A SUPERYACHT COST ESTIMATION TOOL

CONNECTING YACHT DESIGN & YACHT BUILDING COST

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"*I love it when a plan comes together"*

- George Peppard, alias Colonel John Hannibal Smith

PREFACE

Performing a master thesis, is for the writer the last requirement to obtain the degree of MSc Marine Technology at the Delft University of Technology. While studying, a great interest for superyachts has grown. Therefore, a superyacht related subject for the master thesis was preferred. The university gives the opportunity to graduate at a company. Azure Yacht Design & Naval Architecture was open for discussion about several subjects. One of them was about establishing a connection between yacht design and yacht building cost which resulted in the subject: a superyacht cost estimation tool.

At Azure, knowledge, know-how and data about yacht design and naval architecture are available. However, Azure has limited cost data available of superyachts. Initially the idea was to establish a cooperation with several superyacht builders in order to have access to cost data. At first sight yards were enthusiastic, but in the end no cooperation was established because the yards found their cost data too confidential. In order to obtain the lacking information, more than 30 subcontractors were interviewed. The advantage of interviewing subcontractors, is that they have more knowledge on how their cost estimations are built up, compared to yards which only have the quotations of subcontractors. The combination of the available information from Azure and the collaboration with the subcontractors have made it possible to complete this thesis.

There are two persons that have played a key role during this thesis. I would like to thank Hugo van Wieringen for the invested time, the constructive meetings and the possibility to do my graduation at Azure. I would also like to thank Robert Hekkenberg for being my supervisor, all the meetings at the TU Delft and the guidance through this master thesis. Without the already mentioned subcontractors / specialists, the thesis could not have been completed, thank you for your cooperation. I would like to thank the management of the yard, who played an essential role during the validation of the tool. Employees of Azure, thanks for the enjoyable working environment and for all the interesting conversations during all the lunches, especially Peter Jeeninga thank you for all the valuable help. The following two people reviewed my thesis, Xavier Soubeyran and Charlotte van der Leer. I appreciate the effort, the thesis is significantly improved. Friends and family, thank you. The best is saved for last. My dear wife Ilse Zoutewelle, without your unconditional love, support and motivation I would be nowhere and my thesis neither.

Ruben Zoutewelle
Haarlem, November 14th 2016

SUMMARY

Introduction
Yachts have significantly grown in number and size the past decades. The superyacht business has grown along and the number of superyacht builders has increased. In previous decades, potential customers were queuing for their superyacht to be build. The result was that yacht builders were able to set the price of a yacht. Nowadays there is much more competition amongst superyacht builders and therefore it is harder to sell yachts. The increased competition has introduced significant price negotiations in the world of superyachts. As yard it is important to estimate the costs of a superyacht early on in the sales process, to be able to negotiate healthy and realistic prices with a customer. Due to the inherent customization of superyachts estimating the costs is challenging as there are many unknowns during the estimation and it is time consuming. Currently there are no tools existing, that help yards estimate the costs of a superyacht in the early phases. Therefore, the research objective of this thesis has been: to develop an accurate cost estimation tool in order to help designers and yards with the newbuilding cost estimations of superyachts during the design phase. At the beginning of this design phase, almost all characteristics of the superyacht are unknown. At the end of this phase brief specifications are known which contains several main yacht characteristics. During the phases after design, the tool should function as a basis. The maximum allowed inaccuracy of the cost estimations during the design phase is 15 percent, but of course a higher accuracy is pursued. The defined research objective has led to the main research question: how to develop this cost estimation tool?

Working method and support of the conclusions
Relations between main yacht characteristics were determined by regression analysis on an established superyacht data base. These relations are programmed in the Superyacht Design Tool (SDT) in order to estimate unknown main yacht characteristics. The most applicable cost method to use during design phase, is found by literature review. This is the parametric cost estimation method that uses cost drivers and Cost Estimating Relationships (CERs). A cost driver is a parameter that influences the cost and CER is the relation between this parameter and the cost. In order to facilitate a clear built up of the cost of the superyacht, the cost of the superyacht is divided in 16 groups. For each group, individual cost drivers and CERs are defined with NASA’s parametric cost modelling process as guideline. Also more detailed cost drivers are defined, which functions as basis for the cost estimation after the design phase. The used sources were: literature, available quotations of superyachts, but mainly interviews with subcontractors. The estimations of the quantities are connected with the known/estimated main yacht characteristics. The tool is validated with two cases.

Conclusions
The Superyacht Cost Estimation Tool (SCET) is developed. The SDT is part of the SCET. Based on two validation cases the maximum inaccuracy of less than 15 percent is achieved. In practise yacht design and yacht building cost were separated, this thesis made a connection between these subjects. The main advantages of the SCET for yards and designers are as follows:

- SCET can produce in a few minutes price and cost estimations of custom superyachts during the design phase with less than 15 percent deviation compared to the actual price and no input of a naval architect is required
- SCET functions also as basis for the following phases with its advanced calculation setup
- Gives a clear overview how the cost of a superyacht is built up
- Performs estimations of main yacht characteristics when they are unknown with the SDT
- Yard specific values can be inserted to make the SCET yard specific

Recommendations
Further usage will help to understand how useful and accurate the tool is. SCET is a starting point and is based on limited data, especially limited cost data. The main recommendation is to gather more data. More detailed cost data is required to verify and to improve the selected cost drivers and CERs. More naval architecture data is required of yachts between the 30 - 50 meters and between the 110 - 140 meters in order to validate and to improve the SDT for these ranges. The current validation of the SCET is based on two cases, it is recommended to increase the number of cases. The last recommendation is to validate the cost estimations of the groups. For these groups additional detailed cost data is required in combination with detailed data of the groups.

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Nomenclature

A	Dependent constant
B	Independent constant
BWL	Beam waterline
C_b	Block coefficient
CER	Cost Estimating Relationship
CV	Coefficient of Variation
D	Depth
Displ.	Displacement
GA	General arrangement
GM	Metacentric height
GT	Gross Tonnage
kVa	kilo Volt ampere
kW	kilo Watt
LOA	Length Over All
LSW	Light Ship Weight
LWL	Length Waterline
m	meters
NA	Naval Architecture
PYC	Passenger Yacht Code
SCET	Superyacht Cost Estimation Tool
SDT	Superyacht Design Tool
SYBAss	Superyacht Builders Association
T	Draught
UNAS	Uniforme Administratie in de Scheepsbouw
V_max	Maximum speed in knots
WBS	Work Breakdown Structure
X	Amount of the cost driver
Y	Cost

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1. INTRODUCTION

In this chapter, the approach of this master thesis will be explained. First, the topic will be introduced and then the research objective will be presented. With the boundaries and research questions, the general direction of this thesis is provided. The last paragraph describes the structure of the report.

Background / intro cost estimation
Cost estimations are not new, people were familiar with them millenniums ago. *“28 Suppose one of you wants to build a tower. What is the first thing you will do? Won't you sit down and figure out how much it will cost and if you have enough money to pay for it? 29 Otherwise, you will start building the tower, but not be able to finish. Then everyone who sees what is happening will laugh at you. 30 They will say, “You started building, but could not finish the job.”* (Luke, pp. 14:28-30) This quote is still accurate nowadays and gives the relevance of cost estimations.

Shipbuilding cost estimations were already executed a long time ago and various books and papers were published about this topic. There is no specific literature available about superyacht cost estimations. A thumb rule for the cost of a yacht is that it will be roughly one million euro per meter length (Boon, 2014), (Warburton & Kanabar, 2015). It is logical that there will be a relation between the length and the cost of a yacht, but is this really a linear relationship?

Basic problem description
Superyachts are semi to fully customised vessels. If a superyacht is fully custom the designer and yard will start with a blank page. This means that all the engineering work has to be done from scratch. The building process of fully custom superyachts is challenging as some work has never been executed before. Superyacht one-offs are significantly different than other one-off ship types because they have different influential parameters. Besides, there are the quality standard and the level of details which are extremely high and require real craftsmanship. An example why superyachts are complex vessels, is that there are a lot of systems on board and they cannot be visible.

Each fully custom yacht is different and this complex one-off nature is the reason why it is hard for the builders of superyachts to know in an early phase what the cost will be of a specific new yacht. Knowing which design choices will lead to a major influence on the total cost is not easy to answer because the cost depends on many different factors. Taking this all into consideration leads to the problem that cost estimations of superyachts are difficult to make in an early stage and also time consuming.

Importance and relevance
The importance and relevance of cost estimations during the early stage in shipbuilding are described by Caprace & Rigo:

> “Cost assessments during the early stages of ship development are crucial. They influence the go, no-go decision concerning a new development, [1]. If an estimate is too high, it could mean the loss of a business, for the benefit of a competitor. If the estimate is too low, it could mean the company is unable to produce the ship and make a reasonable profit” (Caprace & Rigo, 2012, p. 1).

How are superyacht builders executing these cost estimations nowadays? This question is asked to a superyacht builder and the provided answer is: manual. In order to perform a cost estimation during the early stage, the following is needed: several persons from the management, input from naval architects and at least a whole week of time.

Nowadays there is much more competition than in the old days, there are more yards building superyachts. People use to stand in a queue to buy a yacht, but now it is harder to sell a yacht and there are substantial negotiations about the price according to Frans Heesen (Boon, 2014). Due to this competition it would be even more interesting for the designers and yards to have a cost estimation tool which can give a quick indication with a certain accuracy of the total cost in an early stage. This tool can be used for example during meetings with clients. Certain information is required as input for this tool and the cost and desired price will be calculated. If more parameters are known and inserted, the accuracy of the cost will be increased. The client benefits also from this tool because the yard will know earlier expected cost, so the yard can calculate the selling price which depends on the market conditions. Hence, the waiting time of the client can be reduced.

1.1 RESEARCH OBJECTIVE

This paragraph defines the research objective of this thesis. But first, several questions need to be answered in order to define the research objective.

When is cost estimating necessary and which accuracy is required? In the master thesis of Shetelig answers are found that are applicable to the shipbuilding industry. According to Shetelig there are three bidding phases, see Table 1. So these three phases are requiring each a cost estimation. But in the table price is mentioned instead of cost. Shetelig: *"there is a difference between price and cost. However, these numbers give an indication of the required accuracy for cost estimates used in the bidding processes"* (Shetelig, 2013, p. 3). In the table corresponding accuracies are given for the different bidding phases. "*The requirement for cost estimation accuracy is different for different stages of the design. As the design matures, more cost information becomes available and the uncertainty of the estimate decreases*" (Shetelig, 2013, p. 3). This table is checked with a yacht specialist and it is founded that it is also applicable for the yacht world.

Bidding Phase	Requirements for accuracy
Price indication (Brief spec)	10 – 15 %
Budget Price (Outline spec)	5 – 10 %
Contract price	0.5 %

Table 1: Requirement of accuracy of estimates, from Shetelig 2013 p.3

It is already mentioned by Shetelig that more cost information becomes available, when the design matures. But which information is available when the cost estimations have to be executed? It should be noticed that in the literature various definitions are used to describe different stages / phases. In this thesis design phase is used and covers: the first orientating conversations with the Owner, first stage, early stage, concept and preliminary design. In the beginning of this design phase, almost nothing is known. At the end of this phase, brief specifications are known which are containing several main yacht characteristics. It could happen, that a cost estimation needs to be executed during the first conversations with the Owner were almost nothing is known. But it could also when the main yacht characteristics are already defined. Concluded, the available information during the design phase depends on the part of the phase. In the following phase, a 'budget price' estimation is required. The available information in the beginning of this phase are a profile and a General Arrangement (GA). In the end of the phase a 3D model is available. For the last phase, were the contract cost/price needs to be estimated more information is required. In practise, the contract price that is presented to the Owner, is based on requested quotations from subcontractors. However, still some uncertainties will occur is this phase. From the above mentioned phases, cost estimating during the design phase provides the most scientific challenge.

What the importance and relevance of cost estimations during design phases are, is already described. Shetelig underlines this: "*it is important to focus on the economic consequences of decisions during the early phases of ship design"* (Shetelig, 2013, p. 9).

Answers are given and are taken into account, in order to define the research objective.

The research objective is to develop an accurate cost estimation tool in order to help designers and yards with the newbuilding cost estimations of superyachts during the design phase. During the following phases, the tool has to function as basis. The maximum allowed inaccuracy of the cost estimations during the design phase is 15 percent, but of course an increased accuracy is pursued.

In order to achieve the research objective: helping designers and yards, the tool has to fulfil the following functional specifications which are defined by the writer:

- The tool has to be able to produce a cost estimation in a limited time frame, because then the tool can be used for example during client meetings.
- The tool needs to be able to perform a price estimation for a potential Owner.
- The tool needs to be able to perform a cost estimation of the total cost of a superyacht. Here the profit of the yard is excluded.
- The tool needs also to be able to perform a cost estimation of only the cost of the superyacht. This estimation excludes the yard costs, which are covering in this thesis the following costs: overhead of the yard, classification, insurance and unforeseen & warranty.
- The output of the tool will be the estimated cost. It is required to show how this estimated cost is built up. The reason hereof is, that the tool should also function as basis for the phases after the design.
- The tool has to be able to produce estimations, based on the assumption that the yacht will be fully custom. There are yards that are building superyachts fully custom, other yards start with a certain platform and other ones are producing limited series.
- The tool will be made for different companies, so it has to be designed in Excel. The reason is that every company has already Excel licences, so no additional investment is needed.
- Every shipyard is different and has for example different labour rates, it is required that a shipyard can change the default constants into their own specific constants.
- The tool has to be able to calculate what kind of influence certain design choices and special features have on the total cost. Which kind of choices there are, are not yet known. They need to be discovered and defined.
- When limited input is available, the tool should still be able to perform the cost estimation.
- Ship dimensions, parameters and constants have to be estimated by the tool if they are not known in order to help the designers and yards during the design phase.
- If more data for the input is available, the accuracy of the calculated cost of the yacht has to increase.

1.2 BOUNDARIES

Boundaries are required to determine what is in the scope of this thesis and what is out of the scope. The boundaries of this thesis are:

- The range of the yacht length will be between the 30 and 140 meter. All yachts smaller than 30 meter are not considered superyachts and yachts above the 140 meters are very limited and the data from these superyachts is as a result very limited.
- Only new build superyachts are within the scope. Refits are not in the scope because this is a different branch.
- Motor yachts are within the scope, motor sailors and sail yachts are excluded. The reason of this scope is that the majority of yachts are motor yachts. Data of motor sailors and sail yachts are not available at Azure.
- The tool will only be focussing on displacement yachts, semi-displacement yachts and planing yachts are excluded. The reason being that these are three different hull configurations and each hull configuration has its own materials, characteristics and relationships. The beam/draught ratio for example will be totally different for a displacement yacht compared with a planing yacht. The displacement yachts mainly have a steel hull and an aluminium superstructure, semi-displacement yachts are mainly build with an aluminium hull and superstructure or Glass-Reinforced Plastic (GRP) hull and superstructure. Planing yachts have mainly GRP hulls and superstructures. If the three different hull configurations were all included in this thesis, it would result into doing everything three times. Another and even more valid argument to only include displacement yachts is that the available data of semi-displacement yachts is limited and that the data of planing yachts is very limited.
- Almost each of the displacement superyachts have a steel hull and an aluminium superstructure. This will be also the case in the tool, material of the hull is steel and material of

the superstructure is aluminium. Other materials such as: wood, composite and glass-reinforced plastic are not inside the scope.
- The input data will be delivered by Dutch yards and subcontractors, so the method can only be validated for Dutch yards.
- Owners' deliveries are excluded in the cost estimation because this is a clear list which is always delivered by the owner and is out of the scope of the yards. This list is completely dependent on the Owner's taste, it includes for example pieces of art, chinaware, etc. The Owners' delivery list is provided in appendix A.
- What the influence of Passenger Yacht Code (PYC) is on the design, weight and cost is not known. Data and time are required to investigate the influence of PYC. Therefore PYC is outside the scope.
- Most of the superyachts have a conventional diesel propulsion. Data from diesel-electric propulsion and other unconventional methods is not available. The influence of these unconventional propulsion methods on the design and cost are not known and therefore these are outside the scope.

1.3 RESEARCH MAIN AND SUB-QUESTIONS

The defined research objective leads to the main research question: how to develop this cost estimation tool? In order to obtain an answer on this main question, research have to be done to provide answers on the following sub questions:

- Which existing cost estimation methods can be used and which one will be used?
- Which group division is preferred for the cost estimation built up?
- How to estimate unknown main yacht characteristics?
- How to estimate the cost of each group?
- How to validate the developed cost estimation tool?

1.4 STRUCTURE OF THE REPORT

Before starting with costs, a Superyacht Design Tool (SDT) is needed to determine the unknown main characteristics of a superyacht. The SDT will be explained in chapter 2. In chapter 3, the literature reviews on cost estimation methodologies and its implementation will be provided. The dividing and categorizing of the superyacht groups is executed in chapter 4. To know how the parametric cost estimation method will be applied and what the cost drivers and cost estimating relationships (CER's) per group will be, read chapter 5. In chapter 6, the SDT will be connected with the defined cost drivers. To know how the Superyacht Cost Estimation Tool (SCET) will work, see chapter 7. Validation will be done in chapter 8. The conclusions and recommendations are presented in chapter 9. To show how the chapters are depending from each other a dependency chart is made and provided in Figure 1. Example: chapter 5 is depending on chapter 3 and 4, which are dependent from chapter 1.

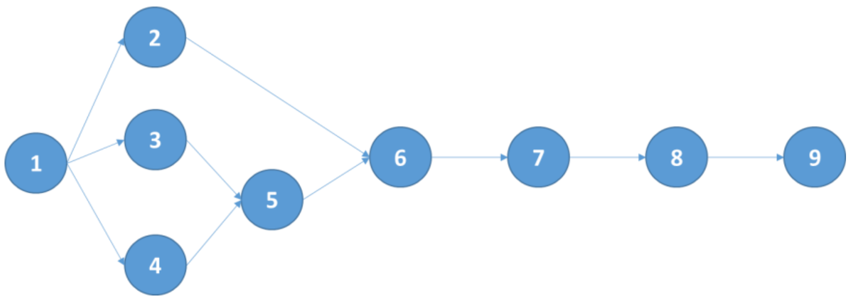

Figure 1: Dependencies of the chapters

2 ESTIMATING THE UNKNOWN MAIN YACHT CHARACTERISTICS

In this chapter an answer will be given on the following sub-research question: how to estimate unknown main yacht characteristics? The main yacht characteristics are expressing the desired superyacht in values. The main yacht characteristics are: Length Over All (LOA), Length Water Line (LWL), Beam (B), Draught (T), Depth (D), Displacement, Light Ship Weight (LSW), Gross Tonnage (GT), Maximum Speed (V_max) and the Propulsion Power. During the design phase, not all of these main yacht characteristics are known. In order to estimate them, relationships are required between the known and unknown characteristics. If a LWL is known but the beam for example not, then an estimation of the beam can be made with the Length/ Beam relationship. Why is it relevant to estimate the unknown main yacht characteristics? The reason is that cost estimations are dependent from the main yacht characteristics, so if there is a good base, then the cost estimating is more accurate.

Now the question is how and where to find these relationships. Watson describes the dimensional relationships for general cargo ships, tanker, bulk carriers, fishing vessels and frigates but not for yachts (Watson, 1998, p. 65). The conclusion is that there is no specific literature available about these relationships for yachts. This leads to the need of a database with yachts only, so the relationships can be derived from a regression analysis from this database. These relationships together are called the Superyacht Design Tool (SDT) because they will be able to define the unknown superyacht main characteristics.

2.1 THE SUPERYACHT DATABASE

Before making a yacht database, requirements have to defined. Each yacht which will be inserted into the database has to be between the length range of 30 till 140 meters, this range is according to paragraph 1.2. Also described in paragraph 1.2 is that only displacement yachts are within the scope. So each yacht has to be checked with a method to determine whether the yacht is a displacement yacht or not. The yachts need to be relevant to today's market because the regression analysis will only give the current relationships. Hence, it was decided that only yachts delivered from the year 2000 and later, can be inserted into the database. Azure has already a database which will be increased by the writer. The aim is to gather more data and at the same time to get familiar with the data. Superyachts.com has 4160 yachts in their superyacht fleet and this source will be used to gather more date (Superyachts.com, 2016).

To verify the data of added yachts and to exclude types faults three checks have to be executed. The first check will be executed when the yachts are manually inserted into the database, the data has to be retyped from superyachts.com into Excel. This first check contains the following: if something of the data seems strange, the data has to be verified with other sources such as the website of the yards. If these data are conflict, it cannot be used. The second check will be analysing the first order relations in scatterplots. First order means that the main yacht characteristics are plotted against each other. If there is a clear relationship visible and there are outliers, these outliers have to be verified. When the verification is not possible, the outlying yachts have to excluded from the database. The last check is almost the same as the second check but a second order relation is scatter plotted instead of a first order. For example, the B/D ratio is plotted against the LWL.

In paragraph 1.2, it is described that semi-displacement and planing yachts are outside the scope, the focus is only on displacement yachts. To make sure that there are only displacement yachts inside the database, the Froude number has to be calculated of each yacht. The normal Froude number will be used and not the volumetric Froude number. The reason is that more data of the length is available than the displacement data. As the LWL is not always available, it will be estimated when necessary. This is done with the LOA/LWL relation, which is determined from the 'unfiltered' database. According to the displacement regime is up to a Froude number of 0.39, the pre-planing regime from the Froude number 0.39 till 1.4 and the planing regime from 1.4 (Ferrando, 2011, p. 7). However, the separation between displacement and semi-displacement at a Froude number of 0.39 resulted in some yachts which were known as displacement yachts were considered semi displacement yachts. Due to trial and error the Froude number of 0.45 was established and resulted in a sufficient separation. The total number of displacement yachts that are inside the database and comply with the requirements from paragraph 2.1 is 304. After filtering the database, the LOA/LWL relation was checked again. The effect was that the relation was slightly different but the effect is not more than one percent of difference. The LWL estimation was only used to exclude the semi-displacements and planing yachts. The improved

LOA/LWL will be used further on in the thesis, but will not be used for an additional iteration to filter the database again.

2.2 RELATIONSHIP DETERMINATION WITH REGRESSION ANALYSIS

The database is finished. In this paragraph the relations between the main yacht characteristics will be determined with regression analysis. The R^2 will be used to determine which type of relation will be the best fit between two main yacht characteristics. But what is exactly this R^2 and how does it work?

> 'The coefficient of determination, R^2, is the statistic that will be used more than any other as a measure of the accuracy of the regression line fit to the sample data points. can have a value between 0 and 1 (or 0 percent and 100 percent), where the higher the number, the better the fit of the regression line to the actual data' (National Aeronautics and Space Administration, 2015, pp. C-15).

The relation type that results in the highest R^2 will be used, except the polynomial relation. When the order of the polynomial relation is increased, R^2 is also increasing but the relation is getting far from realistic and therefore it is excluded. In Table 2 the relation types between the main yacht characteristics are presented, together with their corresponding R^2 and their formulas. From which value of R^2 is the relation reasonable? *"It seems to be a common rule of thumb that R2 > 0,7 shows good relation between data, while R2 < 0,7 is not."* (Bjørhovde & Aasen, 2012).

It is good to be aware that the trend line approximations, formulas and the R^2 calculations can be affected by missing data of the yacht. Therefore, an additional filter is made so if some data is lacking it will not be plotted and there for it cannot affect the trend lines, formulas and R^2 anymore.

	RELATION	FORMULA	R^2
LWL VS GT	[redacted]		
LWL VS B			
LWL VS DRAUGHT			
LWL VS DEPTH			
LWL VS DISPL			
LWL VS LSW			
LWL VS LOA			
LSW VS GT			
DISPL VS GT			
DISPL VS LSW			
D VS T			
B VS D			
B VS T			
KW VS DISPL & V			

Table 2: Relations from the regression analysis

It should be noted that when the data was inserted into the database it was unknown which beam of the yacht was meant. It could be the maximum beam, the moulded beam or the beam on the waterline. Probably it would often be the maximum beam that is provided. All the founded relations have an R^2 of at least 0.8. There is one relation which seems not very logical in the scatterplot and that is the depth against the draught. Inside this plot two relations can be found, a logarithmical and a linear. The draught and depth are driven by various factors. Two examples of these various factors will be explained. The desired sailing area can have influence on the maximum draught because some areas will have a limited depth. The second example is: designers want to have a smooth exterior design where all the sizes are in balance with each other, so the designer can have influence on the freeboard.

2.3 SUPERYACHT DESIGN TOOL

The relations are provided in paragraph 2.2 and the relations with the highest R^2 will be used for the SDT. The SDT needs to estimate the following characteristics: LWL, B, T, D, Displacement, LSW, kW and GT. The When more information of the characteristics is known the estimation of the other characteristics have to improve. This is done in seven steps. The three most importantly characteristics that needs to be estimated are: LSW, propulsion power and GT. Why they are important will be discussed in chapter 5. In paragraph 8.1 the SDT will be validated.

Step one is as follows, LOA and V_max are the two characteristics that should be inserted in the SDT, as minimum. A check is needed, if this superyacht is inside the limits of this thesis: a displacement superyacht with a length between the 30 and 140 meters. To check if it is a displacement superyacht, the Froude number check will be executed. The border between displacement and semi-displacement is already defined in paragraph 2.2, the Froude number 0.45. In order to calculate the Froude number, the LWL is estimated with the LOA relationship.

The beam, draught and displacement are estimated by their LWL relation. LSW is dependent on the displacement. The propulsion power is estimated with the relation that is dependent on the displacement and maximum speed. GT is estimated from the relation with the displacement. Depth is estimated by the draught relation. Till now, no difference can be made if a superyacht is slender, average or a full design. A superyacht with a larger superstructure, needs more displacement in order to facilitate the addition weight. The block coefficient (Cb) is a number which reflects the fullness of a ship. Insight the tool, the Cb is not an input but a number which is available when the length, beam and draft are known or estimated and the displacement is estimated. In the end a correction on the displacement will be made, so it is possible to choose the fullness of the desired superyacht. The correction is 0.95 for slimmer superyachts and 1.05 for fuller superyachts.

The second step is to insert the 'real' LWL once it is known. All the other characteristics that are depending on LWL, are automatically updated when LWL is inserted. The regression analysis is done on superyachts that have a conventional bow. It needs to be detected by the SDT when a straight or reverse bow is inserted because different relations will occur. No data is available to see what the influence will be and it is recommended to investigate this. However, a dirty solution to simulate a straight bow, is to use a virtual LWL. The calculation of this virtual LWL is based on experience of a naval architect. From the LOA a conventional LWL is estimated, when these two are summed and divided by two, the virtual LWL is established.

The third step is to update the beam and or draught. In Formula 1, the formula of the displacement is shown. The displacement is linearly dependent on the beam and draught. If the beam increases and LWL, T and Cb do not change, the displacement will also increase linearly. The same applies to the draught, this is the fourth step. A check is required, in order to verify if the 'updated' beam and or draught are not unrealistic. To achieve this, the updated beam and or draught will be checked with the already estimated beam and or draught. The maximum allowed change of the beam is 1,5 meter, this number is based on the lower and upper bound from the regression analysis. For the draught this is 0,75 meter of maximum allowed change. When they are within the bounds, the estimated displacement will change linearly because it is assumed that Cb will not change and LWL is already fixed. LSW, kW, GT and the D estimations are depending on the displacement, so they will change automatically.

Step five. If the displacement is already known, the estimation can be improved by inserting the 'real' displacement. Only one check needs to be executed here. The LWL, BWL and T are already inserted or estimated. From the regression analysis, it can be said that the Cb of displacement superyachts is between the 0.4 and 0.6. Multiplying LWL, BWL, T, density and the minimum block coefficient leads to a minimum allowed displacement. Using the maximum Cb, leads to a maximum allowed displacement. So if an 'updated' displacement would be inserted, it needs to be checked if it is within the range described by the minimum and maximum displacement.

In step six the 'updated' propulsion power can be inserted. A check is required to filter out the unrealistic values. The inserted propulsion power is compared with the estimated power, with the limit of 20 percent difference.

The last step the estimation of GT can be updated with a real GT. A check is required to filter out the unrealistic values. The inserted GT is compared with the estimated GT, with the limit of 20 percent difference.

$$Displacement = LWL * BWL * T * \rho * C_b$$

Formula 1: Displacement

The seven explained steps, are summarized in a schematic overview, see Figure 2. The real SDT is presented in grey, where the seven input steps are the same as the above explained steps. At the right in the figure, the estimated values are presented. The way how these estimations are established is presented in colour. When a beam is known and inserted, it will overwrite the estimated beam. This overwriting is represented in the figure with a dotted line, which is also possible for the other main yacht characteristics.

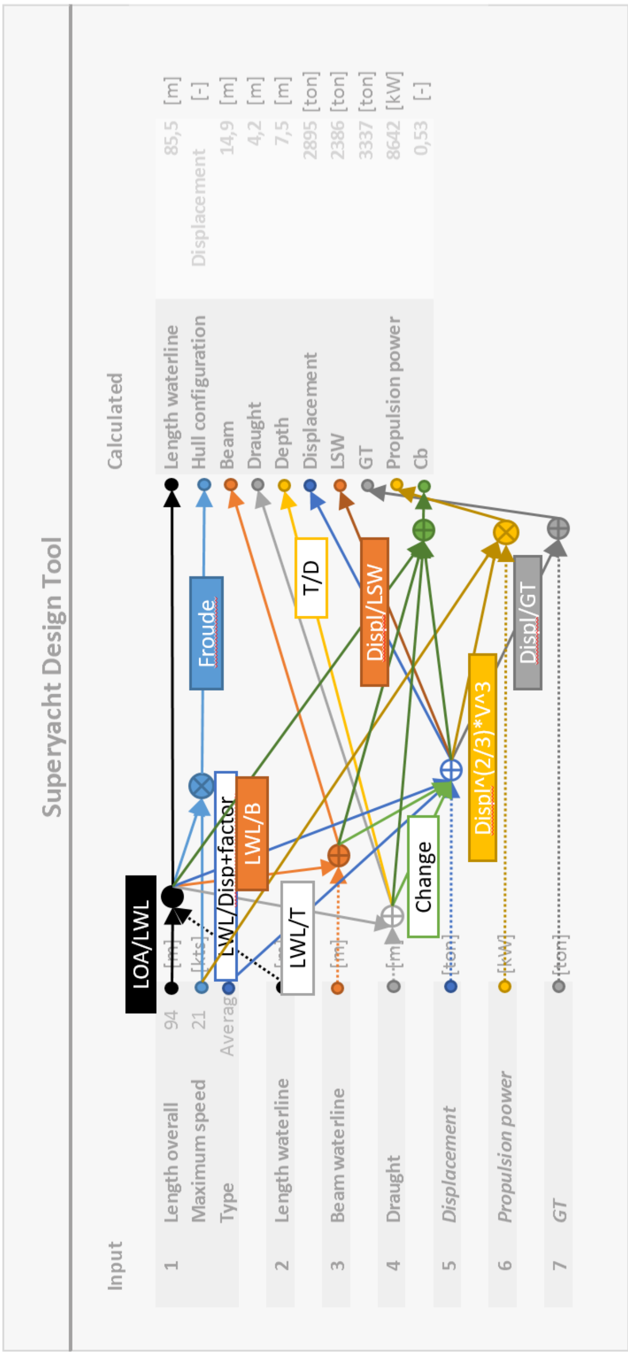

Figure 2: Schematic overview of the estimations from the Superyacht Design Tool

3 LITERATURE REVIEW ON COST ESTIMATING METHODOLOGIES AND ITS IMPLEMENTATION

In this chapter answers will be given on the questions: which existing cost estimation methods can be used and which one will be used? This thesis is about the cost estimations of newbuilding superyachts. Connecting yacht design and yacht building cost is the subtitle of the thesis. The choices of the yacht design have to be covered in the cost estimation in two ways. The first, is the possibility of variation of the main ship parameters. Secondly, yacht design choices with a binary character, like underwater lights, should be covered by the cost estimation. In this chapter the available cost estimation methods that are described in the literature will be explained if they have potential to be used.

Paragraph 3.1 divides the literature in two, first there is a review on general cost estimations and secondly the ship cost estimations will be discussed. Which cost estimation method will be used, is discussed in paragraph 3.2. In paragraph 3.3 a literature review on cost drivers and cost estimation relationships will be given. Paragraph 3.4 will explain NASA's Parametric Cost Modeling Process.

3.1 LITERATURE REVIEW ON COST ESTIMATING METHODOLOGIES

In chapter 1 is already mentioned that there is no specific literature available about cost estimations of superyachts. The cost breakdown of a vessel depends on the ship type. For example, a yacht will have a totally different cost breakdown than a merchant ship. The yacht will have a different subdivision of the cost groups and their contributions will also be different, compared with the merchant ship. Chapter 4 will get into more detail on the cost contributions of the groups. That there is no specific literature does not directly imply that the available cost estimation methods from literature will be irrelevant. The goal of the following literature review is to get an overview of which kind of cost estimation methods are available nowadays for ships. A certain method can be used as base and or inspiration for the cost estimations for superyachts.

The choice of which cost estimation method will be used, depends on the phase were it has to function in. Ross divides the cost estimating approach into three tiers in order to reflect the three design phases: concept, preliminary and contract (Ross, 2004). For each different phase, a different cost estimation method is required.

3.1.1 LITERATURE ON GENERAL COST ESTIMATION METHODS

Before diving into the cost estimations designed for ships it is interesting to see which general cost estimation methods are used worldwide in different industries. The most general breakdown of the cost estimates types that are applicable for different industries are the top-down (macro) estimate and the bottom-up (micro) estimate, this is described in the book 'The Art and Science of Project Management' of Warburton & Kanabar (2014).

> "The top-down estimate is made early on in the project, typically from the scope. The estimate is typically derived using a mathematical relationship between the scope items (parameters) and historical cost data. However, many other aspects of the scope, such as the schedule or assumptions, will affect the cost estimate. The estimate may be refined by analogy with other projects. Sometimes, a group of experts confer to reach a consensus.
>
> There are several methods for performing a top-down cost estimate: A parametric equation, section 11.5: The Delphi Technique, section 11.5.1: and reasoning by analogy, section 11.5.2" (Warburton & Kanabar, 2015, pp. 134-135).

The following examples are given to show what these models contain. The first example is about the method: 'parametric equation'. To calculate the cost of a graduation party the following parametric equation can be used, Formula 2. The parameters are: n, h and x. The constant is a.

$$C = n * h * x * a$$

C = total cost of the drinks at the graduation party

n = number of guests at the party

h = hours that the bar will be open

x = number of drinks per person per hour

a = average cost for each drink

Formula 2: example

The second example is about the method: 'reasoning by analogy'. The driving time from the TU Delft to Azure is just less than an hour, however during rush-hour it will be one and a half hour. This estimation is executed though reasoning by analogy because this road is often driven by the author of this thesis, so the estimation is done by an experienced person. Reasoning by analogy requires that a new project will be similar to the ones that were already executed. The experience of the driving time from TU Delft to Azure cannot be the base of an estimation for the driving time from the TU Delft to Utrecht.

Warburton & Kanabar are giving an example and a good explanation about the Delphi technique:

> "Wideband Delphi is an expertise-based process that a team can use to generate any kind of estimate. Delphi is an anonymous, group approach to estimation, based on the theory that:
> - Group opinions are fairly reliable.
> - Extreme views get annulled.
> - Informal one-on-one conversations are susceptible to bias and intimidation.
> - An individual might not estimate frankly in the presence of managers, customers or other stakeholders.
>
> To begin the Delphi technique, the project manager chooses an estimation team, and asks each person (or small sub-team) to estimate a series of quantities (cost or schedules). The teams are then informed about the other teams' estimates, and the process is repeated. The Delphi technique can be used when no historical data exists, and is useful when estimating a unique product or project with no history" (Warburton & Kanabar, 2015, p. 143).

The top-down approach is a different approach than the bottom up. Warburton & Kanabar are describing the bottom-up estimate as follows:

> "The bottom-up estimate is typically derived by estimating the cost of the individual activities in the WBS. Each element of the WBS (at some appropriate level) is independently estimated, and the layers summed to derive a total cost for the project. The estimates may be derived through a mathematical relationship, even at the lowest levels of the WBS"
> (Warburton & Kanabar, 2015, p. 135).

With the abbreviation WBS that Warburton & Kanabar are using, stands for Work Breakdown Structure. There is one other source which is not connected with shipbuilding but which cannot be ignored: the National Aeronautics and Space Administration (NASA). They wrote a Cost Estimating Handbook and version 4.0 was published in 2015. This handbook is written for NASA's needs but the cost estimating methodology is generally described and it goes not into Aerospace specifications. In Figure 3 the three basic cost estimating methods: analogy, parametric, and engineering are displayed with by their phases.

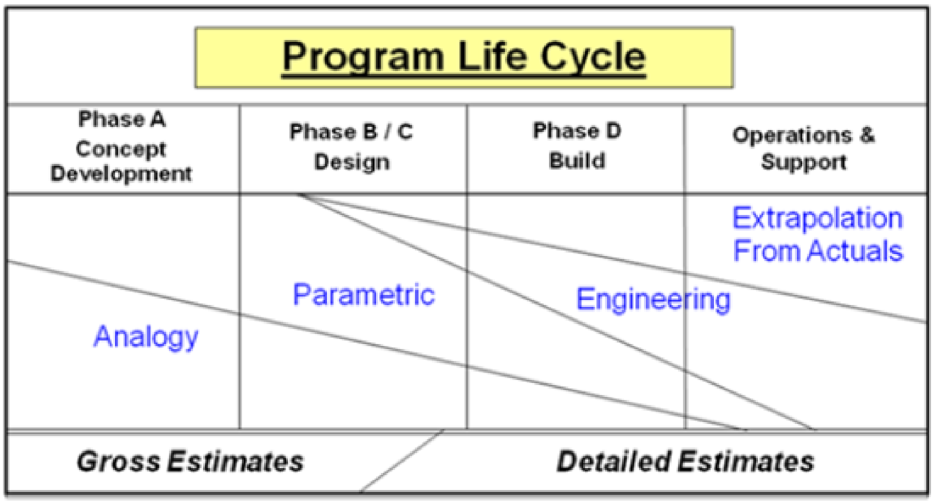

Figure 3: Taken from "Use of Cost Estimating Methodologies by phase", by National Aeronautics and Space Administration, 2015, p. 14.

Next to the three basic methods a fourth method is displayed in Figure 3: extrapolation from actuals and uses Earned Value Management. "*EVM is an integrated management control system for assessing, understanding and quantifying what a contractor or field activity is achieving with program dollars"* (NASA, 2016). The EVM will need detailed input which will not be available, so this method is left outside the scope. Analogy and parametric are two terms that were also used by Warburton & Kanabar, the terms are covering the same content. The only difference is that for the parameterical method NASA goes one step further in their explaination. *"Generally, an estimator selects parametric cost estimating when only a few key pieces of data are known, such as weight and volume. The implicit assumption in parametric cost estimating is that the same forces that affected cost in the past will affect cost in the future"* (National Aeronautics and Space Administration, 2015, p. 16). Also two new terms are introduced within the parametric cost estimating: 'Cost Estimating Relationships' (CERs) and 'cost drivers'. The definition of the CER is according to the Business Dictionary: "*Mathematical equation in which a cost is expressed as a dependent variable of one or more independent cost driving (see cost driver) variables, or as a function of one or more technical parameters"* (Business Dictionary, 2016). The cost driver definition is: "*A factor that can causes a change in the cost of an activity. An activity can have more than one cost driver attached to it"* (Business Dictionary, 2016). The cost drivers can also be called the independent variables. To explain how the CER and the cost driver are working, NASA gives the following example:

> "For example, the assumption may be made that the weight of a component drives its total cost. Figure 7 provides an example of how this may be portrayed as a standard Cartesian coordinate graph. The dependent variable is the Y axis (Cost) and the independent variable is the X axis (Weight). By using historical data that compare cost to an independent variable and plotting, we can establish whether there is a relationship between the variables. From these data points, a "line of best fit" can also be plotted (depicted as the blue line in Figure 7). The line of best fit to the data can be tested and used for a CER." (National Aeronautics and Space Administration, 2015, p. 17).

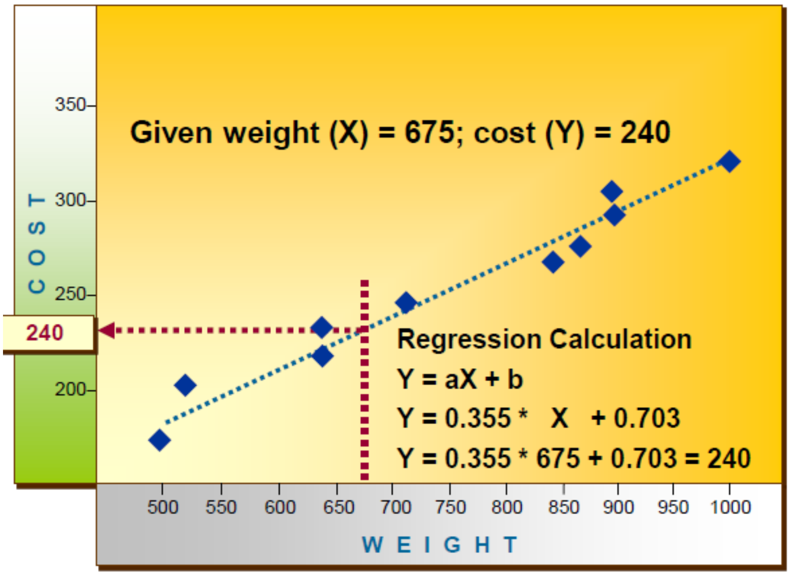

Figure 7. Scatterplot and Regression Line of Cost (Y) Versus Weight (X)

Figure 4: Taken from "NASA Cost Estimating Handbook," by NASA , 2015, p.17

The last method of NASA which is not yet explained is the 'engineering' method. This method is exactly the same as the bottom-up approach. *"This costing methodology involves the computation of the cost of a WBS element by estimating at the lowest level of detail (often referred to as the "work package" level) wherein the resources to accomplish the work effort"* (National Aeronautics and Space Administration, 2015, p. 27). All the methods of NASA are discussed, but which one is the most usable method for this thesis? A clear overview of the strengths, weaknesses and applications of the analogy, parametric and engineering method is given Table 3, Table 4 and Table 5.

Strengths	Weaknesses	Applications
Based on actual historical data	In some cases, relies on single historical data point	• Early in the design process • When less data are available
Quick	Can be difficult to identify appropriate analog	
Readily understood	Requires "normalization" to ensure accuracy	• In rough order-of-magnitude estimate • Cross-checking
Accurate for minor deviations from the analog	Relies on extrapolation and/or expert judgment for "adjustment factors"	• Architectural studies • Long-range planning

Table 3: Strengths, Weaknesses, and Applications of Analogy Cost Estimating Methodology. Taken from "NASA Cost Estimating Handbook," by NASA , 2015, p.15

Strengths	Weaknesses	Applications
Once developed, CERs are an excellent tool to answer many "what if" questions rapidly	Often difficult for others to understand the statistics associated with the CERs	• Design-to-cost trade studies • Cross-checking • Architectural studies • Long-range planning • Sensitivity analysis • Data-driven risk analysis • Software development
Statistically sound predictors that provide information about the estimator's confidence of their predictive ability	Must fully describe and document the selection of raw data, adjustments to data, development of equations, statistical findings, and conclusions for validation and acceptance	
Eliminates reliance on opinion through the use of actual observations	Collecting appropriate data and generating statistically correct CERs is typically difficult, time consuming, and expensive	
Defensibility rests on logical correlation, thorough and disciplined research, defensible data, and scientific method	Loses predictive ability/credibility outside its relevant data range	

Table 4: Strengths, Weaknesses, and Applications of Parametric Cost Estimating Methodology. Taken from "NASA Cost Estimating Handbook," by NASA , 2015, p.18

Strengths	Weaknesses	Applications
Intuitive	Costly; significant effort (time and money) required to create a build-up estimate Susceptible to errors of omission/double counting	• Production estimating • Negotiations • Mature projects • Resource allocation
Defensible	Not readily responsive to "what if" requirements	
Credibility provided by visibility into the BOE for each cost element	New estimates must be "built up" for each alternative scenario	
Severable; the entire estimate is not compromised by the miscalculation of an individual cost element	Cannot by itself provide "statistical" confidence level	
Provides excellent insight into major cost contributors (e.g., high-dollar items).	Does not provide good insight into cost drivers (i.e., parameters that, when increased, cause significant increases in cost)	
Reusable; easily transferable for use and insight into individual project budgets and performer schedules	Relationships/links among cost elements must be "programmed" by the analyst	

Table 5: Strengths, Weaknesses, and Applications of Engineering Build-Up Methodology. Taken from "NASA Cost Estimating Handbook," by NASA , 2015, p.19

From this information, the following question arises: which presented method will be the most appropriate for this thesis? The 'Analogy Cost Estimating Methodology' can be used early in the design process, but the disadvantage is that it gives a rough estimation and this method will not provide information about how the cost are build up. The 'Parametric Cost Estimating Methodology' on the other hand fits more into the functional specifications that were set up in chapter 1. In Table 4 the design-to cost trade study is presented as application of this method. Table 5 shows that the weakness of the 'Engineering Build-Up Methodology' is that it requires significant effort in time and money. It also shows also that this method can be used for production estimating. It is clear that this method pursues a more detailed level than is needed for the Superyacht Cost Estimation Tool (SCET).

3.1.2 LITERATURE ON SHIP COST ESTIMATION METHODS

After discussing the general literature about cost estimating methods it is time for the literature specialized in ships. The goal is to look only at the different methods, to keep this subparagraph readable no specific formulas are presented. In chapter 5 the formulas will be discussed.

Bertram, Maisonneuve, Caprace and Rigo made in their paper 'Cost Assessment in Ship Production' the same classification as made in the general literature. For the estimating method of the production cost Bertram et al. described the top-down and bottom-up method (Bertram, Maisonneuve, Caprace, & Rigo, 2004). The parametric approach is included by the top-down approach.

Shetelig devoted his master thesis to 'Shipbuilding Cost Estimation' and divided the cost estimation methods in: bottom-up, top-down and parametric (Shetelig, 2013). These terms are corresponding with the cost estimation methods described in 3.1.1. The only difference is that parametrical method is mentioned separate. This leads to the question: how to put this method into relation with the others? This question is answered in his thesis: *"Between the global top-down methods and the accounting bottom-up methods is where we find parametric cost estimation"* (Shetelig, 2013, p. 12). But is the parametric cost estimation method closer to the top-down or the bottom-up approach?

> "Whether a parametric cost estimation method is closest to a top-down or a bottom-up approach is dependent on how the costs are summarized. If the CERs calculate the total cost based on global parameters like length overall (LOA) or deadweight (DWT), some would call this a top-down approach. The opposite would be if costs of every little subsystem were found by CERs and then used an accounting bottom-up approach. In reality, most parametric cost estimation methods are considered closest to top-down methods because of the independent cost drivers chosen and the use of parametric estimation in early phases of design" (Shetelig, 2013, p. 12).

'Towards a Short Time "Feature-Based costing" for Ship Design' is a paper written by Caprace & Rigo. Their idea is to distillate automatically all the required ship details out a CAD or CAM model, which is available at a certain stage and use this for the cost estimation. The required details to perform a detailed cost estimation are for example the plate area's and the total amount of welding meters. They also described the current methods to calculate the production costs: the familiar top-down and bottom-up approach (Caprace & Rigo, 2012).

There is also literature which is mainly focussing on the preliminary cost estimations: Michalski (2004), Carreyette (1977), Watson (1998), Miroyannis (2006) and Aalbers (n.b.). Michalski wrote a report: 'Parametric method of preliminary prediction of ship building costs' where a parametric (top-down) method is described (Michalski, 2004). He assumes that the total cost of ship building is build up out of the following cost: material cost, labour cost and other shipyard costs. These shipyards costs consist of: hull construction, ship equipment, power plant and propulsion system. *"It has been also assumed that costs of each of these groups are related to the weight of a respective group."* (Michalski, 2004, p. 17).

In Carreyette's paper: 'Preliminary Ship Cost Estimation', different formula's are made to estimate the weight of the materials and the amount of labour needed for the groups steelwork, outfit and machinery (Carreyette, 1977). He also devoted a paragraph to the cost of ship features. For different ship features as stabilisers and thrusters are formula's presented to calculate the cost difference.

Watson describes a detailed estimating method in his book: 'Practical ship design'. First he divides the costs into two categories: estimated and actual. "*The estimated cost is that calculated when the shipyard is tendering: the actual cost is that ascertained to have been incurred at the end of the contract."* (Watson, 1998, p. 465). It is clear that the focus in this thesis will be on the estimated cost. The detailed estimation for merchant ships of Watson is using 8 groups: structure, structure related, accommodation related, outfit cargo related, deck m/c related, propulsion, machinery auxiliaries and related. Services & miscellaneous is an additional group. For each group the following subdivision is made:

- weight tonnes
- material cost per tonne
- man hours per tonne
- man hours
- labour rate per man hour and overheads

Putting this all together leads to the total cost.

At Massachusetts Institute of Technology (MIT), Miroyannis graduated on the topic 'Estimation of Ship Construction Costs'. He has an interesting statement about weight based cost estimations: *"Finally using only a weight based approach to ship cost estimating is insufficient. It is necessary to develop and use a model that incorporates other cost driving factors in order to develop estimates of sufficient quality at the preliminary design level"* (Miroyannis, 2006, p. 6). In the thesis four main types of cost estimating methods are presented that are available at the preliminary stage: analogy, parametric, extrapolation and expert opinion. All these methods are already discussed.

Aalbers dedicated a paragraph of his paper 'Evaluation of ship design options' to weight & cost estimates. With parameters he predicts the costs of various system which are classified in nine groups of the work break down structure (Aalbers). For each of these groups formulas are presented per group to calculate the materials and man-hours. It is not written on which kind of vessels the data is based. But it is likely that the ship types were Aalbers data is based on, are general cargo ships, container ships and coasters.

The last source is Ross (2004), which will be discussed inside this literature review. He is using different terms for the approaches:

> "Approaches to cost estimating vary from the informal to the formal, as described below:
> - "Black book" – cost estimators create formulas, tables, and charts based on years of experience, industry trends, and vendor data. Typically, estimators guard this information closely, thus making its accuracy difficult to confirm. The black book approach can produce acceptable results in cases where the shipyard constructs a single or a few ship types and sizes. This approach is not so dependable for ship types or sizes beyond those normally constructed at the yard, or as costs become outdated.
> - Parametric approach – System and subsystem costs are characterized in a spreadsheet or cost estimation program as a proportion of overall metrics such as length, volume, displacement and propulsion power. The proportions are estimated through comparisons with similar ships. As with the black book approach, if correlation levels are high, then the parametric approach yields good predictions: otherwise, the estimates may not be sufficiently accurate for many technical and business decisions.
> - Standard ship approach – Some shipyards offer standard ship designs for which cost characteristics are well known. This enables the yards to very quickly and confidently develop detailed bids for prospective customers, and is an excellent solution if the designs match the customers' requirements. However, even with the flexibility for making limited changes to the design, many customers prefer to purchase a ship that is more closely aligned to their business needs.
> - Direct analysis approach – As the design matures, costs may be estimated based on drawings, bills of materials, historical vendor costs, and existing quotes. This approach is only practical after the design has reached a level of significant technical maturity." (Ross, 2004, p. 2).

The term parametric does not require additional explanation. The standard ship approach is not applicable for fully custom superyachts. The direct analysis approach can be compared with the bottom-up approach, which requires too much work. Enough literature about cost estimating methods/approaches is presented. In the following paragraph there will be elaborated which method(s) will be useful for the SCET.

3.2 THE CHOICE OF THE COST ESTIMATING METHOD

There are no fundamental differences between the general cost estimating methods and the ship cost estimating methods. Of course a different WBS is used for a space shuttle than for a ship, but the same principles are used. Four methods came back often: (reasoning by) analogy, the bottom-up method / engineering build-up, the top-down method and the parametric method. For the parametric the opinions differ if the parametric is a totally separate method, or that it is covered by the top-down approach. It is clear that the choice of the method depends on the stage were the cost estimation has to function. The SCET will be designed for use during the preliminary/design phase, so this excludes the detailed bottom-up approach. Here the lowest level of the SWBS is required in order to perform a cost estimation. Reasoning by analogy will also not work for the tool because the whole idea of the SCET is that the ‘road’ will be different every time. The top-down method on the highest level will not be accurate enough, here the total cost will be estimated as function of the Gross Tonnage for example. The cost per GT for a superyacht can be roughly between the 30.000 and 70.000 euros, this is not the accuracy which is pursued.

The question is: which method is the right one to use? The parametric method with the approach of the Cost Estimating Relationships (CERs) and the cost drivers would be a good fit in combination with the main groups of the WBS. The CER is a mathematical equation, were the cost driver is an independent variable. In subparagraph 3.1.1 the exact definitions and an example are given. The main groups of the WBS for superyachts have to be determined, this will be done in chapter 4, but an example is the main groups from Watson: hull, structure, electrical and etcetera. The reasons why this is a good fit are the following ones: the method is applicable in the phase where the tool has to function. The second reason is that this method gives the possibility to be programmed and therefore a fast calculation will be made possible. The third reason is that the possibility for other designs is made available, assumed that the main cost drivers will be the same for different yachts. The last reason is that the cost estimation in this way is not only dependent on the weight.

3.3 LITERATURE REVIEW ON COST DRIVERS AND CER’S

Are there already cost drivers and or CER’s defined in the literature for shipbuilding that can used as inspiration or maybe even used as basis? Shetelig divided a Platform Supply Vessel (PSV) into five technological groups and connected each group with several cost drivers. For example, the hull group of Shetelig is connected with the cost drivers: DWT, LOA and deck area (Shetelig, 2013, p. 20). The purpose of a PSV is to supply offshore platforms, it is logical that DWT and deck area are important here. The second technological group is machinery and propulsion with speed, power and dynamic positioning class as cost drivers. Here again, a PSV is another ship type were DP is found important. The defined cost drivers cannot be implemented in this thesis, but a conclusion can be drawn from Shetelig: a group can contain multiple cost drivers.

Cost driver and CER are words that are not often used in the shipbuilding. However, there are synonyms and words that come close to cover the same understanding. Hopman, Pruyn and Hekkenberg from the TU Delft defined Key Performance Indicators (KPIs) for shipbuilding, on behalf of the SuperYacht Builders Association (SYBAss), see Table 6. In the rest of this thesis, there is referred to the KPIs of SYBAss.

#	Name	KPI	UNAS Groups Present
0	General Object Costs	GT	[000] - [090]
1	Hull, Ship's Body	Lws	[100] - [120]
2	Small Steelwork	Lws	[130] - [150], [170]
3	Piping	Lws	[300] - [360], [380], [390]
4	Painting	LBD^(2/3)	[160]
5	Propulsion	kW	[200] - [220]
6	Ventilation	m3 cargo hold	[371]
7	HAC	crew/passengers	[372] - [374]
8	Electrical	kVA	[400] - [490]
9	Joinery	crew/passengers	[700] - [790]
10	Other Equipment	LxD	[500] - [520], [600] - [690], [800] - [890]
11	Special Equipment	GT	[530] - [590], [900]

Table 6: SYBAss KPI’s. Data taken from: “Determination of the Compensated Gross Tonnage factors for Super Yachts” on behalf of SYBAss and by TU Delft, 2010, p.27

These KPI's are partly useful. The KPI GT for general object costs sounds logical. That the hull, small steelwork and piping are depending on the Light weight ship (Lws) is also reasonable. The KPI of the paint group is for merchant ships logical, but not for superyachts. The depth of merchant ships is rather fixed, were the depth of a superyacht can be dependent of the exterior design. The KPI of ventilation group is 'm3 cargo hold', this is not directly compatible with a superyacht. But that a cost driver of the ventilation group is connected with a certain volume seems logical. Group HAC and Joinery have the same KPI: crew/passengers, this cannot be applied directly to superyachts. That the electrical group has kVA as KPI can be used. For group 10 and 11 it is hard to say already something about the usefulness of these KPI's. Concluded can be that several KPI's defined by Hopman, Pruyn and Hekkenberg of the SYBAss can be used as starting point chapter 5.

Shetelig and SYBAss only defined the cost drivers. Aalbers goes one step further because he is the only one who is providing CER's, see
Table 7. This table requires more explanation. In the table the group breakdown of Watson is used. For each group there are one or more parameters defined, these can be translated with cost drivers and the abbreviations are explained in Table 8. How the values of 'a' and 'b' are connected with each other, is presented in Formula 3.

$$K = c * a * W^b$$

K = costs/manhours

W = weight/size

a = factor for local conditions

b = factor in the range 0.5...1.0

c = factor for complexity of specific equipment

Formula 3: Aalbers CER formula

Aalbers method is made for merchant shipping, but it can also function as basis for certain groups. In chapter 5 the cost drivers and CER's of each group of a superyacht will be discussed. But how to extract the right cost driver and the right CER? NASA described has a NASA Parametric Cost Modeling Process. This will be used as guideline and is explained in the following paragraph, paragraph 3.4.

	System	Parameter	Materials		Man-hours	
			a_m	b_m	a_h	b_h
1	General & Engineering	Wsm	2500	0.72	27	0.90
2	Hull& Conservation	W_steel, LBD, Cb	950	1.00	120	0.89
3	Ships Equipment	W_equip, L(B+D)	7500	0.80	8.5	0.86
4	Accommo-Dation	Area_acc	750	1.00	250	0.55
5	Electrical Systems	P_gen	9250	0.62	20	0.55
6	Propulsion & Power System	P_b, nr_p_b	2050	0.84	6	0.75
7	Systems for Prop&Power	P_b, nr_p_b	1500	0.70	35	0.70
8	Bilge, Ballast San.Systems	hullnr	150	0.93	2.75	1.00
9	Cargo Systems	W_cargos				

Table 7: Values for Aalbers's formula. Taken from Aalbers

BASIC PARAMETERS	
Lightship weight	Wsm
Steelweight total nett	W_steel
L*B*D	LBD
Blockcoefficent	Cb
Equipment weight	W_equip
Accommodation area	Area_acc
Installed generator power	P_gen
Prime power per ind. System	P_b
Nr of independent power systems	nr_p_b
Hull numeral L(B+D)	hullnr
Cargo system weight	W_cargos

Table 8: Basic parameters. Taken from Aalbers

3.4 IMPLEMENTATION OF NASA'S PARAMETRIC COST MODELING PROCESS

In the literature review on cost estimation methologies, it became clear that the parametric method will be used. Inside this paragraph NASA's Parametric Cost Modeling Process will be explained, because this process will be used as guideline to identify and determine the cost drivers and CER's. NASA visualizes their seven steps of the Parametric Cost Modeling Process, shown in Figure 5.

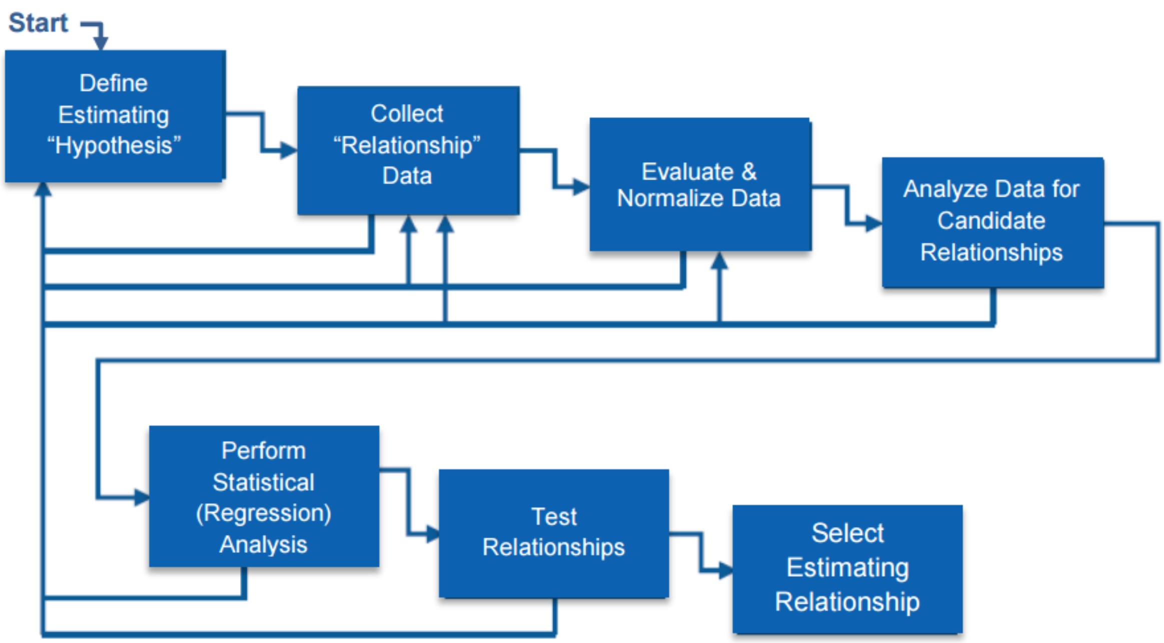

Figure 5: NASA Parametric Cost Modeling Process, taken from NASA Cost Estimating Handbook Version 4.0 C-6

This process will help to identify the cost drives and CER’s for the new build cost of superyachts. An explanation of the steps and how these steps will be implemented is as follows:

1. Define Estimating “Hypothesis”. The advantage of NASA’s process, is that it gives guidelines were to start. A hypothesis needs to be defined. But when data is lacking it is possible to define a hypothesis, that is just made on experience. If the hypothesis is found not true, then an iteration is needed.

   > “Estimates created using a parametric approach are based on historical data and mathematical expressions relating cost as the dependent variable to selected, independent, cost-driving variables. Generally, an estimator selects parametric cost estimating when only a few key pieces of data, such as weight and volume, are known” (National Aeronautics and Space Administration, 2015, pp. Appendix C-6).

2. Collect “Relationship” Data. The sources of the data are: literature, interviews with subcontractors, experts and technicians, employees of Azure and internal information. This internal information includes some detailed quotations of superyachts.

3. Evaluate & Normalize Data. Due to the limited data, normalization will not always be possible.

4. Analyze Data for Candidate Relationships

   > “After studying the technical baseline and analyzing the data through scatter charts and other methods, the cost estimator should verify the selected cost drivers by discussing them with engineers, scientists and/or other technical experts” (National Aeronautics and Space Administration, 2015, pp. Appendix C-6).

5. Perform Statistical (Regression) Analysis. NASA: *“a cost estimator applies regression analysis to create a CER”* (National Aeronautics and Space Administration, 2015, pp. Appendix C-7). “*To develop a parametric CER, the cost estimator must determine the drivers that most influence cost”* (National Aeronautics and Space Administration, 2015, pp. Appendix C-6).

   > “Note that there are many cases when CERs can be created without the application of regression analysis. These CERs are typically shown as rates, factors, and ratios. Rates, factors, and ratios are often the result of simple calculations (like averages)) and many times do not include statistics” (National Aeronautics and Space Administration, 2015, pp. Appendix C-7).

6. Test Relationships. NASA *“uses analysis of variance (ANOVA) to evaluate the quality of the CER”* (National Aeronautics and Space Administration, 2015, pp. Appendix C-7).

7. Select Estimating Relationship.

   > “The CER can then be developed with a mathematical expression, which can range from a simple rule of thumb e.g., dollars per kg) to an equation having several parameters (e.g., cost as a function of kilowatts, source lines-of-code [SLOC], and kilograms) that drive cost” (National Aeronautics and Space Administration, 2015, pp. Appendix C-7).

In chapter 5 the explained steps of NASA’s will be applied to identify and determine the cost drivers and CER’s.

4 DEFINING AND CATEGORIZING GROUPS

The first goal of this chapter is providing a workable group breakdown. In order to achieve the highest possible accuracy of the cost estimation in an efficient way, groups with a significant contribution to the cost of a superyacht will deserve more effort than groups with a lower contribution. To get a feeling which groups are contributing a significant share to the cost of a superyacht, the groups will be categorized. The categorizing will be made on the basis of two detailed quotations of two different superyachts.

4.1 GROUP BREAKDOWN

In order to see how the total cost of the superyachts are built up, a certain group breakdown needs to be established. Only one number as outcome, which represents the total cost estimation will not be enough. It is required to know how the cost are built up. Therefore, different groups needs to be defined. Watson's approach of the group breakdown, already mentioned in literature review paragraph of chapter 3.1, can be used as reference. Another way to categorize the groups is with the UNiforme Administratie in de Scheepsbouw (UNAS) code. However, Azure already has inside the company a group breakdown for the lightweight and deadweight of the yachts. Watson's breakdown is made for merchant ships, Azure's breakdown is made for yachts. The available weight data of Azure is in their own breakdown structure. If Azure's breakdown will not be used, all the data have to be transferred into another breakdown and this costs time. To save this unnecessary acquisition the choice is made to use Azure's group breakdown. Another reason is that it will be easy for the company to implement the cost estimation when the research is finished. The deadweight items of Azure will not be taken into consideration for the cost estimation because it is assumed that the deadweight items are paid directly by the owner. At Azure the deadweight items are specified as follows: crew + guests & effects, provisions + stores, tenders + jetskis, Owners' supplies, spare parts & tools, pool & jacuzzi water, fuel, oil, fresh water, grey & black water and ballast water. The Owners' supply list is enclosed in Appendix A, in this list tenders and jetskis are also included because they are normally an Owners' delivery. The main LSW breakdown of Azure is displayed in Table 9 .

1	Steel hull
2	Aluminium superstructure
3	Engine room equipment
4	Propulsion system
5	Electrical system
6	Steering and mooring
7	Piping system
8	Ventilation system
9	Paint fairing insulation
10	Interior
11	Exterior joinery
12	Outfitting

Table 9: Azure's LSW breakdown

For getting a better understanding what exactly is inside each main group of Azure, subgroups are provided in appendix B. This appendix shows that foldable doors are covered by the outfitting group. It has to be mentioned that in the steel hull and aluminium superstructure groups the glass is included. For the cost calculation it is desired that glass will have his own group. The groups from Azure are directly related with the light ship weight and this group breakdown is not covering the non-directly related cost. In the end the total cost needs to be estimated. This is the reason why the group breakdown needs to be expanded with the following groups and subgroups:

00 Naval Architecture & Engineering

13 Glass

100 – Portholes:
200 – Glass in hull:
300 – Glass in superstructure:

14 Yard

100 - Overhead:
200 – Classification:
300 – Insurance:
400 – Unforeseen & warranty:
500 – Profit:

15 Miscellaneous

100 – Financing:
200 – Exterior & Interior design:
300 – Diverse:

These groups are added to the list of Azure's. Group 15 miscellaneous is normally excluded from the scope of the yard. The build-up of the groups is explained in the paragraphs **Fout! Verwijzingsbron niet gevonden.**, **Fout! Verwijzingsbron niet gevonden.**, **Fout! Verwijzingsbron niet gevonden.** and **Fout! Verwijzingsbron niet gevonden.**. These groups are added to the list of the group breakdown, including the subgroups. This final group breakdown is provided in appendix B, the non-direct related LSW groups are represented in blue.

4.2 CATEGORITIZING GROUPS

The goal of the categorisation of the groups is to see which groups are the most important ones. The amount of the contribution from the groups to the cost of a superyacht will be used to categorise the groups. Till now the contribution of the groups to the cost is vaguely described. Which exact cost will be used? The total cost of all the groups, or only from the weight related groups? In order to provide an answer, it is required to zoom into which costs should be estimated by the SCET.

Explanation of the differences between the three estimations

Inside the paragraph 1.1 the functional specifications are provided of the SCET. Here is defined that the SCET has to be able to perform a price estimation for a potential Owner. Also is defined that the SCET has to be able to perform a cost estimation of the total cost of the superyacht. What are these three estimations covering exactly and how are the three connected with each other? When the yard is ordering or outsourcing items/systems, this can be seen as cost for the project because they are purchased by the yard. When inside this thesis the price of the Owner is mentioned, it includes the cost and profit of the yard. When it is about the total cost of the superyacht, the profit of the yard is excluded. In order to clarify the relations of the three estimations and summarize what they are including, Figure 6 is provided.

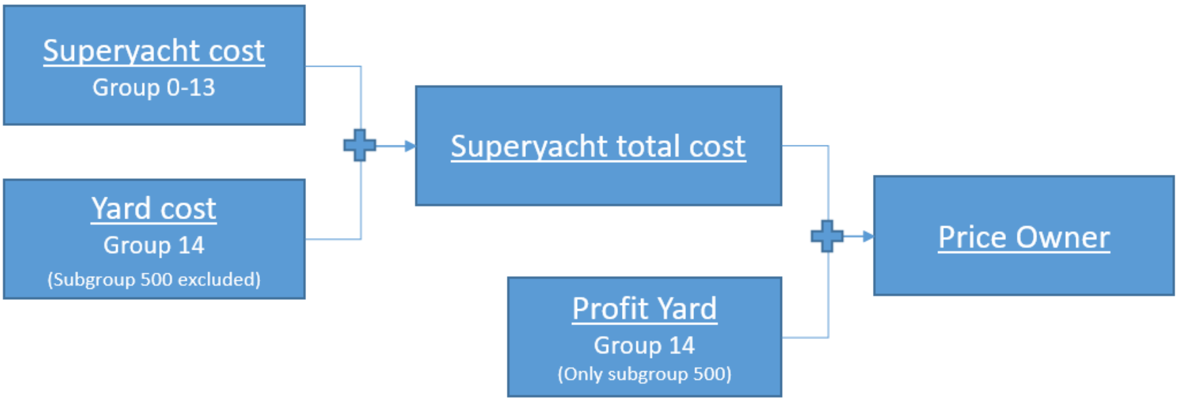

Figure 6: Relations of the three estimations

The contribution to the total cost of Group 0 -13, is the best one as basis for the categorizing. Why is this the best one? An example: Group 01 is representing a certain amount, when this amount is divided by the price, the contribution will be lower than when the amount is divided by 'Yard estimation'. The SCET needs to be able to produce three different estimations and the categorisation should be valid for all of them. If the categorisation would be based on the price, certain groups would be less significant and therefore they would be put inside a lower category. The solution is to use the cost of Group 0-13. Group 14 is expressed as a percentage of the cost of Group 0-13, see paragraph **Fout! Verwijzingsbron niet gevonden.** for more detail on the yard costs. The contribution of Group 14 to the total cost is significant. The amount can lead up to almost the same as the largest contribution group, Group 10. The size of Group 15 is not interesting because these costs are normally outside the scope of the yard.

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5 APPLYING THE PARAMETRIC COST ESTIMATION METHOD: DEFINING COST DRIVERS AND CERS PER GROUP

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5.17 OVERVIEW

Group		Final Cost Driver(s) (design phase)	CER (default)	Literature	Quotation	Interview
00	Naval Architecture & Engineering	GT	LOG	X		X
01	Hull	Weight 01	Linear	X	X	X
02	Superstructure	Weight 02	Linear		X	
03	Engine Room Equipment *100 Main Machinery*	Propulsion power	Linear	X		X
	200 Exhausts	Propulsion power	Linear	X	X	X
	400 Stabilizers	LWL	EXP		X	X
04	Propulsion System *100 Main Propulsion*	Propulsion power	Linear	X	X	X
	200 Bow thruster	Bow thruster power	Linear		X	
05	Electrical System	Weight 05	Linear	X	X	X
06	Steering and Mooring System	Weight 06	Linear		X	
07	Piping System	LOA	Linear		X	X
08	Ventilation System	Weight 08	Linear		X	X
09	Hull insulation, Paint and Fairing	Weight 09	Linear		X	X
10	Interior	Area interior	Linear	X	X	X
11	Exterior Joinery	Weight 11	Linear		X	X
12	Outfitting	GT	Linear	X	X	X
13	Glass	Weight 13	Linear		X	X
14	Yard	% of costs 0-13	Linear		X	
15	Miscellaneous	% of costs 0-13	Linear		X	X

Table 10: Overview of the defined cost drivers & CERs of H5

6 CONNECTING THE SUPERYACHT DESIGN TOOL WITH THE COST DRIVERS

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7 THE SUPERYACHT COST ESTIMATION TOOL

This chapter contains the establishment of the cost estimation tool. The tool is named: Superyacht Cost Estimation Tool (SCET). The functional specifications of the SCET have been described in paragraph 1.1. All the sub-research questions, except the validation, are answered through the chapters 2 to 6. These answers were necessary in order to program the SCET. The structure of this chapter is as follows, first an analysis of the users is provided, a tool setup and lastly an overview of the SCET usage is given.

7.1 ANALYSIS OF THE USERS

Not defined in the functional specifications are the users of the SCET. Yards and designers are mentioned in the research objective, but whom exactly are the potential users? The potential users are the management of superyacht yards, sales managers, cost estimators and designers. It can be possible that users have no maritime background. The possible lack of maritime background leads to an additional requirement of the functional specifications: a feasibility check needs to be executed by the SDT. Some users are potentially less familiar with cost estimations. Therefore, two menus are introduced: SCET main menu and calculation menu.

7.2 TOOL SETUP

The data flow chart in Figure 7 explains the setup of the SCET. This needs to be explained before the presentation of the SCET. The data flow chart exists of the following parts: SDT, Choices & Cost, Calculation menu, Breakdown and three orange boxes; Input, Choices and Yard specific values.

First the main yacht characteristics are defined by the SDT, with as minimum input the LOA and the required speed. The SDT is explained in chapter 2. The SDT box in the data flow chart, contains a boundary check and a feasibility check. The boundary check is responsible to verify whether the desired superyacht is within the boundaries of this thesis. If the superyacht would be a semi-displacement or planing yacht, then no cost estimation is presented. If the superyacht is smaller than 30 or larger than 140 meter, than a warning is given. A notification is given when a straight or reverse bow is pursued. Despite these warnings, a cost estimation is still given because it can provide the user with a global estimation. The feasibility check verifies the inserted main yacht characteristics. A warning will also be given for questionable input values for LWL, BWL, draught, displacement and or propulsion power. These input values are considered questionable when they are not within the defined relation ranges of chapter 2.

In the box 'Choices & Cost', presented in Figure 7, the following choices need to be made: whether the default or advanced calculation method is used, whether certain subgroups are included or not, and choices with regard to design and production. The cost estimation is presented per group. The sum of the all the costs of the groups results in the price or cost of the superyacht, this value is presented. In the breakdown, contributions of the groups are displayed in percentages.

In the 'Calculation menu', data from SDT is loaded. With the LSW estimation from the SDT, estimations of the weight from each group are made. Also in this section the interior area estimation and the bow thruster estimation are made. These estimations and the default values are inserted in the CER, which calculates the cost estimation per group. It is possible to insert yard specific values here, these values can overwrite the default values. This should only be done by a user who is familiar with cost estimations.

The SDT, Choices & Cost and Breakdown together form the SCET main menu. This main menu is the green box in the data flow chart. The interface of the main menu of the SCET is presented in Figure 18. The calculation menu of the SCET is visualized with the other green box in the data flow chart. Appendix C presents the interface of SCET calculation menu. No actual default values are presented here, due to confidentiality.

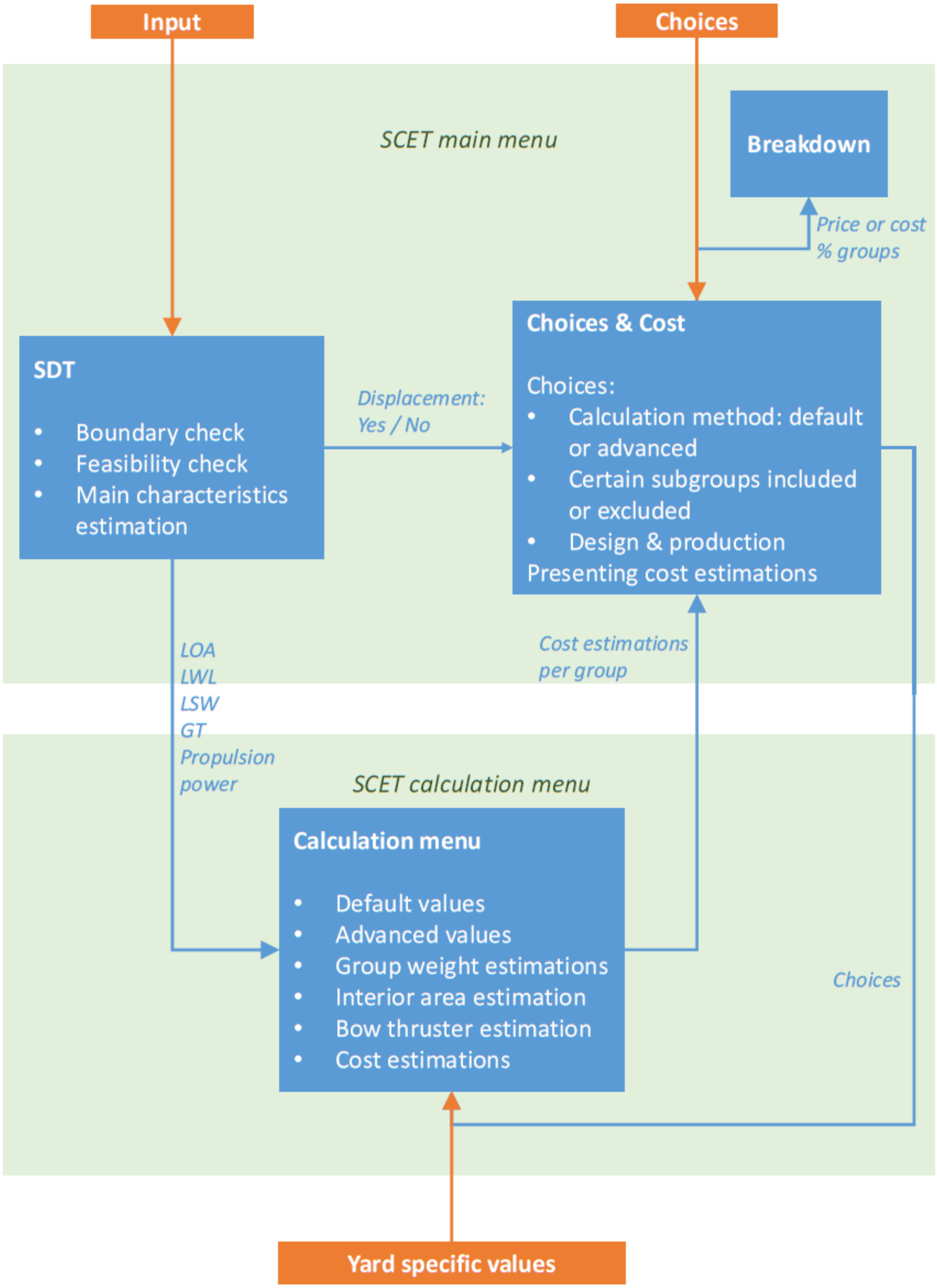

Figure 7: Data flow chart SCET

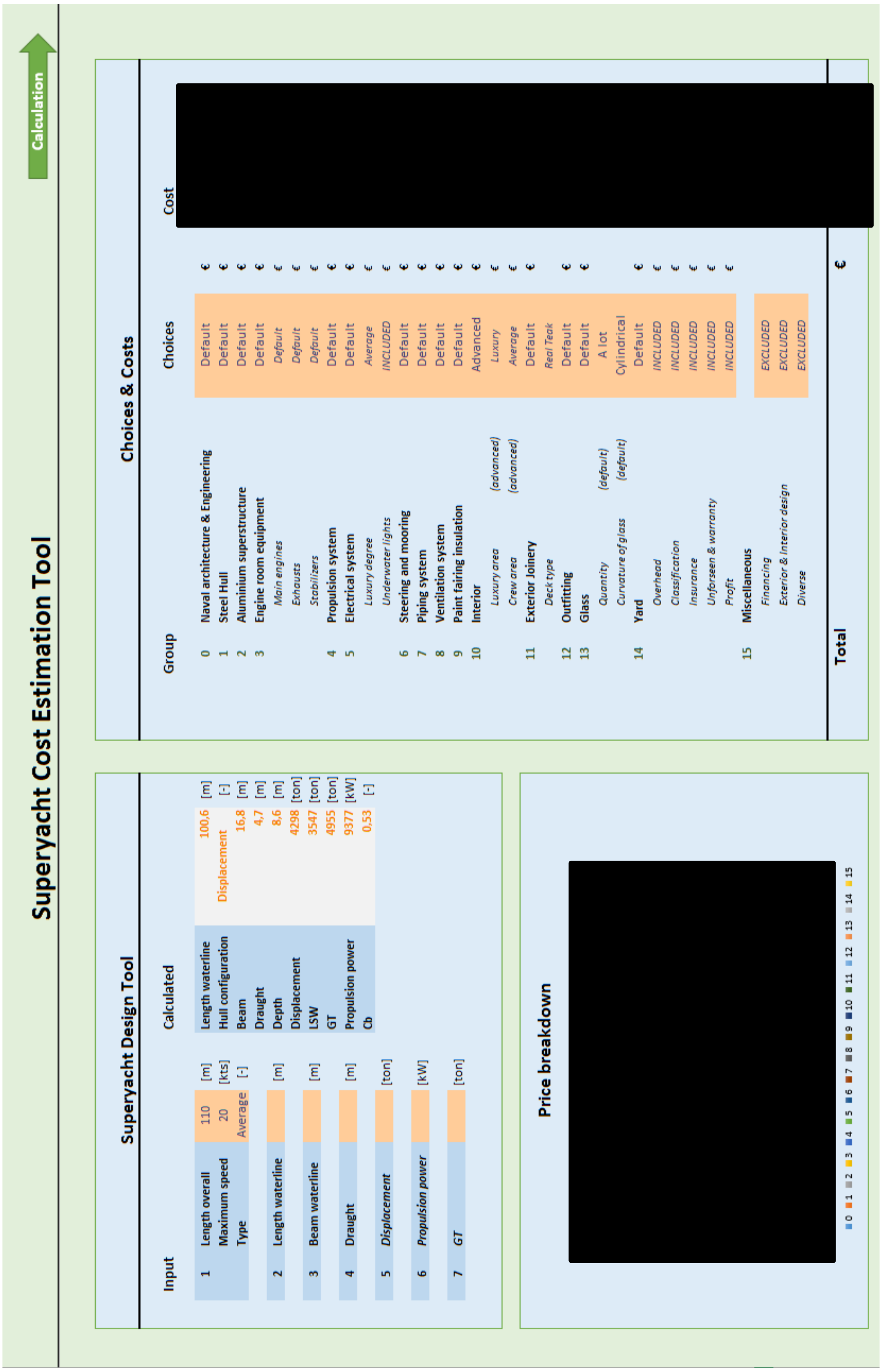

Figure 8: Interface SCET main menu

7.3 OVERVIEW OF THE SCET USAGE

An overview of the SCET usage is provided in Table 11. Herein the successive steps are provided. For each step is explained in which phase this step should be made and what the required action is. Also is provided in which part of the SCET this action needs to be done.

Step	Phase	Action	Part tool
0	-	Inserting yard specific values	Calculation menu
1	-	Choosing desired estimation: Price, superyacht total cost or superyacht cost. This is achieved by including or excluding the subgroups of Group 14 and 15.	Choices & costs
2	Design	Inserting at least LOA and V. Inserting when one or more are known: LWL, BWL, T Inserting when one or more are known: displacement, propulsion power, GT	SDT
	Design	Choices to simulate the desired yacht:	Choices & costs
3	Design	Main engine: default, MTU or Caterpillar	Choices & costs
4	Design	Exhaust: default, IMO II or IMO III	Choices & costs
5	Design	Stabilizers: default, Rolls Royce, Naiad or Anti-Roll	Choices & costs
6	Design	Luxury degree electrical system: basis, average or luxury	Choices & costs
7	Design	Underwater lights: included or excluded	Choices & costs
8	Design	Luxury degree of luxury interior area: budget, average, luxury or exclusive	Choices & costs
9	Design	Luxury degree of crew interior are: budget, average or luxury	Choices & costs
10	Design	Deck type: real teak or fake teak	Choices & costs
11	Design	Glass quantity: normal, a lot	Choices & costs
12	Design	Curvature of glass: flat, cylindrical or spherical	Choices & costs
13	Design	Inserting rough or detailed values of additional items. *Example: cost of a swimming pool*	Calculation menu
14	Design	Overwrite estimated quantities of the cost drivers with exact quantities	Calculation menu
15	Following	Using the advanced cost estimation method. Inserting the quantities of the cost drivers. Overwrite the default values when actual values are known *Example: # m2 paint, €/m2 when known*	Calculation menu
16	Contract	Overwrite the cost estimations with requested quotation values of subcontractors	Calculation menu

Table 11: Overview of the SCET usage

8 VALIDATION

This chapter validates the developed cost estimation tool. First the SDT is validated in paragraph 8.1, because when the SDT is insufficient, the input for the cost estimation is insufficient. In paragraph 8.2 the SCET is validated.

8.1 SUPERYACHT DESIGN TOOL VALIDATION

The SDT is based on a large database of superyachts from builders all over the world. In the end the Superyacht Cost Estimation Tool (SCET) is based on quotations from Dutch companies. The LSW, propulsion power and GT estimations are important, because the cost estimation will mainly depend on these values. The SDT is validated by two persons; a naval architect and the writer of this thesis.

SDT validation by a naval architect
A naval architect of Azure validated the SDT. The estimations of yachts between 30 and 50 meters are hard to validate because Azure has limited data of these yachts. More data is required to validate this part of the SDT. But from experience is noticed that the inaccuracy of the estimations: GT, LSW and propulsion power is increased for this range. The estimations of the superyachts between 50 and 110-meter length are validated and these estimations are found accurate. Above 110 meter, there is not sufficient data available within Azure in order to validate the SDT.

SDT validation by the writer of this thesis
In order to validate the LSW, propulsion power and GT estimations, the dimensions (LOA, LWL, B, T) and the speed of several Dutch superyachts that were built, are inserted in the SDT. Here for, main dimensions of 36 superyachts from seven different yards are available. But the real LSW, propulsion power and GT are not for all of them available. The defined superyacht type, which is representing the fullness of the yacht, is set on average for the calculations. Output of the tool is compared with the real LSW, installed propulsion power and GT.

For the LSW estimation validation, 22 Dutch superyachts were inserted. Resulting in an average of the estimated LSW's, which is 3 percent lower than the real ones. Thus, on average the tool has estimated the LSW 3 percent too low. The Coefficient of Variation (CV) is 0.10. In Figure 9 the distribution of the estimated LSW divided by the real LSW is shown. It should be noted that in practise a margin of 5 percent is introduced inside the LSW calculation.

For the power validation data is available from 36 superyachts. Here the outcome is that the estimated propulsion power is estimated on average 5 percent too high. The CV of the power is 0.15. In Figure 20 the distribution is shown of the estimated propulsion power divided by the real installed propulsion power. It should be noted that the maximum speed of the superyachts that are inside the database, are often lower than the real maximum speed. This could be an explanation why the average of the estimated propulsion power is 5 percent higher than the real power.

From the 36 superyachts, the real GT is available from 19 superyachts. These are compared with the GT estimation by the SDT. Resulting in an average that is 3 percent higher than the real GT and a CV of 12. In Figure 11 the distribution is shown of the estimated GT divided by the real GT. From the distribution can be concluded that a significant variation occurs.

What can be concluded? The LSW estimation is the most proper one of these three estimations. Taking the variations from the estimations of LSW, propulsion power and GT into account, leads to a challenge to reach the research objective: cost estimating with less than 15 percent inaccuracy during the design phase. If the research objective can be reached with these estimations, depends on the how large the influence of these three yacht characteristics will be on the cost of the superyacht.

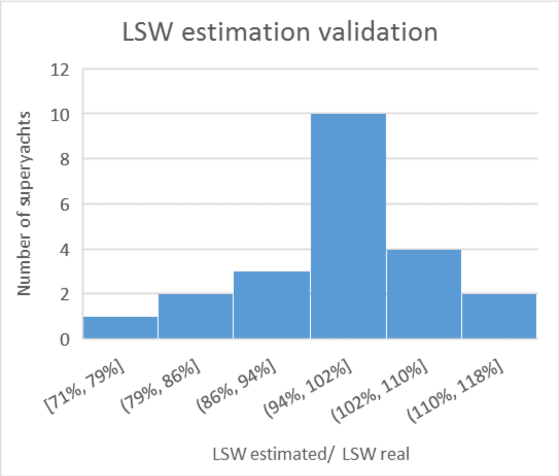

Figure 9: LSW estimation validation

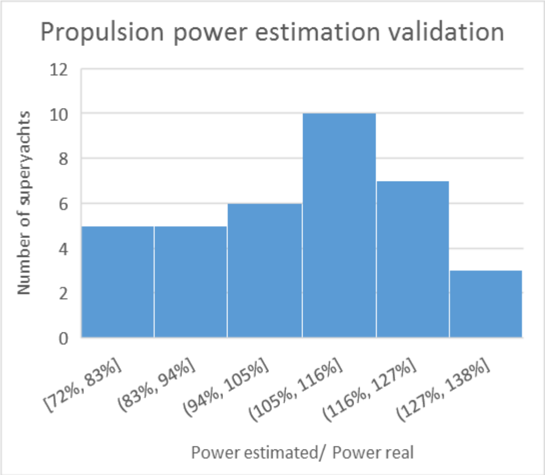

Figure 10: Propulsion power validation

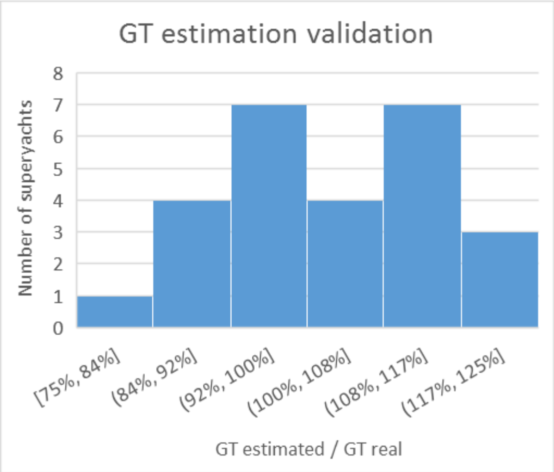

Figure 11: GT estimation validation

8.2 SUPERYACHT COST ESTIMATION TOOL VALIDATION

How to validate the SCET? No cost data is available which is required when the writer has to validate the SCET. Cost data is not provided by yards and prices are not published by them. On the internet prices are mentioned, but these do not need to be the actual price for which they are sold and can therefore not be used for validation. The final and group-specific cost/price estimations can only be validated by experts who provide these estimations for a specific yard.

SCET validation by the board of a superyacht builder
The director, CEO and sales manager of a Dutch superyacht builder were willing to have a meeting, in order to validate the SCET. They are responsible for the needed price/cost estimations in their own company. Normally the delivery of an estimation takes at least a week. This emphasizes the potential of a SCET which can produce an estimation within a couple of minutes.

The way how the SCET is validated, comparing real values of a superyacht that is built at this yard with the estimated values from the SCET.A superyacht is inserted in the SCET and was between the 50 and 110 meter. Values were inserted into the first four blocks of the SDT. These blocks are containing the main yacht characteristics; LOA, LWL, BWL, T and the speed. No values for the propulsion power, displacement and GT were inserted, in order to see the functionality of the SDT. The board declared the SDT to be accurate. The estimations of GT and propulsion power were reported to deviate less than two percent from the real values. Because of confidentially, nothing could be mentioned about the LSW.

Secondly, in order to simulate the built superyacht choices were made in the SCET block choices & costs. The presentation of the chosen cost drivers per group was accepted without any critical comments. On the explanation of the selected default values, some suggestions where given based on the board's experience. From their perspective, the cost of the after treatment system of the main engines needs to be raised. The board also expects the cost per kg of the steel hull to be underestimated. After a discussion it became clear that this yard includes already several pipes during the casco building, which results in a higher cost per kg. It was also mentioned that this yard has an extremely high standard for the steel hull, this could be the cause of the difference in kg cost. In the SCET it is possible to insert yard specific values. For the final cost estimation, their specific steel cost per kg is inserted. According to their experience, the price of an underwater light is twice as high as what is currently assumed. This specific value is also inserted in the SCET and overwrites the default value for this estimation. Lastly, the board considers the factor two difference between fake and real teak an overestimation, in their experience these prices are almost the same. The price per square meter of teak deck that is used in the SCET, was provided by the subcontractor of paragraph **Fout! Verwijzingsbron niet gevonden.**. This value is of the price per square meter of fake teak, is two times lower than what the yard uses. This difference can be explained, the yard uses a worldwide known producer, where the subcontractor produces their own fake teak. Deck covering is covered by Group 11 Exterior Joinery, in the advanced estimation of the SCET it is possible to insert the area of the deck and the price per square meter.

The estimated final price given by the SCET are found to be within the maximum 15 percent deviation of the actual values. This means that the objective of this research in this case is reached. The cost estimations per group were found not unrealistic by the board, but no further comments or directions could be given because of confidentiality. The overall feedback of this meeting was that the SCET has a logical construction and that the main advantage is that the SCET can save time because a lot of assumptions and estimations are automated.

SCET validation by a project manager of a yard
A project manager of a different yard, has inserted a built superyacht of this yard into the SCET. The LOA, LWL, BWL, T and speed were inserted and the available choices inside the SCET were made. No yard specific values were used. The resulting difference between the real and estimated price is less than five percent, well within the obtained maximum range.

9 CONCLUSIONS AND RECOMMENDATIONS

This chapter contains the conclusions and recommendations.

9.1 CONCLUSIONS

The research objective of this thesis is to develop an accurate cost estimation tool in order to help designers and yards with the newbuilding cost estimations of superyachts during the design phase. During the following phases, the tool has to function as basis. The maximum allowed inaccuracy of the cost estimations during the design phase is 15 percent, but of course a higher accuracy is pursued.

The defined research objective leads to the main research question: how to develop this cost estimation tool? In order to obtain an answer to this main question, research is done to provide answers to the following sub questions:

How to estimate unknown main yacht characteristics?
A superyacht database is established, containing around 500 superyachts. Relationships between the characteristics are determined with regression analysis. These relationships are programmed in such a way that it can estimate the unknown main yacht characteristics. This program is called the Superyacht Design Tool (SDT).

Which existing cost estimation methods can be used and which will be used?
A literature review focused on cost estimating methodologies is done. General cost estimation methods and ship cost estimations methods are investigated. The following subdivision of four different methods is often made in the literature: (reasoning by) analogy, the bottom-up method / engineering build-up, the top-down method and the parametric method. The parametric method that uses Cost Estimating Relationships (CERs) and cost drivers is the best method to use during the design phase.
According to the Business Dictionary the definitions of cost driver and CER are:

> Cost driver: "*A factor that can causes a change in the cost of an activity. An activity can have more than one cost driver attached to it"* (Business Dictionary, 2016).
>
> CER: "*Mathematical equation in which a cost is expressed as a dependent variable of one or more independent cost driving (see cost driver) variables, or as a function of one or more technical parameters"* (Business Dictionary, 2016).

Which group division is preferred for the cost estimation built up?
Azure's Light Ship Weight (LSW) structure is preferred as basis for the group division. Glass was inside the steel hull and aluminium superstructure groups. The choice is made by the writer to introduce a separate group for glass. For the cost estimation are also non-direct related groups necessary. Three groups are introduced: naval architecture & engineering, yard and miscellaneous. All these groups together are the preferred group division.

How to estimate the cost of each group?
Cost drivers and CERs are defined for each group with NASA's parametric cost modelling process as guideline. Due to confidential nature of cost, it was hard to collect cost data. The used sources are literature, available quotations of superyachts, but mainly interviews with subcontractors. A conclusion is that cost drivers and CERs are phase depending. During the design phase, the length of the superyacht is selected as the most usable cost driver of the group: "Piping systems". The cost is of this group is linear related with the cost driver. When the actual length of the piping system is known, this would be a more accurate cost driver. Though, the length of the piping system is only available in more detailed phases and not yet during the design phase.

Another group is the steel hull. The cost driver during the design phase is the weight of the steel hull. But how to proceed? By research is concluded that the highest accuracy is gained if a linear CER is used. This linear CER is provided in the following formula: $Y = A * X + B$. 'Y' is representing the total cost of the group. 'A' is a constant that represents a certain quality, it is possible for a yard to use their own constant. 'X' is the amount of the cost driver, in this case the weight of the steel. 'B' is representing independent cost, such as transportation cost. But how is the total weight of the steel hull estimated?

The LSW is estimated with the SDT. By research is found that the size of superyachts has no significant influence on the LSW breakdown. An average breakdown is established in percentages. So, the steel hull percentage multiplied with the total LSW, results in the weight of the steel hull. When this value is inserted into the CER together with ‘A’ and ‘B’, the cost of the group steel hull is estimated.

How to validate the developed cost estimation tool?
First the tool had to be made. It is named: Superyacht Cost Estimation Tool (SCET). To validate two cases are tested. The validation is done with yachts of which the actual price is now known. The main characteristics of the cases will be fed into the SCET. The outcome will be compared to the actual price. The goal of the tool is to have less than 15 percent deviation between the estimation and the actual price.

The first validation case was organised with the Board of a Dutch superyacht builder. A superyacht of this builder has been inserted in the SCET. The total estimation made by the SCET was somewhat low compared to the real value. Though, the real price deviated less than 15 percent of the estimated value. The Board of the company also noted that the cost estimations that were defined per group were not unrealistic.

A project manager of a different yard, who knew the price and specifications of an already built superyacht was asked to insert this Dutch superyacht in the SCET. The result was that the difference between the real and estimated price was less than 5 percent.

Overall conclusions
This thesis is connecting yacht design and yacht building cost. In practise these subjects are separated and are now brought closer to each other. SCET is developed, which can produce price and cost estimations during the design phase. But also functions as basis for the following phases. Till now the maximum deviation between estimated and actual value has not exceeded 15 percent.

The overall feedback of the meeting with the direction of the superyacht builder is that SCET is built up logically and that the main advantage is that the SCET saves time because a lot of assumptions and estimations are automated.

The advantages of the SCET for the yard and designers are as follows: it is an automated tool, saves valuable time, gives a clear overview how the cost of a superyacht is built up and the estimation can be performed without input of a naval architect.

9.2 RECOMMENDATIONS

Further usage will help to understand how useful and accurate the tool is. SCET is a starting point and is based on limited data, especially limited cost data. The main recommendation is to gather more data. More detailed cost data is required to verify and to improve the selected cost drivers and CERs. More naval architecture data is required of yachts between the 30 - 50 meters and between the 110 - 140 meters, in order to validate and to improve the SDT for these ranges. Naval architecture data of yachts with reverse and straight bows is needed, in order to be able to investigate the influence of bow types on the cost relations. The validation of the SCET is currently based on two cases, it is recommended to increase the number of cases. The last recommendation is to validate the cost estimations of the groups. For these groups additional detailed cost data is required in combination with detailed data of the groups.

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APPENDICES:

A. OWNERS' DELIVERY LIST

The articles specified in the list below are not included and will be selected, ordered and handled by the Owner:

- Loose interior and outside furniture and cushions/covers
- Carpet and other floor covering materials including underlay and fixing provisions
- Bedspreads, duvet covers, mattresses, pillows, linen, towels, etc. in Owners and guest areas
- Decorator items, pieces of art
- Ornamental lighting fixtures purchases
- Silverware, china, glassware, cutlery, cooking utensils and appliances, etc
- Luxury tenders, crew tenders(s) and wave runners, water-sports equipment
- Personal Owners and crew effects
- Consumables (cleaning materials), medicines etc.
- Spare parts, tools (except where normally supplied with equipment)
- Helicopter with all (class) required equipment and tools
- Provisions and stores
- Exercise equipment, etc.
- Loose items for chartroom, navigation, bosun store
- Crew uniforms

B. GROUP BREAKDOWN

00 Naval Architecture & Engineering
01 Steel Hull:
100 - SHELL + STIFFENING:
200 - DECKS + STIFFENING:
300 - BULKHEADS +STIFFENING:
400 - PRIMARY GIRDERS + WEBS:
500 - SIDEWALLS (N/A):
600 - PILLARS:
700 - FOUNDATIONS:
800 - STAIRS:
900 - VARIOUS STEEL:
1100 - Full steel OD adds::
02 Aluminium superstructure:
100 - DECKS + STIFFENING:
200 - BULKHEADS + STIFFENING:
300 - SIDE WALLS:
400 - BULWARKS, CEILINGS:
500 - FOUNDATIONS:
600 - VARIOUS ALU:
800 - STEEL IN SUPERSTRUCTURE:
900 - Full steel OD, aluminium deductions:
03 Engine room equipment:
100 - MAIN MACHINERY:
200 - EXHAUST LINES:
300 - PUMPS:
400 - STABILIZERS:
500 - MISCELLANEOUS:
04 Propulsion system:
100 - MAIN PROPULSION:
200 - STERN THRUSTER:
300 - BOW THRUSTER:
400 - MISCELLANEOUS:
05 Electrical system
100 - GENERATORS:
200 - MAIN COMPONENTS:
300 - CABLES & FIXTURES:
400 - BATTERIES:
500 - NAVIGATION EQUIPMENT:
600 - AUDIO / VIDEO EQUIPMENT:
700 - SECURITY EQUIPMENT:
800 - COMPUTER & IT EQUIPMENT:
06 Steering and mooring
100 - ANCHORING EQUIPMENT:
200 - CAPSTANS:
300 - OTHER MOORING EQUIPMENT:
400 - STEERING EQUIPMENT:
07 Piping system
100 - Pipes:
200 - Appendages:
300 - Fluids in systems:
400 - Fixtures:
500 - Equipment in systems:
600 - Miscellaneous:
08 Ventilation system

Legend:

Black = Azure's LSW group breakdown
Green = added group for the LSW
Blue = non direct related LSW groups

- 100 - Air handling units & fancoils:
- 200 - Ducting:
- 300 - Mechanical ventilation units:
- 400 - Misc equipment:

09 Paint fairing insulation

- 100 - PAINT, FAIRING BELOW DWL:
- 200 - PAINT, FAIRING ABOVE DWL:
- 300 - INTERNAL COATINGS:
- 400 - INSULATION:
- 500 - FLOATING FLOORS:

10 Interior

- 100 - TANK DECK:
- 200 - LOWER DECK:
- 300 - MAIN DECK:
- 400 - OWNERS DECK:
- 500 - BRIDGE DECK:
- 600 - SUN DECK:

11 Exterior Joinery

- 100 - DECK COVERING:
- 200 - CAPRAILS & RAILINGS:
- 300 - EXTERIOR CEILINGS:
- 400 - EXTERIOR FURNITURE:
- 500 - STAINLESS STEEL FITTINGS:

12 Outfitting

- 100 - (CABIN) INTERIOR ITEMS:
- 200 - SHELL/BULWARK DOORS ETC:
- 300 - OUTFITTINGS - ON DECK:
- 400 - OUTFITTINGS - BELOW DECK:
- 500 - INT/EXT DOORS & HATCHES:

13 Glass

- 100 - Portholes
- 200 – Glass in hull
- 300 – Glass in superstructure

14 Yard

- 100 - Overhead:
- 200 – Classification:
- 300 – Insurance:
- 400 – Unforeseen & Warranty:
- 500 – Profit:

15 Miscellaneous

- 100 – Financing:
- 200 – Exterior & Interior design:
- 300 – Diverse:

C. INTERFACE SCET CALCULATION MENU

Group			Insert	Used	
0	Naval architecture & Engineering				
	Default		-	-	[€]
	Advanced *			0	[€]
1	Steel Hull				
	Default	Steel weight		638	[ton]
		Cost	-	-	[€/kg]
		Total		#WAARDE!	[€]
	Advanded	Steel weight		638	[ton]
		Labourrate	-	-	[€/hours]
		Man-hours per ton	-	-	[hours/ton]
		Waste	-	-	[%]
		Material	-	-	[€/ton]
		Processing	-	-	[€/kg]
		Engineering	-	-	[%]
		Overhead	-	-	[%]
		Profit	-	-	[%]
		Transport cost	-	-	[€]
		Total		#WAARDE!	[€]
2	Aluminium superstructure				
	Default	Aluminium weight		122	[ton]
		Cost	-	-	[€/kg]
		Total		#WAARDE!	[€]
	Advanced	Aluminium weight		122	[ton]
		Labourrate	-	-	[€/hours]
		Man-hours per ton	-	-	[hours/ton]
		Waste	-	-	[%]
		Material	-	-	[€/ton]
		Engineering	-	-	[%]
		Overhead	-	-	[%]
		Profit	-	-	[%]
		Transport cost	-	-	[€]
		Total		#WAARDE!	[€]
3	Engine room equipment				
	Default	Labourrate	-	-	[€/hour]
		Propulsion power	-	-	[kW]
		Main engines: CAT	-	-	[€/kW]
		Main engines: MTU	-	-	[€/kW]
		Exhaust	-	-	[€/kW]
		Aftertreatment	-	-	[€/kW]
		Stabilizers RR	-	-	[€]
		Naiad	-	-	[€]
		Anti-Roll	-	-	[€]
	Advanced *			€ -	[€]
4	Propulsion system				
	Default	Propulsion system	-	-	[€/kW]
		Bowthruster	-	-	[€]
	Advanced	Shaftline	-	-	[€/kW]
		Gearbox	-	-	[€/kW]
		Torsion coupling	-	-	[€/kW]
		Flexible coupling	-	-	[€/kW]
		Propeller	-	-	[€/kW]
		Installation, allignment and classification	-	-	[€/kW]
		Sub total		#WAARDE!	[€/kW]
		Bow thruster	-	-	[kW_bow]
		Bow thruster	-	-	[€/kW_bow]
		Stern Thruster		0	[kW_stern]
		Stern Thruster		0	[€/kW_stern]

			Sub total thruster		€ -	[€]
			Total		#WAARDE!	[€]
5	Electrical system					
		Default	Weight Group 5		78	[ton]
			Price per ton	-	-	[€/ton]
			Factor basic		0,85	[-]
			Factor average		1	[-]
			Factor luxury		1,15	[-]
			Choosen factor		1	
			Total		#WAARDE!	[€]
			Underwater lights per piece	-	-	[€]
			Interval		3	[m]
			Total pieces		53	[#]
			Total		#WAARDE!	[€]
		Advanced *	Gensets (including exhausts)		0	[kW]
				-	-	[€/kW]
					#WAARDE!	[€]
			Cables		0	[km]
				-	-	[€/km]
						[€]
			AV		0	[€]
			NAV/COM		0	[€]
			Miscellaneous		0	[€]
			Total		#WAARDE!	[€]
6	Steering and mooring					
		Default	Weight		32	[ton]
			Price per ton	-	-	[€/ton]
			Total		#WAARDE!	[€]
		Advanced *			€ -	[€]
7	Piping system					
		Default		-	-	[€]
		Advanced *	Meters pipe		0	[m]
			Price per meter		€ -	[€/m]
			Appendages			[€]
			Fluids in systems			[€]
			Fixture			[€]
			Equipment in systems			[€]
			Miscellaneous			[€]
			Pumps			[€]
			Total		€ -	[€]
8	Ventilation system					
		Default	Weight		36	[ton]
			Price per ton	-	-	[€/ton]
			Total		#WAARDE!	[€]
		Advanced *	M3 cooling		0	[m3]
			Cooling per m3		€ -	[€/m3]
			Total		€ -	[€]
9	Paint fairing insulation					
		Default	Weight		103	[ton]
			Price per ton	-	-	[€/ton]
			Total		#WAARDE!	[€]
		Advanced *	M2 painting&fairing above WL		0	[m2]
			Price per m2 above WL	-	-	[€/m2]
			M2 painting&fairing below WL		0	[m2]
			Price per m2 below WL		€ -	[€/m2]
			Sub total		#WAARDE!	[€]
			Insulation		€ -	[€]

			Floating floors		€ -	[€]
			Total		#WAARDE!	[€]
10	Interior					
		Default	Weight		214	[ton]
			Price per ton	-	-	[€/ton]
			Total		#WAARDE!	[€]
		Advanced	Conversion		150	[kg/m2]
			Area		1425	[m2]
			Ratio luxury:crew		0,33	[-]
			Luxury area		955	[m2]
			Crew area		470	[m2]
			Luxury area			
			Budget	-	-	[€/m2]
			Average	-	-	[€/m2]
			Luxury	-	-	[€/m2]
			Exclusive	-	-	[€/m2]
			Crew area			
			Budget	-	-	[€/m2]
			Average	-	-	[€/m2]
			Luxury	-	-	[€/m2]
11	Exterior Joinery					
		Default	Weight		36	[ton]
			Price per ton	-	-	[€/ton]
			Total		#WAARDE!	[€]
		Advanced *	Teak area		0	[m2]
			Teak price	-	-	[€/m2]
			EcoDeck	-	-	[€/m2]
			SubTotal		#WAARDE!	[€]
			Caprail		0	[m]
			Caprail price	-	-	[€/m]
			SubTotal		#WAARDE!	[€]
			Ceiling area		0	[m2]
			Ceiling price	-	-	[€/m2]
			SubTotal		#WAARDE!	[€]
			Stainless Steel Weight		0	[kg]
			Price per kg	-	-	[€/kg]
			SubTotal		#WAARDE!	[€]
			Total		#WAARDE!	[€]
12	Outfitting					
		Default	GT		2219	[ton]
			Price per GT	-	-	
			Total		#WAARDE!	[€]
		Advanced *			0	[€]
		Foldable doors & balconies	1) Length		0	[m]
			1) Height		0	[m]
			1) Contour		0	[m]
			1) Cost		€ -	[€]
			2) Length		0	[m]
			2) Height		0	[m]
			2) Contour		0	[m]
			2) Cost		€ -	[€]
			3) Length		0	[m]
			3) Height		0	[m]
			3) Contour		0	[m]
			3) Cost		€ -	[€]
			4) Length		0	[m]
			4) Height		0	[m]
			4) Contour		0	[m]
			4) Cost		€ -	[€]
			5) Length		0	[m]
			5) Height		0	[m]
			5) Contour		0	[m]
			5) Cost		€ -	[€]
			Sub total		€ -	[€]
		Outfittings on Deck	Jib crane		€ -	[€]

			Mast		€ -	[€]
			Passerelle		€ -	[€]
			Jacuzzi		€ -	[€]
			Pool		€ -	[€]
			Helideck		€ -	[€]
			Additional 1		€ -	[€]
			Additional 2		€ -	[€]
			Additional 3		€ -	[€]
		Outfittings below Deck	Overhead Crane		€ -	[€]
			Jib crane		€ -	[€]
			Sauna		€ -	[€]
			Additional 1		€ -	[€]
			Additional 2		€ -	[€]
			Additional 3		€ -	[€]
			Interior doors			[#]
					€ -	[€/piece]
			Exterior doors			[#]
					€ -	[€/piece]
			Hatches			[#]
					€ -	[€/piece]
			Sub total		€ -	[€]
			Total		€ -	[€]
13	Glass					
		Default	Normal		13	[ton]
			A lot		40	[ton]
			Current		13	[ton]
			Flat	-	-	[€/kg]
			Cylindrical	-	-	[€/kg]
			Spherical	-	-	[€/kg]
			Current		-	[€/kg]
			Total		#WAARDE!	[€]
		Advanced *	Total glass area		0	[m2]
			Area flat		0	[m2]
			Area cylindrical		0	[m2]
			Area spherical		0	[m2]
			Price flat		€ -	[€/m2]
			Price cylindrical		€ -	[€/m2]
			Price spherical		€ -	[€/m2]
			Total		€ -	[€]
14	Yard					
		Default	Overhead	-	-	[%]
			Classification, documentation & fl	-	-	[%]
			Insurance	-	-	[%]
			Unforseen & warranty	-	-	[%]
			Profit	-	-	[%]
		Advanced *			€ -	[€]
15	Miscellaneous					
			Financing	-	-	[%]
			Exterior & Interior design	-	-	[%]
			Diverse		€ -	[€]