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Application of set-based concurrent engineering to shipbuilding projects

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Abstract

In today's shipbuilding industry, companies are looking to make their design process more efficient so they can have more economically viable and faster lead-times on their ships. Much of today's shipbuilding is being done through customized design, and companies like the Ulstein Group evolve new designs from previously performed engineering. Recent research projects like SUSPRO are doing studies on how to implement more standardized design to move the customer order decoupling point further along the process to ease and speed up future design.

This thesis gives a theoretical insight and adds to this effort by suggesting product configurators and knowledge-based engineering (KBE) in accordance with the principles of set-based concurrent engineering (SBCE). It suggests two separate product configurators and looks into why it is important to store knowledge within a company. The work concludes with general tips for implementation of SBCE in shipbuilding companies.

Sammendrag

I dagens skipsindustri er selskaper interesserte i å gjøre deres designprosesser mer effektive, slik at de kan senke utgifter knyttet til disse og gjøre ledetiden kortere for deres skip. Mesteparten av dagens skipsdesign foregår i form av høyt nivå av tilpasning til hver enkelt kunde, og selskap som Ulstein Group driver med mye omarbeiding av tidligere ingeniørarbeid. Nyere forskning, som SUSPRO prosjektet, har begynt å se på hvordan skipsdesign kan standardiseres mer, slik at kundens innblandingspunkt skyves lenger ut i prosjektet, og dermed gjør framtidig design raskere.

Denne masteroppgaven er en literaturstudie og føyer seg til i dette arbeidet ved å foreslå implementering av produktkonfiguratorer og kunnskapsbasert ingeniørvitenskap (KBE) i regi av prinsippene til såkalt set-based concurrent engineering (SBCE). Mer konkret så foreslår forfatteren to separate konfiguratorer, som kommuniserer med hverandre. Videre diskuterer forfatteren hvorfor det er viktig å lagre oppsamlet kunnskap og gir også generelle tips til implementering av SBCE i skipsbyggingsselskap.

Preface

This text is my Master's thesis and final piece of work at the Norwegian University of Science and Technology (NTNU) at Trondheim, Norway. The subject of the thesis came to me through my supervisor, associate professor Cecilia Haskins, to whom I would like to express my deep gratitude for her support through both verbal and written contact, and giving me pointers in the right directions when I needed them. Thank you.

In addition, I would like to thank my mother for bearing with me through all my studies, trials and errors, and most importantly for being there for me my whole life. I would like to thank all the wonderful people that I met at NTNU and my year abroad in Prague for all the amazing experiences and memories that I will cherish for the rest of my life.

Lastly I would like to thank NTNU and Norwegian State Educational Loan Fund (Lånekassen).

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List of abbreviations

CD = Customized design

SD = Standardized design

CODP = Customer order decoupling point

SBCE = Set-based concurrent engineering

PBDA = Point-based design approach

OEM = Original equipment manufacturer

OSV = Offshore supply vessel

KBE = Knowledge-based engineering

DA = Design automation

1 Introduction

This paper is the author's Master's thesis written at the Norwegian University of Science and Technology (NTNU) in Trondheim, in the author's final semester. It was written under The Department of Engineering Design and Materials (IPM) under the supervision of associate professor Cecilia Haskins from The Department of Production and Quality Engineering (IPK) and supports the SUSPRO project.

Companies in the manufacturing industries are doing whatever they can to stay competitive in an ever-changing and dynamic industry and in this regard the shipbuilding industry is no exception. Most of the shipbuilding done today is on a customized design (CD) basis, while much of the literature focuses on modularization, standardized design (SD) and lean production as some of the most competitive methods available. The customized design allows a variety of variables in the design, which in turn can result in longer lead times and higher costs per ship.

If one could move the customer order decoupling point (CODP) further out in the project, i.e. standardization of parts and/or design, it would lead to easier design and production processes and at the same time ease the sales and marketing processes. In the literature set-based concurrent engineering (SBCE) is a way of designing that has worked very well in the automotive industry, first and foremost in Toyota and their suppliers, and seems to be promising in other original equipment manufacturer (OEM) industries when applied.

This thesis compares these problems and examines whether or not the principles of SBCE can be applied to the initial design phase of shipbuilding when constructing offshore supply vessels (OSVs). The author performed a literature study on the field of shipbuilding and SBCE to see if it is possible to couple these areas with the use of product configurators and knowledge-based engineering (KBE). There is also some special focus on a case study of the Ulstein Group, especially considering the ship types evaluated: OSVs.

The problem definition is stated as:

Can SBCE help reduce the uncertainty in early phases of the OSV shipbuilding project lifecycle?

With the following auxiliary questions to be answered:

- *What are the challenges in the concept design phase for OSV shipbuilding projects?*
- *Can SBCE address the uncertainty of the earliest phases of a product lifecycle?*
- *Can SBCE be applied during concept design for OSV?*
- *Can SBCE be applied as a modern day configurator for OSV?*

The thesis continues with chapters on theoretical foundations and research design before reporting the results of the analysis and ending with a discussion and conclusions.

2 Theoretical foundation

In the literature review, the thesis establishes some important background for subjects relating to the research questions. First, it was necessary to establish an understanding of what a ship really is: What are the constituent components, which components are crucial, and what makes a ship an offshore supply vessel (OSV).

The literature review also established definitions for set-based concurrent engineering (SBCE) and how it is applied in other industries, such as automotive, aeronautical and construction industries.

This part of the thesis will also look into what configurators are, and if they are used in ship building. Lastly, an introduction to SUSPRO project is given, along with the Ulstein Group, which served as the empirical study.

These aforementioned areas are the main focus of this thesis, and although it falls outside of this thesis' scope, the author finds it important to note that there is research being done in several of these areas, with a different focus, as can be seen in Appendix IV.

2.1 The design of ships

2.1.1 Important components

If one is to get a good understanding of ship building projects and the design of ships, one needs to first establish what a ship actually is. What sort of components is a ship made of and which one of those are important, perhaps even crucial, for a ship. In this section the author will try to establish this, while the next section will look further into what it takes to make a ship be classified as an Offshore Supply Vessel (OSV) and what makes an OSV differ from "just a ship".

There is a lot of complexity involved in ship design, due to the specific requirements set by the stake holders, and the general conditions set by the environment it is supposed to operate in. Not only are the different parts complex, but there is great interdependency there as well. For instance a motor may only move a hull of a certain size, the hull can be a certain weight, which then again influences other subsystems [1]. Furthermore, when designing a ship, the manufacturer is trying to meet requirements and expectations set by the customer while trying to stay within statutory rules and regulations and keeping the whole process within the set budget and timeframe. This type of design is also referred to as Rules-Based Design [2].

A ship in itself can be looked upon as a system, with subsystems, that again have their own subsystems. For instance the hull of a ship contains a lot of the ship, i.e. accommodation, storage, electrical systems, seatings etc. Depending on the outside influences, the hull must endure different types of environments [3], and it needs to withstand elements such as corrosion, varying temperatures, dangerous waters, wind and ice etc. [4]. The hull should be designed such that it has minimum resistance while travelling. Table 1 shows what kind of subsystems are usually to be found under the main “hull system”.

The hull is a crucial component for any ship, and so is the propulsion system. Within the propulsion system you have many subsystems that are vital to the ships movement, like propulsors, intakes and exhausts, electrical and mechanical systems for the propulsion control. The subsystems pertaining to propulsion are also shown further in Table 1, while the complexity of a propulsion system (and its subsystems) is shown in Figure 1.

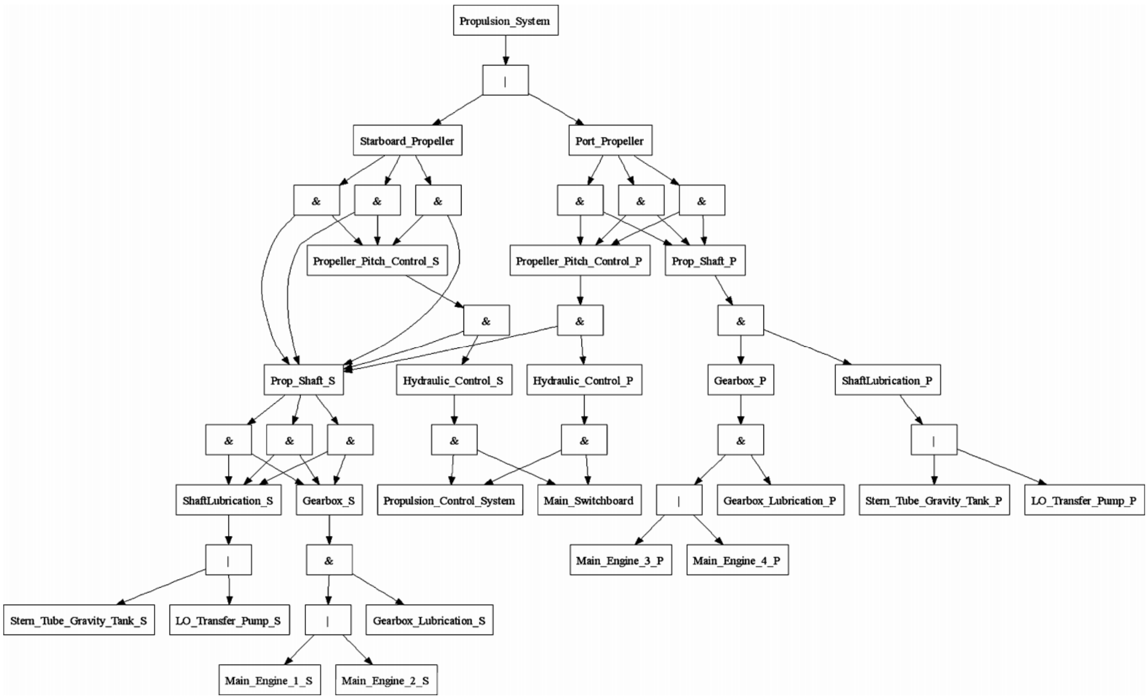

Figure 1. Complexity of a propulsion system. Taken from Vassalos [2].

The last crucial components, which are found on a ship, are the "ship systems". Be they electrical or mechanical. These include, but are not limited to, heating and ventilation, fresh water systems, waste and disposal etc. Like the hull and propulsion systems, all of these must be able to operate in the given environments. Table 1 shows a few of the systems that are important to a ship.

Table 1. View of ship parts and their subsystems, as per Andrews [4].

Hull and structures	Ship systems	Main propulsion
Hull structures	Heating and ventilation	Reduction gearing
Superstructure	Sea Water Systems	Propulsors
Substructure	Chilled Water Systems	Shafting Arrangements
Appendages	NBCD & Firefighting	Intakes & Exhausts
Weather decks & Seamanship	Waste Disposal Systems	Int. Platform Management
Finishings	Fresh Water Systems	Machinery management
Seatings		Primary Machinery Plant
Accommodation		
Other Stores		
Hydrodynamics		
Seakeeping		

In addition to these vital components, ships are customized to fill the needs of the customer, the purpose of the vessel, to fit the rules and regulations set by the overseeing entities and very importantly to conform to safety regulations. Furthermore the ship needs some other quite universal (non-dependent of type of ship) components, for instance crew quarters, water and sewage and lifeboats. As the displacement in water is a sum of the lightweight (the weight of the ship and its components) and deadweight (weight of cargo, crew, fuel etc.), when designing ships it is important to take these into account, and particularly strive to make the lightweight as light as possible while maintaining the ship’s strength [5]. The distinction between components that support ship functions versus payload functions is illustrated in Figure 2.

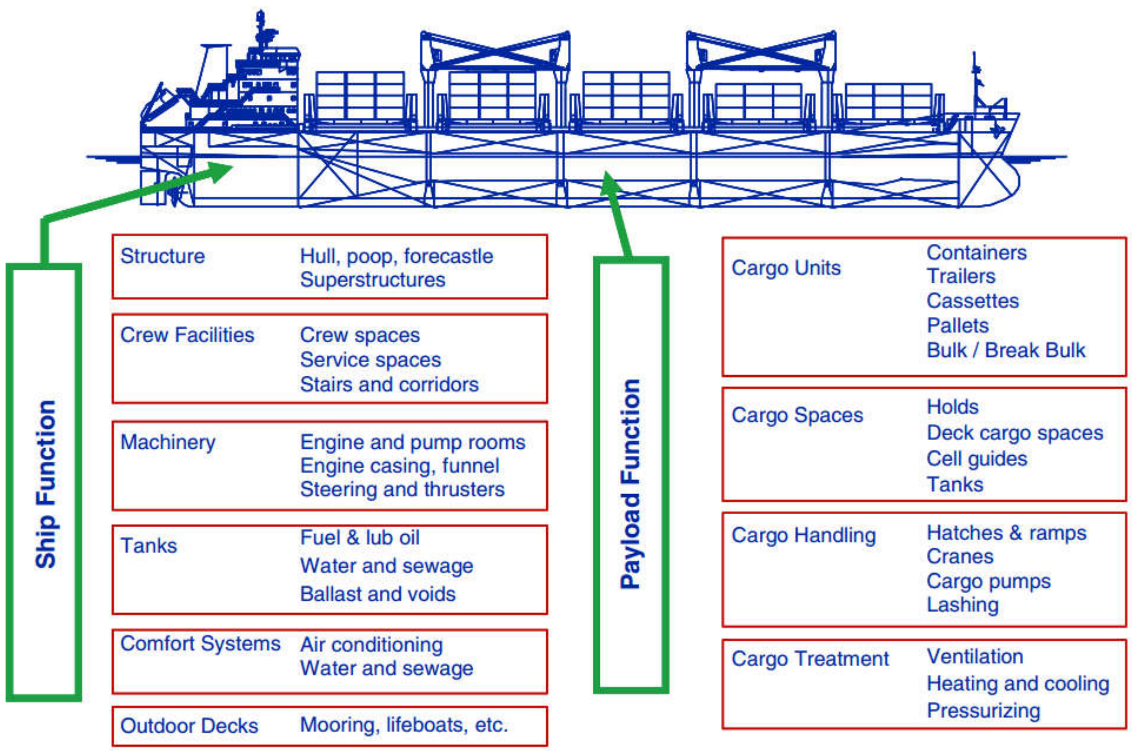

Figure 2. Ship components, taken from Papanikolau [6].

2.1.2 **Design process**

When it comes to the design process itself, it is very reliant on the knowledge and experience of the engineers involved [6], and this fact can also lead to complications in cases of insufficient experience and/or knowledge within the engineering team. As stated earlier, there is very large interdependency in ship design, and high-to-extreme complexity, making this process at times hard to handle for engineers. As time has gone by, more and more ship design became computer-aided [6-8] and these tools have greatly reduced the amount of work and uncertainties for naval architects and marine engineers during the design process, making their jobs somewhat easier.

During the start of the design process, one usually goes through three stages: concept, preliminary and contract design. The design spiral (proposed by Harvey-Evans [9]) illustrates these three stages of the design phase and the amount of iteration that goes into ship design and is often used by naval architects [4]. See Figure 3.

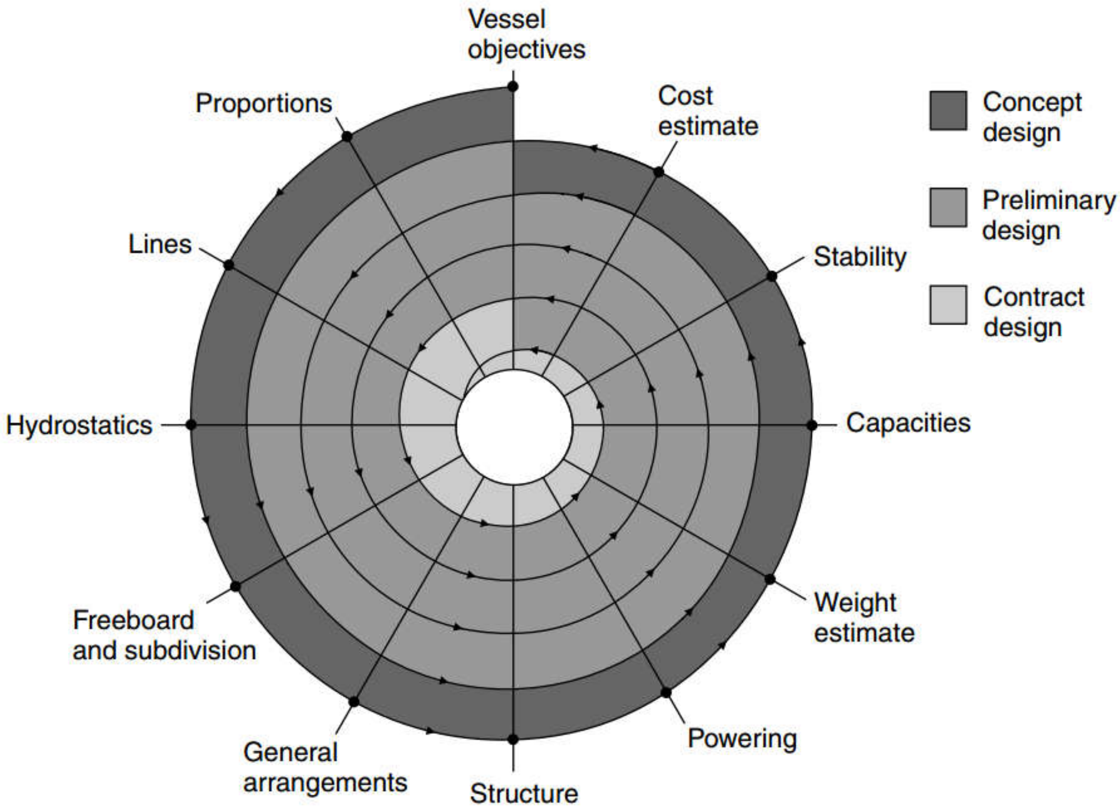

Figure 3. Design spiral, as proposed by Harvey-Evans, taken from "Ship construction" [5].

In this initial design phase, the concept phase is, as the name suggests, very conceptual. This is where one gets a rough outline of the ship at hand. One should have a picture of the size, speed, economic restraints, purpose and operating environments, in other words "a basic techno-economic assessment of the alternatives to be made" [5]. The preliminary phase is what follows, and this is where the outlines get more to the point and one tries to analyze and refine the design from the concept phase [5]. More and more details should be generated during this stage [4], and at the end of this phase one should have a general overview of the items presented in Table 2, which can then be furthered looked upon in greater detail if/when necessary.

Table 2. Outcome of the preliminary design phase, as per "Ship Construction"[5].

• **Dimensions**	Length, height, width, cargo weight
• **Displacement**	Lightweight, deadweight
• **Stability**	Beam, depth, sheer, weight distribution
• **Propulsive characteristics and hull form**	Hull form, desired speed, average speed
• **Preliminary general arrangements**	Stowage and cargo requirements, accommodation
• **Principal structural details**	Requirements of classification societies, material, thickness

The initial design phase can be considered crucial, as that is when one has the most amount of design freedom available and the impact it has on the later stages of production is large due to changes in later stages being very costly compared to changes in the early stages [10]. As the project goes on, the designers accumulate more knowledge, but changes in the design can be costly [10] and hard to execute [2] in the figure below (Figure 4), one can see the representation of this problem.

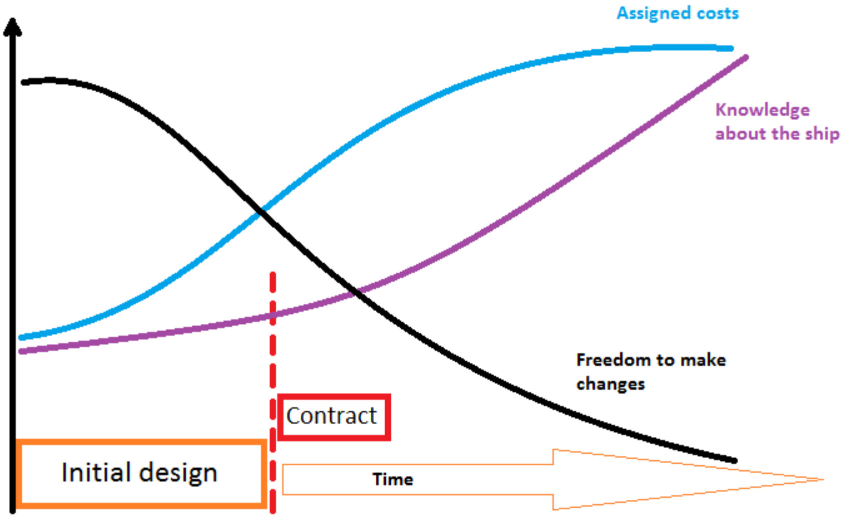

Figure 4. The visual representation of the increase in knowledge and costs while the freedom to make changes decreases, over time. As per [2][10].

2.2 Offshore Supply Vessels

In Norway, the oil and gas industry accounts for approximately 16% of the GDP [11] and approximately 42% of the total Norwegian export [12], according to the 2015 numbers provided by Norwegian Statistics. This industry takes place offshore [13] and is dependent on cargo supplies to be able to run continuously. If the offshore installments do not have the necessary goods to run due to failure of cargo delivery, the worst case scenario would be halting in production leading to millions of dollars in lost profit [14]. In order to keep these installations supplied, one needs a so-called Offshore Supply Vessel (OSV) to transport the goods [15, 16]. The Norwegian OSV fleet was the second largest one in 2009, according to Kongsvik [17].

OSVs are sometimes seen as the "trucks" of the ocean, connecting the onshore suppliers of materials and equipment with the offshore operators [18], with the materials and equipment being categorized as either general or bulk cargo [19]. Cargo classified as "general" are things such as food, pipes, equipment, tools, spare items etc., while "bulk" pertains to liquid mud, ore, dry cement, fresh water etc. These vessels are also important for transporting goods, such as drill cuttings, *from* the offshore installments as well [20].

As one can see, the name OSV covers ships that supply offshore installations, but the term OSV is debated. Some authors believe it to be the same as Platform Supply Vessel (PSV) [21], stating that "… some industry participants like to think of a PSV as the larger version of an OSV", while others [18, 22] claim that OSVs encompass several offshore support vessels such as platform supply vessels (PSVs), crew boats (CBs), anchor handling towing supply vessels (AHTSs) and others. As the author found the term "Offshore Supply Vessel" together with the term "Platform Supply Vessel" used as a term for a vessel that handles the supplying of goods and drilling materials in much of the literature (i.e. Diaz [23] and others [14, 15, 19]), for the remainder of this thesis, the author will look at OSVs and PSVs as the same, and they will be treated as interchangeable terms.

When it comes to the design of these ships, they are usually quite characteristic in their looks. They have a large flat cargo deck with tanks underneath [20], with the bridge at the front of the ship. One can also see that based on Appendix II, which is a collection of pictures of OSVs from different suppliers like Ulstein Group, Farstad and Leevac, that the look that these vessels have is quite similar to one another, and below is a 3D model (Figure 5) and a general arrangement (GA) drawing (Figure 6) of such a vessel (OSV).

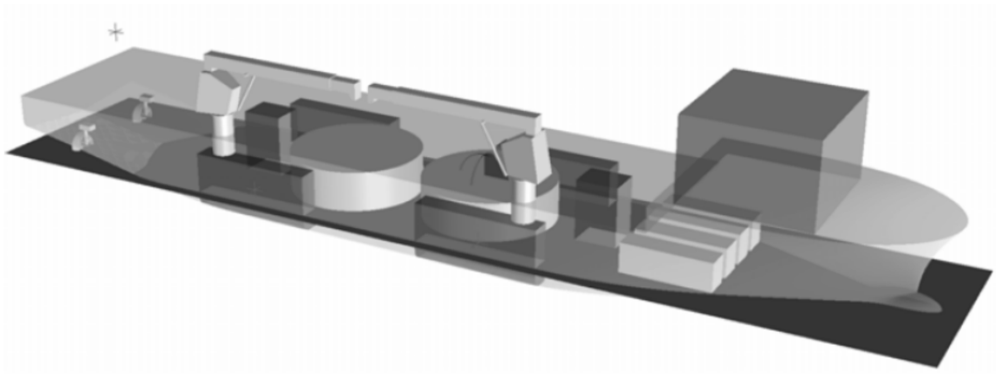

Figure 5. Schematic of an offshore supply vessel, taken from [24].

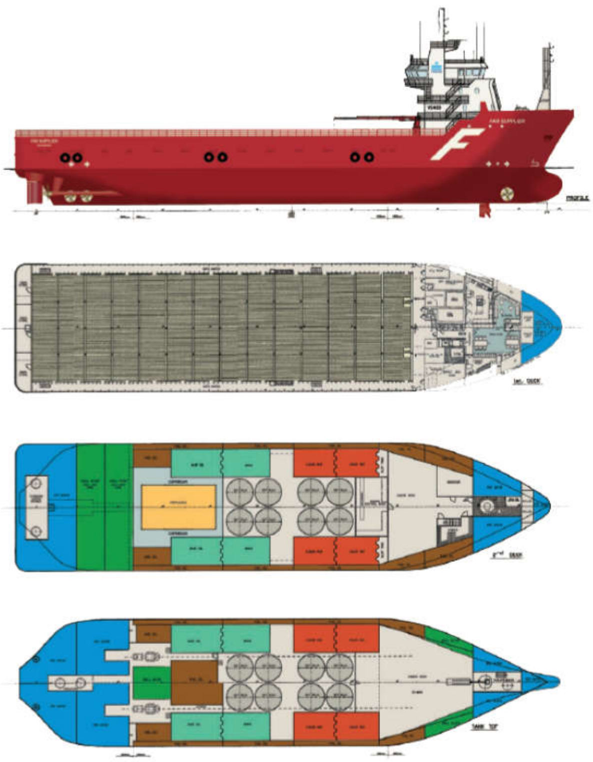

Figure 6. GA drawing of a supply vessel, taken from [24].

As these ships are used for transportation of goods their economic value lies in the maximum amount of goods carried, while still maintaining good seakeeping. So it is desirable to maintain as low of a lightweight as possible [5] when designing these ships. Seixas et al. [19] argue that the loading/offloading of OSVs is an important factor to their profitability, while Rumawas and Asbjørnslett [20] argue that human factors are very important when it comes to the design of OSVs. Furthermore it is important to take into account the total size of an OSV when designing, which is mainly determined by weight of the cargo, while components such as propulsion machinery, crew, structure etc. [4] also influence this, as previously described.

2.3 Set-Based Concurrent Engineering

The more traditional approach to product design in engineering is tied to the so called point-based design approach (PBDA) [25], a view that is supported by many researchers and papers, [26-30]. When one looks at PBDA it works in a streamlined manner. One design solution, which is deemed best, is chosen early on, in part because this will reduce complexity and in part to reduce the costs associated with design [28]. Then it goes through an iterative process, where this "best" solution gets modified until it gives a satisfying solution. Thus this point-based design approach is said to be an inductive approach [31]. See Figure 7 for a visual representation.

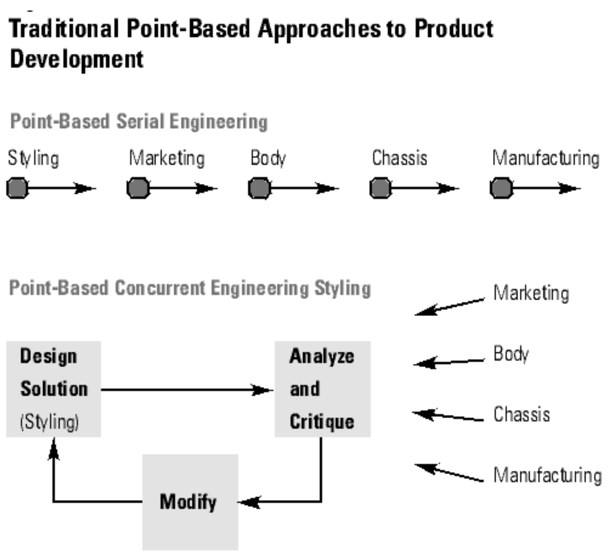

Figure 7. Point-based PD, taken from [38].

On the other side of the spectrum, you have the deductive approach in form of Set-Based Concurrent Engineering (SBCE). In 1994, a group of researchers [32] discovered a part of Toyota's "secret" to product development (PD), which was unique to them and different from the more conventional PBDA approach. At that time Toyota's Production System (TPS) was well documented by Toyota [33] itself, but their Toyota Product Development System (TPDS) was unfortunately not. Therefore it took a while before someone established any sort of "guidelines" to their PD.

What they discovered was an approach they dubbed Set-Based Concurrent Engineering (SBCE). In this approach, one proposes multiple feasible solutions [26], which are now said to be sets. These sets are worked on simultaneously and in parallel of each other as one eliminates the weakest sets while converging towards a final solution. As the projects go on, the participants encounter stage-gate reviews where they must make decisions [26], often taken by the head engineer. These decisions to eliminate the weakest alternatives are based on accumulated knowledge, either prior or new. To correctly draw these conclusions, the SBCE approach makes use of different tools like checklists, matrices for communication alternatives and trade-off curves [34]. The SBCE approach to PD is said to be more robust, due to the consequences of an "incorrect call" being much smaller [35] compared to PBDA, and more efficient [36].

By this kind of front-loading of resources, one puts in a lot of work into the early stages of a project, which may or may not bear fruits in the end. Even so, this is something that Toyota does not look upon as necessarily a failure, as they set a high value on the knowledge established during the process, which can then be used in future development processes [37].

SBCE can be broken down into three main principles (Table 3) [38], with Al-Ashaab et al. [27] reworking the list slightly and making it a five principle theory, in their LeanPPD project [31]. See Figure 8.

Table 3. The three principles of SBCE, as per [38].

Map the design space	- *Define feasible regions* - *Explore tradeoffs by designing multiple alternatives* - *Communicate sets of possibilities*
Integrate by intersection	- *Look for intersections of feasible sets* - *Impose minimum constraint* - *Seek conceptual robustness*
Establish feasibility before commitment	- *Narrow sets gradually while increasing detail* - *Stay within sets once committed* - *Control by managing uncertainty at process gates*

The principles according to Al-Ashaab et al. [39] were as follows:

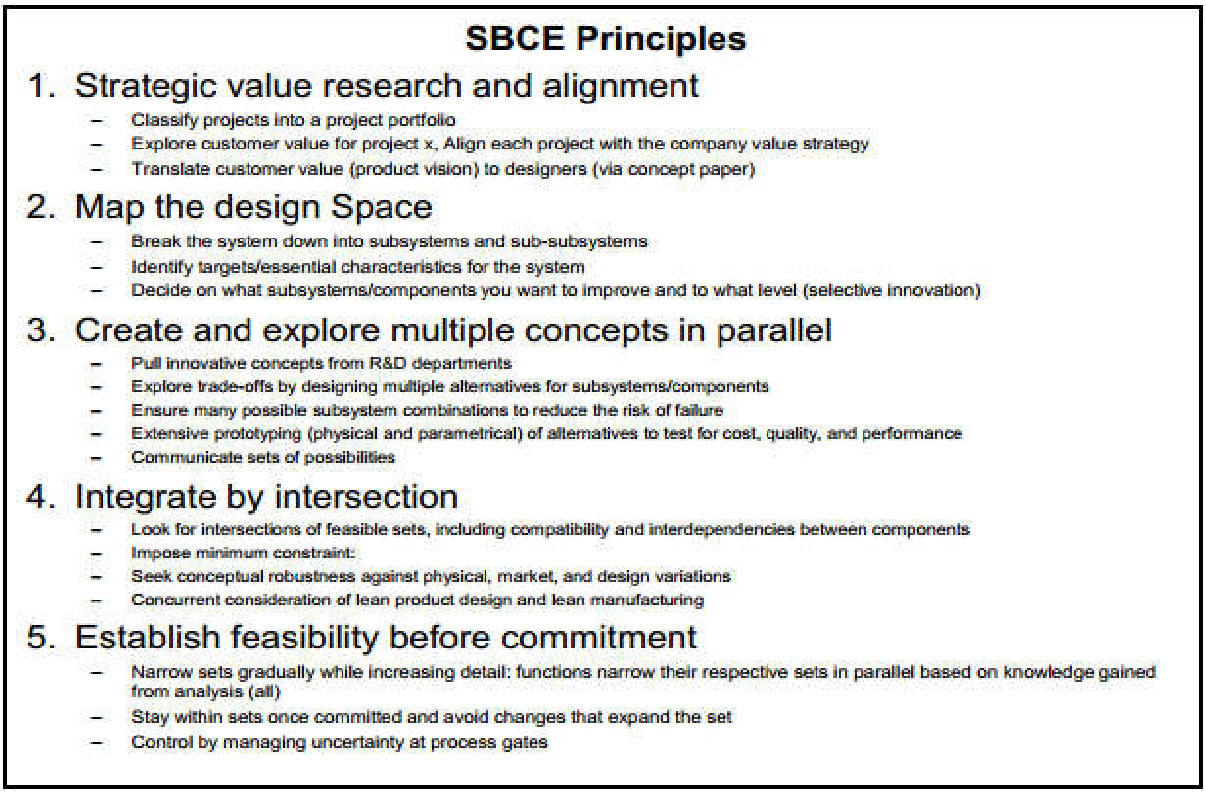

Figure 8. SBCE principles, according to Al-Ashaab et al., taken from [39].

It is important to note that these principles help guide establishing an SBCE-culture, but they are not "how to"-'s and finite methods. Another figure that illustrates the principle and idea of SBCE is Figure 9, which can be found in the same, or very similar, form in several published works [38, 40-43]. Here one can see that sets of possibilities are mapped out, then one looks for an intersection, and the sets converge towards a final solution.

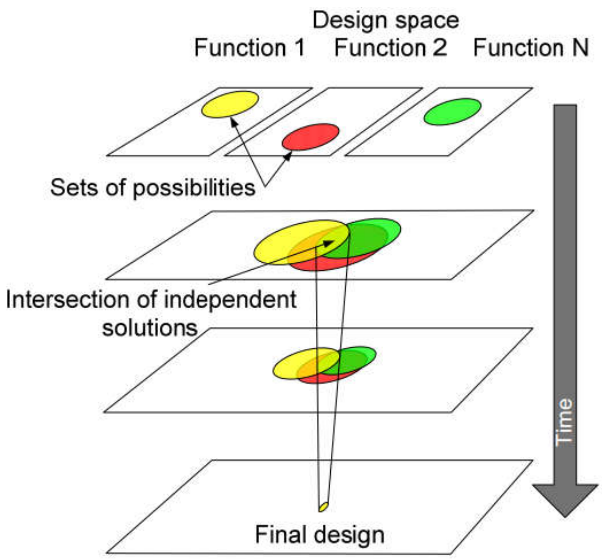

Figure 9. SBCE approach to PD, taken from [29].

A simple anecdote that portrays how the SB approach can work will follow, it was written in [44] and shows up again in [30] and takes on the simple subject of a well-known problem, selecting a meeting time for a group of people:

> The meeting organizer selects the time and date most convenient for himself and starts inviting people. The first person may not be able to attend then; together, they select a new time. However, the third person may not be able to make the new time and suggests an alternative, forcing a check with the first person, and perhaps another change. For large, busy groups, convergence to a satisfactory time for all parties can require lengthy communications — the disadvantage of a point-to-point search in which no individual has all the required knowledge.
>
> There are two common strategies for shortening the search yet retaining the point-to-point model. First, the group can have a meeting to decide when to have a meeting: this accelerates the communication, at the cost of some members' time. The corresponding strategy in automobile development is to collocate and dedicate the engineers and require them to meet more often, increasing their communication. Second, some powerful member(s) of the group can set a time and force everyone else to comply, generally producing a suboptimal solution, albeit quickly. Similarly, auto development teams often seek to freeze specifications early in the development cycle.
>
> A third, set-based approach to planning a meeting requires all participants to submit the times that they are available, perhaps with preferences. A convenient time can quickly be found by taking the intersection of all the sets of available times, a process now often automated.

While some authors claim that following an SBCE-methodology can improve productivity by up to four times [45-48] others have conducted their own studies [35] that show clear improvements but not at all to that extent.

In the LeanPPD project [49] SBCE is the "core enabler of the model" [39], and some of the same authors also discuss the pros and cons of SBCE in one of their other works [27]. The main pros are related to the results of SBCE, such as "avoidance of costly reworks in later design stages" and "risk of failure is reduced because of the considerable amount of generated solutions". The cons on the other hand are mostly related to SBCE itself, and the lack of a clear cut model and methods on how to implement it.

2.3.1 **SBCE in other industries**

2.3.1.1 The considered industries

When looking at the uses and experiences with SBCE in industries, it is preferred to look at industries that can be relatable and/or comparable to the shipbuilding industry. To do so, we will need to consider the term original equipment manufacturer (OEM). A colleague of the author [50], whom the author agrees with, argues that shipbuilding is comparable to the aerospace and automotive industries as they all share the characteristic of being OEMs. He goes on to argue that the term OEM in recent literature is used to describe companies that purchase original components from other companies and resell them to customers as part of their own end-product. Figure 10 is a visual representation, prepared by Erdal [50], of the three industries and shows how they compare to one another.

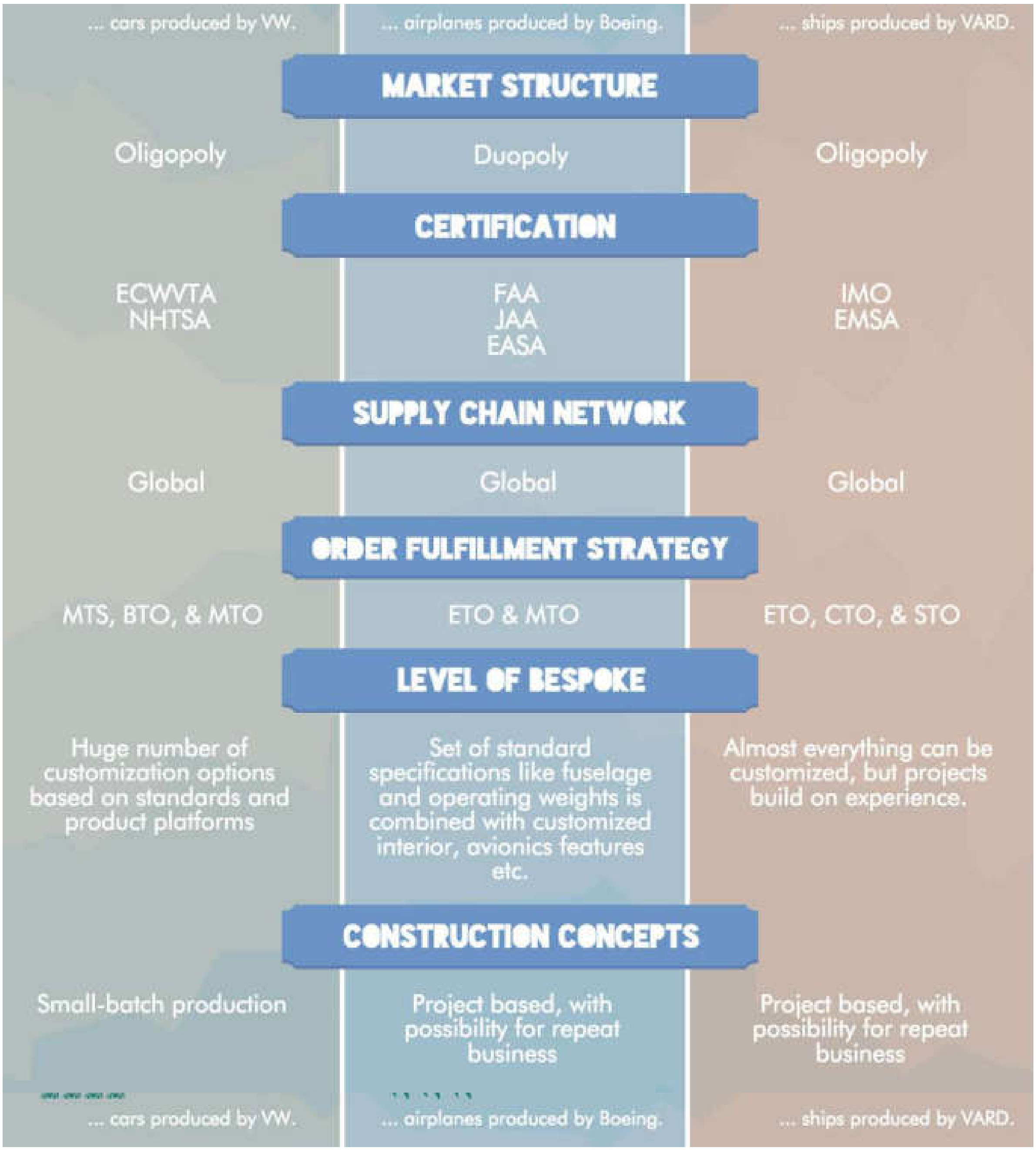

Figure 10. Comparison of three OEM industries, taken from Erdal [51].

Another industry that can be compared to the shipbuilding industry is the construction industries, particularly large civil engineering projects and architectural buildings, due to the complexity and amount of interdependent subsystems [8].

2.3.1.2 Use of SBCE in relevant industries

Following the methodology of the research for this thesis, the author struggled to find adequate literature that investigates the use of SBCE in these industries thoroughly. As late as 2013 [49], researchers have argued that the amount of SBCE research and implementation in industries is very limited and that there is need for more research on the subject.

Although what the author did find is that Raudberget [35] conducted case studies in four companies with three of them being OEMs and the fourth being a "first tier automotive supplier with in-house production and design". What he found was that the participants claimed positive effects of the SBCE implementation to their design process. Another author [52] also found improvements in Schlumberger's design process after an industrial trial of implementing SBCE, and both of these authors agreed that the SBCE methods were not well established in industry. Rossi et al. [53] conducted a survey on fourteen Italian companies and found that only 11% of the companies were using practices resembling those of SBCE. Al-Ashaab et al. [27] conducted a study trying to implement SBCE elements in the aerospace industry by trying to implement it in the PD at Rolls Royce for a helicopter engine. They concluded that the feedback received from the engineers was positive and might lead in improvements in the PD.

This leads the author to conclude that beyond Toyota, which has had great success with SBCE, the application of SBCE is not very prevalent in other industries. In the cases of where it is implemented, or has been tried, the results seem to be mostly positive, albeit usually not to the extent claimed by Kennedy [45].

2.3.2 **SBCE in shipbuilding**

As it stands, Set-based concurrent engineering in shipbuilding has not been documented thus far. An article by Singer et al. [54] in the Naval Engineer's Journal from 2009 talks about Set-Based Design (SBD) as a synonym for SBCE and refers to studies conducted in the period of 1999-2003, one such being the one written by Parsons and Singer [55]. So it is quite evident that in 2009 there was already a big gap in the research done in this field regarding SBCE. The author has not succeeded in finding newer publishing directly tying SBCE to shipbuilding.

When one looks at the principles of SBCE, one can see that a part of the SBCE approach is to seek conceptual robustness, which is something that Sobek et al. [38] explain as being approachable by strategies such as standardization, manufacturing flexibility and trying to achieve a design that works well regardless of what other teams within a project come up with. This approach can be said to be quite close to what the IGLO-MP 2020 project was doing, with their research into modularization in the shipbuilding industry [56]. But even this quite extensive project report concludes that modularization in shipbuilding is quite limited.

This leads the author to conclude that there is in fact no documented proof of SBCE being used in the shipbuilding industry today, although there are similarities to some principles of SBCE in the industry at times. The paper presented by Parsons and Singer also argues that there are good implications of SBCE being an improvement to the design processes within shipbuilding.

2.4 KBE and Configurators

Due to ship design being a complicated process, which is largely dependent on the designers' experience [7] it is needed and desired to develop expert systems to help with this process. Such systems might be in form of configurators with emphasis on knowledge-based engineering (KBE), and reuse of knowledge and design. This chapter gives an introduction to configurators and KBE.

2.4.1 Knowledge-based engineering (KBE)

In such highly complex processes as ship design, the variables are many and a lot of the knowledge is "locked" behind the experienced engineers. Computer programs can be used to handle and control the complexity of such, at times, daunting tasks [57]. Earlier experiences are important for future projects and knowledge is an extremely important part of the design process in engineering. A knowledge base can be used in different ways, like for instance [58]:

- Sharing knowledge between individuals within an organization.
- Re-using knowledge in different ways for different purposes.
- Development of intelligent systems capable of performing complex design tasks.

Knowledge management combines concepts from various disciplines and is the process of creating value from generated knowledge within an enterprise [59]. The engineering knowledge management (EKM) is a great way of optimizing the design process [60], and the main way of doing this is through knowledge-based engineering (KBE), which is now one of the most prevalent sectors within intelligent design [7].

Traditionally, KBE used to be looked upon as something that had to do with geometric modelling in computer-aided design (CAD) [61], but is now regarded as the capture and re-use of engineering knowledge by the application of advanced software [62, 63]. According to Quintana et al. [60], KBE systems should be used for purposes as shown in Table 4.

Table 4. What a KBE system should entail, according to Quintana et al. [60].

Use	Description
• **Capture expert knowledge**	*Methods and tools to capture knowledge from experts (i.e. interviews and forms)*
• **Access the knowledge by KBE tool(s)**	*Retrieve stored knowledge by use of KBE application(s).*
• **Knowledge lifecycle management**	*Methods and tools that determine what knowledge should be accessed by KBE applications.*

By implementing KBE in one's company, one strives to reduce the time and cost of product development by [62, 64]:

- Automating repetitive, non-creative, design tasks.
- Supporting the multidisciplinary integration in the conceptual phase of the design process, and beyond.

Due to these points above, KBE is said to be an enabling technology for mass customization [64], and due to the growth of the knowledge base over time, KBE leads to acceleration of design processes in future projects. A visual representation of KBE and the knowledge storage is presented in Figure 11. For a representation on how this knowledge is then re-used, see Figure 23.

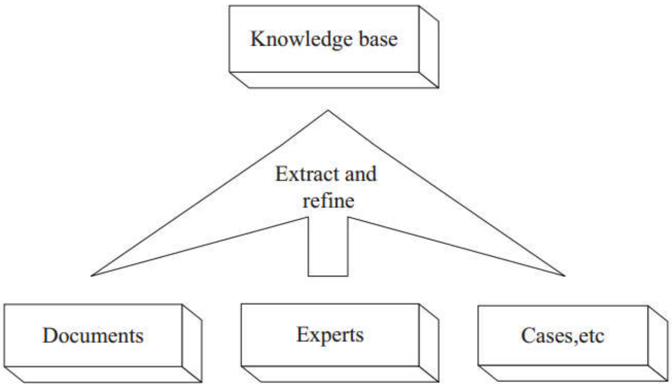

Figure 11. Capturing of expert knowledge into a knowledge base, taken from [7].

2.4.2 **Configurators**

Configurators are computer systems based off of KBE [65], which can also be referred to as design automation (DA) or in the case of industrial engineering as mechanical design automation (MDA) [66]. These can be defined as tools, methods and applications which can help the design process and are often focused on well-defined aspects of the engineering process [61]. This means that they don't try to automate the whole dynamic process like some KBE applications do, which leads some to debate configurators' usefulness. On the other hand a study by Christansen and Vesterager [67] shows that implementation of a configurator at a Danish shipyard showed promise of working, and that small (as low as 1%) reductions in the iterative processes of PBDA could lead to quite large savings. Cui et al. [68] also implemented a configurator which showed to reduce time spent during new design development and that this machine learning approach "shows great potential". Examples of configurators in shipbuilding are programs like Quaestor and Rhinoceros [24].

According to Jensen [69] configurators can be mainly split into two types: sales and engineering, while a third type appears in Jensen et al. [70]: production. The engineering configurators focus on product design in customizable products, within a system that is rule-based off standards and requirements and the sales configurators are there to help customers see what is available, and configure the design to their wishes in the scope of what the seller can make possible. The sales configurator is a great tool to gather information from the customer, while keeping interaction costs low [71], and not "scaring" customers with too many complexities and choices. Production configurators are at the lowest levels, for manufacturing purposes, i.e. to see what materials are available. Figure 12 gives a representation of this in a building construction setting. Product configurators can help the users in all of these instances by letting them propose and examine quick solutions, without having to hash out all the details [72].

Van der Velden et al. [61] argue that configurators, as opposed to KBE applications, are much more suited for businesses with, to a certain extent, limited resources as they will still provide benefits and lead to improvements, although at the expense of flexibility and adaptability provided by KBE applications.

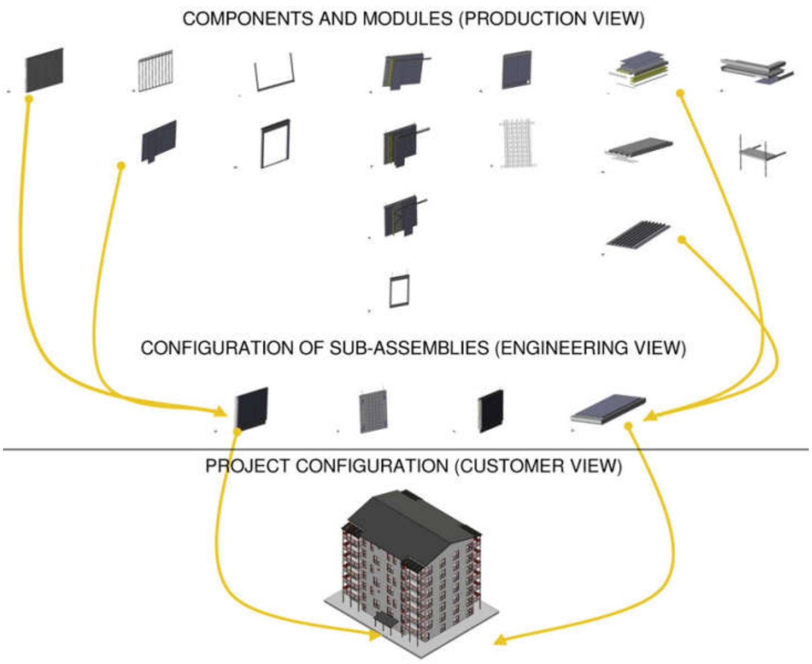

Figure 12. Overview of how configurators can be used, and what view the different actors have of the system and its parts. Taken from Jensen et al. [70].

2.5 SUSPRO and Partner

2.5.1 SUSPRO

The SUSPRO project is funded by the Norwegian Research Council, and is a collaboration between NTNU, Ulstein International AS, Fiskerstrand Holding AS and PON POWER AS, and is set to run from Autumn 2013 until Autumn 2017. (see https://www.ntnu.no/suspro)

The objective of the project is to "Achieve sustainable and life-cycle-oriented ship production in an uncertain, fluctuating market." And this is where the name stems from, SUStainable PROduction. Following is a figure (Figure 13) of the main actors in the industry that have interests in the SUSPRO project. This shows the main actors performing ship design and ship construction with the material flows being represented by the black lines and the information flows being represented by the orange lines.

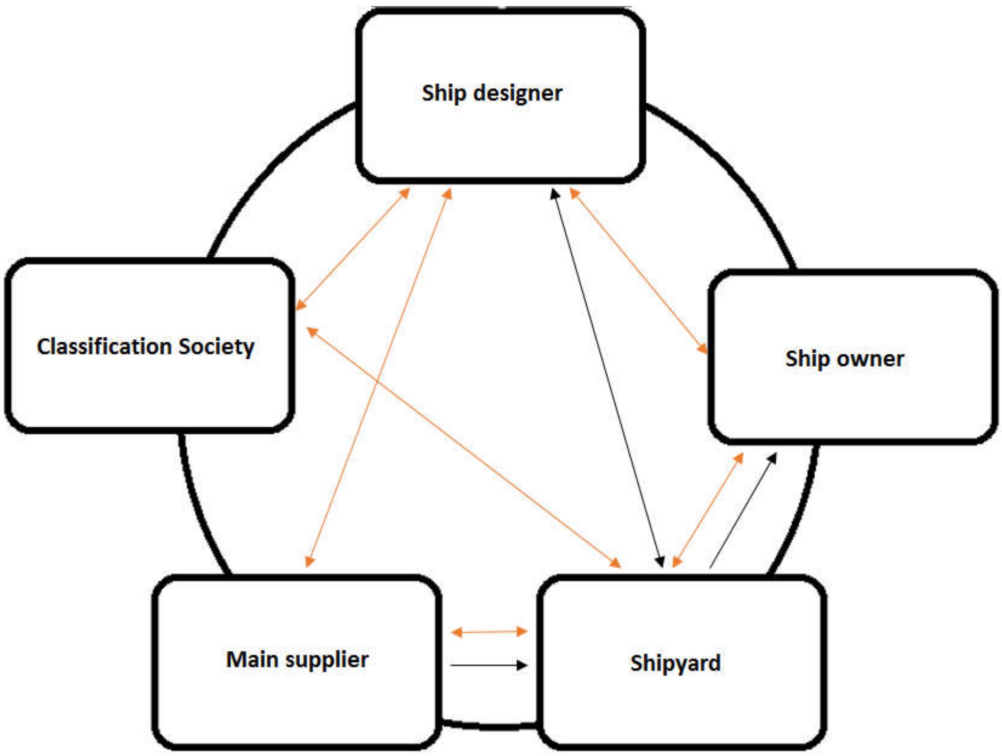

Figure 13. Visualization of the main actors in the industry, with representation of the material and information flows, as per [73].

The SUSPRO expands upon an earlier project and is striving to achieve the following goals:

- The ability among partners to produce their products in a sustainable manner
- Increased sales through better market awareness and world-leading sustainable solution
- Reduced operational costs through more effective production, reduced lead-times and better coordination in the supply chain.

2.5.2 Empirical Study: Ulstein Group

Ulstein Group ASA is the parent company of a group of maritime companies, specializing in ship design and maritime solutions, shipbuilding, power and control and shipping [74], the company that is responsible for ship design is Ulstein Design & Solutions AS.

Their current model sees them doing different types of design like Engineering-to-order (ETO), customize-to-order (CTO) and standardized-to-order (STO). The difference between these is the amount of design and engineering that is applied before the finalized product. A representation of this can be seen in Table 5.

Table 5. Representation of the different production and design processes at ULSTEIN, as told by their representative.

Type of order	Type of design	Notes
ETO	Bespoke	4-5% engineering, design in Norway or Netherlands
CTO	Modules (Add, remove or change)	Approx. 2-3% engineering
STO	Standard	<1% engineering, built in Norway or China

Ulstein has developed some benchmarks and a competitiveness model for design and final product performance, and they are looking for ways to better their design and become as competitive as they can, while being sustainable. The current makeup of their ship building projects are visualized in Figure 14. UDS stands for Ulstein Design and Solutions and UVE is the acronym for their Norwegian shipbuilding site (Ulstein Verft).

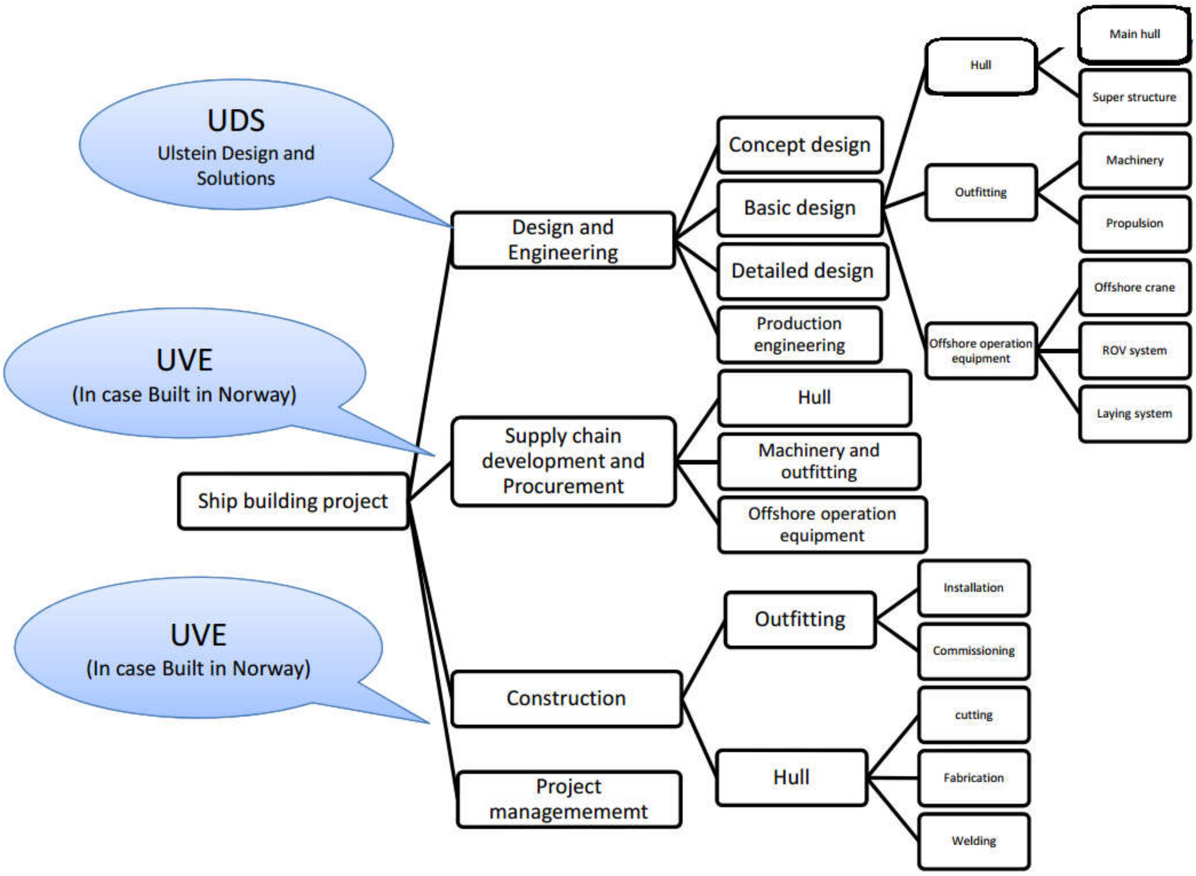

Figure 14. Shipbuilding projects at ULSTEIN, taken from Ebrahimi [75].

Ulstein's interest is to ensure that they can control the design complexity and that their designs, and thereby design process, is competitive in today's ship building market.

2.6 Summary of the literature review

Figure 6 gives a tabular and short summary of the findings in the literature review of this thesis.

Table 6. Summary of the findings in the literature review.

Topic	In summary
Design of ships	- *Complex and interdependent* - *Relies on engineer's personal knowledge* - *Iterative*
OSVs	- *Offshore support vessels* - *Used for transportation of bulk and general cargo to/from offshore installations* - *Particular design*
SBCE	- *Set-based concurrent engineering* - *Deductive design process* - *High success rate within Toyota, where it stems from.* - *Principles for robust design*
KBE and configurators	- *Knowledge-based engineering* - *Use of computer programs to manage production and design by automating processes* - *Creation of knowledge database within a company* - *Re-use of knowledge and design*
SUSPRO and Partner	- *SUStainable PROduction* - *Ulstein Group* - *Achieve sustainable and life-cycle-oriented ship production*

3 Research Design

In this chapter the author provides an insight into the process of writing this thesis, looking into different aspects of the study, i.e. the way it was conducted, by whom and where. The author followed Fink's [76] definition of a literature study by making it systematic, explicit, comprehensive and reproducible. This chapter will be broken down into several subchapters that will look into the following [77]:

- Setting and participants
- Data collection procedures and tools
- Data analysis
- Formatting

3.1 Setting and Participants

This study was conducted at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, under The Department of Engineering Design and Materials (IPM) as the final thesis in the author's Master's degree. This thesis contributes to the SUSPRO project, in which the author's supervisor, associate professor Cecilia Haskins from The Department of Production and Quality Engineering (IPK) participates. Information on Ulstein was provided from the project and by Ali Ebrahimi at Ulstein Group.

3.2 Data collection procedures

In order to improve his knowledge of academic methods, the author attended a lecture on data collection for Master's thesis, arranged by the NTNU library [78]. This lecture and a few select articles [79, 80] set the precedent for how the literature-based and other data was collected in this thesis. The literature used in this thesis was mined/collected from mainly four different databases.

- Oria
- ScienceDirect
- Web of Knowledge
- Google Scholar

Beyond this, the author also collected data through a technique called 'snowballing' [81] by examining the relevant references in said literature and exploring them further. The author's supervisor also supplied the author with literature, especially the literature that relevant to SUSPRO and Ulstein.

The author applied certain keywords in the data collection, as shown in Table 7. As the literature can at times refer to the same subject with different names or titles, some of the subjects warranted many different searches while others were relatively straightforward. An additional reason for several keywords was that initial searches spawned results with keywords that had not been used, but seemed relevant, so these were used subsequently.

Table 7. Keywords used for sifting through databases and their respective subjects.

Subject	Keyword(s)
Ship design	• *Ship design, shipbuilding, shipbuilding design process*
SBCE	• *Set based concurrent engineering, set-base concurrent engineering, SBCE, set-based design*
SBCE in other industries	• *Set based concurrent engineering +* • *Industry, automotive, auto, aero, aeronautical, aerospace, construction, building*
KBE	• *Knowledge-based engineering, KBE, EKM, engineering knowledge management*
Configurators	• *Configurator(s), product configurator, design automation, mechanical design automation, DA, MDA*
OSVs	• *Offshore supply vessel, Offshore support vessel, Platform supply vessel, Platform support vessel, supply vessel + design*

These searches could result in all from 8 to approximately 48 000 search results. In the more extreme cases (searches with 250+ results), the selected results were the top 200-250 in each search, as this cut-off exhausted the relevant sources.

3.3 Data analysis

The selected data was any and all literature that looked "promising" after a performed search. Data was deemed promising based mainly on the title and how relevant it was to the keywords searched and data desired. If a piece of literature wasn't clear on whether or not it was promising, the author read the abstract before potentially saving the data. The author avoided biases in the literature and gathered anything that was viable to provide information on the topics of product configurators, ship design, SBCE and KBE.

After collecting a, deemed by the author, sufficient amount of data, the author would then classify the literature based on the subject matter. Some of the literature provide necessary background knowledge but was not directly referenced; these are documented as the bibliography included in Appendix III. This classification process was performed following recommendations by Machi & McEvoy [82]: by skimming. Skimming in this context is defined as reading the abstract, introduction and conclusion, and thereafter skimming the rest of the data at hand. Each piece of literature warranted its own text file in which the most important information, and any thoughts that the document inspired in the author, were saved for future references. See Figure 15.

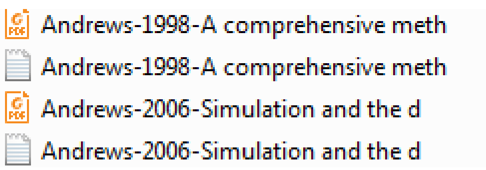

Figure 15. Example of an article and its associate text document.

The text files were then saved in locations where they were see fit for use, e.g. "Results" folder if it was relevant for Chapter 4: Results.

After all the data had been vetted, the author wrote each chapter in the following order: Chapter 3 > Chapter 1 > Chapter 4 > Chapter 5 > Chapter 2. Although Chapter 2 was written last, parts of it were written beforehand as a reference point and a recipe of sorts for the author. The various chapter are explained in short in the following subchapter, "Formatting".

3.4 Formatting

This thesis is written according to the formatting guidelines set by NTNU. The selected reference style is Vancouver, which was coordinated by the use of EndNote. The layout of the thesis is split into five chapters (explained further below) with the chapters being created per suggestion from the author's supervisor, previous theses written by students at IPM [83], and the book "How to Write a Master's thesis" [77].

Chapter 1: Introduction

Statement of the problem and quick introduction into the thesis.

Chapter 2: Research Design

Looks into the methods by which this thesis was made, who participated in it and in what way it was written and formed

Chapter 3: Technical Background

Literature review of the available literature and research on the following subjects, obtained by the means as described in Chapter 2:

- Ship design
- OSVs
- SBCE
- Configurators and KBE
- SUSPRO and case study

Chapter 4: Results

Chapter 4 gives answers to the stated problem and auxiliary questions as set by the author and his supervisor.

Chapter 5: Discussion

Discussion of the findings and the weaknesses in the study and/or findings. Chapter 5 also includes the conclusion and suggestions for future research.

Figure 16 provides a visual summary of the research methods employed in creating this work.

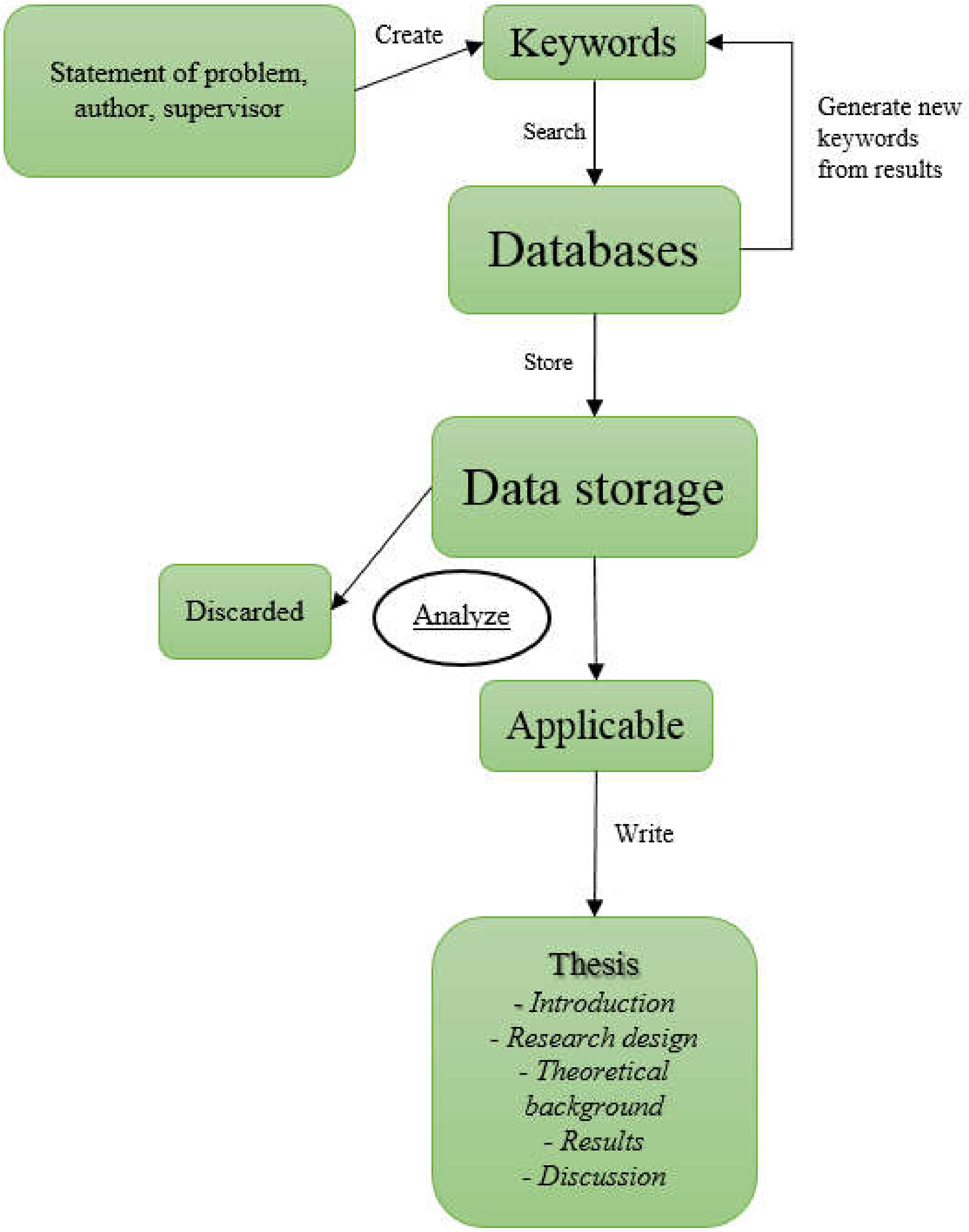

Figure 16. The methods of this thesis in summary.

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4 Results

In this chapter the author examines the main research question as well as the auxiliary questions. The knowledge accumulated during the literature review is used to give a narrative, visual and tabular presentation of the acquired results. First the challenges of the early concept design phase in OSV shipbuilding projects are identified, and then how these challenges can be tackled by the use of SBCE and product configurators/KBE.

Following is the summary of this chapter's content:

- Challenges in the design phase
- Uncertainties in the early phases of a product lifecycle
- Application of SBCE in concept design
  Using the principles of SBCE to create a product configurator

4.1 Challenges in the design phase

4.1.1 OSV projects

Before establishing any kind of results related to shipbuilding and SBCE, it is important to identify the challenges tied and address them.

The design phase in OSV shipbuilding is first and foremost very complex. There is a wide variety of components, systems and subsystems involved. Many of these components have a high level of interdependency and this makes the design phase a daunting task.

When it comes to how this phase is being tackled in today's industry, it is a very iterative process [57, 67] where a best and most preferred solution is selected early in the process and the rest of the design phase is spent trying to adapt to this solution. Furthermore, the designs are very reliant on the engineers and their experience with various components, many times obtained in earlier projects. Unfortunately this knowledge finds itself often not stored within a company beyond having the "correct people" employed with this tacit knowledge.

4.1.2 **Ulstein Group**

Ulstein Group has said that they spend time doing re-engineering with each new project for their customized designs, e.g., re-calculating many of their previous calculations at each new project, even though they have done the particular calculation many previous times. This is a form of waste by rework that uses resources and time and thereby results in longer lead times than wanted. Since the OSVs are highly complex and customizable, their sales process can suffer from too many variables and unclear boundaries of what is and is not achievable by the engineering team.

4.1.3 **Challenges in SBCE**

When it comes to SBCE, one of the main challenges is implementation. First and foremost one must have enough information and knowledge on the subject to implement it. Due to the low amount of research and expertise on the subject, it is hard to find qualified personnel. It is also hard to find sufficient literature on the subject as pointed out by [49]. Furthermore, once one does obtain sufficient information for implementation it is hard to implement unless management is "all-in". Some of the literature [29, 35, 42] addresses this and it is clear that unless management decides to fully commit, any implementation of SBCE ends up as time wasted testing and implementing something that had no chance of succeeding. SBCE also seems to benefit OEMs and manufacturers of design products that are more standardized. This is due to one of the principles encouraging "broad" design, i.e., a design that is as general as possible before it becomes specialized and customized, for instance, by use of modularization. Table 8 provides a summary of the challenges that are faced in the design phase from the point of view of OSV design, SCBE and the Ulstein Group.

Table 8. Summary of challenges in the design phase.

Challenges in the design phase		
OSV design	**Ulstein Group**	**SBCE**
High level of complexity	Re-work	Lack of knowledge
Interdependency	High level of customization	Implementation perseverance
High level of customization	At times long lead times	Modularization
	High level of complexity	Not well documented
	Uncertain parameters for sales and marketing teams	Front-loading of resources

4.2 Uncertainties in early phases of a product lifecycle

The uncertainties in the early phases of a product lifecycle are many, and most are tied to the following:

- Marketing aspect of the new design
- Prototyping and testing new design
- Production
- Conceptualization of new design

4.2.1 Marketing

Marketing of OSVs has its challenges. As mentioned in the previous subchapter, due to the high complexity and vast possibilities in the engineering process, the sales and marketing teams are not always sure as to what they can deliver. It is therefore beneficial to these departments to work with designs that are more modularized and standardized with a limited level of customization.

One way of addressing these issues is by implementing product configurators in the sales and marketing processes, with the implementation of said configurators being based on SBCE principles. A more detailed description of an SBCE sales configurator is given in a later section. As SBCE also proposes and encourages more modularized and "general" design of products, it is in fact beneficial for the marketing and sales departments in the OSV shipbuilding industry.

4.2.2 Design

There are several ways SBCE can help the design phase in the early product lifecycle of OSVs. The SBCE can be implemented on its own, it can be implemented with the use of product configurators and KBE. In short, using SBCE design principles begins with a broad array of solutions that converge towards the best one, thereby front-loading projects, and supporting re-use of previous design knowledge through a database.

4.2.3 Prototyping and testing of design

A big part of the SBCE literature preaches the importance of prototyping and testing during the design phase before a final decision is made. Unfortunately ships are hard to prototype due to the sheer size and economical restraints this would put on a shipbuilding company.

Fortunately, digital technologies support prototypes by using computer programs for both prototyping and testing designs, before converging further towards the best design solution. There are many 3D modelling programs out there today that allow for modelling of ships in a 3D environment and simulation of stresses on components. A shipbuilding company could also put resources into implementation of a more specialized product for themselves, or propose to help develop an existing product further, to better suit their needs.

4.2.4 **Production**

The production process can benefit from SBCE due to the robustness of the solution that is agreed upon. As SBCE principles require that several engineering processes and departments within one enterprise are involved in the design process, the production department will also be included and have a say in what is possible to produce and what isn't possible to produce. These practices are linked to concurrent engineering (CE). CE strengthens the final solution in the design phase and ensures a design that in fact can be produced within the technical and mechanical restraints set by the company's manufacturing facilities. This leads to reduction of later changes in production due to non-optimal design and better lead times in production. By using SBCE principles, and especially considering modularization of components in the design, the production process is, to a certain degree, standardized and becomes easier to perform and maintain. In case of external production of components, these same principles would help ensure that the subcontractors would have clear instructions which would lead to shorter lead times in the delivery of said components. Figure 17 shows where the SBCE principles are employed, and which other aspects they (in)directly contribute towards.

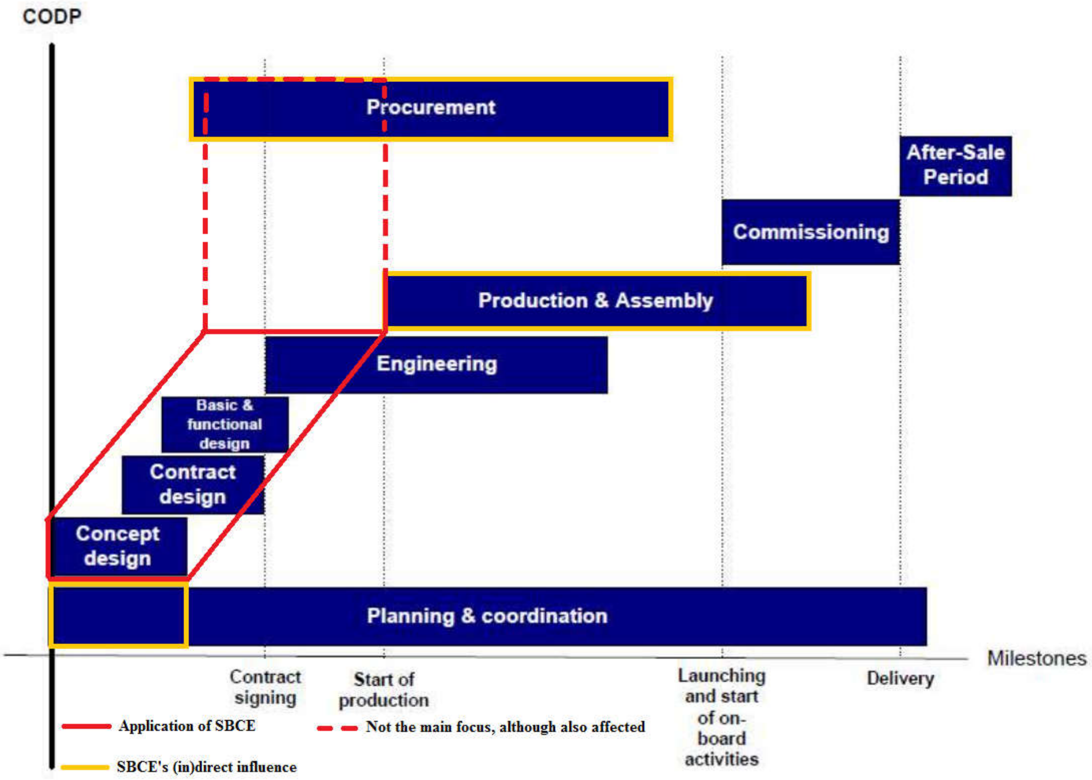

Figure 17. Application of SBCE in a CD environment. As per Haji-Kazemi [84].

4.3 Application of SBCE in concept design

The principles of SBCE focus on a way of designing that are quite different from the current design processes in shipbuilding. This subchapter will look into how one can apply these principles in the concept design of OSVs.

Some of these solutions will look into product development at a level before the customer gets involved, to try to move the customer order decoupling point (CODP) further out in the process, thereby ensuring a more robust design with a more standardized approach to component and system design.

Figure 17 showed where the SBCE is intended to work, and where the CODP in Ulstein Group's shipbuilding is located, while Figure 18 shows where the CODP is preferred.

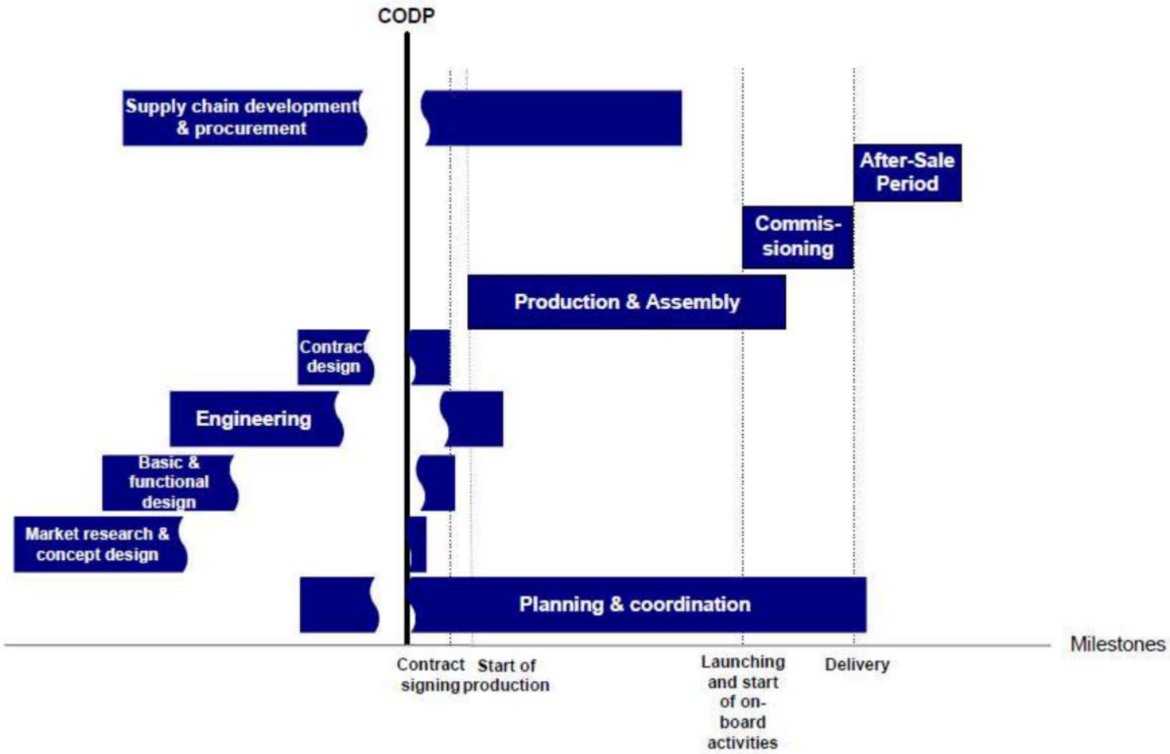

Figure 18. CODP in SD projects. Taken from Haji-Kazemi [84].

4.3.1 **Map the design space**

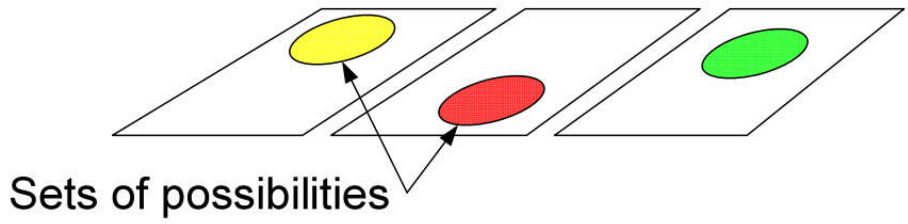

Figure 19. Map the design space. Altered from Raudberget [35].

As the SBCE principles rely on sets of solutions, it is important to start off by defining the feasible regions of possible solutions. Depending on what the design is based on, direct customer feedback and requirements or market predictions, different aspects of the ships should strive to have flexible restraints. Instead of focusing on making, for instance a hull, a certain size, i.e. 45 m x 25 m, the designing of it should strive to keep the requirements in ranges, for a wider variety of possible solutions, e.g., 40-50 m x 22-28 m hull specifications. By having all these possibilities, one then starts exploring trade-offs between them, for instance by the use of matrixes. Example of such a matrix can be seen in Figure 20.

	Solution X	Solution Y	Solution Z
Restraint 1	1	2	3
Restraint 2	3	2	2
Restraint n	5	4	3

1 = unacceptable
2 = poor
3 = satisfactory
4 = acceptable
5 = excellent

Figure 20. Example of a trade-off matrix. As per Sobek et al. [38]

In a CE design process, several actors in a company are involved; design team, engineers, production, research and development (R&D). The SBCE principles promote communication between these actors throughout the whole design process. Therefore, it is important for shipbuilding companies to encourage their workers to communicate sets of solutions between one another often.

4.3.2 **Integrate by intersection**

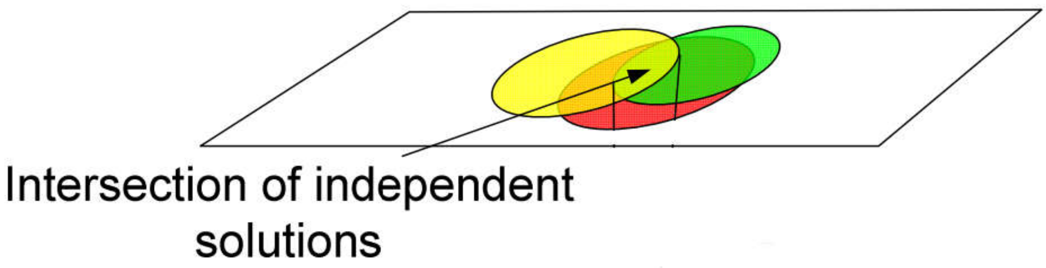

Figure 21. Intersection of possible solutions. Altered from Raudberget [35]

Once the design space has been mapped, and different sets have been communicated, it is time to look for intersections of feasible sets. By doing so, the sets that do not overlap, are eliminated and the range of possibilities is concentrated. While doing so, keep in mind that minimum restraints on the requirements should be employed, as to not lock in a solution too soon, and perhaps miss out on a good design due to too strict restraints.

It is in this phase that the design should be made as robust as possible, i.e., a design that will last, and won't be re-worked due to poor design decisions and/or communication. One of the best ways of seeking conceptual robustness is to modularize the design. Seek out designs that are easily re-usable in future designs with as little re-work as possible. For instance a "base OSV" design that mostly meets previous requirements, which is then easily customizable for new customer who may wish to alter parts of the design.

4.3.3 **Establish feasibility before commitment**

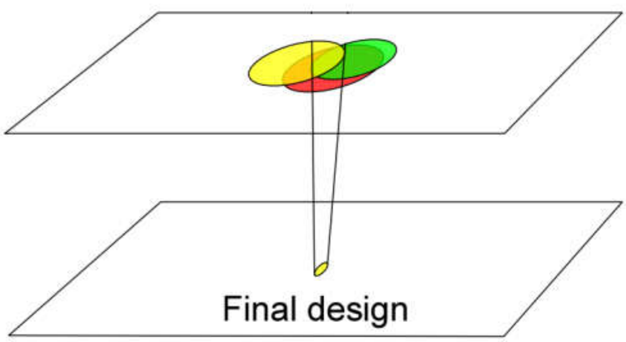

Figure 22. Convergence towards a final solution. Altered from Raudberget [35].

At this point the possible sets of solutions have converged somewhat, and it is time to impose stricter restraints by increasing the detail of the design and continuing to gradually narrow the sets. Furthermore, the design space has now decreased, and it is important to remember that in the process, the weakest solutions have been eliminated and the ones left are the best ones. Due to time and economic constraints, shipbuilding companies should now stay within the sets and continue to further converge and look for the final solution(s).

When uncertainty arises in the design phase, it is important to address it. Some process gates should be implemented throughout the whole design process, and these uncertainties should be addressed at these stages. The design team decides how often these process gates should occur but there should be a team leader who schedules these gates, and calls for the tough design decisions to be made.

4.4 Product configurator with principles of SBCE

This section combines all the accrued knowledge on SBCE, product configurators/KBE and OSV and ship design to propose a way of implementing a product configurator that will ease the engineering and sales processes. These recommendations have three main parts:

- Creating a knowledge database
- Implementing two separate product configurators, one for sales and another for engineering.
- Creating product configurators with SBCE principles in mind.

4.4.1 Creating a knowledge database

By creating a database of a company's knowledge within their area of expertise, a company creates higher value and shorter lead-times for future projects. For each new project, more knowledge is accumulated and is then accessible to all engineers and other interested parties for future reference. When starting a new design, the employees may utilize the database to hinder re-engineering of common parts, take better-informed design decisions and draw inspiration for new designs.

There are two ways of creating a knowledge database in a company. One way is to set up a fresh database that stores all newly generated knowledge from engineering and new customer orders from the implementation date and onward. This ensures little extra work to be done in the set-up and transition phase for the storage of knowledge in the database, and will provide the newest information according to the newest calculations and market demands for reuse. Figure 23 gives a representation of how a project creates information that strengthens the firm's knowledge and where the starting point is with this first method.

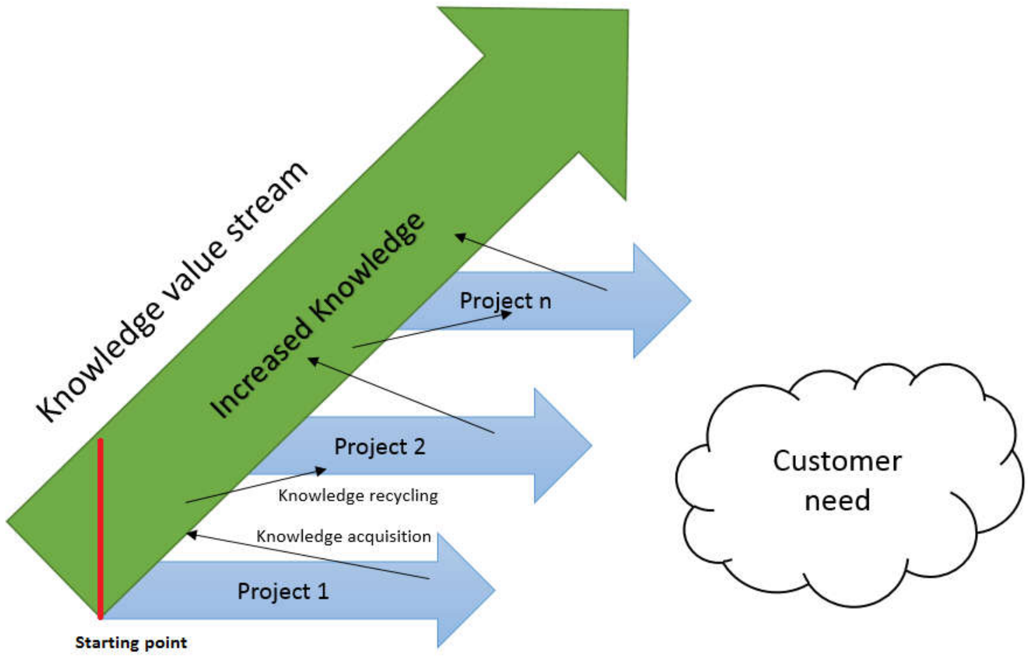

Figure 23. Knowledge creation for future projects, method 1. As per Raudberget [29].

A second way is to implement a database containing previous knowledge of customer orders, market demands and engineering experience. This method is more demanding in terms of creation and knowledge accruement and eventual transition of the database.

To adequately use method two, one would need to define what the customer *usually* expects from an OSV. In order to do so, one could look into the order history over the last five to ten years, and research what type of dimensions and customizations these OSVs had. This could be a time consuming activity, which would involve a lot of front-loading of resources which may or may not always pay off in the end. The author suggests that one could have parts of this work be given to students at a university, i.e. NTNU, who could have this work as their

Master's thesis, or as their semester project. Thus leading to lower costs, although with the risk of less qualified work than a paid employee. To lower this risk, the company at hand would need to clarify and be precise about what the student is specifically looking for, i.e. which dimensions, interdependencies and perhaps other aspects like for instance lead-time, economical aspects and safety aspects. Once this data is collected, engineers could validate the information before using it in creation of new design.

In addition, the engineers in a company retain a lot of individual experience and tacit knowledge. Some of this can be re-used and quantified. How this knowledge should be captured and entered into a database will vary depending on the given experiences, but should be captured when possible. Figure 24 shows where the starting point of accrued knowledge would be with this second method.

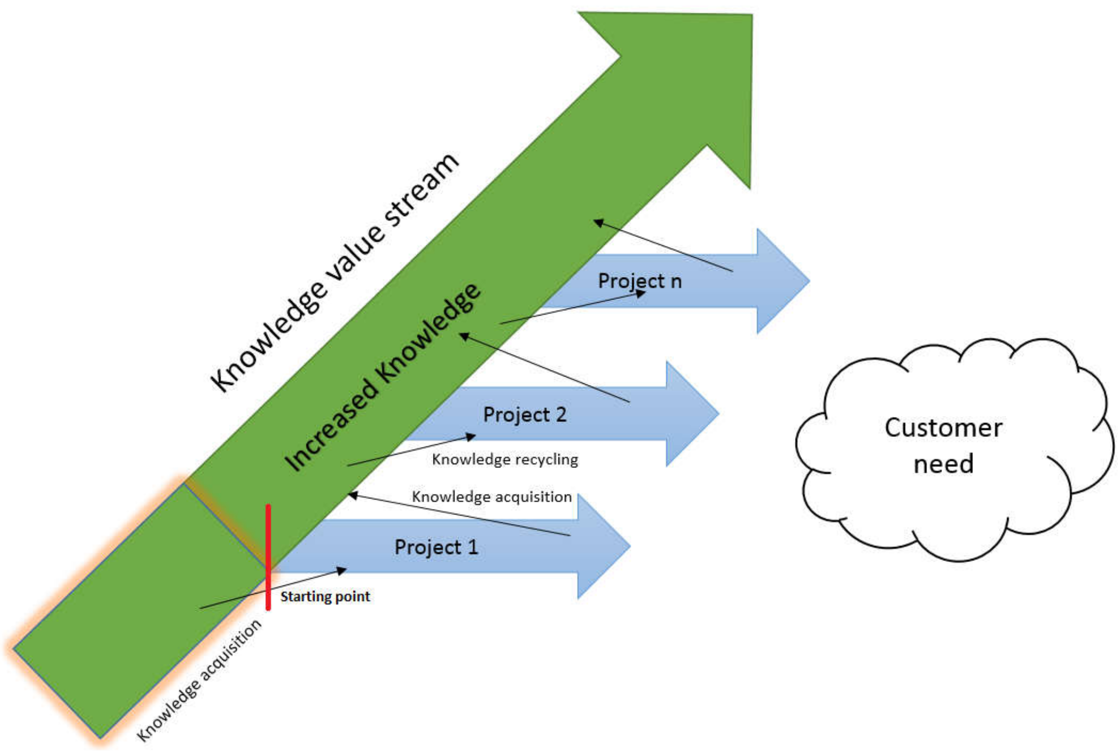

Figure 24. Knowledge creation for future projects, method 2. Altered from Raudberget [29].

4.4.2 **Product configurator**

The proposal is to implement two (sales and engineering) separate configurators, which communicate and use KBE in the design process of new ships. The engineering configurator will have direct access to the knowledge database established by the shipbuilding company. The sales configurator on the other hand will communicate with the engineering configurator and be its own version of a configurator, simplified compared to the engineering one.

By doing so, the sales and marketing can be eased and communication with the customer simplified. It makes the engineering process faster as well, due to the work the configurator will automate. Figure 25 gives a visual representation of the product configurator network within a shipbuilding company, focusing mainly on the configurators.

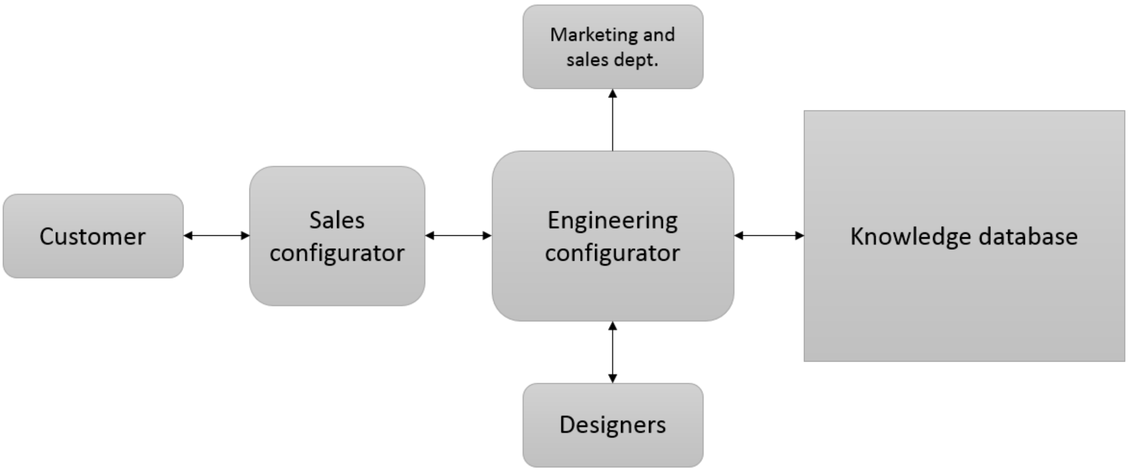

Figure 25. Product configurator network.

4.4.3 **Sales configurator**

The sales configurator should be a simple version that presents what the company can currently provide. It needs to have a simple layout as to not scare off potential customers with too many options, while at the same time offer enough customization to entice the customers with extra needs. The author proposes here two different sales configurator options, which are both viable.

4.4.3.1 Sales configurator option 1

The engineering team needs to decide what the most important features of a ship are, based on previous customer demands, especially in the contract and concept design phase. The design is not overly detailed at this stage and the sales configurator should mirror this. An example can be seen in Figure 26, which is a very simple representation of a proposed sales configurator.

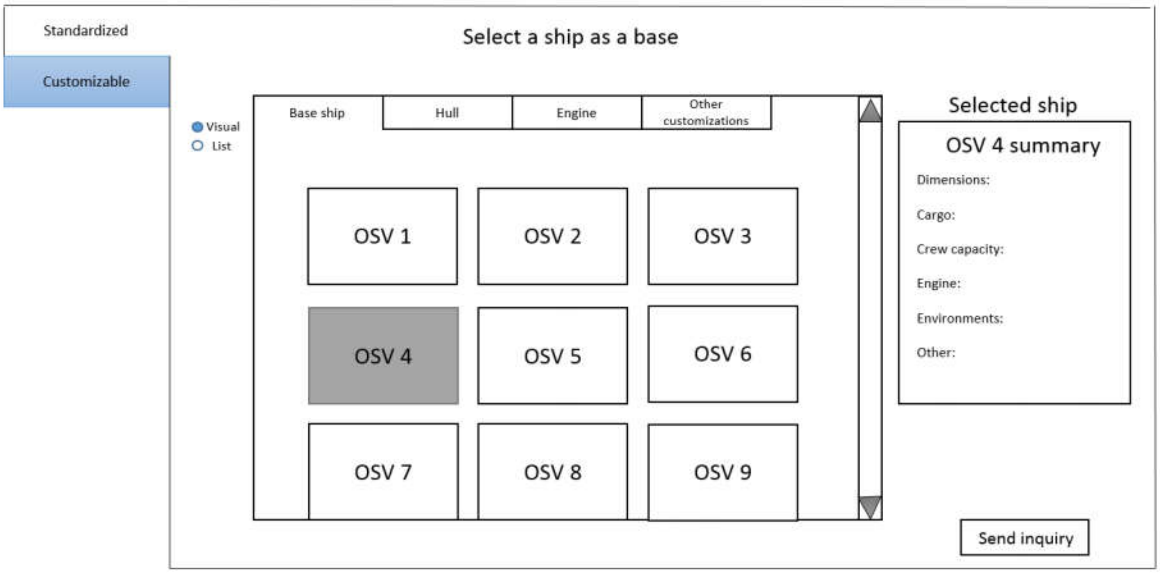

Figure 26. Example of a sales configurator for standardized OSV.

In this example, we see that the customer is presented with two main possibilities, a customizable ship design, and a preset more standardized (with available customizations) ship design. Further the customer is presented with fields that they may fill in and/or mark to complete a conceptual design in which the customer gets to express their requirements. This proposed design and requirements are then sent to the engineering configurator, where the marketing/sales and design teams are notified about the inquiry (as illustrated in Figure 25). How the designers receive and process this information will be further explained in the next subchapter.

4.4.3.2 Sales configurator option 2

Another way of implementing a sales configurator is to apply the set-based principles of SBCE. The sales configurator could be made to ease the customization of a ship design for the customer, by giving instant feedback on the proposed requirements requested by the customer.

Example: A customer desires to have a vessel that requires a hull that has XYZ dimensions. Once this is selected, the sales configurator returns with sets of engines that can power this type of ship. After the engine is selected, the sets of possible further components are narrowed down to fit that given engine and hull size.

The customer continues doing this process until they have exhausted their options, at which time the inquiry is stored and sent to both the sales and engineering teams. In this scenario, the engineering configurator will not need to perform the scoring system as proposed in the following subchapter, but will rather be used for more convenient designing of the ship, as defined by the customer, using the stored and easily accessible knowledge.

These next figures gives a visual representation of what this second proposed sales configurator might look like to a customer. First the customer chooses one main component size, hull size, in either m^3 or height x width x depth, depending on the implementation (Figure 27), the customer is also given the choice to use another parameter as the first one.

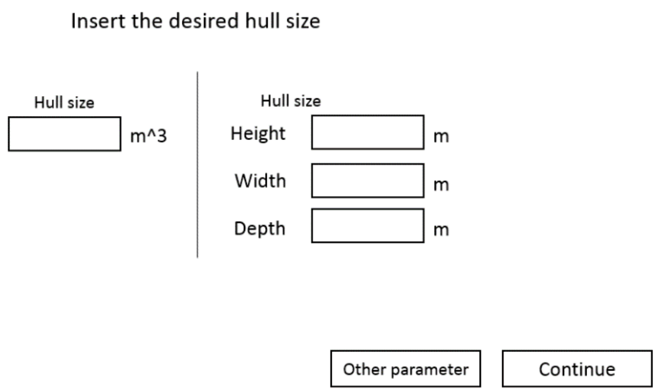

Figure 27. Proposed sales configurator 2, first selection process.

Then once this is chosen, the customer is given options based on the requirements inserted (Figure 28). As the customer chooses a new component, the lists are updated to reflect the sets of choices the customer is left with, based on the previously chosen components and their limitations (Figure 29).

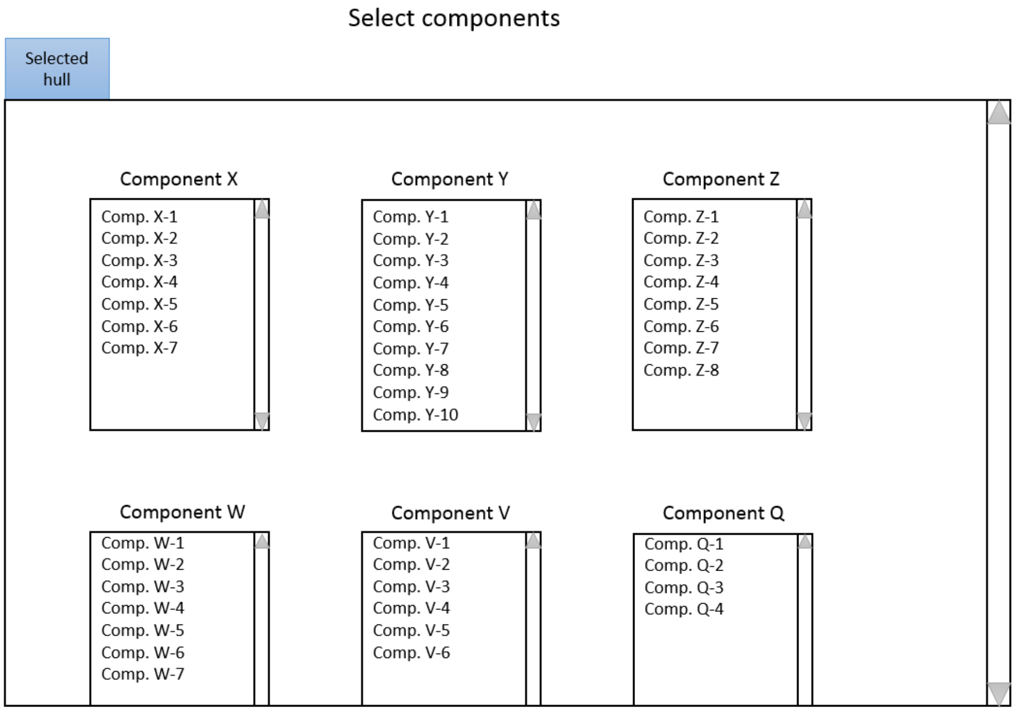

Figure 28. Proposed sales configuration, selection of components.

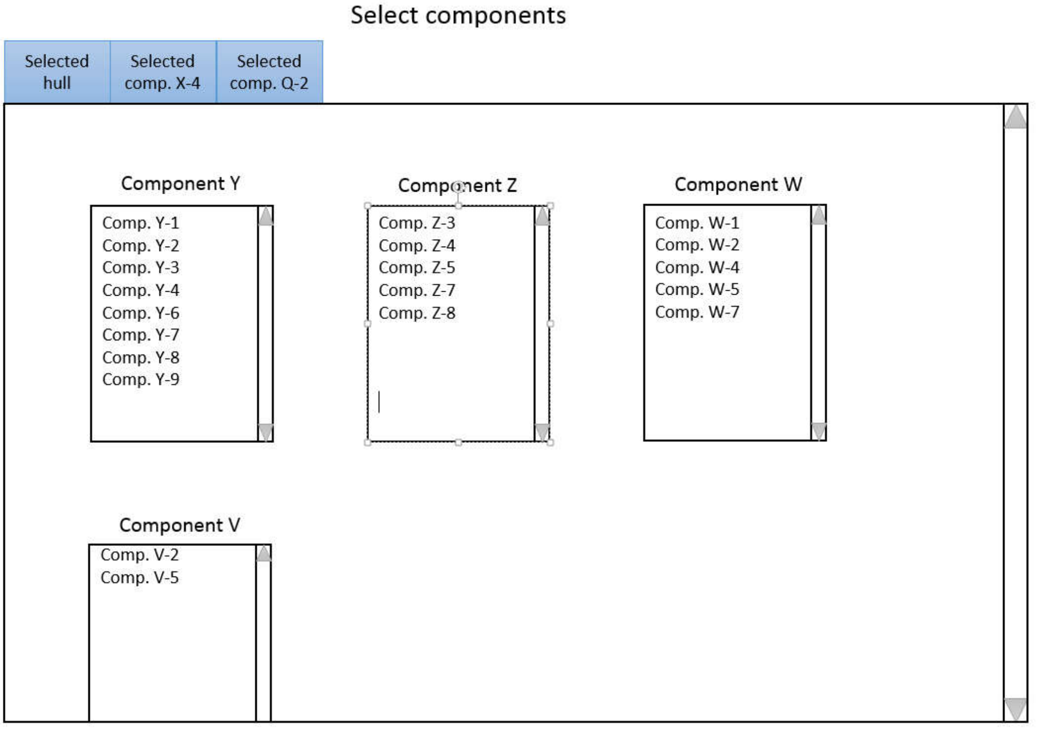

Figure 29. Representation of a customer view after selecting specific components in the sales configurator.

4.4.4 **Engineering configurator**

The engineering configurator notifies the sales/marketing department of new inquiries, and at the same time notifies the designer team. Once the designer team is notified, they are able to generate solutions that the customer will find satisfactory. The engineering configurator should be designed and developed with SBCE principles in mind. The author proposes that the implementation of SBCE principles is done by developing the configurator to “think” in terms of SBCE.

For instance, as the customer specifies requirements, the configurator should break down these numbers and match them up to previous designs that are in the same range. Example: The customer requires a ship that can handle 100 tons of cargo; every ship that can carry 5% less than desired (95) until 100 tons, will be given a score of 1, and every ship that can carry 100 or more will be given a score of 2. All the requirements given by the customer will go through the same matching progress, and each earlier ship that coincides with the requirement is given 1 or 2 point per match or partial match. After this matching process, the engineering configurator presents the designer team with a list of ships sorted by their descending total scores, the highest score indicating a previous design that best matches the current customer’s needs. This process should be optimized to the needs of the company and their customers so that the returned values are deemed viable. A visual representation of this is given in Fig 30.

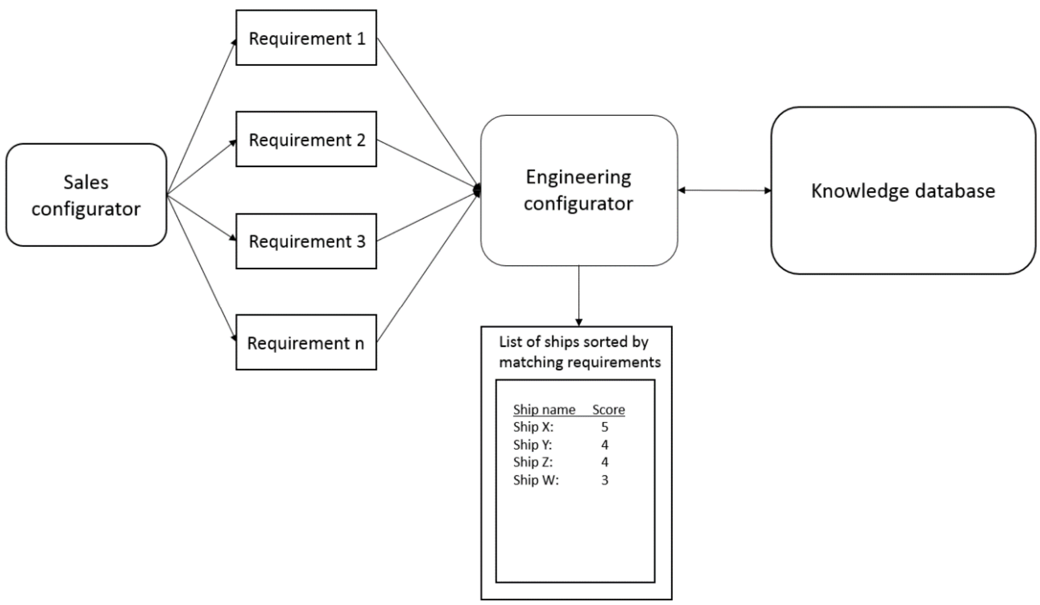

Figure 30. Proposed configurator, inner process.

Once the designers are presented with these results, they are free to customize and make new calculations and engineering work in order to fulfill the customer’s needs, in case the proposed list returns results that do not meet all the customer’s requirements. Whatever new knowledge, or new combinations the design team pairs up at this point, should then be inserted into the knowledge database through the engineering configurator.

The engineering configurator would then work as both a tool to create new designs, and to store acquired knowledge. This dual use will make it a great tool for storing knowledge and re-using said knowledge in new product development (NPD).

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5 Discussion and conclusion

This thesis looks into how shipbuilding design, especially OSVs, can be made more efficient, through the use of product configurators/KBE and SBCE principles. The author demonstrates how product configurators can be implemented in this domain. The SBCE principles are present in the way the configurator interacts with the engineers and customers, by focusing on sets of solutions and creation of a knowledge database.

The proposed solutions presented in the results will give a new perspective to how the shipbuilding can be conducted at the Ulstein Group, and the author stresses the importance of knowledge storage and sharing across the enterprise.

The first tier suppliers of ship parts are an important aspect of the design and production phase, as the process is reliant on them. In Toyotas case, the suppliers also adhere to SBCE principles, or methods resembling these, and the author feels that the design process would be helped if the first tier suppliers of ship parts were also using SBCE principles, as this would create parts that are easier to implement in the final design.

5.1 Limitations

One of the bigger weaknesses in this thesis is the lack of research in the field of SBCE, and especially the lack of SBCE in shipbuilding. This leads to the results being based on very limited literature. In spite of this, the author does feel that the results are applicable, because there are clear researched advantages to the application of SBCE in NPD, though few in numbers.

Due to the time limitations on a Master's thesis, the author acknowledges that it is hard to really become an expert in several fields, and that due to the study being based purely on literature there might be a weakness in the study due to failure to find all the relevant literature on the subjects.

5.2 Future research

The author recommends that future research be done in the industrial application of SBCE, focusing primarily on NPD in shipbuilding. There are still clear holes in the research when it comes to both the application of configurators and KBE, as well as SBCE, in the shipbuilding industry, and this is something that needs to be further researched.

As this thesis proposes an idea for a configurator, how this configurator would be developed and configured still remains an important question for future research work.

5.3 Conclusion

This study proposes that it is possible to create a product configurator for shipbuilding, implemented through the use of the SBCE principles. The author believes that the best solution is to create two separate configurators which communicate with one another and are connected to a knowledge database created by the company it is implemented in. One simplified version of a configurator is used for sales, and is intended for use by the customers, while the more complex configurator with much higher range of customization and information access is used for engineers.

There is still research to be done in this field, and there is need for a development of such a tool, but the author is positive that this thesis is a start of an important shift in shipbuilding towards more standardized and automated design processes, which in return will result in shorter design and production times, and thus be more economically viable than today's methods.

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Appendix I

THE NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

MASTER THESIS AUTUMN 2015
FOR
STUD.TECHN. VUK MILANOVIC

Application of set-based concurrent engineering to ship building projects

In today's ship building industry most of the ship building projects are customized design (CD) projects, with the minority being standardized design (SD) projects. All these custom elements can lead to longer production times and more uncertainties in both the design and production processes.

If one could move towards more SD projects for ship building, it would make the sales and marketing process easier. We are interested in seeing if it is possible, by the way of set-based concurrent engineering, to go towards more modular and standardized ship building. Thereby making the sales, marketing and production processes in ship building projects easier from the engineering and technological aspect.

The student should strive to do the following:

- Conduct a literature study on set-based concurrent engineering and its uses today.
- Focus the literature study toward the aerospace and automotive industries in addition to the ship building industry
- See how SBCE can relate to making the sales and marketing process of ship building projects easier, and strive to minimize technological risks, by moving towards standardized ship design.

Formal requirements:

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (http://www.ntnu.no/ipm/masteroppgave). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.

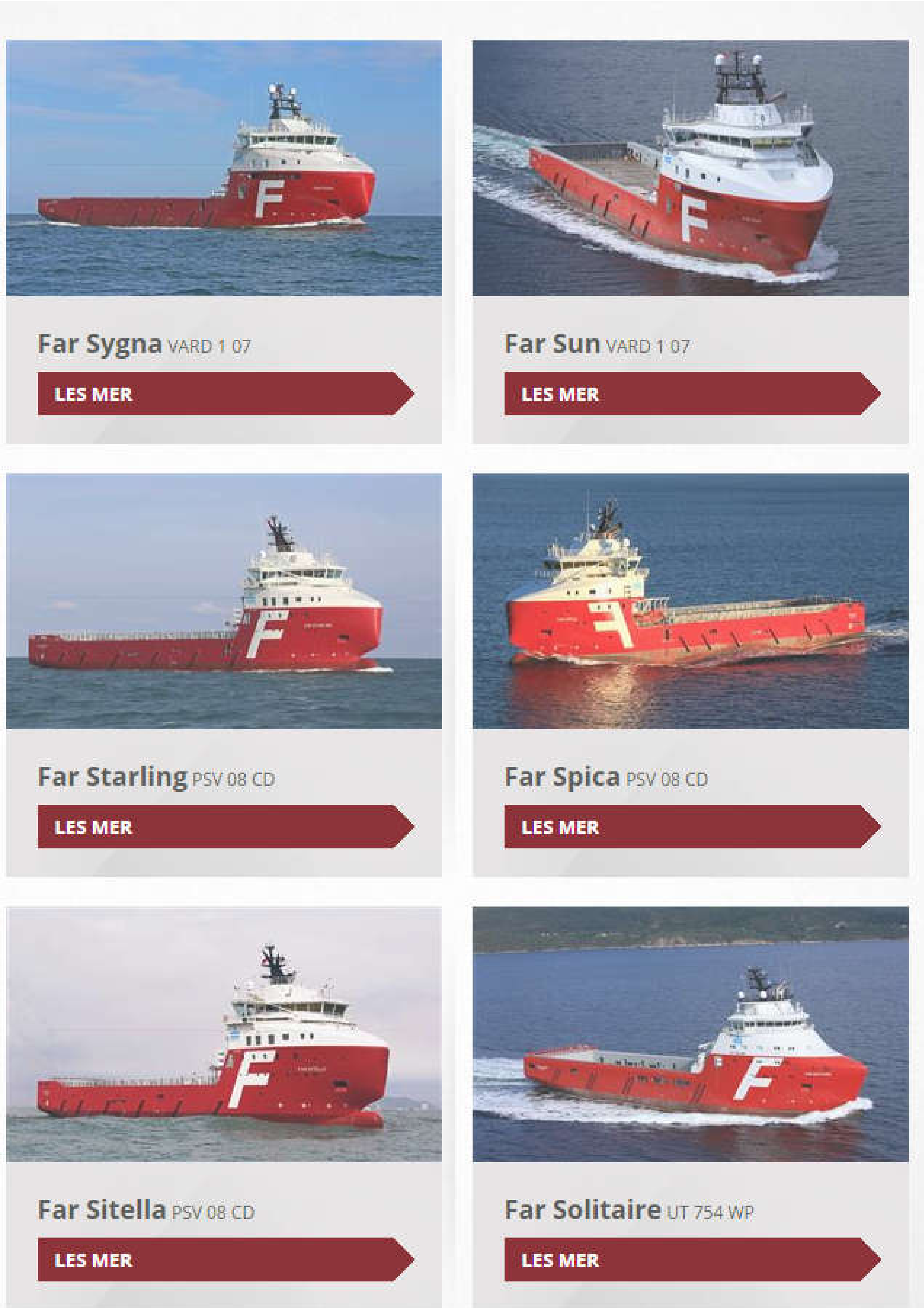
The contact person is Cecilia Haskins (IPK).

Torgeir Welo
Head of Division

Cecilia Haskins
Professor/Supervisor

NTNU
Norges teknisk-naturvitenskapelige universitet
Institutt for produktutvikling og materialer

Appendix II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Far Sitella PSV 08 CD
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Far Solitaire UT 754 WP
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Far Skimmer PSV 08 CD

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Far Scotsman PSV 08 CD

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Far Server Havyard 832 CD

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Far Swan VS 470 MK II

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Far Serenade UT 751 CD

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Far Searcher UT 751 E

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REFERENCE VESSELS

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GO MICHIGAN
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SEA SWAN
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SEA SUPRA
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SEA SPRINGER
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SEA SPIDER
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SEA SPEAR
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SEA FROST
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SEA SPARK
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SEA FORTH
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SEA FLYER
PX105

SEA FALCON
PX105

NORMAND AURORA
P105

CREST ANDROMEDA 1
PX121

VOS PATRIOT

VOS PATIENCE

ENERGY EMPRESS

Appendix III - Bibliography

Reviewed literature that provided background, but was not explicitly referenced:

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Sifakis, J. - System Design Automation: Challenges and Limitations (2015)

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Inoue et al. - Collaborative engineering among designers with different preferences: Application of the preference set– based design to the design problem of an automotive front-side frame (2013)

Ruiz et al. - Generating knowledge in maintenance from Experience Feedback (2014)

Sobek, D. – A set-based model of design (1996)

Wu, Y.; Shaw, H. - Document based knowledge base engineering method for ship basic design (2011)

Appendix IV – Other research

There is research being done in different fields related to shipbuilding. One of the most topical being done on clusters and the innovation from these, as can be seen in [85, 86]. Furthermore, simulations are proving to be very important in studies related to shipbuilding and ships. These range from scheduling within shipbuilding companies to dealing with reduction of heat stress in ships [87-89].

Although one of the main focuses in this thesis is Set-based concurrent engineering, it is in fact the proposal of a set-based version of the already established concurrent engineering (CE), which, like SBCE, is being studied further [90-93].