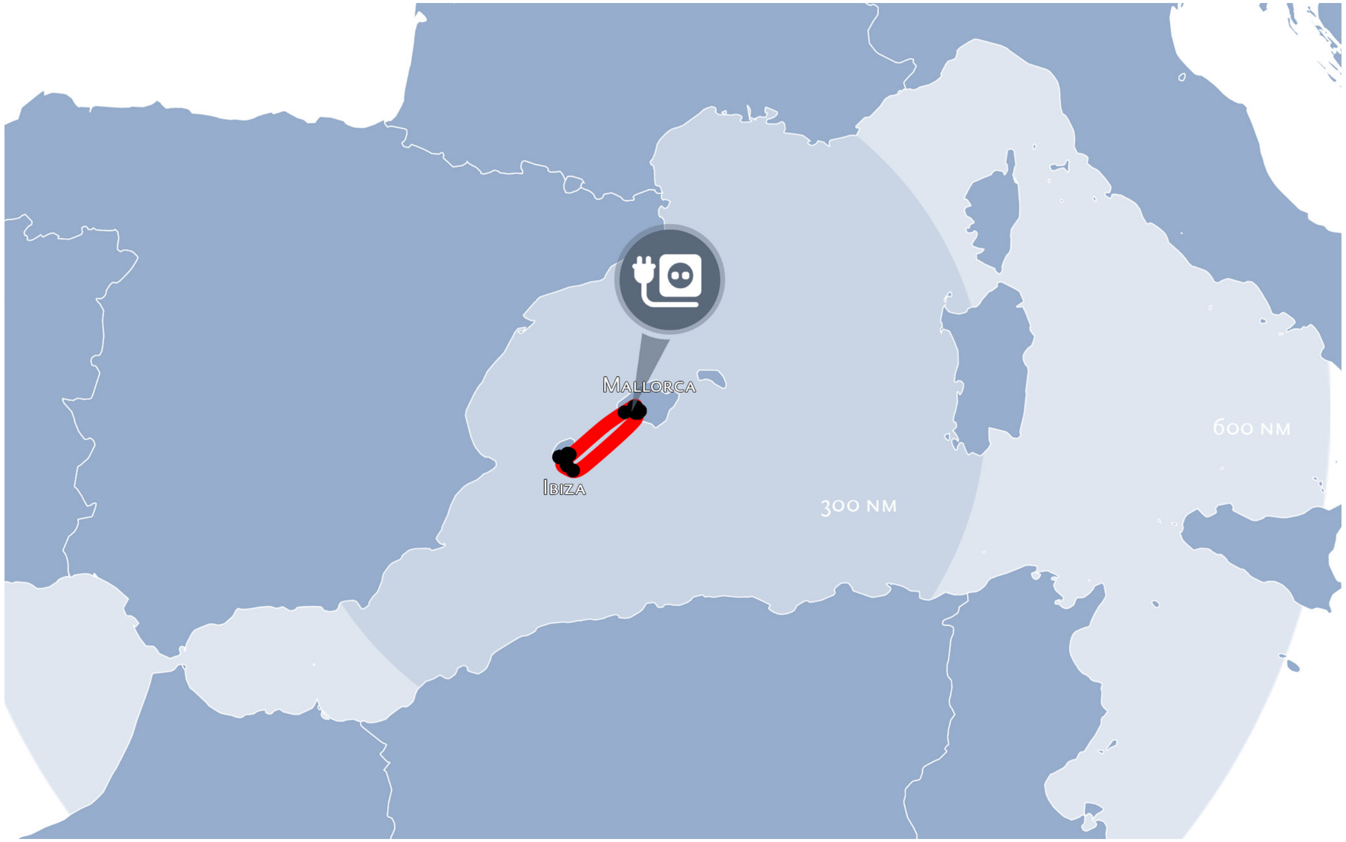


Fig 52. Scenario 4

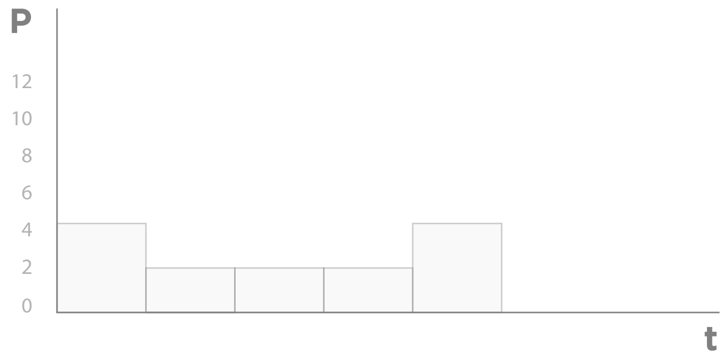


Fig 53. Scenario 4 Power

SCENARIO DESIGN

Transit scenario

This scenario shows a potential transit route for the yacht to meet the owner in a different city (figure 54). The range of 300 nm is enough to travel from large harbor to another in order to charge up and continue the journey. With a range from point to point of 440 nm, the transits can be even longer, especially if the owner is not aboard (which is usually the case during transit), since the hotelload can be significantly reduced during transit. This would most likely lead to a range of 500+ nm.

Fig 54. Transit Scenario

CONCEPT DESIGN

INFRASTRUCTURE DESIGN

EXTERIOR DESIGN

GENERAL ARRANGEMENT

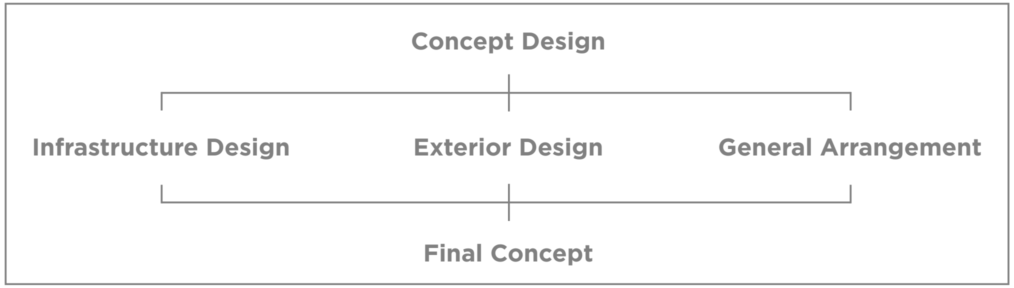


Fig 55. Conceptualization

INFRASTRUCTURE DESIGN

Flexible Infrastructure

The main scenarios have been analyzed based on the design of the infrastructure that supports it. First scenario 1 has been analyzed (figure 56), because it represents the flexible infrastructure options.

This scenario starts from the personal island of the owner where he charged his yacht using the solar panels on his island that transfer the energy to a battery on shore. This battery in turn uses a supercharger on the shore to quickly charge the super yacht.

When the client sails to Dubrovnik he brings the portable supercharger and battery with him using a Tesla truck. In Dubrovnik he then can charge his yacht fully again using the super charger and battery on board of the truck in order for him to sail back to the island.

The solar panels on the island are designed to fully charge the shore battery of 15 MWh in 7 days, which is a common cruise duration. The truck-system could also be implemented using a lease system. Where the portable chargers are adopted in several harbors and clients can lease these when required.

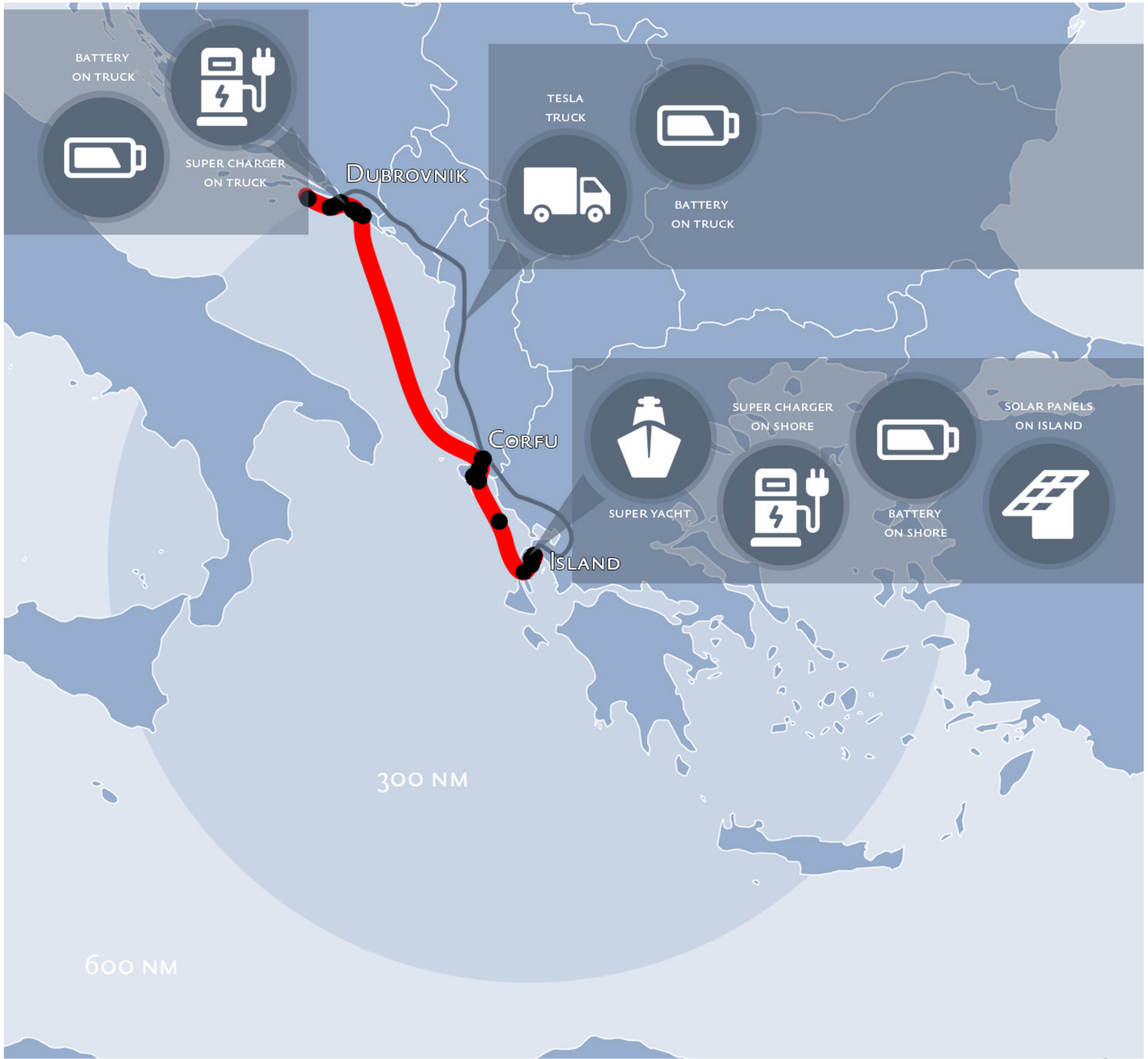


Fig 56. Flexible Infrastructure

INFRASTRUCTURE DESIGN

Port infrastructure

Scenario 3 has been analyzed (figure 57), because it represents the infrastructure options available in the ports currently (or in the near future).

In this scenario the cruise starts in Monaco, which means the transit to Monaco has been completed without the owner on board.

In Monaco the yacht can be connected to the grid using a plug connection of several three-core cables (appendix 3). After the cruise finishes in Marseille the super yacht can charge there at the port again using a plug connection to the grid. These harbors have superchargers available or are developing them for the near future.

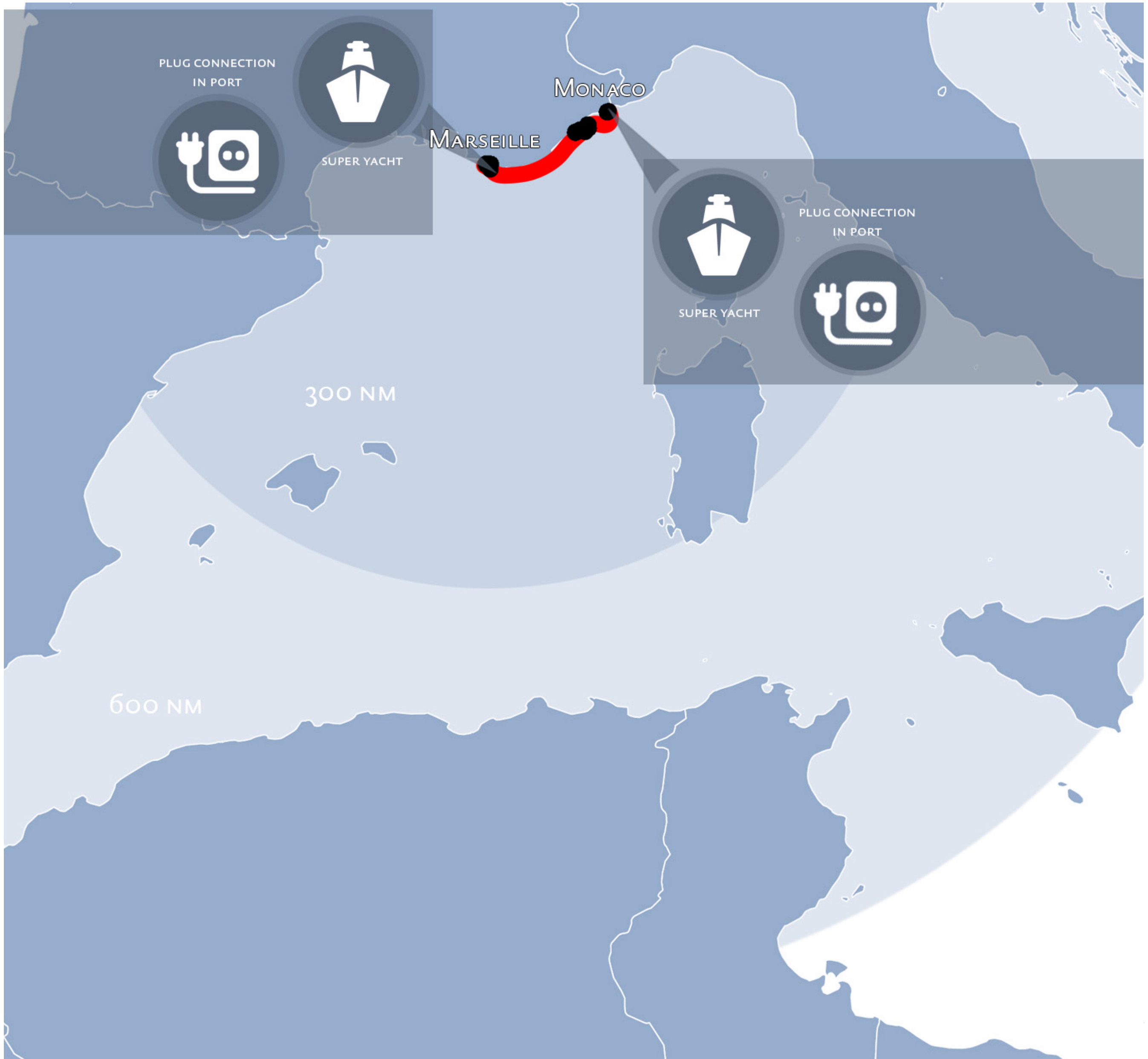


Fig 57. Port Infrastructure

EXTERIOR DESIGN

What changes in the GA are required or possible (fuel > batteries) and how does this influence the design?

To further detail the design of the super yacht, the proportions in side view have to be determined. In order to create a usable GA, the Como (46 m) has been used as an underlay (figure 58), while extending it 4 meters to fit the 50m length as described in the design brief.

This plan is used to determine the important lines in the design; the floor lines for all the levels as well as general shape of the yacht (figure 59). This GA has then been analyzed for potential changes and adapted to the initial sketches of the electric super yacht.

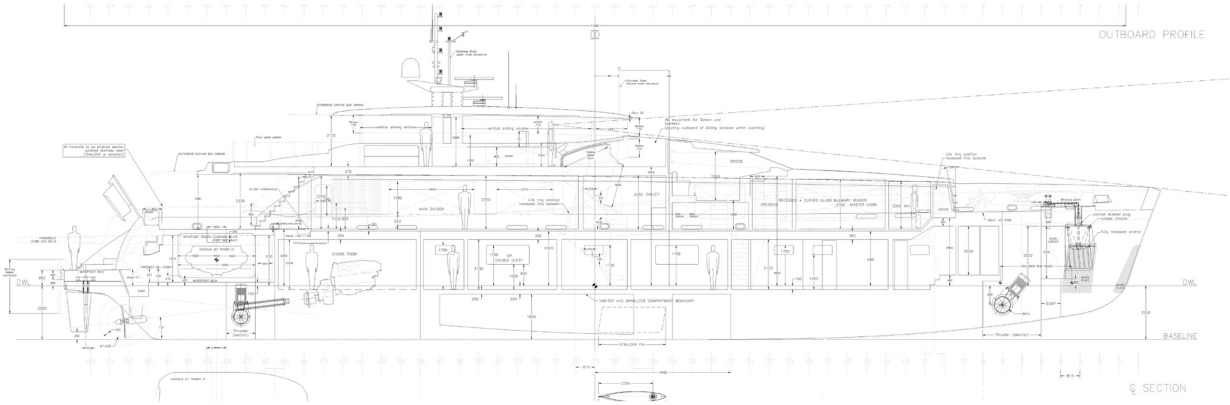


Fig 58. Feadship Como Underlay

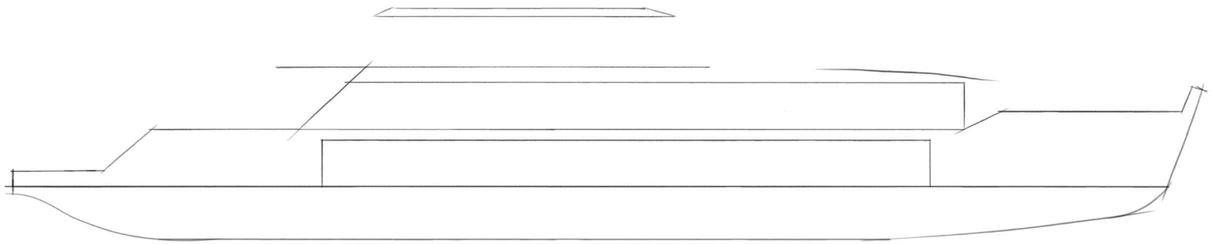


Fig 59. Important Underlay Lines

EXTERIOR DESIGN

Using this picture as underlay, it is possible to work on a side view profile that fits this general GA (figure 60). Since the GA is still very global, changes can still be made, but for the design it is important to set some boundaries in terms of proportions.

The following sketch (figure 61) has been made based on this GA and the ideation sketches. And finally this profile has been shaded to give a more visual representation of the design.

Details, such as windows and the exact placing of all the rooms will have to be determined. This will be done in the GA (from top view), while this side view picture will be used as guideline for the design in general.

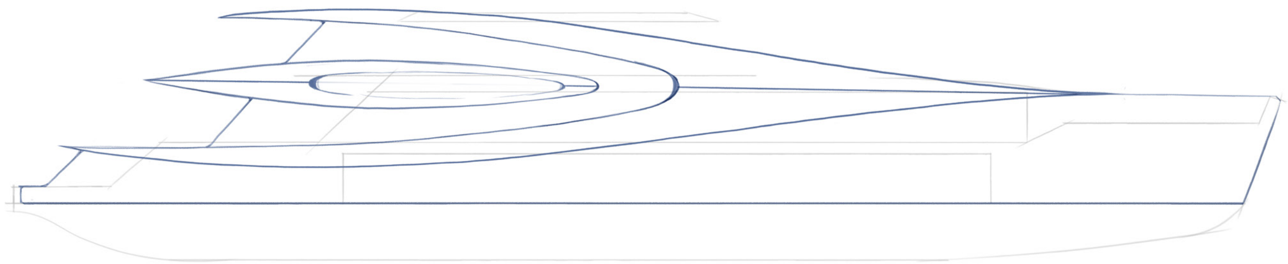


Fig 60. Side View Profile

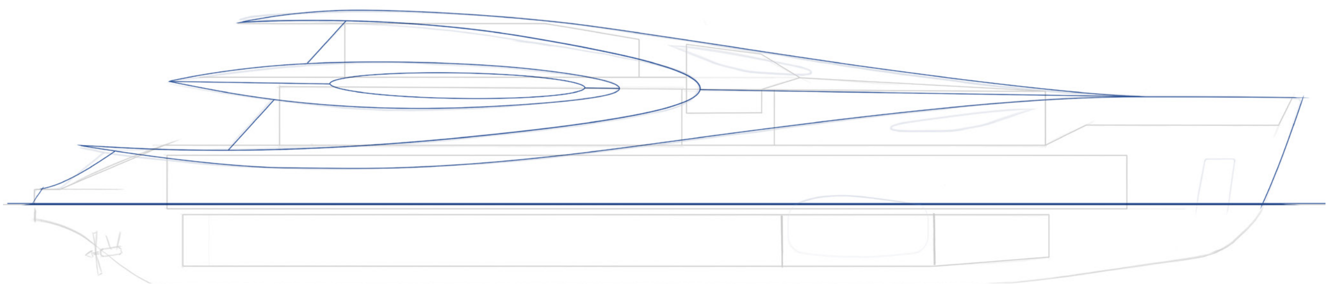


Fig 61. Side View Sketch

EXTERIOR DESIGN

Kinetic Facade

The top of the yacht was full glass in the original design sketches; however in terms of usage it should be possible to regulate the amount of sunlight entering the rooms. This has energy benefits as well, since the AC would require less capacity. In order to regulate the sunlight as well as add biomimicry aspects, there is a possibility to use kinetic facade elements in the roof of the yacht. This adds movable elements on the glass that are able to move in a natural way, allowing sunlight or blocking it from entering the rooms. There are a lot of different possibilities to use this principle, but two from the architecture domain have been highlighted, because they fit well within the vision. They both embody "seamlessness" and "organic" as well as "futuristic", and "dynamic".

The possible options have been sketched to get an overview. Idea 1 is using a conventional roof design, using glass only in the front windows and just a black roof to keep the sun out (figure 64). Idea 2 uses kinetic facades as can be seen in the "One Ocean Pavilion", which can move in a "wave-like" shape to create openings (figure 62). Idea 3 uses the kinetic facades as seen in "Al Bahr Towers", which uses triangle shaped figures to open the building up to the sun or to block it from the sun (figure 63). Finally, Energy Glass could potentially be used to block out sunlight, while still keeping the glass design itself (appendix 6).

For this concept the kinetic facade in idea 3 (inspired by Al Bahr towers), will be used in the final concept, since it is a very dynamic feature that blends in well with the organic shape and feel of the concept. It is chosen over idea 2 because the horizontal lines in idea 2 slow down the dynamic aspect of the concept, besides that, idea 3 has a more premium look as well.

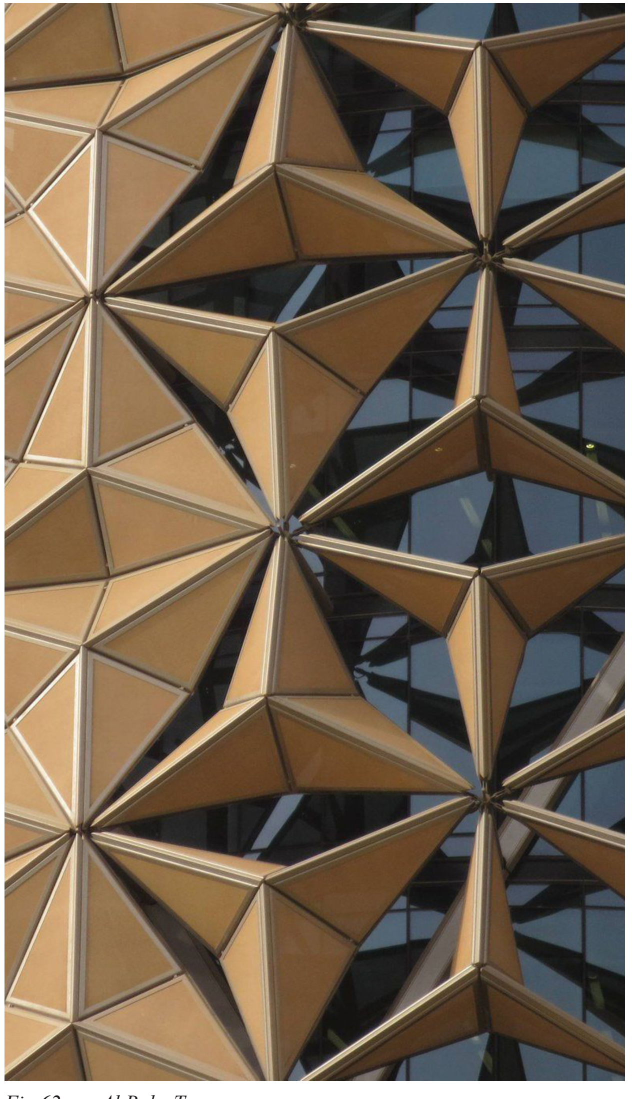


Fig 62. Al Bahr Towers

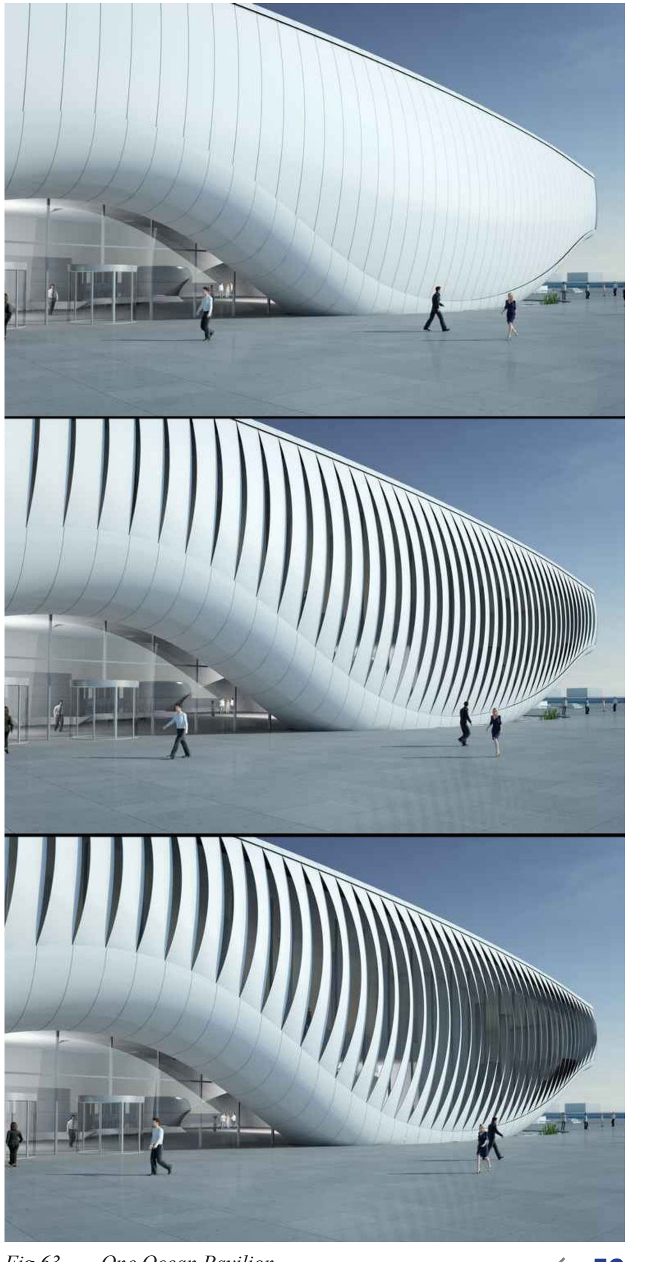


Fig 63. One Ocean Pavilion

EXTERIOR DESIGN

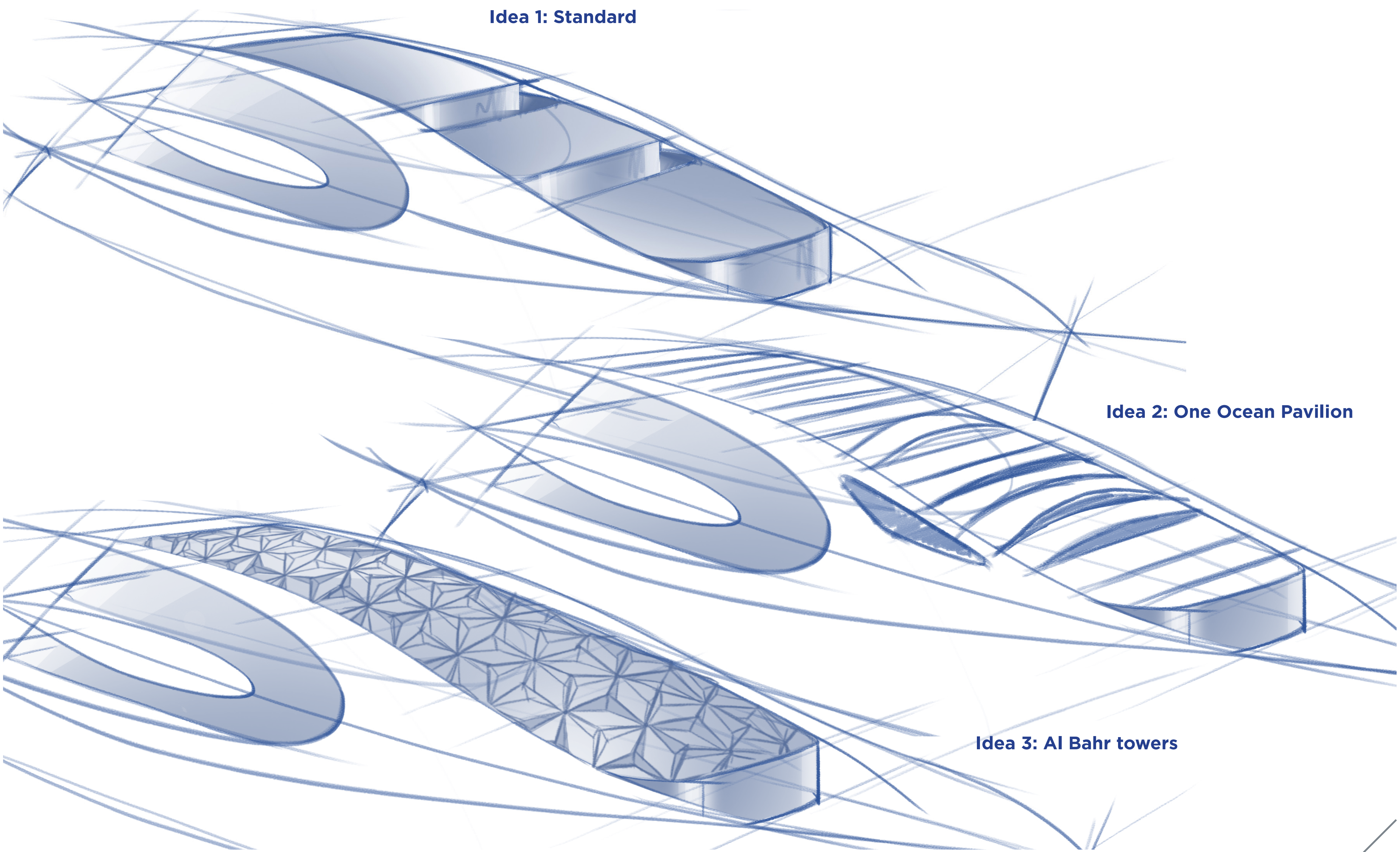
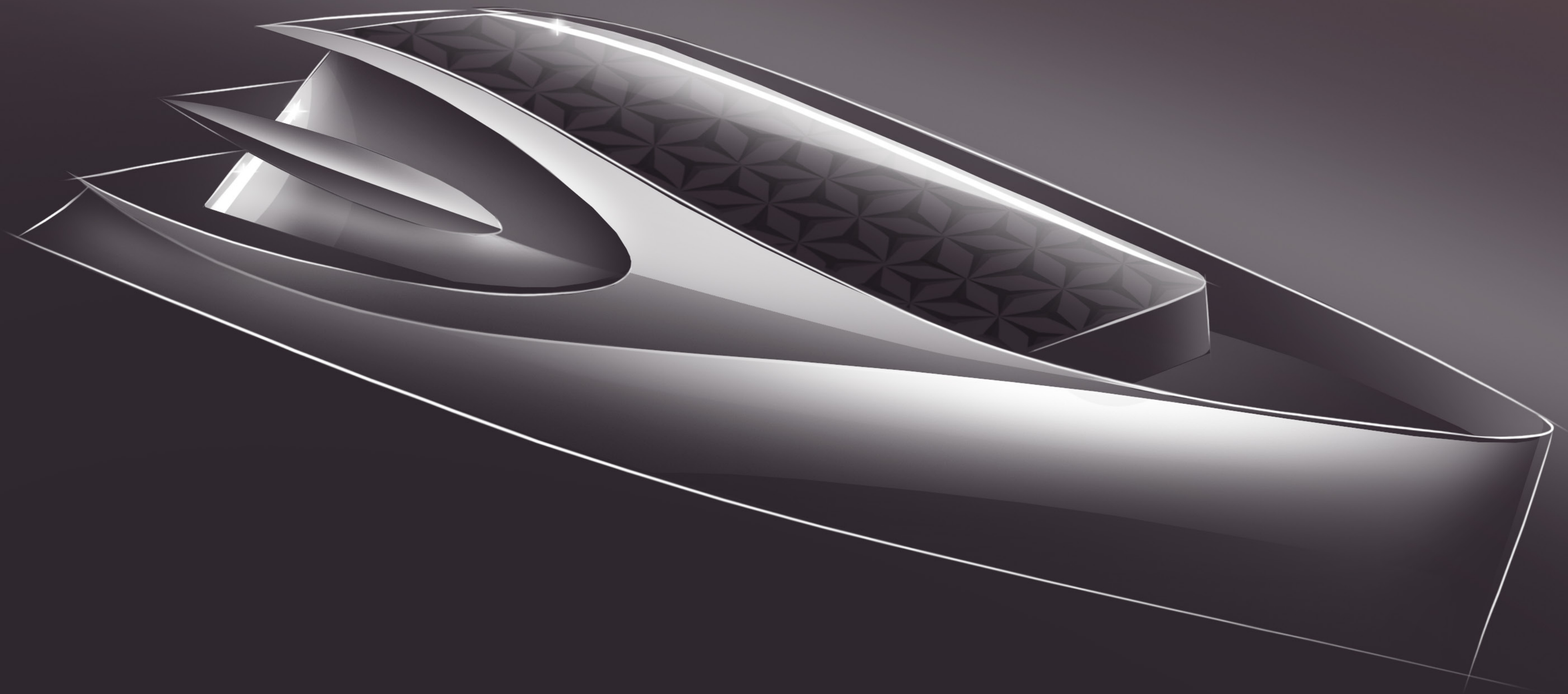


Fig 64. Roof Design



EXTERIOR DESIGN

Final Design

The exterior design of the yacht is based on the ViP vision focusing on the defined product qualities:

- Seamless
- Natural
- Subtle
- Refreshing
- Futuristic
- Premium
- Balanced
- Dynamic
- Organic

Using the selected idea from the ideation phase, the adaptation of the design to the GA lead to the following design (figure 65).

The top window is positioned to allow for a good overview while in the wheelhouse, while the second window is part of the master cabin. The window for the nemo room flows into the line on the side. The smaller windows are tinted and merged into the shape in order to keep the general design of the yacht clean and subtle.

In the large blue glass area, a ellipse shape has been added to fit the seamless theme and to make the overall shape appear less intense. The design as a whole has a wave shape flowing through it, embodying the organic and natural product qualities. The sharp edges and forward motion in the lines express the dynamic and futuristic aspect of the design.

The glass shape, around which the design flows, is a refreshing form in the super yacht industry. The design details and ellipse shapes are seamless and subtle, and integrate in the general design language.

The consistency in flow in the design elements adds to the visual balance of the concept. The long and flowing lines fit well with the futuristic product quality of the vision.

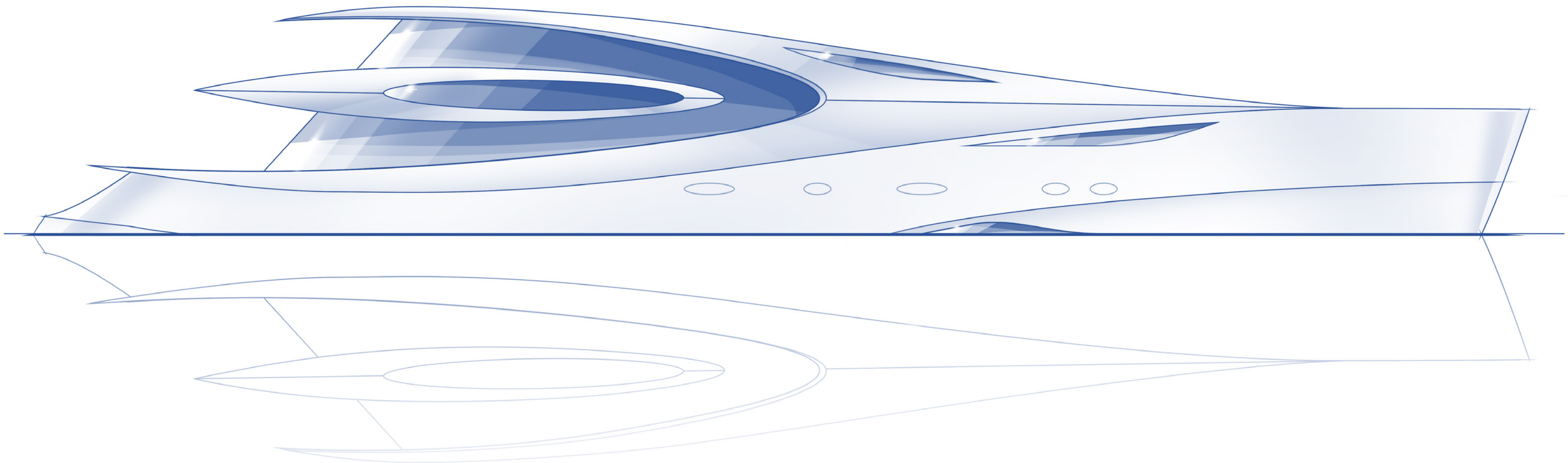


Fig 65. Exterior Design Sideview Sketch

GENERAL ARRANGEMENT

Underwater lounge

Compared to fuel tanks where liquids are handled, batteries are quite flexible in terms of positioning (Feadship 2018). Batteries can be placed wherever, with the main consequence being a displacement in weight (besides from the GA changes).

Using the flexibility of the battery space, it is possible to create an underwater (nemo) lounge in the lower deck space (figure 66). This lounge will be fitted with a large window to get a relaxing view into the ocean. Lights are installed on the exterior to enable more visibility. The window is slightly higher than the waterline, allowing daylight to help with the visibility as well. The room is located all the way in the bottom of the yacht and is therefore very private. Depending on the owners preference could even function as a hideaway or "man cave". This is really in line with the ZEN design principles, such as tranquility and naturalness.

This has an influence on the GA of the superyacht, since the large glass windows will require a certain thickness to ensure safety (figure 67). This impacts two guest rooms, which means they will have less space on the sides. This does not have to be a problem as this is typically where the sinks/beds are located. These beds/sinks can easily be highered or slightly moved to ensure enough space in the guest rooms. Next to that it impacts one of the crew cabins slightly, as well as the laundry room.

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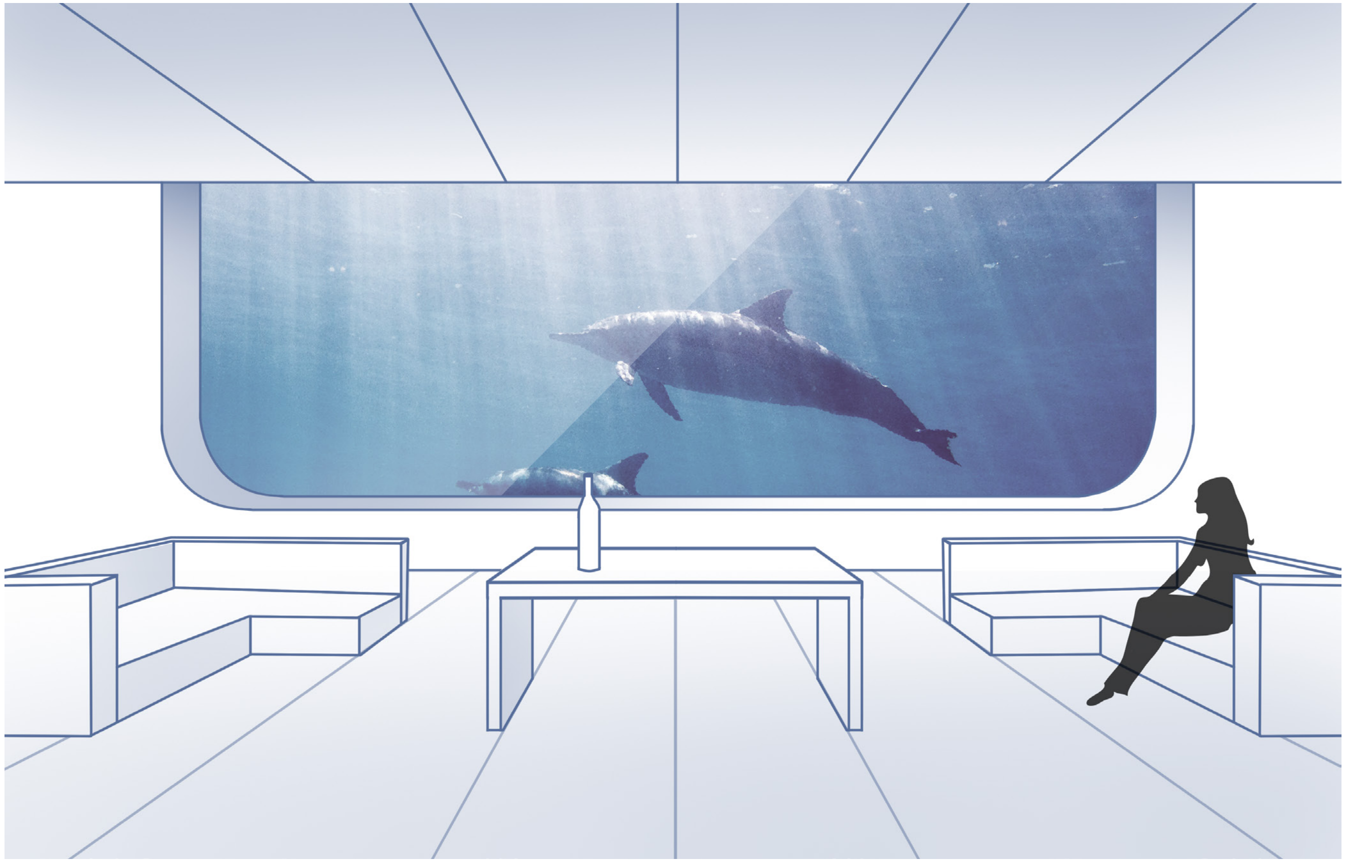


Fig 66. Underwater Lounge Impression

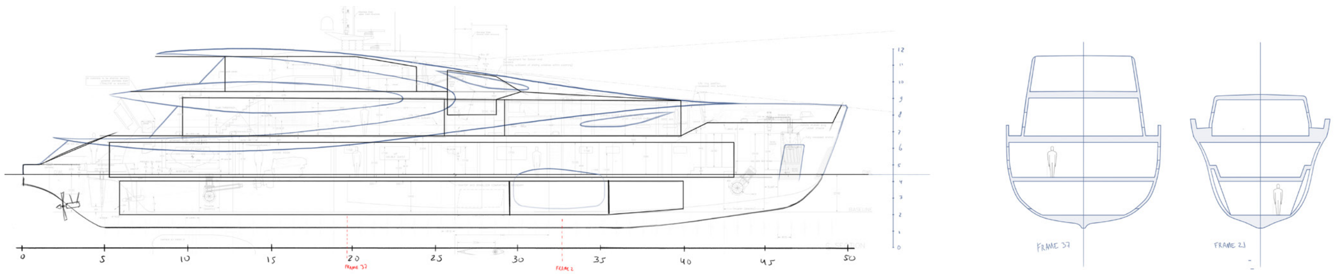


Fig 67. Orthographics GA

GENERAL ARRANGEMENT

Battery hallway

Since the batteries have to be accessible for potential repairs (Feadship, 2018), one of the ideas for the conceptualization phase includes an impressive pathway through all the batteries (figure 68). Furthermore, this can be used as a way to reach the 'underwater lounge' as discussed earlier (figure 69). The batteries are behind glass sliding windows that allow the batteries to be on full display. The engineering crew can slide these windows to the side in order to check and maintain the batteries. This makes the nemo room potentially also an interesting meeting room, since visitors get a brief overview of the fully electric superyacht they are on.

Fig 68. Batter Hallway Impression

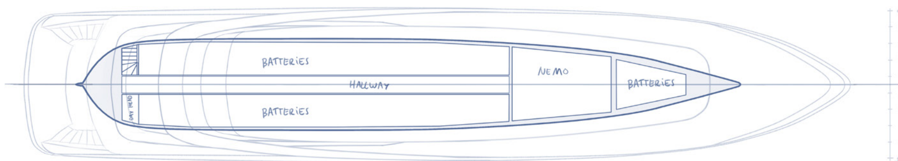


Fig 69. Lower Deck Orthographics

GENERAL ARRANGEMENT

Layout design

The general arrangement (GA) of a super yacht is the layout visualized from the top view (figure 70). The Feadship Como has been used as basis and the new features have been added. Next to that there has been made room for a spa on the top deck as well as a gym on the main deck. Especially the lower deck is interesting, combining the battery hallway as well as the nemo room right between all the batteries (figure 71).

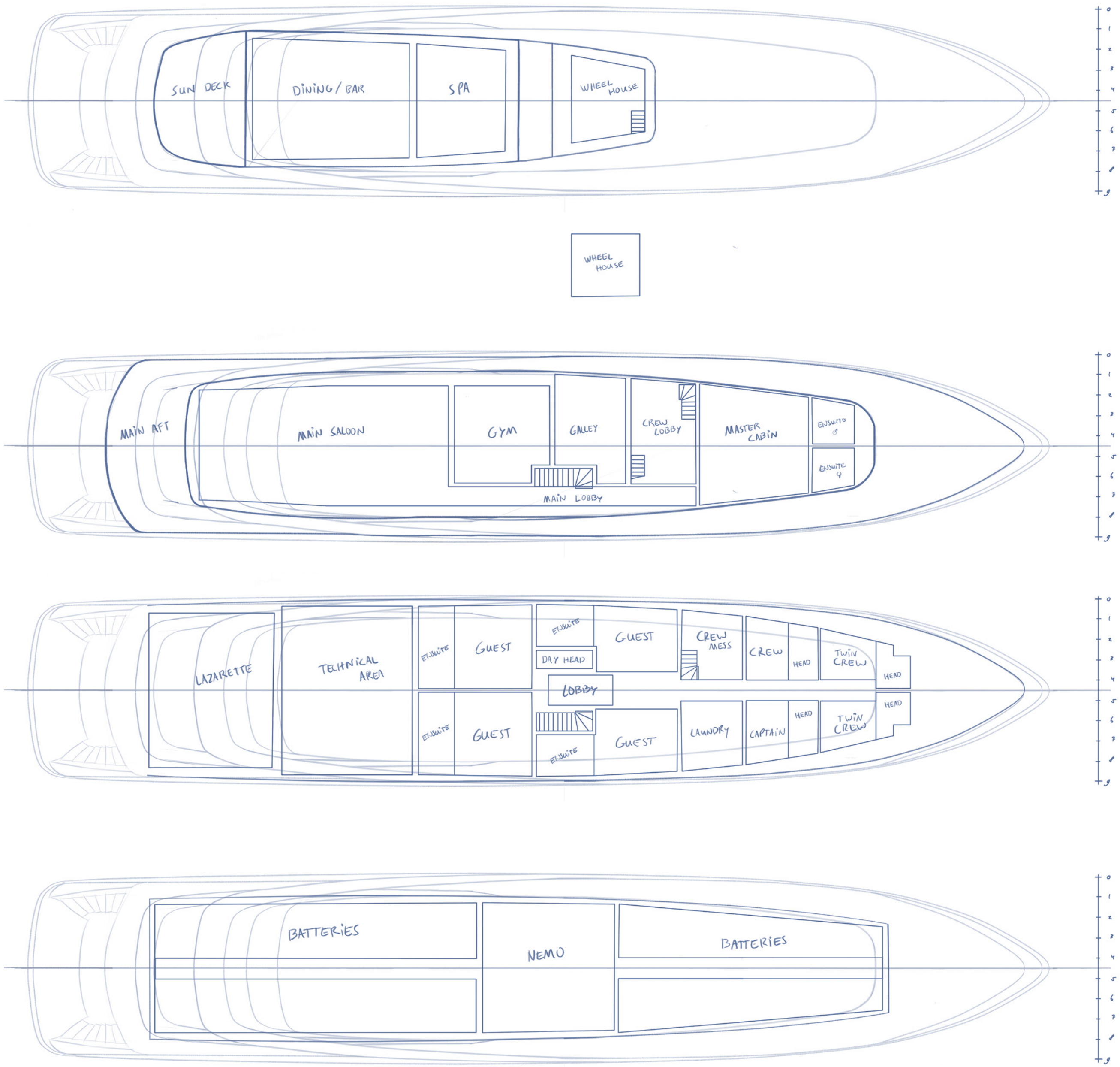


Fig 70. General Arrangement top view v1

GENERAL ARRANGEMENT

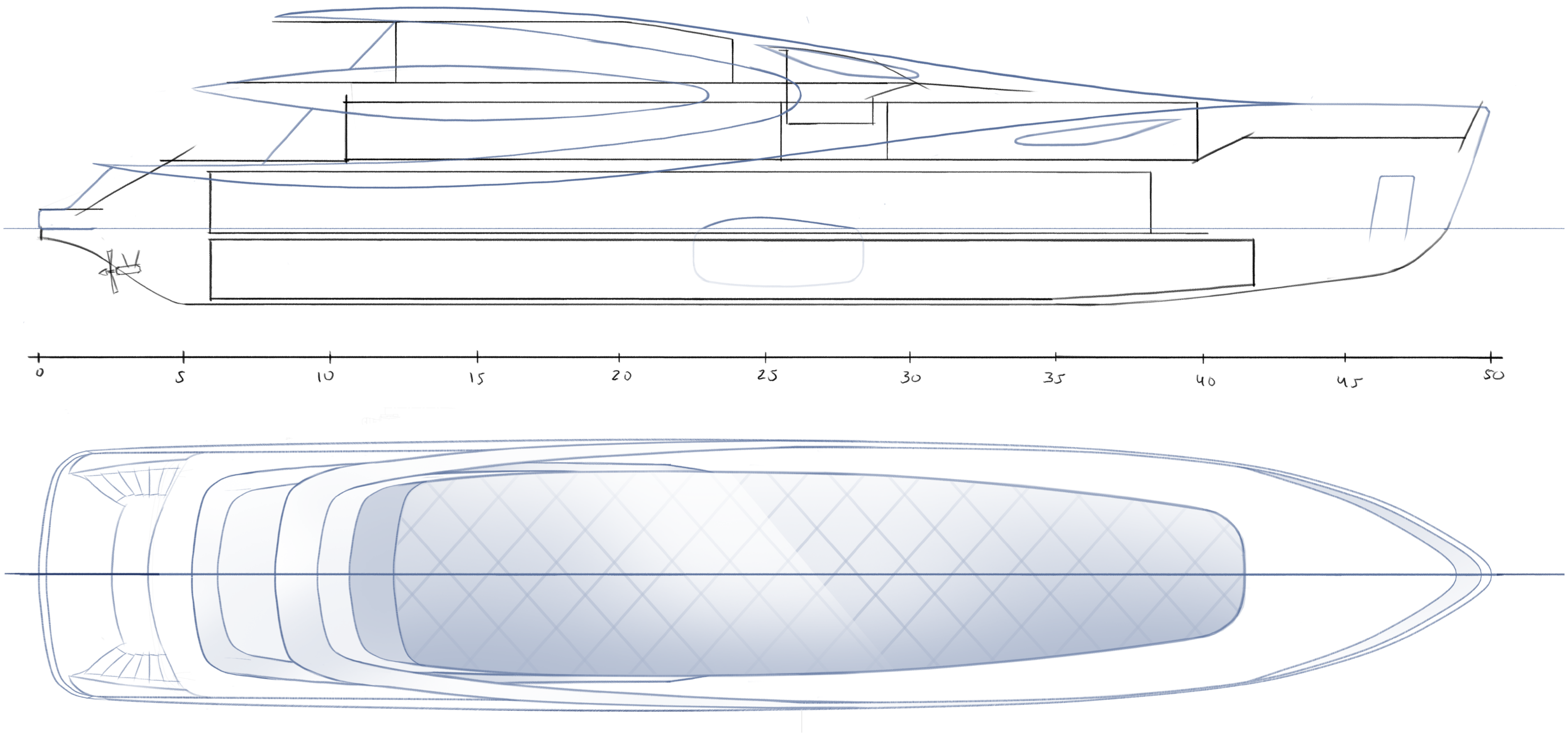


Fig 71. General Arrangement v1

GENERAL ARRANGEMENT

Layout design

However, in order to increase the hallway, the nemo room has been moved more to the front of the super yacht (figure 73). Besides that, the shape of the lower deck has been adjusted to fit the required design in a more realistic way (figure 72 & 74). In order to achieve this, the yacht as a whole has been lowered (compared to the GA of the Como) by 1 meter. This leads to a total baseline of 3.3 meter.

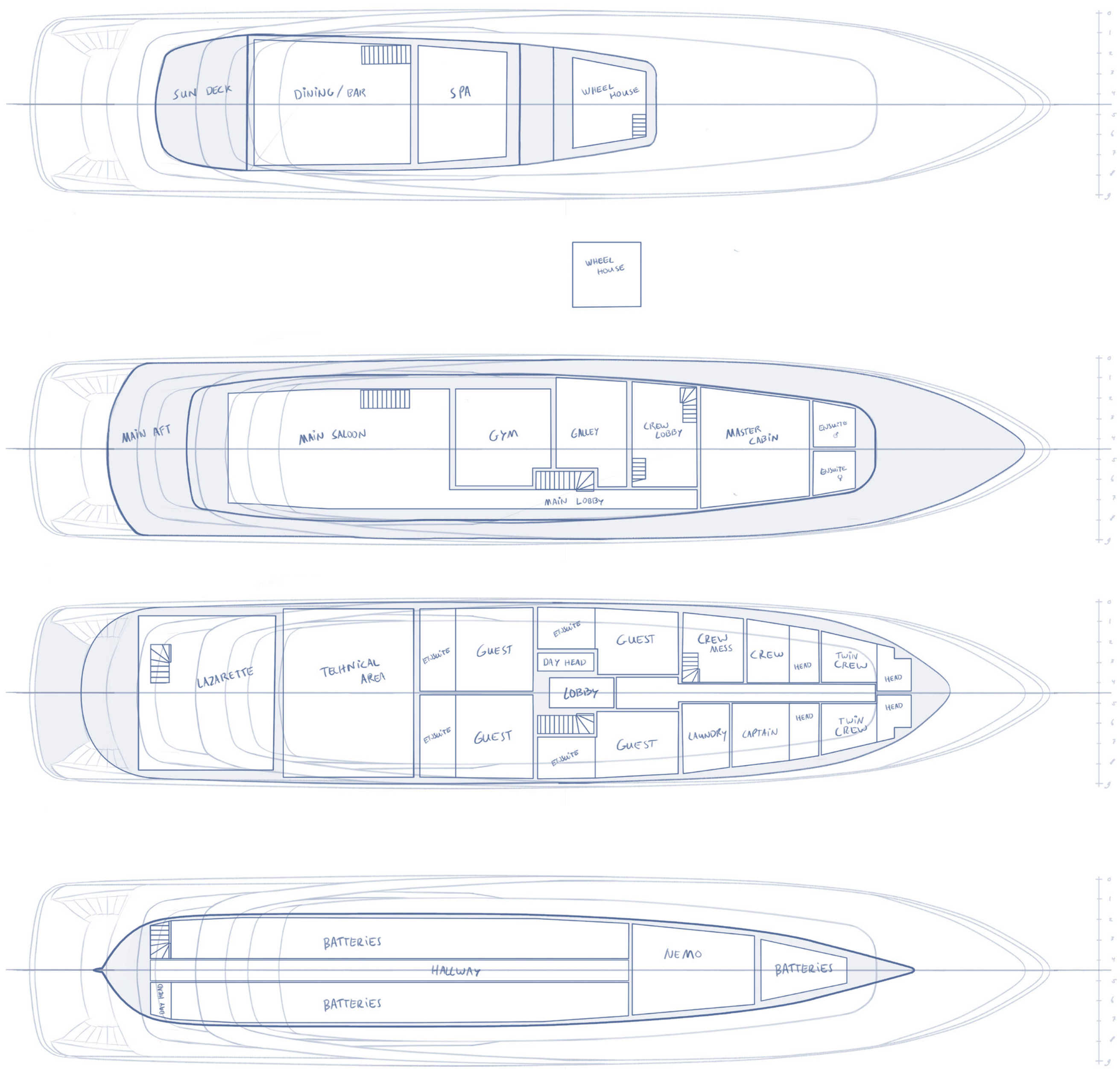


Fig 72. General Arrangement front view v2

Fig 73. General Arrangement top view v2

GENERAL ARRANGEMENT

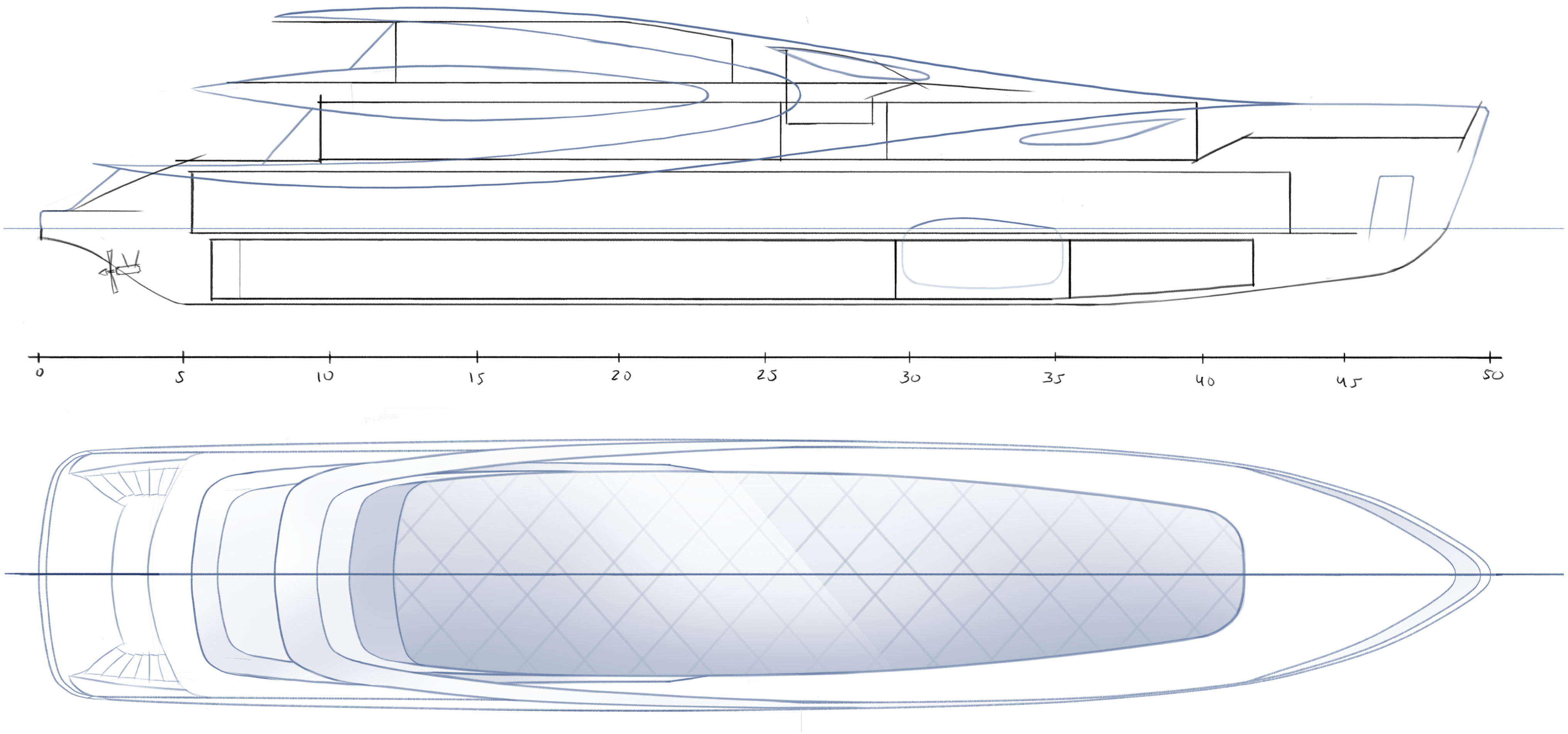
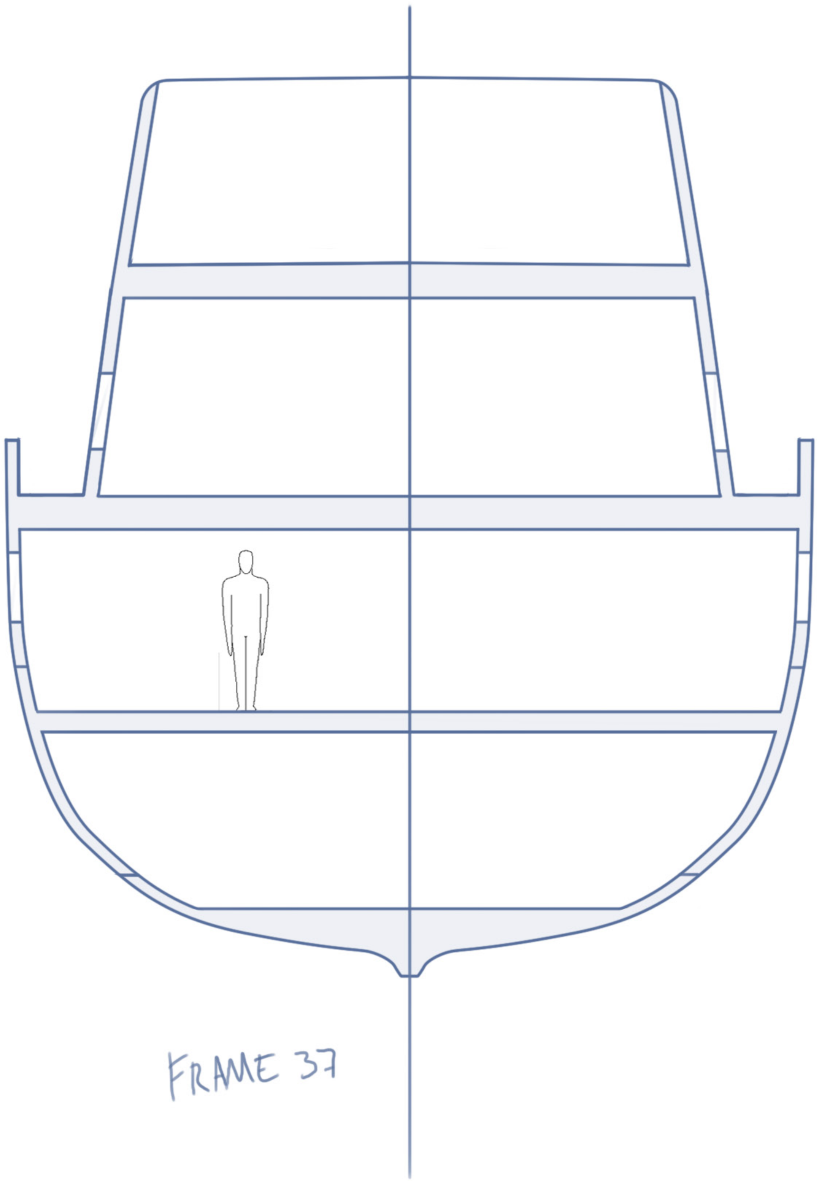
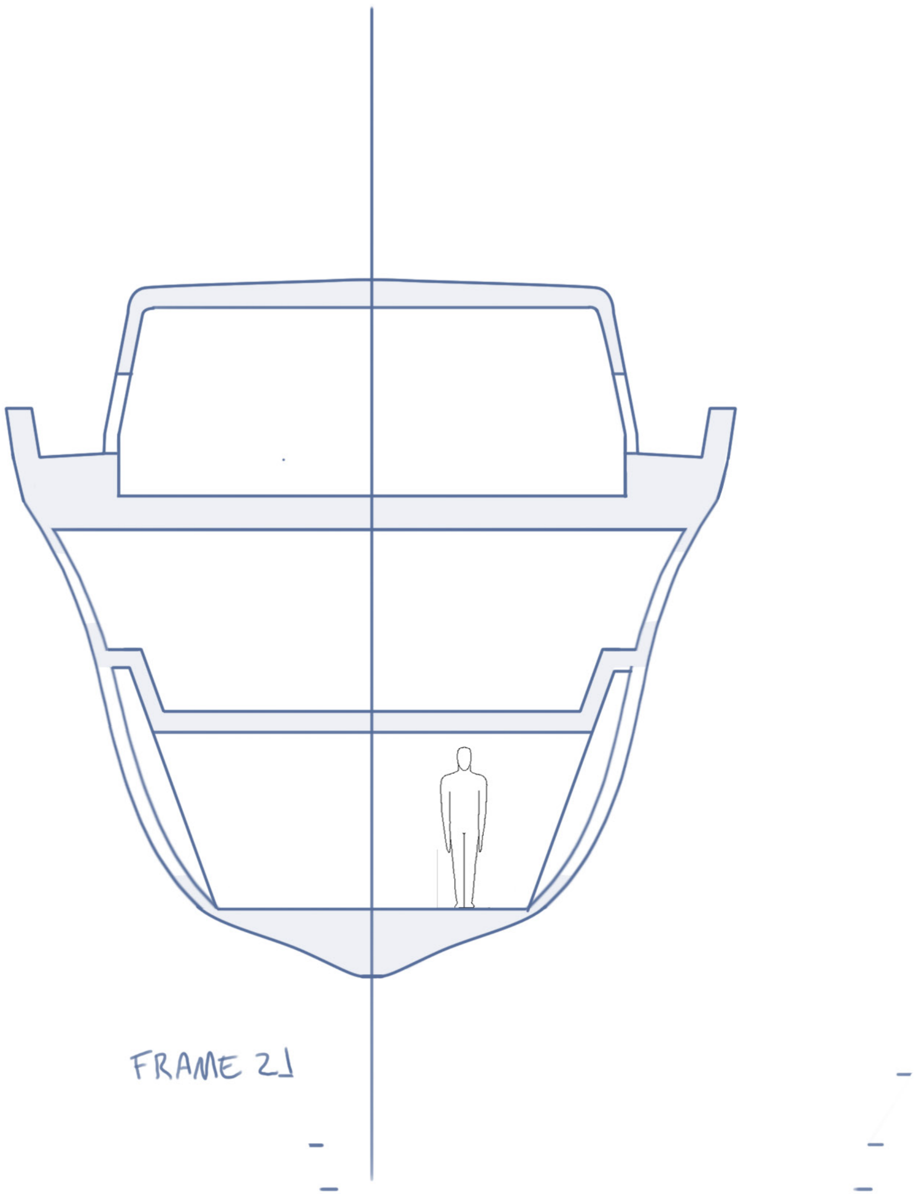
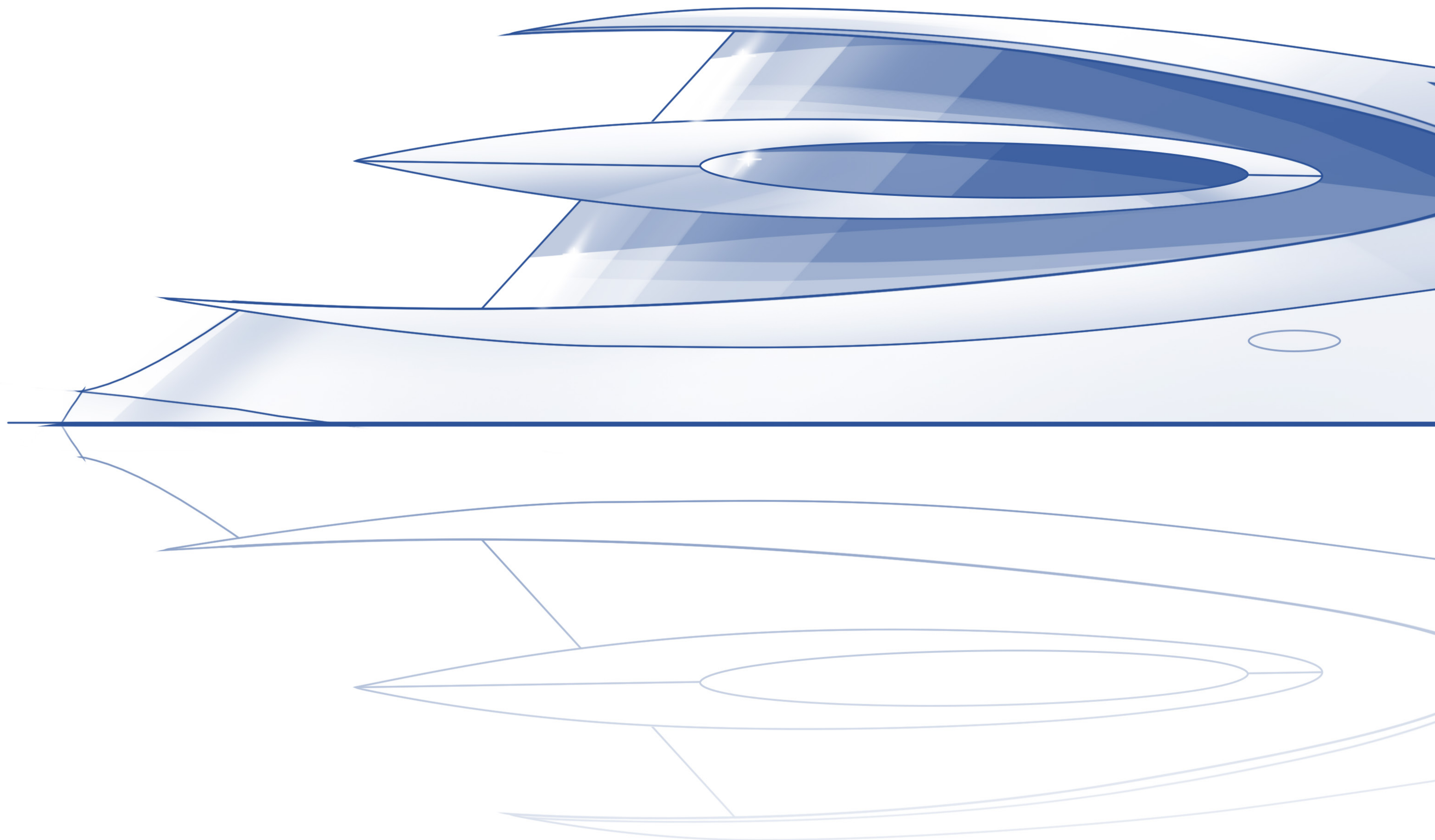


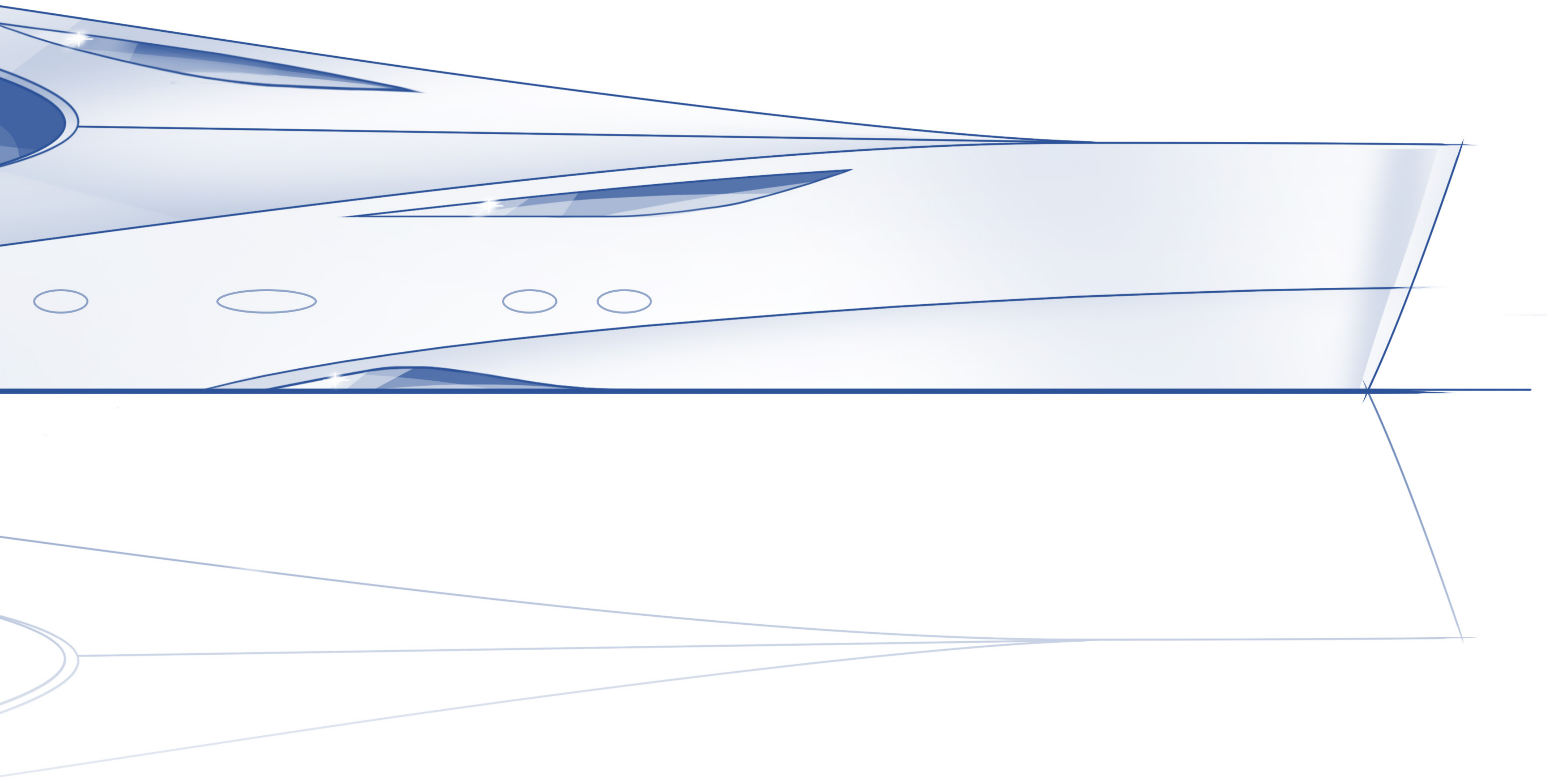
Fig 74. General Arrangement v2

GENERAL ARRANGEMENT









CONCLUSION

CONCLUSION

The vision, context and technology analysis leads to the formulation of several drivers, enablers and barriers for a fully electric super yacht. A concept is developed to further analyze these aspects and translate them in design opportunities, such as aesthetics, business model and user experience.

Drivers are something that makes other things progress, develop, or grow stronger (Cambridge Dictionary, 2018).

Enablers are something that makes it possible for a particular thing to happen or be done (Cambridge Dictionary, 2018).

Barriers are something that prevents something else from happening of makes it more difficult (Cambridge Dictionary, 2018).

Drivers

- Electric propulsion has a positive environmental image
- Authenticity is increasingly important in defining luxury experiences (pioneering)
- Fully electric yachting allows the UHNW to stand out
- Rising philanthropic engagement, fueled by a motivation for personal fulfillment
- Young people tend to be more socially and environmentally minded, fueled by ‘need for being’ trends
- Trend of upcoming young UHNW, that are known to be avid early adopters of new technologies (tech desire)
- Propulsion options for a fully electric yacht are usually relatively compact, efficient and quiet compared to their diesel counterparts
- Self-sufficiency aspect of the envisioned scenario is very interesting for the UHNW
- Batteries are more flexible in terms of positioning in the GA compared to fuel tanks, allowing for more design opportunities

Enablers

- Opportunities for unique market positioning in terms of the design language
- Developed vision for a fully electric super yacht allows for product qualities that will differentiate the design from a regular yacht
- 64% of the trips between ports made by Feadship yachts are less than 300 nm
- 12/35 of Feadship yachts reside exclusively in the Mediterranean Sea
- Feadship yachts are not used for racing, which enables a maximum cruising speed of 10 kn, significantly reducing required battery power
- Flexible and scalable supercharger concepts enable suitable electric yachting scenarios for pioneers
- Itinerary scenario can be similar to that of a current charter yacht
- At least 5 ports in the Mediterranean Sea are planning to install superchargers, able to charge with several MW of power
- Battery costs declining by ~50% and specific energy increasing by ~100% from 2014 to 2022 (based on future predictions)
- Using the Mediterranean Sea as focus area, HVAC load can be minimized
- Batteries can be stored in the lower deck, while the transformers can be stored in the technical area, which previously stored had engine casings, generators fuel systems and exhaust ducks.
- Common charting scenarios fit well with self-sufficient energy generating systems, being able to charge the yacht once a week at a certain port

Barriers

- Speed restrictions are required, since larger common sailing speeds (12-16 kn) will significantly limit the range
- Unable to do ocean crossings, while 23/35 Feadships cross the Atlantic Ocean twice a year
- Sustainable energy generating on board is not significant enough to help power the yacht
- Charging times can not compete with the refueling speed of diesel yachts (~2 hours)
- Battery capacity of at least 14 MWh is required for a suitable scenario, which allows for overnight charging (assuming 1 MW power)
- Usage of the yacht is limited to the designed scenarios (and slight variations) and therefore less flexible than a regular yacht
- Battery technology as well as the required infrastructure is more costly than a regular yacht (1.4 million dollars for the required battery, using Tesla industrial rates)
- Charging technology in most ports is currently limited to a maximum of 1 MW (160 kW in smaller ports), requiring the use of a flexible infrastructure
- Batteries need to be able to be checked individually by engineers for safety reasons, requiring walk-through space as well as a certain height in the lower deck (lowering the lower decks)
- For a 50 m super yacht, the switch from diesel propulsion to electric propulsion leads to a 25% increase in weight (including engines, etc.).

CONCLUSION

In general, the drivers and enablers for a fully electric super yacht will increase in significance and the barriers will decrease in the (near) future. The barriers conclude that in the near future an electric yacht will have several limitations compared to a regular super yacht. These limitations are technical; consisting of the range, speed, charging times and infrastructure. However these aspects are all decreasing in significance in the future, because battery technologies are developing rapidly and several ports are already investing in superchargers (battery costs are also decreasing in the future).

The main barriers for a fully electric super yacht are defined by the technology research, with some usage barriers as well. The context factors and the vision mostly shape the drivers and enablers, showing that there is a clear ‘reason of being’ for a fully electric yacht and that the future developments in technology could help realize the design.

The enablers consist of the design opportunities that were found when designing a fully electric super yacht, as the final concept embodies. This can be seen in the nemo room, the battery hallway and the (self-sufficient) scenario. These opportunities originate from the flexibility of the battery placing, the safety regulations and the infrastructure.

The drivers consist of the vision as set up with the ViP method. The vision is set up using main trends regarding authenticity, biomimicry, Zen and ‘need for being’. The rest of the drivers are related to technology research; increasing battery specific energy with decreasing costs, increasing amount of superchargers at ports and the advantages of electric propulsion.

The combination of all the drivers, enablers and barriers led to the design of a fully electric super yacht concept. This concept will be judged in the discussion on viability, feasibility and desirability.

DISCUSSION

After analyzing the drivers, enablers and barriers of electric yachting in the near future, the claim made by Feadship; "a fully electric yacht is feasible, desirable and viable", will be discussed based on the final concept design.

Feasibility (figure 75); what is functionally possible within the foreseeable future? (Brown, 2009).

Desirability (figure 76); what makes sense to people and for people? (Brown, 2009).

Viability (figure 77); what is likely to become part of a sustainable business model? (Brown, 2009).

Feasibility

The energy system consists of the batteries, the engines and the transformer. The engines and the transformer replace the engine casings, generators fuel systems and exhaust ducks in the technical area. The batteries replace the fuel tanks in the lower deck, while also lowering the total lower deck in order to fit them. The feasibility of this system will increase in the future as battery costs decline and specific energy increases.

The infrastructure would require investments in superchargers by the ports or the clients will have to invest in their own flexible infrastructure. This limits the feasibility of the infrastructure, but in the near future several large ports are planning to use superchargers. The flexible infrastructure options provide options for the pioneers of electric yachting and could potentially be developed in a sharing/lease system between owners, increasing the usability.

The current usage will have to change as well in order to fit fully electric super yachts. 64% of the current trips between ports can be made, however charging times (compared to refueling times) will change the usage of these yachts. Besides that, transit scenario's will take significantly more time, as the yacht will need to charge after 300-400 nm. Long trips to distant locations, will be difficult with the system, as the charging infrastructure is required. The flexible infrastructure could solve some of these issues, but transporting it to small islands for example increases the difficulty.

Desirability

The overall design is mainly influenced by biomimicry, authenticity and Zen. The general shape is organic and so are the design details. Elements like the charging system and the kinetic facades add to the uniqueness of the design. The seven principles from Zen have been applied too; the design is shaped by 'minimal elegance', 'naturalness' and

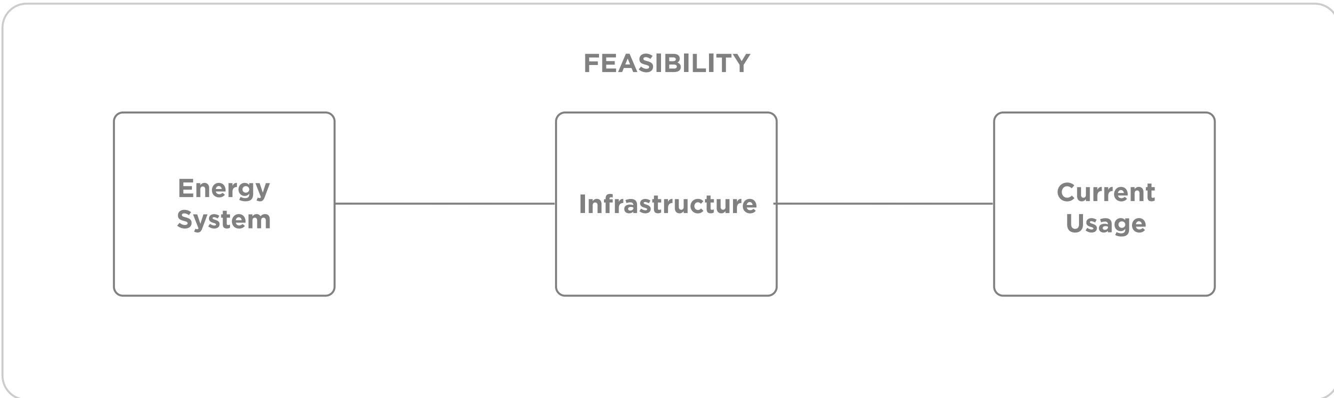


Fig 75. Feasibility

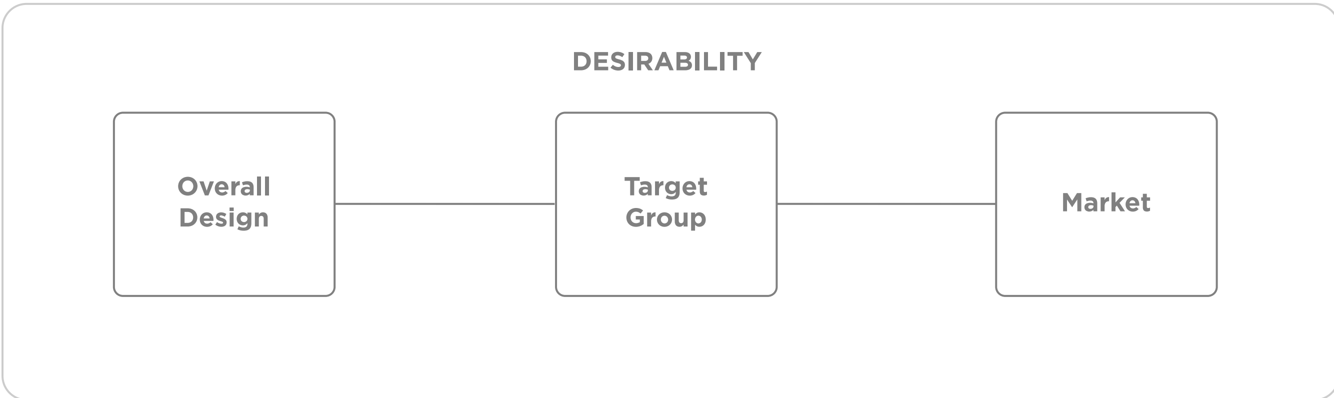


Fig 76. Desirability

DISCUSSION

'simplicity'. The charging design element is formed by 'suggestion rather than revelation' and the kinetic facades are influenced by 'transcending the conventional' and 'dynamic balance'. The design details are designed to be subtle and add to the 'tranquility' of the design.

However it can be argued that the design leans towards dynamic, futuristic, refreshing and premium product qualities, while seamless, natural and subtle product qualities are less in-cooperated in the final design.

The project has been initiated by Feadship to answer clients that showed interested in a fully electric yacht. Besides that, the selected target group (young UHNW millennials) fits the vision set for a fully electric super yacht concept. They have a 'tech desire' as early adopters and are looking for authentic luxury experiences, but are also interested in sustainability and philanthropy.

The market experiment shows that the aimed design from the vision enables a unique positioning in the market. This fits with the authenticity trends from the vision. The concept is aims to be modern/organic and simplistic/dynamic, which is shaped by the product qualities from the vision analysis. This helps to position the concept based on current and upcoming trends.

Viability

The design opportunities that derived from the analysis led to the development of a battery hallway that is connected to a nemo room. Besides that the GA has remained similar to that of a regular yacht (the Feadship Como in this case). In general the transition from fuel to batteries is not that inspiring. The flexibility of the batteries is the main driver for the design opportunities. The required investments are assumed to be relatively high, compared to the design opportunities, which impairs the viability of the concept.

The scenarios that were designed for the concept are all more complicated compared to regular diesel itineraries, since the range, charging times and charging possibilities influence the scenario. Therefore it requires more planning and investments into potential flexible infrastructure. Unlike a diesel yacht, a fully electric yacht also has less flexibility in terms of scenarios. On the other hand, the self-sufficient scenario option offers something that could be very interesting to the UHNW.

The vision describes the look and feel of the electric super yacht concept as well as the interaction. The concept offers authentic and pioneering experiences in the form of the battery hallway leading to the nemo room and the self-sufficient scenario of cruising on sustainable energy. Especially the self-sufficiency of the scenario refers to the 'need of being' principle from the vision. The Zen experience is expressed in the exterior design and in the GA (with the inclusion of a spa, a gym and the nemo room). The biomimicry aspect has been integrated in the exterior design as well as in the kinetic facades.

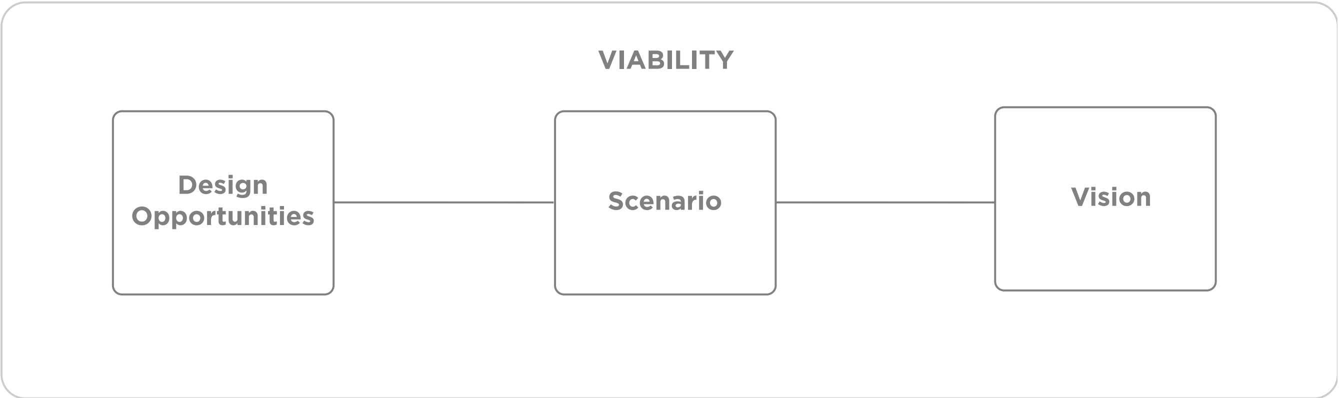


Fig 77. Viability

CONCLUSION

RECOMMENDATIONS

The focus of this project was to find the drivers, enablers and barriers of electric yachting through a "research by design approach". In order for Feadship to continue developing this concept, the barriers will have to be further analyzed in order to increase the viability, feasibility and desirability of the concept.

Ocean crossings

One of the main barriers, when comparing current super yacht usage to the envisioned electric super yacht usage, is ocean crossings. The focus for this project was on the operational profile that does not cross the ocean (which includes12/35 Feadships), but in order for wider acceptance, options such as tug-boat services, support vessels or transport on carriers will have to be considered.

Sustainable energy saving/generating

Various sustainable energy generating methods on board have been analyzed on their potential, but have been deemed as not significant compared to the daily hotelload of 2 MWh. However, further analysis into this subject and potential energy saving techniques, such as innovative coatings, hull shapes, etc, could decrease the hotelload and therefore increase the significance of sustainable energy generating on board.

Charging infrastructure

In order to accelerate the adoption of fully electric super yachts, the infrastructure will require large investments in many of the major ports. When pitching electric yachting to their clients, Feadship might have to collaborate with these ports in order to create a lease system of super chargers. They could work together with clients as well, because investments in super chargers on ports will support the clients and their electric super yachts, as well as generate revenue for these clients.

Costs

This report has not focused on the potential costs of fully electric yachting nor on the required investments of (flexible) infrastructure. It can be assumed that the costs are significantly higher compared to a regular super yacht. Clients will require a clear picture and business plan in order to invest in fully electric yachting. Analysis into potential investment options is also required, to offer clients a choice.

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APPENDIX

APPENDIX 1

ViP CONTEXT FACTORS

Using the different themes from the ViP method; trends, developments and principles have been searched for that relate to the domain. These trends have grouped into the different categories as advised by the ViP method (Hekkert, 2017).

Biological

- Upgrading health > rich people (development)(Harari, 2018)
- Biomimicry > imitation of nature > solve complex human problems and inspire design (trend)
- Need for being > sensing connection with something larger than ourselves (principle) (META-Health University, 2017)

Evolutionary

- Attaining status > achievement (principle) (The Resident, 2016)
- Sense of adventure > choosing unfamiliar options > sampling the unknown (principle) (ScienceDaily, 2008)

Psychological

- The more choice a person has, the less likely it is that he or she will make a decision (principle)
- Urge to share information about one's life > same sensations in the brain synonymous with eating food (principle) (Newman, 2013)
- Desire to escape reality (trend) (Lewis, 2018)
- Desire to accumulate wealth and possessions > especially true for highly ambitious and competitive people (trend) (Gregoire, 2013)
- Change from materialism to a more purposeful idea of what it means to live the good life > mindfulness (development) (Gregoire, 2013)
- Authenticity matters > sentimentality that comes from having purchased a genuine luxury good is part of the reason we seek authenticity (principle) (MXM, 2013)
- Exposure to the same stimuli for extended periods of time triggers boredom (principle) (Lewis, 2018)
- Experiences make people happier than possessions (feel alive) > become accustomed to an object (principle) (Gregoire, 2013)
- Pursuit for wellness > especially for millennials (trend) (Wealth-X, n.d.)

Cultural

- Personalization > be different from the rest (development)
- Gamifying other domains > the spread of gaming to new audiences and new activities (trend) (MXM, 2013)
- Immersive Layered Entertainment > multiple environments > maximizing moments (trend) (MXM, 2013)
- Sustainability & environmental awareness > consumers are increasingly interested in sustainable and ethical products (trend) (Hancock, 2017)
- Yachts, like cars, are an expression of identity (trend)
- Cultural norm that we should all work towards a sustainable future (state) (Hancock, 2017)
- Successful pioneering (setting an example) helps the widespread use of a new technology/product (principle)
- Informality > more openness (development) (Crouch, 2014)
- Desire for local, embodied presence > setting roots > local culture (trend) (Crouch, 2014)
- People go on vacation for novelty and education (next to 7 other socio-psychological motives) (state) (Crompton, 1979)

Demographic

- Ratio of children to older citizens is declining (trend) (Badkar, 2014)
- Young adult geographic mobility is at its lowest level in 50 years (development) (Crouch, 2014)
- Shift from privacy demands > millennials do not worry about privacy (development) (The Resident, 2016)
- Global inequality is growing (development)

Technological

- Artificial intelligence > incorporated in more and more applications (trend)
- Digital centralization (IoT) > convenient way to manage everything from as few devices and locations as possible (development)
- Augmented (Virtual-) reality > increasing immersion (trend)
- Energy generating systems on board and/or portable (development)
- Full lifecycle sustainability > focus is not just on the product anymore, also recycling and usage for example (trend) (Hancock, 2017)
- Autonomous systems taking over (trend)
- Seamless integration > discreet way of hiding technology (trend) (MXM, 2013)

APPENDIX 1

VIP CONTEXT FACTORS

Sociological

- Community focused lifestyle > connect with others > move from individualism to collectivism (trend) (Crouch, 2014)
- Need to belong to a certain social group (principle) (META-Health University, 2017)
- Aiming to be unique > be interesting (principle) (META-Health University, 2017)
- Importance of how other people perceive you > bragging > self-promotion (principle) (META-Health University, 2017)

Economic

- Wealthier people tend to give a smaller percentage of their income to charity > yet the more generous people were, the happier they reported feeling (principle) (Raghunathan, 2016)
- Wealth makes you distance yourself from others > value independence more and social connectedness less (principle) (Gregoire, 2013)
- Spending money on experiences or to regain time increases happiness > which we share with others (principle) (Raghunathan, 2016)
- Spending more money on education > rich people especially (development) (Crouch, 2014)

These context factors help shape the focus of the assignment and determine the scope. They have been structured into different themes, which will be used to create a statement, human-product interaction and product qualities.

APPENDIX 2

YACHT LAYOUT

What do current yacht layouts look like?

In order to explore the current layout of 50m super yachts (with around 400-500 GT), two Feadships have been analyzed (~50m). The focus has been on the Como, since that is where the original battery and range calculations from Feadship are based on (figure 78 & 79). The Kiss has been used as comparison, since it has a similar GT and size (Feadship, 2017).

Como

- Length: 46.22 m
- Draught (diepgang) 2.20 m
- Beam (widest point) 9.00 m
- Gross tonnage (GT): 406 m3
- Owner area: 46.5 m3
- Guest area: 97.7 m3
- General area: 141.3 m3
- Crew area: 122.4 m3
- Technical area: 103.9 m3
- Guests: 8
- Crew: 8

Kiss

- Length: 46.40 m
- Gross tonnage: 423 m3
- Owner area: 27.8 m3
- Guest area: 113.1 m3
- General area: 157.3 m3
- Crew area: 152.4 m3
- Technical area: 87.4 m3
- Guests: 12
- Crew: 8

Based on the layouts from the Kiss and Como, the crew area is larger than the general area, while also the technical area is significantly large. The guest areas are about twice the size of the average owner's areas, which shows the social aspect of yachting and the amount of guests that is usually on board.

For a fully electric yacht, the size of the technical area might be reduced (not taking into account the batteries), since casings and such will be removed, while the electric propulsion system is generally smaller than its diesel counterparts (Feadship, 2017). The crew size will be assumed to be on the lower side (8 crew members), since the electric propulsion system should require less technical crew members (Feadship, 2017). For guests, the aim will be accommodating 8 guests comfortably.

Typically, the standard layout of a 50 meter super yacht consists of a lower deck, main deck, upper deck and a sun deck. This has been concluded by analyzing the similarities in terms of interior of three ~50 m super yachts from Feadship (Como, Hurricane Run and Promise).

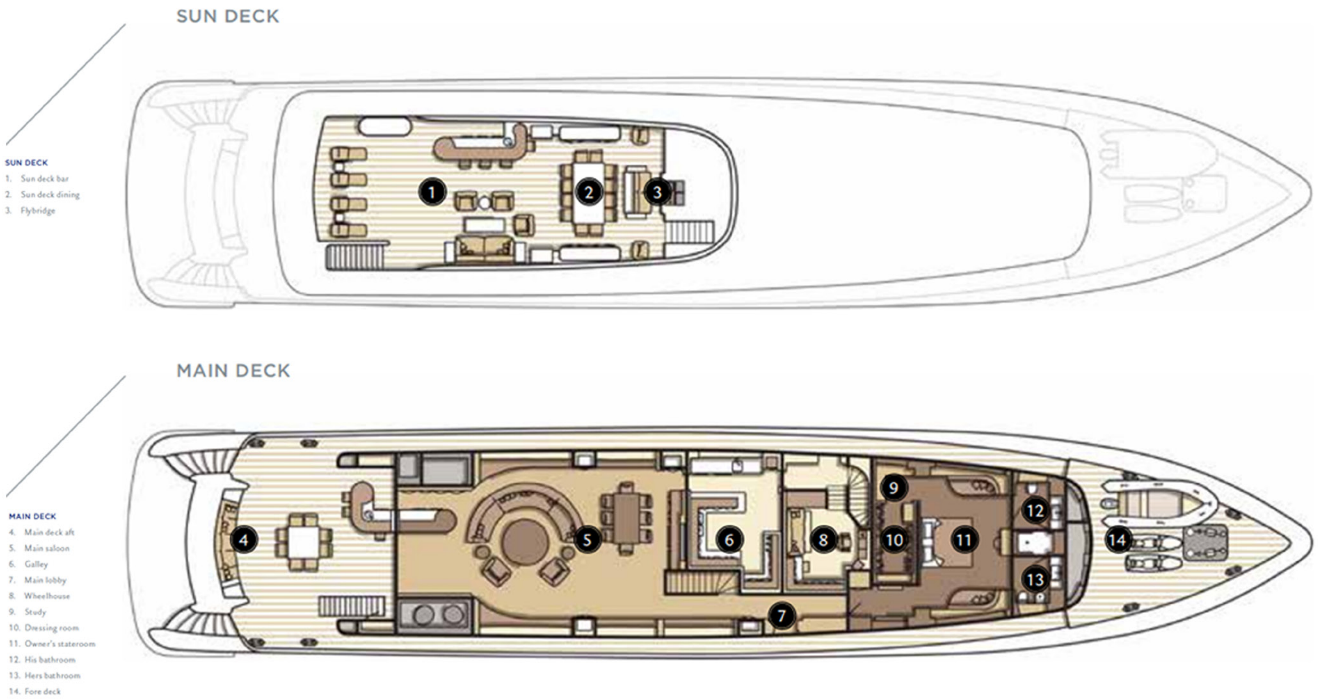

Fig 78. Feadship Como

APPENDIX 2

YACHT LAYOUT

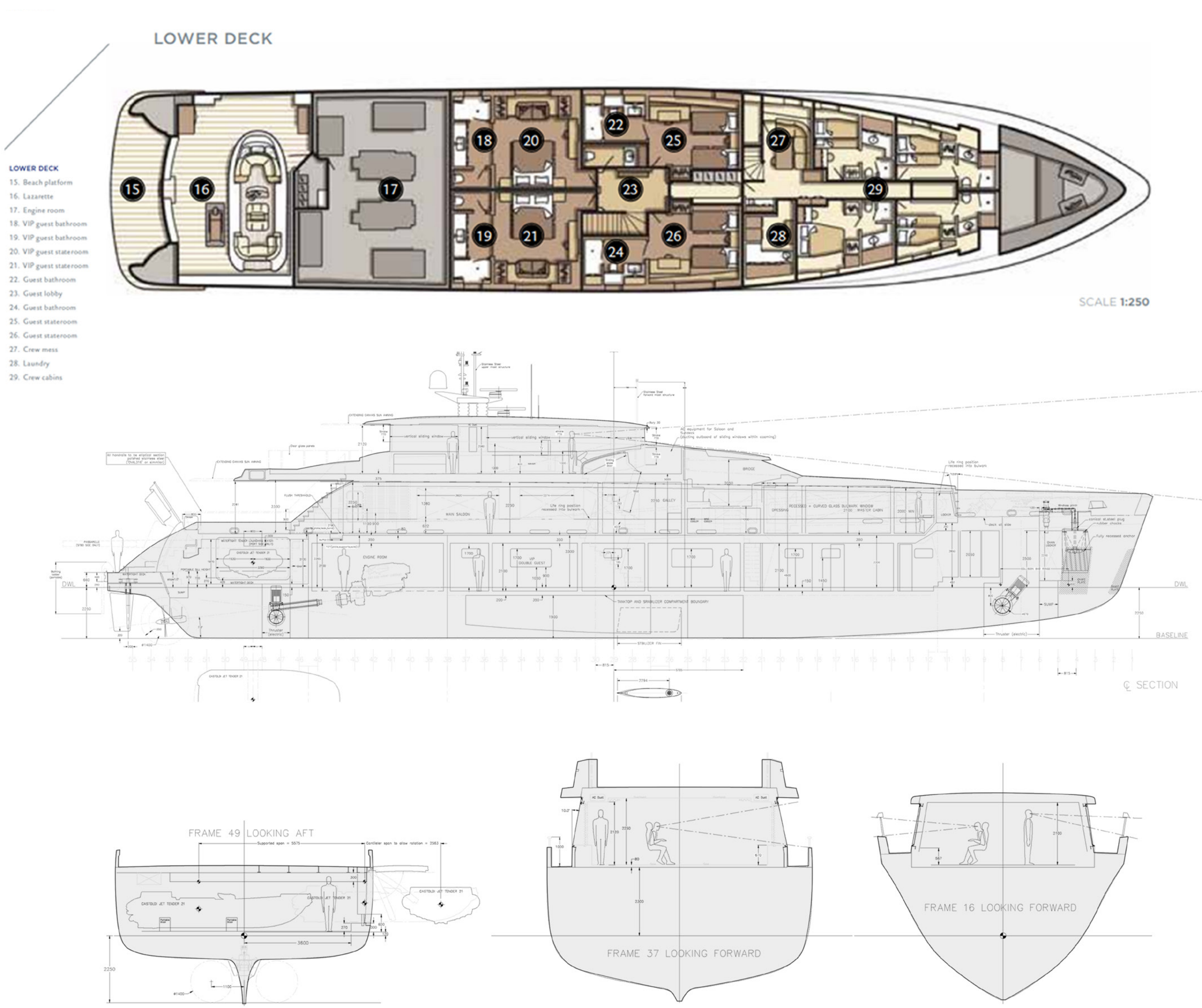

Fig 79. Feadship Como

- Lower deck: Beach club, Lazarette (toy garage), Engine room, guest rooms (4-6) with en-suite bathrooms, crew quarters and lounge, laundry room.
- Main deck: main deck aft leading into the main saloon (bar/lounge), galley, main lobby, wheelhouse, owner's study, dressing room, owner's stateroom with his/her bathrooms and the fore deck.
- Upper deck (optional): upper deck aft leading to the lounge, captain's cabin and the wheelhouse.
- Sun deck: sun deck aft leading to the bar, dining room, flybridge (optional), Jacuzzi/whirlpool (optional)

APPENDIX 3

INFRASTRUCTURE ANALYSIS

What harbors are available for high speed charging, using just the infrastructure of the harbors itself? The harbors in Europe have been analyzed to find out where a fully electric super yacht potentially can be charged (Ecofys, 2015).

These countries are mostly Western countries, not connected closely to the Mediterranean area; however some countries are currently developing a better electric infrastructure (Ecofys, 2015).

In this list (figure 80) several ports in France, Italy and Spain are mentioned, showing the future potential for high speed charging in the Mediterranean area (Ecofys, 2015).

Ports close to a housing or industrial area, medium voltage power (6.6-11 kV) may often be available close at hand or within a few kilometers (Ecofys, 2015). The high speed charging as mentioned before is mostly more than 1 MW, while that would suffice for a fully electric super yacht (figure 81). Therefore for the charging scenario, more ports can be taken into consideration to charge the super yacht.

Port	Country	Port	Country	Port	Country	Port	Country
Amsterdam	Netherlands	**Helsinki**	Finland	**Livorno**	Italy	**Riga**	Latvia
Barcelona	Spain	**Hong Kong**	China	**Marseille**	France	**Rome**	Italy
Bergen	Norway	**Houston**	U.S.A	**Nagoya**	Japan	**South Carolina**	U.S.A
Civitavecchia	Italy	**Kaohsing**	China	**Oakland**	U.S.A	**Stockholm**	Sweden
Georgia	U.S.A	**Los Angeles**	U.S.A	**Oslo**	Norway	**Tacoma**	U.S.A
Genoa	Italy	**Le Havre**	France	**Richmond**	U.S.A	**Tallinn**	Estonia
Tokyo	Japan	**Venice**	Italy	**Yokohama**	Japan	**Hamburg**	Germany

Fig 80. High Speed Charging

Year	Port Name	Country	Capacity (MW)	Freq. (Hz)	Voltage (kV)	Ship types	Berths with SSE	SSE unique calls	SSE annual calls	Supplier
2000-2010	Gothenburg	Sweden	1.25-2.5	50 & 60	6.6 & 11	RoRo, ROPAX	6	11	1515	
2000	Zeebrugge	Belgium	1.25	50	6.6	RoRo	1	3	200	
2001	Juneau	U.S.A	7-9	60	6.6 & 11	cruise	1	3		Cochran Mar.
2004	Los Angeles	U.S.A	7.5-60	60	6.6	container, cruise	24	54	46	
2005-2006	Seattle	U.S.A	12.8	60	6.6 & 11	cruise	2	9	83	
2006	Kemi	Finland		50	6.6	ROPAX				
2006	Kotka	Finland		50	6.6	ROPAX				
2006	Oulu	Finland		50	6.6	ROPAX				
2008	Antwerp	Belgium	0.8	50 & 60	6.6	container				SAM Elec.
2008	Lübeck	Germany	2.2	50	6	ROPAX				Siemens
2009	Vancouver	Canada	16	60	6.6 & 11	cruise	2	10	104	Cochran Mar.
2010	San Diego	U.S.A	16	60	6.6 & 11	cruise	3	4	18	Cochran Mar.
2010	Verkö	Sweden	2.5	50		cruise				Cavotec
2011	Long Beach	U.S.A	16	60	6.6 & 11	cruise	1	1	118	Cochran Mar.
2011	Oslo	Norway	4.5	50	11	cruise	1	1	360	
2011	Prince Rupert	Canada	7.5	60	6.6		1			
2012	Rotterdam	Netherlands	2.8	60	11	ROPAX	2	4		
2012	Ystad	Sweden	6.25-10	50 & 60	11	cruise		7		
2013	Trelleborg	Sweden	0-3.2	50	10.5		6			

Fig 81. High Speed Charging

ITINERARY

How do the ultra-rich use their super yacht, in day-to-day usage?

Detailed usage statistics are not available, which means that a suggested user scenario will have to be developed based on the predicted use of the yacht. Since the concept of a fully electric yacht is new and requires an updated use and infrastructure, previous data regarding usage will only be used as guidelines.

Most charter cruises are about 7-14 days and mostly during the warm summer months (Feadship, 2017). This means there is a sunrise at 5:30-6:00 and a sunset at 20:30-21:00, this leads to long and active days and diners during sunset (Feadship, 2017).

Next to the activities on the yacht, the ultra-rich have a certain agenda of important events throughout the year to attend (figure 82, Wealth-X, 2017):

It consists of the main elitist events all around the globe. These events are very important to the ultra-rich as it provides a chance for them to network and share their experience with others.

Based on usage data and the envisioned use of a fully electric super yacht, the following itinerary has been developed for sailing from Genoa for a week (figure 83):

Day 1:

- 9:30: Entering the yacht in Genoa
- 10:00: Welcoming guests on the yacht
- 11:00: Transit to Monaco (90 nm) > 9 hour journey
- 13:00: Brunch on board
- 14:00: Entertainment (fun with guests)
- 20:00: Anchoring at Monaco
- 21:00: Dinner on board
- 23:00: Going out in Monaco(nightlife)
- 5:00: Returning to the yacht and going to bed

Day 2:

- 13:00: Breakfast in bed
- 14:00: Activities in Monaco (city exploring)
- 20:00: Diner in Monaco
- 23:00: Returning to the yacht
- 23:30: Entertainment (relaxing)
- 1:30: Going to bed
- 4:00: Transit to Saint-Tropez (50 nm) > 5 hour journey

Day 3:

- 9:00: Docking in Saint-Tropez
- 10:30: Breakfast on the yacht
- 11:30: Entertainment (exercising)
- 13:00: Lunch on the yacht
- 14:00: Activities in Saint-Tropez (city exploring)
- 20:30: Diner on the yacht
- 23:00: Going out in Saint-Tropez (nightlife)
- 03:00: Returning to the yacht and going to bed

Day 4:

- 4:00: Transit to Marseille (90 nm) > 9 hour journey
- 13:00: Docking in Marseille and charging the yacht

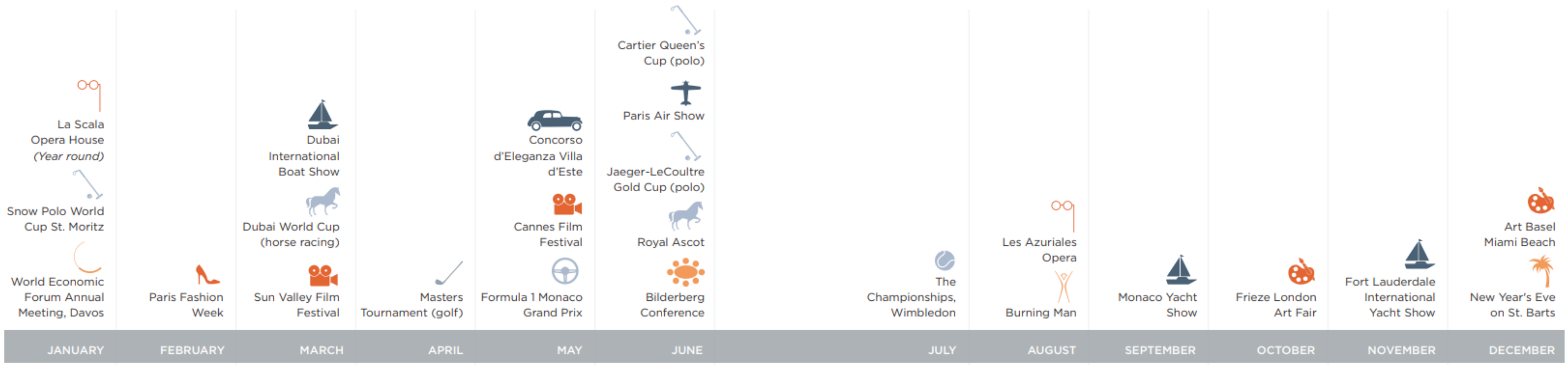

Fig 82. Agenda of the UHNW

ITINERARY

(11 hours until fully charged)
- 13:30: Brunch on board
- 14:30: Activities in Marseille (city exploring)
- 20.00: Diner in Marseille
- 24:00: Returning to the yacht and going to bed

Day 5:

- 00:00: Transit to Barcelona (200 nm) > 20 hour journey
- 10:00: Breakfast on board
- 11:00: Entertainment (exercising)
- 13:00 Lunch on board
- 14:00: Entertainment (relaxing)
- 20:00: Docking in Barcelona
- 21:00: Diner on board
- 22:00: Entertainment (party)
- 1:00: Going to bed

Day 6:

- 10:00: Breakfast on board
- 11:00 Activities on board (water sports)
- 13:00: Lunch in Barcelona
- 14:00: Activities in Barcelona (city exploring)
- 20:00: Diner in Barcelona
- 23:00: Going out in Barcelona (nightlife)
- 4:00: Returning to the yacht and going to bed

Day 7:

- 13:00: Breakfast in bed
- 14:00: Activities on the yacht (water sports)
- 20:00: Diner in Barcelona
- 23:00: Returning to the yacht
- 24:00 Activities on the yacht (relaxing)
- 01:00: Going to bed

Fig 83. Itinerary

APPENDIX 4

ITINERARY

Day 8:

- 10:00: Breakfast on board
- 11:00: Guests leaving
- 12:00: Owner leaving the yacht
- 13:00: Charging until ready for transit (13 hours)

The following activities could be pursued on- and off board:

On Board:

- Relaxing (personal rooms)
- Exercising (indoor sports + gym)
- Dining
- Business (meetings)
- Meeting friends
- ‘Playing’ (toys, cinema, etc.)

Off board:

- Dining (restaurants)
- Entertainment (gambling, clubbing, etc.)
- Sight-seeing (education + experience)
- Socializing (yachting club)
- Events (Grand Prix, Yacht Show, etc.)
- Exercising (outdoor sports + team sports)
- Business events

This itinerary gives a better image of the potential usage of the fully electric super yacht, based on the current usage of super yachts (Feadship, 2017).

APPENDIX 5

ENERGY SYSTEM ANALYSIS

Batteries

In order to determine the optimal size of the yacht, a model has been developed by Feadship that can calculate the required energy between charging moments as a function of the size of the yacht. The model parametrized the resistance and hotelload (Feadship, 2017). The data is used from individual trips of the Lady Britt (2012-2013), where a trip is defined between two harbors. For a variation of yacht sizes between 30 and 110m the energy consumption is estimated conservatively, based on Feadship resistance model. This model uses the resistance from various Feadship yachts to determine an average resistance per size (Feadship, 2017). These values must be taken very globally, since it is a rough estimation of the required total energy. It is however a good way to determine which size range is the most viable. The charging power is set on 1 MW, which is the same as the Wartsila concept.

With a yacht larger than 50m, the charging times become too much of a burden for the owner (figure 84 & 85), whereas the 50m range allows him to charge during the day and night, after which he can sail to the next spot.

The Feadship Como has a length of 45 meters and a GT of 406 t. For the ease of the calculations this ratio has been used to scale it up for this concept to 50 meters, resulting in a GT of 451 t.

For a usual scenario of 30 hours sailing, a 50m yacht requires 21 MWh. Hotelload is the required power needed for the yacht when it is docked (lighting, air conditioning, etc.). The speed has been set to 12 kn, as it is the standard cruising speed of Feadships (Feadship, 2018). As discussed in the Scenario, the range goal is 300 nm. The scenario used to calculate this is as follows (Feadship, 2018);

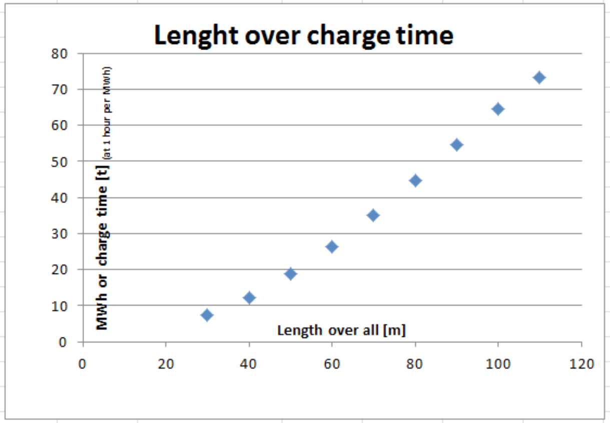

Fig 84. Length over charge time

Day 1:
- o Speed: 12 kn
- o Distance: 150 nm
- o Sail time: 13 h
- o Energy: -9 MWh

Day 2:
- o Speed: 0 kn
- o Distance 0 nm
- o Sail time: 0 h
- o Hotelload: -3 MWh

Day 3:
- o Speed: 12 kn
- o Distance: 150 nm
- o Sail time: 13 h
- o Energy: -9 MWh

The speed is set to 12 kn, since the clients from Feadship indicated that they do not buy a Feadship yacht to race with and this is the most common cruising speed (see Scenario). With the assumed charging speed of 1 MW, this leads to a charging time of 21 hours. In order to fit the scenario where the yacht should be fully charged between anchoring and then leaving again the next day, the required battery capacity will have to be reduced. One of the ways this can be reduced is by analyzing the hotelload.

	30	40	50	60	70	80	90	100	110
Distance	200	200	200	200	200	200	200	200	200
Sail time	20	20	20	20	20	20	20	20	20
Cruise time	72	72	72	72	72	72	72	72	72
Total energy	7,293243	12,32352	18,71835	26,40375	35,19338531	44,78419523	54,7467	64,51392	73,3703
Charge time	7,293243	12,32352	18,71835	26,40375	35,19338531	44,78419523	54,7467	64,51392	73,3703
Weight incr.	0,246718	0,189092	0,165094	0,1492181	0,135613426	0,122741603	0,1096	0,094464	0,07443
Volume	1,371265	1,134877	1,023819	0,9569853	0,907468758	0,86360945	0,81937	0,77116	0,71662
Area	102,0034	172,3569	261,795	369,28322	492,2151792	626,3523809	765,688	902,2926	1026,16

Fig 85. Length over charge time

ENERGY SYSTEM ANALYSIS

Hotelload

In the earlier calculations the hotelload (mostly HVAC) has been set at 3 MWh per day (Feadship, 2017). However for an environment such as the Mediterranean Sea, how much of this capacity is required?

The graphs below indicate the required cooling power for profile A (figure 86 & 87), which has been described as the Mediterranean Sea (Feadship, 2011).

The extreme situation shows a max power of 10.8 kW (with 30 kW being the norm, and used in the original calculations). In the normal condition the max capacity is 6.6 kW. These values are calculated for the main saloon of the Feadship Symphony. The maximum capacity in terms of the norm is 37% and 23%, meaning there is an overcapacity of 63% (and 77%) (Feadship, 2011).

The extreme situation accounts for the maximum amount of people in the room, highest intensity lightning, maximum intensity of the sun and being at the warmest spot on the sea. Therefore it is better to base the HVAC design on the normal situation (figure 86).

This all leads to a smaller chiller, less costs, smaller AC room, smaller air ducts in the walls and ceilings, which means the yacht can have a lower profile. The rosters can be smaller too, which can be beneficial for the design (figure 88), since they have quite a significant influence on the profile of the yacht (Feadship, 2011).

The following table shows the different loads that affect the total hotelload of the super yacht (figure 89). The chiller has been set on ~33% capacity, since it was shown that this would easily satisfy normal situations for the Mediterranean Sea (Feadship, 2011).

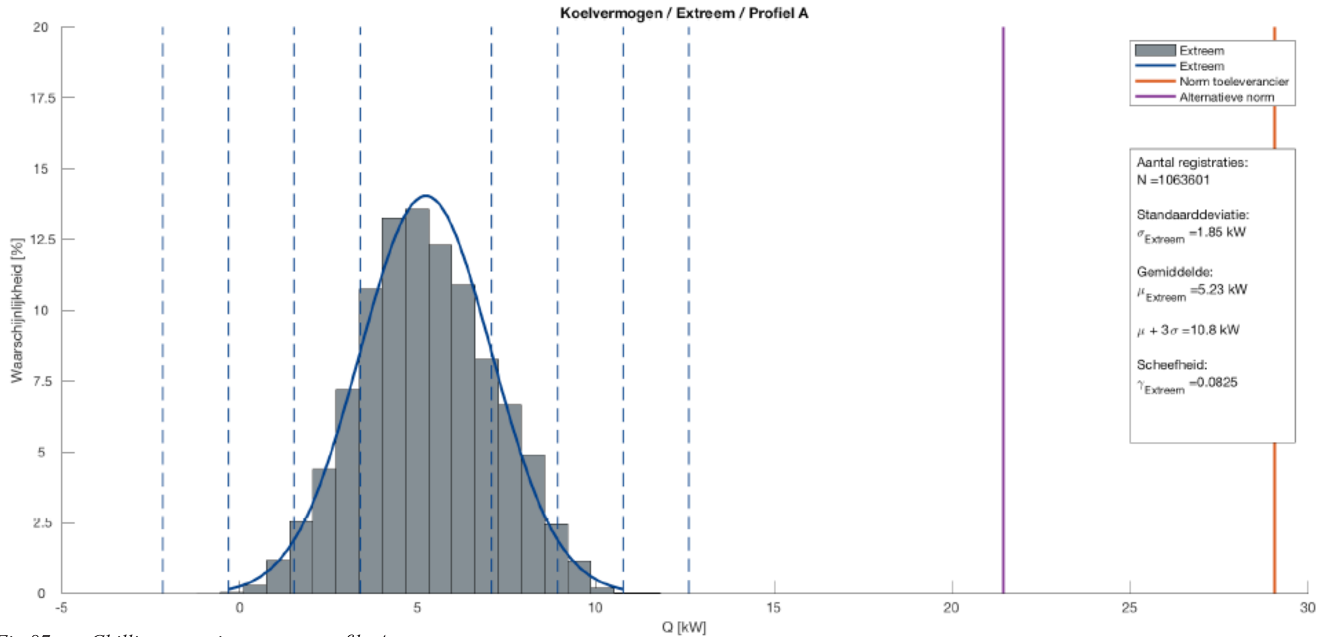

Fig 87. Chilling capacity extreme profile A

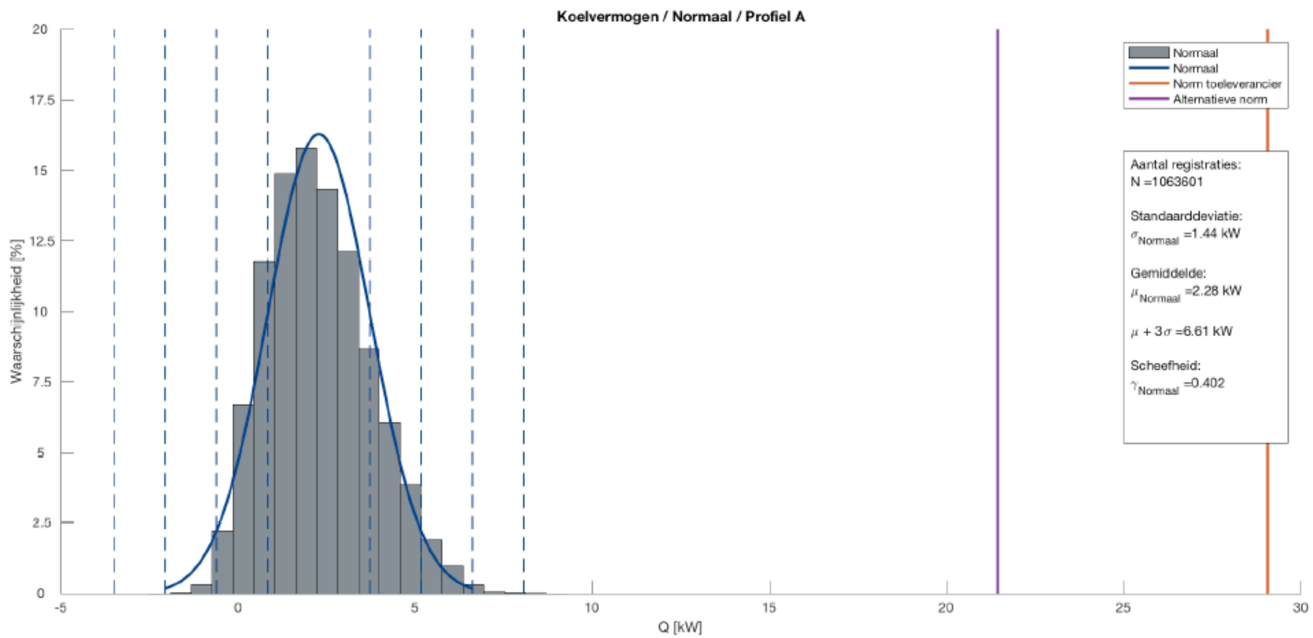

Fig 86. Chilling capacity normal profile A

ENERGY SYSTEM ANALYSIS

HVAC is on average ~44% of the total hotelload (when calculating with maximum capacity). This means that 44% (1.32 MWh) of the 3 MWh hotelload as calculated earlier can be contributed to the HVAC (figure 89, Feadship, 2011).

1.32 MWh has been selected as hotelload, however as discussed earlier this is with a 100% capacity. However for the chosen scenario, there is an overcapacity of 77%. Therefore a power of 0.3 MWh is required per day for the HVAC. This means that 1.02 MWh of hotelload can be removed from the calculations, leading to a total of 1.98 > 2 MWh of hotelload

Concluding, that removes 3 MWh from the scenario (1 MWh per day), leading to a battery capacity of 18 MWh.

Battery size

18 MWh leads to 18 hours of charging time, in order to reduce this value, the cruising speed has been set to 10 kn instead of 12 kn. As can be seen in the scenario analysis, this is still a relatively common cruising speed in the Mediterranean area (speeds of 9-11 kn are used more than 35% of the time, compared to 13-15 kn which is used 45% of the time).

This leads to the following adaptations in the calculation for battery capacity:

Day 1:
- o Speed: 10 kn
- o Distance: 150 nm
- o Sail time: 15 h
- o Energy: -7 MWh

Day 2:
- o Speed: 0 kn
- o Distance 0 nm
- o Sail time: 0 h
- o Hotelload: -3 MWh

Day 3:
- o Speed: 10 kn
- o Distance: 150 nm
- o Sail time: 15 h
- o Energy: -7 MWh

This leads to a total capacity of 17 MWh, where 3 MWh can be removed due to the HVAC analysis, leading to a required battery capacity of 14 MWh. This also fits the scenario, being able to fully charge the battery in 14 hours.

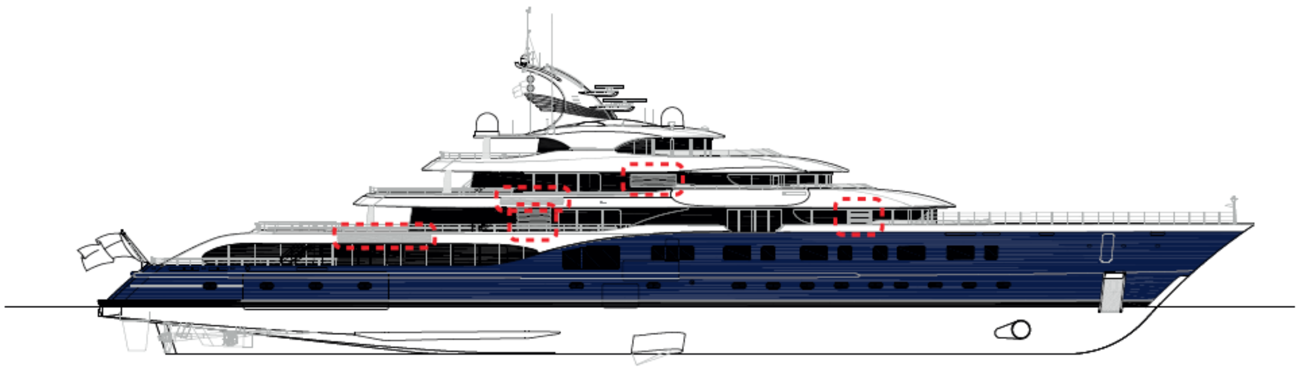

Fig 88. HVAC design impact

SUMMARY OF LOAD LISTS(1)	SAILING WITH GUEST ON BOARD			SAILING WITH CREW ON BOARD			SHORE WITH GUEST ON BOARD			SHORE WITH CREW ON BOARD		
Average ships load page 1-5	A		212,00	A		184,60	A		205,55	A		179,05
Lighting audio/video	B		74,23	B		41,99	B		99,68	B		63,79
Galley	D		58,78	D		58,78	D		58,77	D		58,78
Laundry	E		31,08	E		21,62	E		31,08	E		21,62
Total A,B,D,E			376,09			306,99			395,08			323,24
NORD SEA CONDITION												
Air handling with 33% chiller capacity and Recovery	C		150,07	C		150,07	C		150,07	C		150,07
Total A,B,C,D,E			**526,16**			**457,06**			**545,15**			**473,31**
full thruster consumption			823,50	kW		823,50	kW					
Total power consumption			1349,66	kW		1280,56	kW					

Fig 89. HVAC design impact

APPENDIX 5

ENERGY SYSTEM ANALYSIS

Using the calculations from the Feadship model (figure 90) (with 10 kn speed), using a battery capacity of 14 MWh leads to a total range of 440 nm (direct route). Using a cruising speed of 12 kn, a range of 300 nm is still possible (direct route). These ranges will mostly only be used for transit scenarios, since the owners are usually only on board for smaller trips (Feadship, 2017).

In the first initial calculations by Feadship, Tesla commercial cabinets have been used as benchmark for size and capacity. For a capacity of 14 MWh, a total of 422 m3 is required (Feadship, 2017). These cabinets are however more used for smaller applications and therefore for the size of a fully electric super yacht, larger more industrial batteries can be used.

Kokam is a company that has been developing container batteries that are more efficient then Tesla's commercial cabinets (used in Feadship's original calculations) and more suited for the scale required for this project (Kokam, 2017).

- Kokam container of 40 ft: 12.22 x 2.440 x 2.590 = 77.23 m3 per 5.5 MWh (67 m3 inside capacity).
- Total of 14 m3 per 1 MWh.
- 14 x 14 = 196 m3 for 14 MWh (including extra room to check and repair the batteries when needed, as well as cooling).

This does not include the required Power Conversion System (PCS), which is the size of one 40' container (67 m3). The required total space is 196 + 67 = 263 m3.

Charging cables

Data from the company RH Marine has been used to calculate the required cable connection, since they already calculated this for a different project.

RH Marine calculated the connection for 16 MW (using 690 V), this uses 23188 A. The cables will weigh 3,9-4,2 tons and will be about 39-45 three core cables required (RH Marine, 2018).

For a 440 V connection, still using the 16 MW power, means that the system uses 36363 A and the cables will weigh 6-6,5 tons and require 61-70 three core cables (RH Marine, 2018).

Using this data from RH Marine, leads to the calculation for the amount and weight of cables required for a 1 MW connection (using 690 V);

P=U*I = 690 * x = 1.000.000 = A = 1450
690 * x = 16.000.000 = A = 23188
3,9-4,2 ton = 39-45 cables

1450 = 23188
x = 3,9-4,2 tons
x= 0,24-0,26 tons

1450 = 23188
X = 39-45 cables
X = 3 cables

Therefore to charge the super yacht, at least 3 three core cables are required that weigh a total of 0,24-0,26 tons (240-260 kg). When using the power from potential superchargers on the port itself (max 5.5 MW), how many cables would be required?

Harbor power source (690 V/1450 A) > battery > transformer > ship battery

P=U*I = 690 * x = 5.500.000 = A = 7971
690 * x = 16.000.000 = A = 23188
3,9-4,2 ton = 39-45 cables

	A	B	C	D	E	F	G
1	Input			MODIFIED / BASED ON COMO BN688			
2	Calculated						
3	Result				Distance	300	nm
4					Sail time	30	h
5	Length	50	m		Cruise time	72	h
6	GT	451	t		Total energy	15	MWh
7	Displ.	577	t		Charge time	15	h (@high rate)
8	Gen. power	253	kW		Weight incr.	9%	
9	Charge rate high	1000	kW		Volume	80%	/Carene
10	Charge rate low	150	kW		Area	151	m^2 (2.2m stack)
11							
12	Reference trip (mean values, with guests, displ. penalty excl.)						
13		Speed	Distance	Sail time	Charge rate	Charge time	Energy
14		kn	nm	h	-	h	MWh
15							
16	Day 1	10	150	15			-7
17	Day 2	0	0	0			-3
18	Day 3	10	150	15			-7
19	Day 4						

Fig 90. HVAC design impact

APPENDIX 5

ENERGY SYSTEM ANALYSIS

7971 = 23188
x = 3,9-4,2 tons
x= 1,34-1,44 tons

7971 = 23188
X = 39-45 cables
X = 13-15 cables

Therefore to charge the super yacht, 13-15 three core cables are required that weigh a total of 1,34-1,44 tons (1216-1306 kg).

Energy generating

Several options for energy generating on board of a super yacht have been analyzed, based on their potential to significantly increase the range.

Wind energy

- Flettner rotors

Saving potential of 5 to 30% depending on system configuration i.e. number and size of the Rotor Sails, ship design etc. as well as the area and the route the vessel operates (Vainamo, 2016).

- Kites or spinnakers

Fig 91. Race for Water

can supply 93 kW and power the engine at an average speed of around 5 knots (Race for Water, 2016).

Requires large deck surfaces areas. Solar panels on masts have been developed and are in use for sailing yachts only.

Marine energy

- Wave power

Wave KERS system (kinetic energy recovery system)

5kW for 0.5m waves, 22 kW for 1m waves (Feadship, 2018).

Energy generating on board of a super yacht is not significantly viable as can be seen from the above examples. The Race for Water yacht (figure 91) has a battery capacity of 3 MWh, yet still requires 500 m2 of solar panels (powering 750 kWh batteries), combined with hydrogen (2.25 MWh), reaches a speed of only 5 kn. The fully electric super yacht already requires 2 MWh just for the hotelload.

Therefore off-board options will be analyzed and their potential fit in the scenario of a fully electric super yacht.

APPENDIX 6

ENERGY GLASS

Next to Kinetic Facades, another option is Smart Energy Glass. Smart Energy Glass is used to dim bright sunlight and use the absorbed light for power generation (RVO, 2013). The entire surface of this glass is clear, no grids, dots or lines. Besides that, it is able to switch between dark and light glass (RVO, 2013). It can also introduce a “privacy mode” turning the glass opaque, making it unable or barely able to see through (EnergyGlass, n.d.). Current state-of-the art commercial electrochromic windows reduce cooling loads and lighting energy in buildings, modulating the transmittance up to 68% of the total solar spectrum (Baetens, 2009). The glass can be fabricated in custom lengths, widths and thicknesses (EnergyGlass, n.d.). The windows have been found to be able to reduce up to 26% of lightning energy compared with well-tuned daylighting control by blinds, and around 20% of the peak cooling loads in hot climates as California in the USA (Baetens, 2009).

This technology is relatively new, for example, the first glass from the company Peer+ will be produced at the end of 2017. This version of the product is only the first market introduction and will not include the PV-strips to generate its own power (Tweakers, 2016). The company EnergyGlass claims to have installed multiple Smart Energy Glasses in large office-like buildings in the US (EnergyGlass, n.d.).

The electrochromism technology most commonly used for Smart Energy Glass has been discovered and made public in the 1970s and 1980s (Baetens, 2009). However in 2009 there were still no products available on the market. New sparks of interest in sustainable technology makes that the technology might be more readily available in the near future (Baetens, 2009), however for this project it has been chosen that this technology is not deemed ready enough to be used in a fully electric super yacht.

For this concept the kinetic facade in idea 3, will be used in the final concept, since it is a very dynamic feature that blends in well with the organic shape and feel of the concept. It is chosen over idea 2 because the horizontal lines in idea 2 slow down the dynamic aspect of the concept, besides that idea 3 looks more premium.