Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Marine Technology

Khaled Kassab

Competitive Engineering to Order (CtO) Ship Design and Production – the Norwegian way

Master's thesis in Marine Technology
Supervisor: Bjørn Egil Asbjørnslett
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Summary

Shipbuilding has experienced increased competition over the past few decades, with low-cost countries like Turkey and India competing against high-cost countries like Norway, particularly for constructing large and complex structures such as ship hulls. As a result of the decline in oil and gas prices from 2015 to 2018 and the COVID-19 pandemic in 2020, Norwegian shipbuilding contracts have been lost to lower-cost countries. Shipbuilding industries in Norway must seek solutions to enhance their competitiveness. The intent is to improve the competitive pattern in order to win more building contracts for engineering-to-order shipbuilding.

The ship design process begins with the customer's ideas and involves extensive research to find and optimise the best solution while considering effectiveness, efficiency, and efficacy. During this phase, detailed ship drawings and plans are created, which serve as crucial links between the design and production phases. Having comprehensive and detailed drawings and plans from the outset is critical to saving time and effort during the ship's construction.

Norwegian shipbuilding relies on outsourcing the construction of ship hulls or sections abroad, which are then transported to Norway for outfitting. Foreign hull manufacturing requires effective communication and detailed instructions between workers in foreign countries, who can be less qualified and experienced than their Norwegian counterparts. In order to enhance productivity, foreign shipyards need to communicate efficiently with Norwegian designers. An efficient design and more detailed drawings increase shipbuilding's competitiveness by investing more time early.

This thesis investigates the factors and phases between ship design methods and production phases. By analysing SeaWeb shipbuilding data, specifically Ulstein, Vard, and Damen, valuable insights were gained regarding ship construction, such as construction time, commissioning and testing durations, and market trends. As a result of prototyping and refining construction procedures, building the first vessel in a series takes less time than building subsequent vessels. However, the construction time for the third ship in a series often exceeded expectations, contrary to Ulstein's predictions. Understanding the intricate relationship between ship design and subsequent production phases is challenging in the shipping industry, emphasising the need for further investigation. Detailed inquiries and meticulous examinations are necessary to fully understand this relationship, uncover underlying complexities, and show how ship design and production interact, helping industry stakeholders make informed decisions.

It will require further research to fully understand shipbuilding dynamics and address the discrepancies found in various series of productions conducted by different shipyards. In light of the divergent outcomes discovered thus far, an in-depth examination of supplementary series productions is essential. Through this approach, the construction timelines of various ships in a series can be analysed thoroughly, allowing underlying factors to be identified. By conducting extensive research and expanding the scope of the study, shipyards will be able to optimise production efficiency and minimise construction time.

Sammendrag

Skiproduksjon har opplevd økt konkurranse de siste tiårene, med lavkostland som Tyrkia og India som konkurrerer mot høykostland som Norge, spesielt når det gjelder konstruksjon av store og komplekse strukturer som skipsskrog. Som et resultat av nedgangen i olje- og gassprisene fra 2015 til 2018 og COVID-19-pandemien i 2020 har norske skipsbyggingskontrakter gått tapt til lavkostland. Skipbyggingsindustrien i Norge må derfor søke løsninger for å forbedre konkurranseevnen sin. Hensikten er å forbedre konkurransesituasjonen for å vinne flere byggekontrakter innen ingeniørtilpasset skipsbygging.

Skipdesignprosessen starter med kundens ideer og innebærer omfattende forskning for å finne og optimalisere den beste løsningen samtidig som man vurderer effektivitet og effektivitet. I denne fasen blir det utarbeidet detaljerte skips-tegninger og planer, som fungerer som avgjørende koblinger mellom design- og produksjonsfasene. Å ha omfattende og detaljerte tegninger og planer fra starten av er avgjørende for å spare tid og innsats under skipskonstruksjonen.

Norsk skipsbygging er avhengig av å outsource konstruksjonen av skipsskrog eller seksjoner i utlandet, som deretter transporteres til Norge for utrustning. Produksjon av skrog i utlandet krever effektiv kommunikasjon og detaljerte instruksjoner mellom arbeidere i fremmede land, som kan være mindre kvalifiserte og erfarne enn sine norske kolleger. For å øke produktiviteten må utenlandske skipsverft kommunisere effektivt med norske designere. Et effektivt design og mer detaljerte tegninger øker skipbyggingens konkurranseevne ved å investere mer tid i startfasen.

Denne masteroppgaven undersøker faktorene og fasene mellom skipdesignmetoder og produksjonsfaser. Ved å analysere SeaWeb-data om skipsbygging, spesielt Ulstein, Vard og Damen, ble det oppnådd verdifulle innsikter om skipskonstruksjon, som konstruksjonstid, varighet for iverksettelse og testing, og markedsutvikling. Som et resultat av prototyping og forbedring av byggeprosedyrer tar det mindre tid å bygge det første fartøyet i en serie enn å bygge påfølgende fartøyer. Imidlertid overskred konstruksjonstiden for det tredje fartøyet i en serie ofte forventningene, i motsetning til Ulsteins prognoser. Å forstå det intrikate forholdet mellom skipdesign og påfølgende produksjonsfaser er utfordrende i skipsindustrien, og understreker behovet for videre undersøkelser. Det kreves grundige undersøkelser og nøye undersøkelser for å fullt ut forstå dette forholdet, avdekke underliggende kompleksiteter og vise hvordan skipdesign og produksjon samhandler, og hjelpe bransjeinteressenter med å treffe informerte beslutninger.

Det vil kreve ytterligere forskning for å fullt ut forstå skipsbyggingens dynamikk og håndtere avvikene som er funnet i ulike serier av produksjoner utført av ulike skipsverft. Med tanke på de divergerende resultatene som hittil er oppdaget, er en grundig undersøkelse av tilleggsproduksjonsserier avgjørende. Gjennom denne tilnærmingen kan byggetidslinjene til ulike skip i en serie analyseres grundig, slik at underliggende faktorer kan identifiseres. Ved å gjennomføre omfattende forskning og utvide studiens omfang vil skipsverftene kunne optimalisere produksjonseffektiviteten og minimere byggetiden.

Acknowledgement

I would like to express my deepest gratitude and appreciation to all those who have contributed to completing this master thesis.

First and foremost, I am immensely grateful to my supervisor Bjørn Egil Asbjørnslet and my co-supervisors, Per Olaf Brett and Marco Semini, for their invaluable guidance, unwavering support, and expertise throughout the entire research process. Their insightful feedback and constructive criticism have shaped the direction of this study and enhanced its quality. I am truly fortunate to have had the opportunity to work under their supervision.

I extend my heartfelt thanks to the Department of Marine Technology (IMT) faculty members for their dedication to providing an enriching academic environment. Their passion for knowledge and commitment to excellence have greatly influenced my intellectual growth and inspired me to pursue this research.

I want to acknowledge the support and encouragement of my family, especially my mother [Nesrin], my brother [Omar] and my fiancé [Hanan] throughout this academic journey. Their unwavering belief in my abilities and constant encouragement has motivated me during challenging times. Their understanding, prayers, patience, and unwavering support have been invaluable.

Completing this master thesis has been a transformative and rewarding experience, and I am truly grateful for the opportunity. The knowledge and skills acquired during this research endeavour will shape my future endeavours.

Thank you all for your support, encouragement, and contributions. Your impact on this thesis and my personal growth is immeasurable.

Khaled Kassab

Table of Contents

List of Figures

List of Tables

Abbreviations

ABD Accelerated Business Development
CAPEX Capital Expenditures
CtO Competitive Engineering-to-Order
ETO Engineering-To-Order
OCV Offshore Construction Vessel
OECCD Economic Co-operation and Development
OSV Offshore Support Vessel
PSV Platform Supply Vessel
SOV Service Operation Vessel

1 Introduction

1.1 Background

Over the past few decades, the shipbuilding industry has become increasingly competitive. Several countries with low building costs, such as Turkey and India, are competing against countries with high building costs, such as Norway, in the construction of large and complex structures, particularly ship hulls (Stensvold and Fenstad 2022). Due to several factors, including low labour costs and efficient design and production, this low-cost country is able to offer lower costs, and this is a competitive advantage because of several factors. There is no doubt that all of these factors can adversely affect the quality of the product. Due to the fact that these lower-cost countries are becoming increasingly competitive in the shipbuilding industry, higher-cost countries are being forced to change the way in which they design and manufacture ships in order to remain competitive in the shipbuilding industry (A.Hagen and S.O.Erikstad 2014).

After the fall in oil and gas prices from 2015 to 2018, as well as the Corona pandemic of 2020, the design and production of ships in Norway has become a marginal business. Furthermore, Norwegian shipyards are already losing many contracts for the building of vessels to countries that have lower costs of shipbuilding (Stensvold and Fenstad 2022). This will have a negative impact on the Norwegian shipbuilding industry, as many employees are likely to lose their jobs, and the shipyards will be forced to reduce their capacity to produce ships, which in turn will lead to the loss of expertise and skills in the industry. It is imperative that Norway's shipbuilding industry improves its competitiveness in order to survive on the global market and succeed in the future. There is, therefore, a need for the shipbuilding industry to implement effective strategies and develop new technologies in an effort to reduce lead times, reduce man-hours, and improve ship design as well as the productivity of the entire shipbuilding industry.

1.2 Scope

The scope of this project thesis is to understand the relationship between ship design and ship production by looking at the factors in ship production that can be affected by the ship design and the decision-making in an early stage. This project aims to establish a model that will assist in understanding the relationship between ship design and ship production. Taking into consideration the fact that it will be conducted in a Norwegian manner will enable this to be accomplished. In terms of shipbuilding, a Norwegian way refers to following the Norwegian strategies for design and production as well. Understanding the relationship between ship design and ship production will allow us to determine how Norwegian shipyards can continue to build vessels efficiently and compete on a global scale. During this project, we will answer the question regarding 'How does ship design affect ship production & How does ship production affect ship production?'.
. Through a comprehensive examination of the expected getting data for ships constructed within the Norwegian shipbuilding industry, we aim to identify and analyze potential problems related to various critical aspects such as man-hour utilization, lead time efficiency, cost optimization, and the repetition of production processes as they relate to various critical aspects of shipbuilding. The objective of our analysis is to gain a deeper understanding of the underlying issues within the

shipbuilding industry by delving into the intricacies of the industry and examining the relevant statistical information. This will facilitate identifying and assessing possible areas for improvement and enhancement within the shipbuilding industry.

1.3 Report structure

The subsequent sections of this paper are organised as follows: Chapter 1 presents the introduction to this study. Chapter 2 comprehensively reviews the literature on ship design, ship production, and the interplay between these two domains, focusing on serial production within the shipbuilding sector. Chapter 3 addresses the central inquiry of this thesis, namely, ”How does ship design affect ship production & How does ship production affect ship design?”. An investigation model is presented in Chapter 4, which illustrates the intricate relationship between ship design and ship production and a summary of Ulstein's interview. Chapter 5 discusses the data analysis phase, including data collection and processing. The results of the data analysis are presented and discussed in Chapter 6. Lastly, Chapter 7 presents the study's conclusions and recommendations for further research.

1.4 Limitations

There was a limitation to the research project, primarily due to proprietary restrictions imposed by Ulstein. It was impossible to access data such as man-hours, lead times, cost information, and repeat production data due to these limitations. For this reason, I had to obtain repeat production data from an alternative source, specifically SeaWeb. Unfortunately, the process of acquiring this data occurred late in the semester, resulting in a request for an extension from the university of two weeks to complete the thesis.

1. Data unavailability and proprietary restrictions:
   The primary limitation encountered was Ulstein's proprietary restrictions. This prevented me from accessing data such as man-hours, lead time, cost, and repeat production data. The purpose of these proprietary restrictions is typically to protect sensitive and confidential business information. Unfortunately, I was unable to conduct a comprehensive analysis of the production processes, and my findings could have been more extensive in scale and accuracy.
2. Using alternative data sources:
   To mitigate the unavailability of critical data, I sought an alternative source, SeaWeb, to obtain repeat production data with help from Marco Semini. As a result, I had to modify their analysis and methodologies to accommodate this alternative data source, potentially impacting their overall reliability and accuracy.

It is important to acknowledge these limitations when interpreting the results and conclusions of this study. While I faced many challenges, I made every effort to address these limitations and ensure the validity and reliability of the findings to the fullest extent possible.

2 Literature review

The shipbuilding industry is one of the oldest, most open, and most competitive industries in the world. Even though the shipbuilding industry has a long history of surviving the peaks and slumps of the economy, there are still some challenges it faces. It should be noted that the current global financial crisis has severely affected the shipbuilding industry (Mickeviciene 2011). The ability to produce high-quality ships at competitive prices and quality is essential to success. However, the ability to design and manufacture quality vessels on time and within budget has recently become challenging due to increased competition (Mickeviciene 2011).
This project thesis has positioned the focus on the sequence between those three areas: engineering to order in ship design, ship production and the relationship between ship design and ship production. We will first start by explaining what the engineering to order is. Engineering-to-order (ETO) is one type of product manufacturing where the product is engineered and produced after a specific order has been received from the customer. The product is expected to meet customer needs and expectations using the ETO manufacturing process. It is also likely that the customer will be involved throughout the design and manufacturing phases.

2.1 Ship design

We will first start by explaining what design is. Design is about changing existing situations into better ones within the constraints of scarce resources (Per Olaf Brett, Asbjørnslett, Garcia Agis and Stein Ove Erikstad 2022). And this explanation is still accurate for the ship design because when designing a new ship, we will probably start from where others end up and try to improve it. Roger Martin states: “Design is not just about making things beautiful; it is also about making things work beautifully” (Martin 2009). Design is about responding to customer-specific needs, inquiring about existing conditions, and realising the necessary courses of action based on the outcome (Suh 1990).

The main phases of ship design are; 1) concept design, 2) preliminary design, 3) contract design, and 4) detailed design (Papanikolaou 2014). Furthermore, those 4 phases can combine into just two stages; Basic design and detail engineering, according to (A.Hagen and S.O.Erikstad 2014). In Figure 2 shows ship design is an integral part of the vessel’s life, and how ship design can be divided.

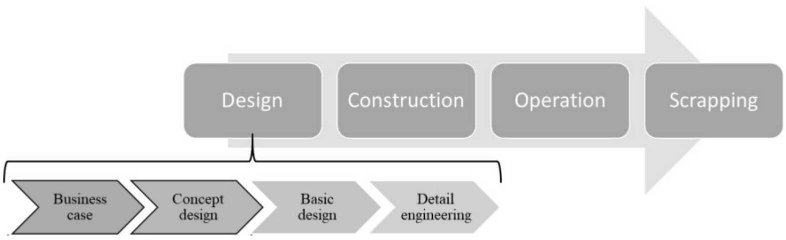


Figure 1: Ship design is an integral part of the vessel’s life cycle (Garcia 2020).

In this project we will look more at the shipbuilding according to A.Hagen and S.O.Erikstad 2014. Basic design is the main outlines, arrangements, and hull are defined when the basic design is completed and the major structural problems are resolved. As part of this process, solutions are created and adapted iteratively and then verified by analysing them. By the end of the process, main drawings and plans have been produced that document the solutions, which may be used by the client for verification. Detail engineering: it consists of detailed analysis, modelling, and drawing production for configuring, dimensioning, and arranging the vessel's structure and systems. Based on the basic design, the results are used as a basis. The results of the previous phase may be contradicted during this phase (A.Hagen and S.O.Erikstad 2014). During the conceptual phase, the most critical design decisions are made. In the early phases of design, decisions are made that affect the development of the product, its architecture, its production process, its cost, and its operational performance (Levin 2007).

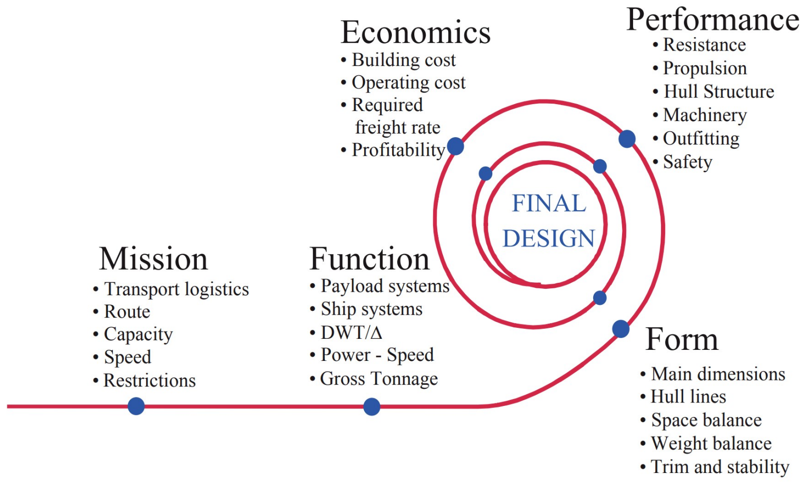


Figure 2: The system-based ship design process according to (K.Levander 2012).

There are many phases that can describe the system-based ship design process, Figure 2 shows the critical steps that can affect ship design, where the starting point is the ship's mission and functions. The basic design is also known as the more general definition of preliminary design. Preliminary ship design is the first stage of design which, is established on the requirements and specifications of the shipowner (Papanikolaou 2014). Most of the downstream activities in ship design and construction are highly influenced by decisions made in the conceptual phase. T. Ulstein and P. Brett 2012 emphasise that the most critical decisions affecting the vessel's overall performance are made during the conceptual phase.

Designing a ship is a complex and critical decision-making process (Gaspar, Rhodes, Ross and Stein Ove Erikstad 2012). In the ship design process, several factors contribute to effective decision-making. The choice between competing vessel design solutions is one of these issues. During the lifecycle of the vessel, a design alternative should be selected based on the mission or set of missions the vessel will perform. There is an expectation and a constraint imposed by each stakeholder on such a set of missions. Current and future market conditions and expectations should be reflected in these expectations and constraints (T. Ulstein and P. Brett 2012).

The complexity of ship design has always been related to the competitiveness of ships in terms of their design. A major focus of ship design companies is to introduce new technologies and, in some cases, additional functional capabilities to improve their success, which has resulted in the design of large and complex vessels in the past decade (Ebrahimi 2021). A complex product as a ship refers to a number of factors, among them its size, the number of components, the interaction between those components, as well as the dynamics of the environment where the ship design is being developed or where it is going to be operated (Ebrahimi, Per O. Brett, Stein O. Erikstad and E 2021). During the conceptual design phase, a variety of stakeholders are involved, and their expectations are usually unclear, diverse, and sometimes contrary, resulting in several design options. It is therefore understood that ship design is a complex decision-making process that aims to achieve the right balance between the expectations and needs of the ship owners (T. Ulstein and P. Brett 2015).

Complexity in shipbuilding is a challenging problem to solve. Therefore, it is important to break down the problem into smaller parts in order to be able to understand and perceive it more clearly. The concept of 'needs-function-form mapping' is one way to break down the problem. It is a design approach that involves aligning the functional requirements of a ship with its physical form. Needs-function-for mapping is shown in Figure 3, where the need domain can be defined as customer needs; it describes what the shipowner or stakeholder wishes to accomplish and his vision for the vessel. The functional domain means functional requirements; it describes what the system should do to meet the needs. The physical domain means design parameters; it describes how we can describe the physical system. By applying needs-function-for mapping, we will see that ship design will be covering needs and functional domains, and ship production will be covering functional and physical domains.

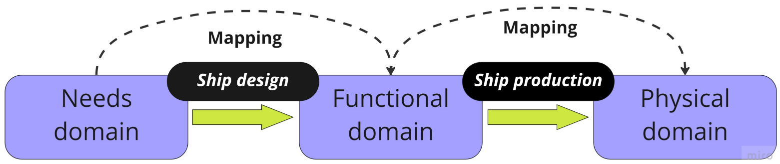


Figure 3: Needs-function-form mapping.

An offshore service vessel can be complex and challenging to design and build. It is evident from Figure 4 that there are many critical decisions to be made about the type of hull, the power system and the top-side systems that must be chosen in order to finalise a design solution. Several design approaches have been developed to manage complexity better and optimise the effectiveness and efficiency of the developed design solution during the early phase of the concept design process. Some of these approaches are system-based design, design-for-X concepts—including design for efficiency of performance, Set-Based Design, Decision-Based Design, Epoch-Era analysis applied to ship design and the Ulstein ABD approach.

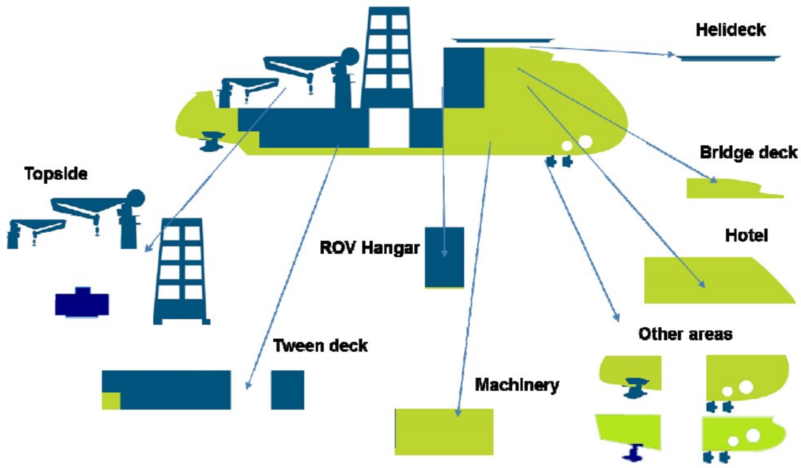


Figure 4: An explanation of the structural complexity of an offshore construction vessel (OCV) (T. Ulstein and P. Brett 2015).

The Ulstein Accelerated Business Development (ABD) approach is a method of structuring the process of converting a vessel business idea into a comprehensive business concept and specifications for the vessel. The purpose of developing the Ulstein ABD was to deal with the inherent uncertainties and complexity of ship design, intending to enable fast, fact-based decision-making during the early stages of the design process (T. Ulstein and P. Brett 2015). During the ABD process, it is not the intention to gather information so that in-depth analyses can be carried out or ship and system drawings can be prepared. It is rather intended to explore in-depth the potential factors that influence the business case and vessel design of the ship, as well as to facilitate a continuous and facts-based real-time decision-making process concerning the specific business case at hand (Garcia 2020).

There are nine modules in the ABD, which can be classified as exploration activities or exploitation activities. Ulstein ABD comprises nine modules that have been developed to require the user to think about all the aspects of the business concept that influence the design of the vessel and to explore areas that would have been overlooked otherwise. Having such an organized structure, as well as a multidisciplinarily oriented group of participants allows information to be exchanged among participants, facilitating the process of learning, as well as facilitating better decision-making (Garcia 2020).

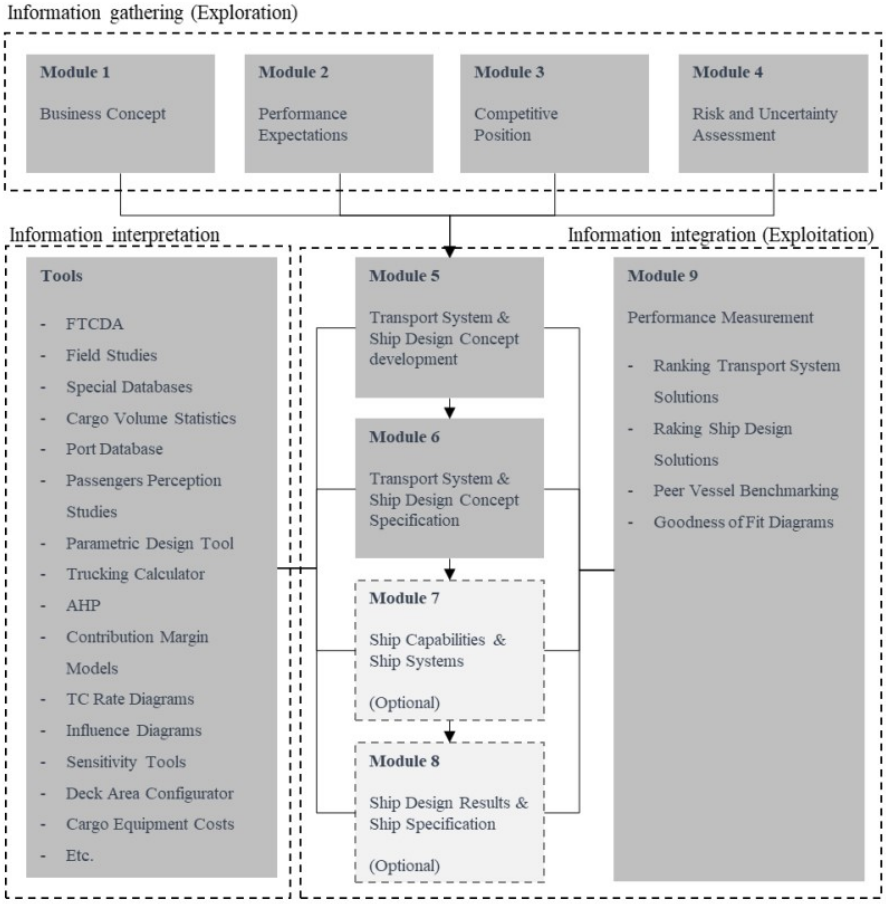


Figure 5: Accelerated Business Development (ABD) modules (Garcia 2020).

As it is shown in Figure 5, Ulstein ABD's nine modules can be divided into two parts, the first from modules 1-4, referred to as (Information gathering), and the second from modules 5-9, referred to as (Information integration & Information interpretation). During Modules 1 to 4, the attention is focused on the development of the business concept, testing the initial expectations of stakeholders (such as shipowners, operators, or charterers) and defining vessel requirements and constraints. Modules are developed in such a manner that they force users to take into account all aspects of the business concept, which have an impact on vessel design, and to explore areas that would be overlooked otherwise. The modules 5 to 9 are concerned with the development of the vessel concept design solution, with the definition of the vessel's functional specifications, capacity specifications, and performance ranking as well as meeting the design requirements elicited in the modules 1 to 4 of the project.
As a result of the availability of a series of complementary analysis tools, it will be easier to perform the necessary analyses and to interpret the information gathered during the exploration phase, and also to support the design decisions taken during the development phase of the vessel concept (Garcia 2020).

According to T. Ulstein and P. Brett 2015, competitiveness refers to the characteristics that make a vessel design solution distinctive, as well as the way that performance metrics support or drive the capability of distinctive vessels to enhance the brand of a design firm. In accordance with their definition, the competitiveness of a design solution may be directly related to the perceived benefits and, in some cases, the functional capabilities of a specific vessel design solution as opposed to the perceived cost-benefits (Ebrahimi 2021).

In order to quantify the competitiveness of a design solution, Ulstein developed a model of concept design business case studies that have been applied to different projects since 2014. Over the last few years, the method has gradually evolved and been expanded. The purpose of creating such a business case is to give a shipowner the advantage of comparing different solutions offered or new design proposals directly-and, not just from the standpoint of price or capacity/capability but also from the perspective of how well the design is balanced in terms of effectiveness, efficiency, and efficacy Ebrahimi 2021; T. Ulstein and P. Brett 2015). They have come up with three definitions:"*Effectiveness is doing the right things, efficiency is doing the thing right, and efficacy reflects the ability to do the things with the right resources*" (Ebrahimi 2021). When such design perspectives are implemented early in the design process, designers and ship owners are provided with a scientific decision-making approach to create balance and compromise in a particular design solution among several influence parameters. This is in order to meet the needs of a particular mission within the life-cycle of a product. Furthermore, simultaneously considering different design perspectives is helpful in balancing other relevant performance yields relevant to decision makers and the competitiveness of products on the market (T. Ulstein and P. Brett 2015, Ebrahimi 2021). There are three different performance perspectives that Ulstein has applied in order to develop a new design solution which can be applied to a new project as it shown in Figure 6.

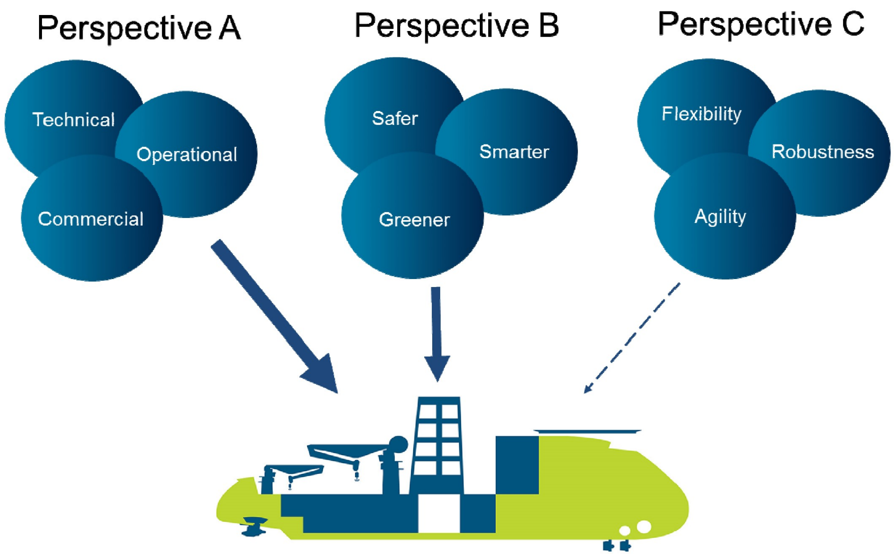


Figure 6: Three different performance perspectives (A, B, and C), which can be used to develop vessel design solutions (T. Ulstein and P. Brett 2015).

As a result of such a design process, the design for effectiveness perspective controls the outcome of the project. Based on the efficiency perspective (perspective A), it is possible to compare the developed solution's technical, commercial, and operational performance yields with those of its market peers. It describes how well design details are utilised in the vessel solution to meet expectations. Based on the effectiveness perspective (perspective B), the primary concern is whether or not the owner's expectations are realistic and whether or not the design needs are aligned with the owner's expectations. In addition, it examines the extent to which those needs and expectations are satisfied by the design solution that has been developed. At the process level, the efficiency perspective reviews how efficient the design process is, in terms of the use of time and resources, to produce different design solutions. Based on the efficacy perspective (perspective C), a design organisation is controlled and evaluated in terms of how well resources are utilised in order to develop the design solution compared to other designs within the organisation as well (Ebrahimi 2021).

Three main design aspects are included in effectiveness: smarter, safer, and greener. Smarter is referred to as a cleaner, neater, intelligent, fashionable, and more usable vessel that is more efficient. Safety refers to reducing the risk and consequences of failure, damage, error, accident, or any other undesirable event in a vessel's design. 'Greener' refers to vessels or systems that use energy and resources efficiently and reduce their environmental footprint (T. Ulstein and P. Brett 2015).
Three main design aspects are included in efficiency: technical , operational, and commercial. A technical aspect is everything that affects the design and construction process. The operational aspect means that the vessel is operationally connected to business, machinery, and systems. The functions of these connections contribute to the effectiveness of the vessel's different mission designs. Commercial aspects include factors that influence valuation, preferences, and the exploitation of the vessel during its operational lifetime and enhance the profitability of the vessel (Ebrahimi 2021).
Three main design aspects are included in efficacy: flexibility, robustness, and agility. Efficacy aspects are defined as the ability to meet design expectations and perform the required mission when the intended means, tools, and resources are available Ebrahimi 2021. To conclude, finding a balance between effectiveness, efficiency, and efficacy for shipowners and stakeholders will be crucial for obtaining the desired results from the ship design phase.

2.2 Ship production

We will first start by explaining what production is. Production means transforming materials into useful items and assembling components and subsystems (Andritsos and Perez-Prat 2000). As for ship production, this explanation remains true since, during the process of building a ship, there is a physical transformation of materials and an assembly of components and subsystems into a finished product. The process usually begins with the cutting and forming of steel in order to construct the hull or the hull blocks of the vessel, then it goes on to include the installation of main equipment (Semini, Dag E. Gotteberg Haartveit, Alfnes, Per Olaf Brett, Arica and Roald 2013).
There has been a significant role played by Norway in the production of ships and marine constructions. A few decades ago, there were yards along the entire coast that built a wide range of types of ships, including tankers, bulkers, ferries, roll-on/roll-off, and various fishing boats of different sizes. There was a significant increase in competition from Eastern Asia during the 1970s due in part to lower labour costs associated with Eastern Asia (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018). Norway's larger yards could not adapt and scale down, and they closed, and their properties were converted into other uses. During the 1990s, most of

the shipyards on the West Coast survived, focusing mostly on ship conversions and repairs and a growing specialisation in offshore oil and gas exploration and extraction vessels. A significant percentage of large ships delivered from Norwegian yards since that time have been offshore support vessels (OSVs), customised, technologically advanced vessels. Other customised, advanced ships have been relevant markets in the past, including fishing vessels, live fish carriers, naval ships, cruise ships, and research vessels (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018).

Depending on the type of strategy the shipyard uses, the shipyard's production processes vary according to the type of approach. There is a common practice among Norwegian shipyards to purchase steel hulls or blocks from foreign yards, where labour is less expensive. Foreign yards perform varying degrees of work on the hulls and blocks of ships, and sometimes the amount of work varies from project to project (Andritsos and Perez-Prat 2000). According to A.Hagen and S.O.Erikstad 2014, effective production can be achieved by using the zones and the stages in a good way and in the right time. Zone-oriented production means equipment at the right time. In order to be able to divide the construction process into groups of connected activities, phases are used. The fabrication phase indicates a specific stage which is linked to the production of the product. The fabrication phases are divided into eight phases:

1. Prefabrication
2. Part production
3. Section building
4. Painting and blasting
5. Block outfitting
6. Hull assembly
7. Dock outfitting
8. Quay outfitting

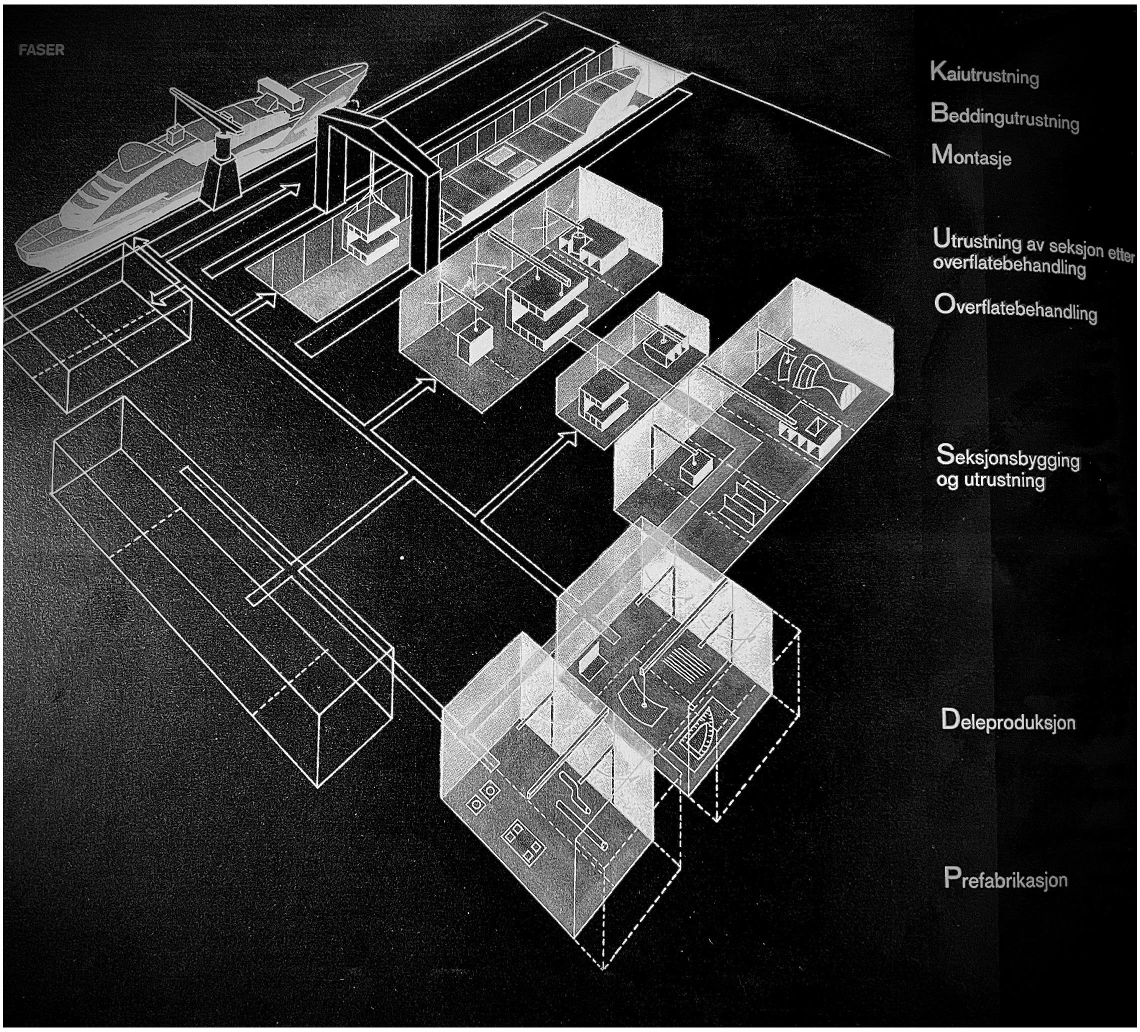


Figure 7: The fabrication phases according to (Hagen, Eide, Grimstad, Hukkelberg, Lønseth, Steinveg et al. 1996).

As this project highlights the Norwegian way of shipbuilding, we will only focus on three phases: the section building phase, the dock outfitting phase and the quay outfitting phase. There are many strategies for ship production, as we can see in Figure 8 according to (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018). In this project, we will be looking mostly at strategy III (Norwegian dock outfitting), where all blocks for the ship are constructed and outfitted into one unit at the foreign yard and assembled into a final structure at the end of the process. As soon as the steel structure is completed, it is towed to Norway, where it will be outfitted for dock and dock quay installations, commissioned, and tested (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018). There is a possibility that other strategies (strategies I, II, or IV) might be more effective on ship production than the one we propose in this study, but we will not consider this in this study. We will use the strategy used in most Norwegian shipyards today (e.g. strategy III).

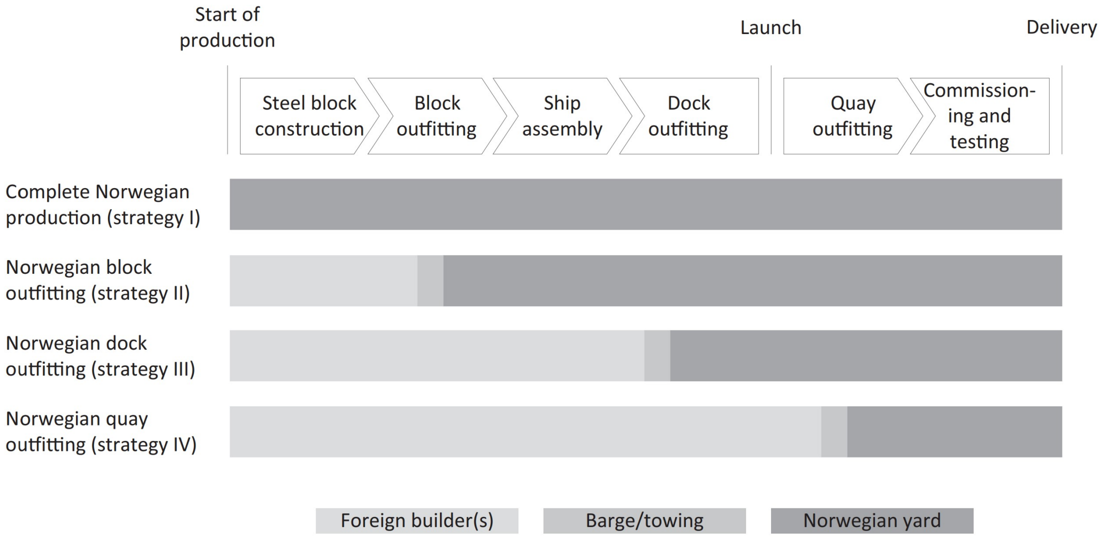


Figure 8: Norwegian ship production strategies (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018).

The section building phase is where the interaction between the foreign yard and the designers or engineers takes place, where communication occurs. The drawings for sections and outfitting are always the link in this phase. During section building, parts are assembled into blocks or sections before surface treatment. In this stage, sections and grand blocks are assembled and outfitted early. The construction, sectioning, and outfitting of the larger modules are carried out in a section building hall, which is also the place where the structure of the larger modules is fabricated. As a result of the phase section building and outfitting, the following products will be produced: part sections, grand sections, grand sections outfitted to the extent planned for outfitting, and modules (A.Hagen and S.O.Erikstad 2014). Many factors can affect the effectiveness of this phase; the quality of drawings for sections and outfitting and the competence of the designers and the engineers in the foreign shipyard can be the most important factors. The lack of detail in the drawings or the presence of incompetent engineers in the foreign shipyard will result in delays and the loss of money.

After the steel structure has been towed to the Norwegian yard, the dock outfitting phase will occur. The main purpose is to bring the ship afloat and complete the outfitting possible for dock conditions. One of the most important tasks in this phase is the installation of the equipment. Moving equipment aboard occurs from the top, from the sides, and the bottom. The steel structure is cut out temporarily for better access to the zones. By the end of the dock outfitting phase, the ship will be a significant part of the finished product in terms of zones and systems which have been partially completed (A.Hagen and S.O.Erikstad 2014). Assembly drawings, arrangement drawings and equipment specifications are important parts of this phase, whereas the detailed drawings will greatly impact the work efficiency and productivity. The quay outfitting phase is the last phase of ship production, and it comes after the dock outfitting phase. The phase's main objective is to complete the installation of all systems and perform their functionality tests before the sea trials commence. As a result of this stage, a ship is completed, and its systems have been tested. It is possible to reduce the workload in this phase by having a good plan and meeting the scheduled equipment degree throughout the project. This will help to ensure a controlled working environment for operators or labourers and prevent the need to hire additional operators in the previous phase (A.Hagen and S.O.Erikstad 2014). The testing of the system is an important part of this phase of the project, and as a result, forms and procedures must be included in the project plan that sets forth the testing procedure. Quay outfitting will result in the vessel being tested and ready for delivery following the completion of the outfitting process.

During the fabrication phase (fabrication engineering stage), several factors may affect production negatively. A change in the drawings may occur, and this may lead to conflict with the results of the previous stages, especially when the drawings differ from the originals. Norwegian yard may have difficulty keeping up with production plans or schedules if the hull is delivered late or if a quality defect requires rework when it arrives at the Norwegian yard. Eventually, this will lead to many delays in the production process and an increase in the costs due to the delays. It is also expected that the productivity of workers in low-cost countries is lower, according to the Organisation for Economic Co-operation and Development (OECD). (Semini, Per Olaf Brett, Strandhagen and Vatn 2022).

2.3 The relationship between ship design and ship production

The shipbuilding industry relies on a close relationship between ship design and ship production, where effectively coordinating these two critical areas is essential to achieving successful results. The concept, functional design, and performance characteristics of a vessel are conceptualised and visualised through ship design, which involves both creative and technical aspects. As for ship production, it is the practical realisation of these design concepts through the fabrication and assembly of ship components, culminating in constructing of a seaworthy vessel. An effective interplay between the design and production of a ship plays a pivotal role in achieving optimal results, ensuring the seamless translation of design intent into tangible reality (Papanikolaou 2014 & A.Hagen and S.O.Erikstad 2014).

The relationship between ship design and ship production is driven largely by drawings and plans, which serve as key communication tools and guidance documents throughout the construction process. It is drawings and plans that serve as the connecting link between the abstract concepts and specifications of ship design and the tangible realisation of ship components during the production phase. A ship's structure, systems, and arrangements are outlined and represented in these documents in a detailed and standardised manner. In this way, ship designers are able to articulate their ideas and technical requirements to the ship production teams in a simplified manner (Papanikolaou 2014).

The different phases of shipbuilding require a variety of different types of drawings and plans to be used during the process. This is accomplished through an assortment of comprehensive plans, encompassing a layout of each space and the outfitting of the space, a capacity plan, a loading plan, as well as a plan for the piping and cabling system (A.Hagen and S.O.Erikstad 2014). In addition, construction drawings are necessary for illustrating the longitudinal profiles of the steel structures as well as the mid-ship sections, decks, and bulkheads. Additionally, detailed construction drawings are essential, comprising meticulous engineering drawings specifically tailored for shipyard production sections. As part of the construction process, intricate construction plans are developed, as well as production instructions specific to the fabrication of panels, mechanical components, piping, and carpentry (Papanikolaou 2014 & A.Hagen and S.O.Erikstad 2014).

As a whole, these diverse drawings and plans serve as indispensable tools in the construction of a ship, facilitating the successful completion of each phase. Their purpose is to provide an overview of the layout of the ship, the distribution of equipment, and its loading logistics (Molland 2011) & (A.Hagen and S.O.Erikstad 2014)). A detailed understanding of the structural elements of the ship can be gained from the construction drawings, allowing the steel structures to be implemented precisely. Also, detailed construction drawings and plans play an important role in facilitating the production process within the shipyard, serving as blueprints for the various workshops. Shipbuilders can ensure an efficient and systematic construction process by using these specialised drawings and plans, which result in a vessel that is well-designed and functionally sound (Molland 2011).

Increasing productivity between shipbuilding's design and production phases and production phases of shipbuilding requires meticulous drawings, comprehensive plans, and efficient communication channels between foreign shipyards and Norwegian designers. In order to achieve optimal efficiency and acquire highly detailed drawings and plans, additional time should be set aside during the initial stages of ship design. As a result of this deliberate approach, the shipbuilding industry could enhance its competitiveness in the near future. During the production stage of the project, it is important to keep in mind that modifications to the drawings may arise that will trigger a cascade of changes across related drawings as a result (Molland 2011) & A.Hagen and S.O.Erikstad 2014).

In order to facilitate a seamless transition from design to production, it is important to emphasise the importance of detailed drawings and plans throughout the shipbuilding process (Molland 2011). The ability to communicate effectively between foreign shipyards and Norwegian designers is essential in order to ensure mutual understanding and alignment of objectives, thereby reducing potential errors and minimising rework. The provision of adequate time during the design phase will enable the identification and implementation of the most efficient solutions to be identified and implemented. Nevertheless, it is essential to recognise that during the production phase, alterations may be made to the original drawing, requiring the corresponding adjustments to be made to associated drawings in order to maintain coherence and consistency throughout the shipbuilding process (A.Hagen and S.O.Erikstad 2014, Papanikolaou 2014 & Molland 2011).

There are several factors that affect the nature of fabrication engineering work in shipbuilding, and these factors include skills, experience, and the cultural context of the shipyard involved in the project. Comparatively, a small shipbuilder in Northern Europe typically requires less detailed drawings for the fabrication than their counterparts in larger shipyards located in Asia, for example, who typically require more detailed drawings (A.Hagen and S.O.Erikstad 2014).

The central components of the work during all phases of section building, dock outfitting, and quay outfitting are meticulous drawings and comprehensive plans (Papanikolaou 2014). The requirement for highly detailed plans and drawings becomes imperative in the case of section building, which occurs in a foreign shipyard. This level of meticulousness must be maintained in order to maximise productivity, prevent misunderstandings, and prevent mistakes, which would otherwise result in prolonged lead times, increased workforce requirements, and additional costs. Furthermore, the level of detail in the drawings and plans may be more flexible and optional in Norway, where the dock and quay outfitting phases are executed by exceptionally skilled personnel (A.Hagen and S.O.Erikstad 2014) & (Molland 2011).

It is imperative that shipyards communicate detailed drawings and plans to foster efficient collaboration and minimise discrepancies, given the varied capacities and requirements of shipyards (Molland 2011). Providing comprehensive documentation to foreign shipyards can prevent ambiguities from developing, ensuring smooth operations and reducing the need for costly revisions. On the other hand, in Norwegian shipyards that employ highly qualified personnel, the level of detail in the drawings and plans may be adjusted according to the employees' level of expertise and proficiency (A.Hagen and S.O.Erikstad 2014). It recognises the differences in fabrication engineering work across shipyards and aims to optimise productivity and minimise unnecessary complexity through this adaptive approach.

2.4 Serial production in shipbuilding

Serial production is a cost-effective method for producing identical vessels in large quantities. In this method, shipyards streamline their production processes and reduce costs by standardising the design and construction of ships. Standardising the design reduces the risk of design errors, and the production process is more efficient (A.Hagen and S.O.Erikstad 2014).

Although serial production isn't a new concept when it comes to shipbuilding, technological advancements have enabled this concept to become even more prevalent in recent years. Shipyards can now produce identical vessels in large numbers more easily and accurately, thanks to the development of computer-aided design and production systems. Consequently, efficiency has been improved, costs have been reduced, and production times have been sped up, giving shipbuilders an advantage over their competitors.

Serial production may limit the ability to customise vessels. Considering the focus is on producing identical ships, there may be little room for customisation or modification to meet specific customer needs. While many shipyards have adapted serial production to cater to the needs of customisation, many have implemented options that provide some customisability within a standardised design. The use of serial production in shipbuilding has proven to reduce costs, improve efficiency, and provide a competitive edge.

A significant change in shipbuilding occurred during the Industrial Revolution of the 19th century. It was a labour-intensive process requiring a large amount of manual labour and skilled artisans before the Industrial Revolution. It was possible to build larger and more complex vessels due to the introduction of new technologies and machines, such as steam engines and iron plates. As a result, the shipbuilding industry was able to grow, paving the way for mass production methods (Koenig and Doerry 2018).

Shipbuilding was significantly impacted by the world wars of the 20th century. The demands of war forced shipyards worldwide to produce military vessels quickly and efficiently during World War I and World War II. As a result, mass production methods were widely adopted, enabling shipyards to produce ships faster and more effectively than ever before. Due to the knowledge gained from these conflicts, the modern shipbuilding industry is heavily reliant on mass production methods in order to construct ships quickly and efficiently (Koenig and Doerry 2018).

Erichsen 1994 discussed the effect of repetition or learning, as he called it, on shipbuilding while building the ships. Erichsen 1994 defines learning as "*the ability to do the same tasks faster and better as experience is gained–has the effect of reducing time and money spent on repetitive building of the same type of ship*". Building a series of identical ships can reduce construction time and cost. In most cases, building the first ship in a series takes the longest because the design and construction process must be tested and refined. In the series, shipbuilders gain experience and become more efficient once they build more vessels of the same type. As a result of this learning process, each successive ship in the series can be constructed in a significantly shorter period of time and at a lower cost (A.Hagen and S.O.Erikstad 2014 & Erichsen 1994.

Also, the use of common components and materials across the entire series of ships will be able to reduce the overall construction cost and build time of each ship by a significant amount. It is possible for shipbuilders to streamline the manufacturing process by standardising the design and production process, improving efficiency and reducing the time spent on design and engineering. Economies of scale are thus more easily achieved, and pricing is more competitive due to lower materials and labour costs (A.Hagen and S.O.Erikstad 2014).

Improving quality control by building a series of identical ships is also possible. By identifying and addressing any defects and issues that arise during the construction process, shipbuilders can continue to improve the design and production of future vessels in the series. Consequently, the performance and reliability of the ships can be improved for customers who purchase them, resulting in higher levels of consistency and quality across the entire series (A.Hagen and S.O.Erikstad 2014).

Obtaining better efficiency and productivity in shipbuilding requires learning through experience (Erichsen 1994). Through experience, shipbuilders gain the necessary knowledge and skills to complete a particular type of ship more quickly and efficiently (A.Hagen and S.O.Erikstad 2014). In the shipbuilding industry, "learning by doing" is used to describe the process by which shipbuilders acquire knowledge through practical experience (Erichsen 1994).

Shipbuilding offers a number of benefits. With increased skills and knowledge, workers are able to perform their tasks more efficiently, resulting in a reduction in the amount of time spent on production and the cost of production (Erichsen 1994 & A.Hagen and S.O.Erikstad 2014). Moreover, as workers become more adept at identifying and correcting errors in the production process, the quality of the finished product tends to improve. By continuously learning and improving shipbuilders' skills and knowledge, shipbuilding companies can increase their productivity, efficiency, and quality (A.Hagen and S.O.Erikstad 2014).

2.4.1 Factors that influence serial production in shipbuilding

In the shipbuilding industry, many factors that affect serial production are closely aligned with those that influence ship design and fabrication phases. Some of these factors, according to (Erichsen 1994 & Moyst and Das 2005), are cost, project conditions, market conditions, design and procurement, construction management, Labour, government policy and education and training.

2.4.1.1 • Costs: There is no doubt that costs play an important role in the serial production of ships, and they can affect the entire production process in a significant way. Serial production building in shipbuilding is primarily affected by costs associated with procuring raw materials and components. Several raw materials are expensive, such as steel and aluminium, and the price of these materials can have a major impact on the cost of the ship in the long run. In serial production, engine and navigation systems can also be costly, and their cost can add up quickly, especially with many ships produced at once. To ensure that the final product is affordable and competitive on the market, cost-effective procurement strategies must be implemented (Erichsen 1994 & A.Hagen and S.O.Erikstad 2014).

Serial production building in shipbuilding can also be affected by cost through the use of technology and automation (A.Hagen and S.O.Erikstad 2014). In spite of the fact that automation can significantly reduce labour costs and increase production efficiency, the implementation of automated systems and software can be costly (A.Hagen and S.O.Erikstad 2014). As a result, shipyards need to weigh the costs and benefits of automating their operations and decide whether or not the investment is worth it.

The workforce can impact the cost of the serial production building. In the shipbuilding industry, skilled workers are essential, but hiring and training them can be expensive, like in Norway (A.Hagen and S.O.Erikstad 2014 & Erichsen 1994). There can be an even greater need for skilled labour in serial production, making the cost of hiring and training workers a significant factor in the overall cost. It is, therefore, imperative that shipyards have a skilled workforce in order to carry out the production process efficiently and that the cost of training and hiring workers are incorporated into the overall cost of the vessel (A.Hagen and S.O.Erikstad 2014).

Last but not least, the pricing strategy of the final product can affect serial production building in shipbuilding. The ship's final price must be competitive on the market, and the shipyard must consider all costs associated with the production process when determining the final price (A.Hagen and S.O.Erikstad 2014). Consequently, if the production costs are too high, the final price may not be competitive, which can adversely affect sales and revenue for the shipyard. To ensure that the shipyard is profitable and competitive, proper cost analysis and pricing strategies should be implemented (A.Hagen and S.O.Erikstad 2014).

2.4.1.2 • Project conditions (e.g., site layout, weather variability) Serial production in the shipbuilding industry is crucially dependent on project conditions such as a site's layout and weather variability. A site's layout has a significant impact on the flow of work, the accessibility to various production processes, and the coordination of those processes (Moyst and Das 2005). An effective site layout streamlines materials, equipment, and personnel movement, reducing delays and inefficiencies. The opposite can also occur if the layout of the site needs to be better planned, resulting in bottlenecks, congestion, and disruptions, which adversely affect the production schedule as a whole (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014).

Furthermore, weather variability poses significant challenges to the serial production of ships in the shipbuilding industry (Moyst and Das 2005). Weather conditions affecting production schedules, hindering the transportation of materials, and affecting outdoor operations, such as storms and heavy rains, can disrupt the production schedule (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014). It is important to note that delays resulting from inclement weather can cascade throughout subsequent stages of production, causing costly disruptions to the overall production process. The impact of weather variability on serial production must be properly considered, contingency plans developed, and measures implemented to ensure uninterrupted progress and timely delivery of vessels (Moyst and Das 2005).

2.4.1.3 • Market conditions (e.g., material shortages, lack of experienced design and project management personnel) In the shipbuilding industry, market conditions have a significant impact on serial production, and factors such as material shortages and a lack of experienced designers and project managers can cause significant delays (Moyst and Das 2005). The supply chain can be disrupted by material shortages, which can cause production delays. Almost any production process can be slowed down or halted if key materials needed for ship construction are not readily accessible. This can lead to increased costs, prolonged production times, and bottlenecks (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014). Material shortages can be mitigated by closely monitoring market conditions, establishing strong supplier relationships, and exploring alternative sourcing options.

As a second point, the availability of experienced designers and project managers plays a direct role in serial production. Professionals with specialised knowledge and skills in the field of naval architecture, engineering, and project management are required for the execution of shipbuilding projects (Moyst and Das 2005). As a result of a shortage of these professionals, design development may be delayed; coordination issues can arise, as well as inefficiency in the production process. To ensure a sufficient supply of skilled personnel who can effectively manage and execute serial production projects, shipbuilders should invest in talent acquisition, training programs, and retention strategies (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014).

A shipping industry's competitiveness can also be affected by market conditions, which, in turn, impact serial production. Various factors influence the frequency and volume of orders, including intense competition and pricing pressures. It may be challenging for shipbuilders to maintain continuous serial production if market conditions are unfavourable. For shipbuilders to maintain a steady flow of orders and sustain serial production capabilities, it is essential to monitor market trends closely, diversify their offerings, and develop strong relationships with their customers (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014).

2.4.1.4 • Design and procurement (e.g., design changes) Serial production in the shipbuilding industry is significantly affected by design and procurement decisions, particularly when it comes to changes in the design of the drawings, as mentioned in (Section 2.3). Modifications to a design can complicate and delay the manufacturing process, causing delays in production and affecting efficiency (Moyst and Das 2005). Changes to the design during serial production often require adjustments, rework, and redistribution of resources. As a result of these changes, the established production process can be disrupted, which can lead to delays in production, as well as possible clashes with existing components or systems. A seamless integration of design changes into the ongoing production process requires effective coordination and communication between the design and production teams.

2.4.1.5 • Construction management (e.g., ineffective communications, inadequate planning and scheduling, lack of sufficient supervisory training) Construction management is a critical component of serial production in the shipbuilding industry, and factors such as ineffective communications and inadequate planning and scheduling can negatively impact production efficiency (Moyst and Das 2005). When communication is ineffective, instructions can be misinterpreted, decisions can be delayed, and coordination issues can occur between the various teams involved in the construction project. Having clear and efficient communication channels is essential to the efficient transmission of information, the resolution of concerns, and the smooth collaboration between different departments (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014). A serial production process can be disrupted and delayed if there is poor communication, resulting in errors, misunderstandings, rework, and delays, as well as interruptions and delays along the way.

The overall production flow can also be adversely affected by inadequate planning and scheduling. An inadequate planning process can result in inadequate resource allocation, such as labour, equipment, and materials, resulting in delay and inefficiency (Moyst and Das 2005). It is possible for production stages to overlap or experience bottlenecks if a construction plan has yet to be defined and realistically outlined. A lack of adequate scheduling may also result in a lack of coordination among different tasks and processes, further exacerbating the delays and preventing the completion of serial production (A.Hagen and S.O.Erikstad 2014). In order to maximise production efficiency, shipbuilders must implement robust planning and scheduling techniques, ensuring the proper sequencing of tasks, accurate estimations of resource requirements, and proactive identification of risks and constraints (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014).

2.4.1.6 • Labour (e.g., restrictive union rules) A critical component of the efficiency and success of serial production within the shipbuilding industry is the role that labour plays in determining its efficiency and success. There is a direct correlation between the speed and quality of production and the availability of skilled workers, such as welders, fitters, and painters (A.Hagen and S.O.Erikstad 2014). As a result of a shortage of skilled workers, projects can be delayed and more expensive to complete, as project deadlines cannot be met and a steady production flow cannot be maintained (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014). In contrast, a well-trained and adequately staffed labour force will ensure that the production process will run efficiently while ensuring that ships will be completed in time and that assembly lines will run efficiently.

It is imperative that shipbuilders maintain high standards through the use of their expertise and experience. In addition to bringing valuable knowledge and craftsmanship to their respective tasks, skilled workers result in superior-quality vessels (Moyst and Das 2005). A variety of skills and attention to detail are required at each stage of the production process, from the construction of the hull to the interior fitting. Competent workers are able to execute complex tasks with precision, which ultimately results in the production of a structurally sound and reliable vessel (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014). Further, effective communication is promoted, errors are minimised, and productivity is maximised through well-coordinated teamwork between the workers, which enables the shipyard to meet market demands and achieve optimal serial production.

2.4.1.7 • Government policy (e.g., slow approvals and the issue of permits) There has been a significant impact on the serial production of ships in the shipbuilding industry due to government policies involving slow approvals and the complexity of obtaining permits (Moyst and Das 2005). These policies hinder shipbuilding companies in terms of efficiency and productivity due to the barriers and delays they encounter. Due to the lengthy approval process, businesses may have to wait a long time before beginning a project. It can also be very time-consuming and difficult to obtain permits for specific activities, such as environmental clearances. Due to these delays and uncertainties, serial production cannot run smoothly, causing deadlines to be missed, orders not to be fulfilled, and production rates to be inconsistent (Moyst and Das 2005

& A.Hagen and S.O.Erikstad 2014). It may result in reduced competitiveness and profitability for the shipbuilding industry, ultimately affecting job creation and economic growth. It may be possible to reduce these challenges and support the growth of serial production in the shipbuilding industry by streamlining approval and permit procedures.

2.4.1.8 • Education and training (e.g., the lack of management training for supervision and project management) A successful industry, including shipbuilding, relies heavily on education and training. Serial production in the shipbuilding sector can be negatively affected by a lack of management training for supervision (Moyst and Das 2005). Achieving smooth operations and timely delivery requires effective management and supervision of shipbuilding's complex processes. Unless supervisors receive proper management training, they may experience difficulty allocating resources, coordinating teams, and dealing with production challenges (A.Hagen and S.O.Erikstad 2014). As a result, serial production can be impacted by inefficiency, errors, and delays, negatively impacting its efficiency and quality. By providing supervisors with the necessary skills and knowledge, comprehensive management training programs can assist them in managing production processes, optimising resources, and enhancing productivity in shipbuilding (Moyst and Das 2005 & A.Hagen and S.O.Erikstad 2014).

Summary of Literature Review

Several topics have been discussed throughout the literature review to gain a deeper understanding of the shipbuilding process. In shipbuilding, ship design and production require meticulous attention to detail and strict standards. A vessel is created by conceptualising, engineering, and integrating various systems and components. This complex industry requires continuous innovation, technological advancements, and streamlined operational efficiencies to stay competitive. Maintaining a competitive edge can be achieved by adopting serial production methods.

Design is the process of producing efficient and high-quality drawings as a result of the design phase. As a part of the ship design process, drawings are used to represent and blueprint the intended ship design. A lot of specifications, dimensions, and configurations are included in a ship's design drawing in terms of its structure, systems, and components. The accuracy and precision of these drawings are essential since they serve as a reference for fabrication, assembly, and installation. When shipbuilders ensure their drawings are of excellent quality, they are able to minimise errors, streamline production processes, and achieve a higher level of accuracy and consistency throughout the entire process.

In the fabrication phase, a lot of action takes place, and different factors can have a negative impact on the production process. A factor that may cause conflict is the occurrence of changes in the drawings, which can alter the results of previous stages. In particular, this is a problem when the revised drawings differ from the original drawings. It is very likely that delays, reworks, and higher costs can be incurred if there is an alignment problem between the revised drawings and the earlier stages. In order to mitigate these issues and maintain a smooth production process, the fabrication engineering team, designers, and other stakeholders must collaborate effectively in order to save time and costs.

Serial production is widely adopted in the shipbuilding industry as a method of reducing costs and construction time for each ship in a series. It is possible for shipbuilders to achieve economies of scale, optimise resource utilisation, and remain competitive by standardising their design, engineering, and manufacturing processes. As a result of replicating the construction process for every ship in the series, shipyards are able to streamline operations, improve efficiency, and reduce labour requirements. As well as facilitating knowledge transfer, serial production enhances productivity by utilising lessons learned from previous ships. In the end, shipbuilders are able to provide more competitive pricing and faster delivery schedules through this approach.

3 How does ship design affect ship production & How does ship production affect ship design?

The ship production process is significantly influenced by the design choices during the shipbuilding phase. It is essential to acknowledge that the complexity of a vessel's design can hinder its manufacturability, leading to practical limitations or even rendering production unfeasible. Therefore, it is of utmost importance to prioritise the consideration of manufacturing feasibility right from the outset of ship design. This entails detailed deliberation on crucial aspects such as the fixed hull size and type, engine power requirements, degree of outfitting, and overall arrangement of components. The decisions regarding these elements hold considerable sway over the overall build costs, primarily by determining the scope and extent of necessary equipment, materials, and labour. Hence, in order to maximise productivity and optimise resource utilisation, it is imperative to make well-informed decisions during the early stages of the ship design phase, setting the trajectory for successful production outcomes.

Shipbuilders and designers can lay a solid foundation for enhanced productivity throughout production by emphasising early decision-making in the ship design phase. Careful consideration of the fixed hull size and type is instrumental in ensuring compatibility with manufacturing capabilities and limitations. Likewise, a thoughtful assessment of engine power requirements allows for selecting an appropriate and feasible propulsion system. Furthermore, determining the degree of outfitting and general arrangement of components provides valuable insights into the construction's labour, material, and equipment needs. These decisions are critical in shaping the overall build costs and resource allocation. Stakeholders can effectively streamline the production process by proactively addressing these considerations during the ship design phase, optimising efficiency and ultimately leading to a more productive and cost-effective shipbuilding endeavour.

As described in the previous chapter, drawings, as the result of the ship design phase, are the link between ship design and ship production. Therefore, drawings are the most critical factor affecting the ship production phase. It is common for some changes to the drawings to be made during the ship production phase. However, significant changes will adversely affect the ship production phase, where many parts will need to be reworked, resulting in higher labour costs and possible delays. Drawings must be as detailed as possible and contain a minimum number of errors/omissions before starting manufacturing to ensure efficient production.

Many fabrication phases rely on the drawings that come out as the results of the ship design phase in order to proceed according to A.Hagen and S.O.Erikstad 2014. Figure 9 shows the relationship between the drawings that we get as results of the ship design phase and fabrication phases.

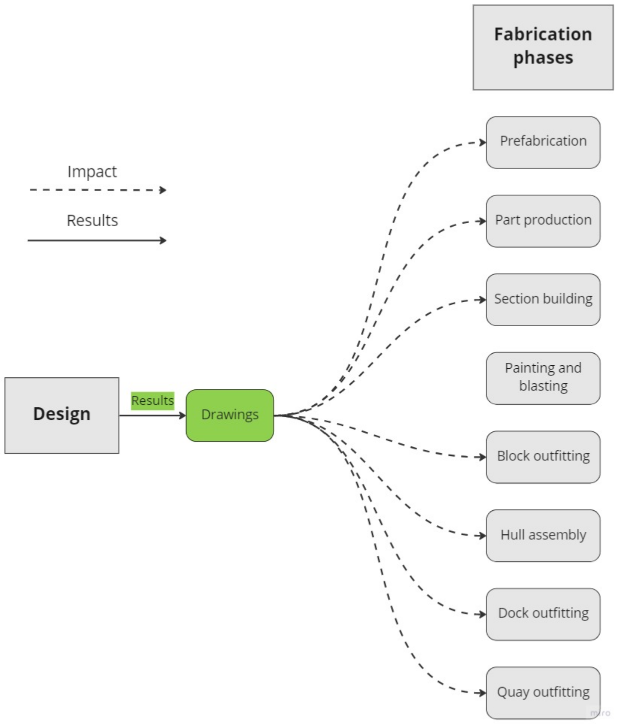


Figure 9: The relationship between drawings and fabrication phases according to (A.Hagen and S.O.Erikstad 2014).

On the other hand, ship production can have an impact on ship design. It is important to keep in mind that the size of the shipyard that is building the vessel will have an effect on its design. The facilities in the shipyard and their equipment will also affect the vessel's design. During the ship design phase, the vessel is divided into blocks, and this decision is influenced by the size of the shipyard as well as the equipment they possess for constructing those blocks (for example, machines and crane capacity).

In the same way that production affects design, design affects production. In conclusion, the design will have the greatest impact on production.

4 Research Methodology

4.1 Research Model

A novel research model was meticulously constructed as part of this project by incorporating relevant model fragments. Given the need for a comprehensive model in the existing literature review, this study aimed to develop a comprehensive understanding of the intricate relationship between ship design and ship production. For a more comprehensive and academic investigation, Figure 10 was used specifically as a tool to explore how ship design-derived drawings and plans affect fabrication phases, namely section building, dock outfitting, and quay outfitting.

This project aims to enhance the scholarly approach to studying the impact of ship design on subsequent fabrication stages by developing this research model. Figure 10 allows a more detailed examination of how drawings and plans originating from ship design can impact critical aspects of production. This academic endeavour aims to illuminate the intricate interaction between ship design and fabrication, thus contributing to a deeper understanding of shipbuilding.

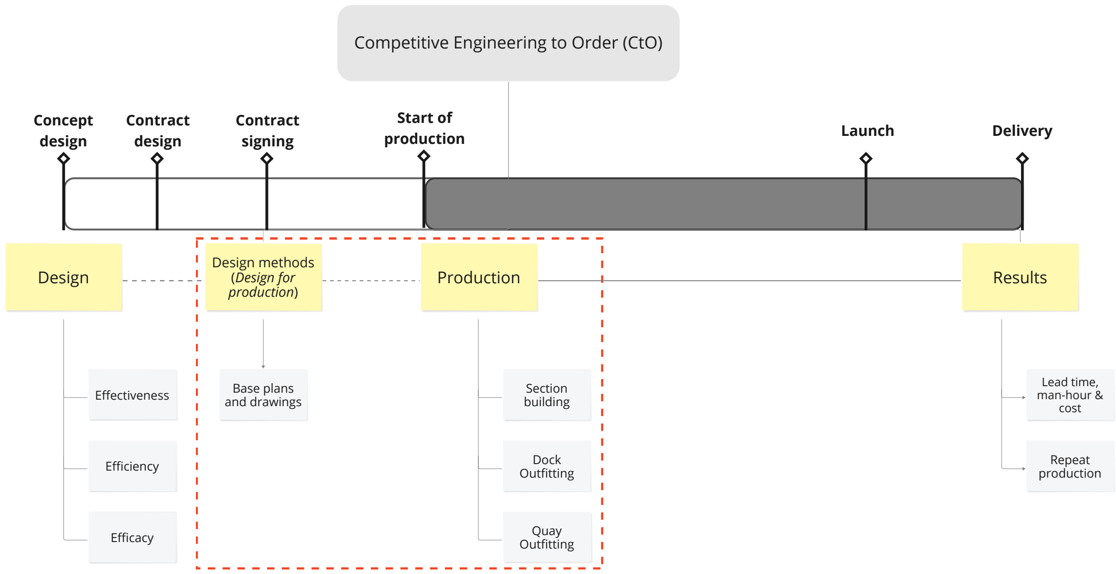


Figure 10: Proposed investigative model.

Figure 10 shows the design phase on the left, followed by the design methods (design for production), where the results of the design phase are translated into drawings and plans that will be used during fabrication (fabrication phases). Based on (Semini, Dag E Gotteberg Haartveit, Alfnes, Arica, Per Olaf Brett and Strandhagen 2014) and (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018), a timeline for both ship design and ship production was developed.

The proposed framework introduces a competitive engineering-to-order (CtO) model that encompasses the entire product life-cycle, commencing with the design phase and progressing towards design methods such as "design for production." Within this framework, the design phase yields an actual output in the form of drawings and plans, which subsequently inform the production or fabrication phases. Through the application of this comprehensive framework, numerous crucial factors can be analysed, including lead time, man-hours, costs, and the potential for repeat production. Furthermore, the framework enables an evaluation of the overarching objectives in relation to lead time and cost while also providing a valuable foundation of experiential knowledge that can be leveraged for future instances of repeat production. This academically-oriented framework empowers researchers and practitioners to gain deeper insights into the engineering-to-order process, fostering informed decision-making and enhancing overall operational efficiency.

The primary objective of the master's thesis revolves around investigating the relationship between design methods, specifically design for production, and the subsequent production stage, encompassing various fabrication phases. A comprehensive exploration of this link is essential to explore avenues for optimising the ship design-production connection, thereby minimising lead time, reducing the number of man-hours required for ship production, and optimising the overall ship construction cost. The central question guiding the upcoming semester's research is understanding how to design effectively for production. Leveraging the anticipated data from Ulstein AS, the study aims to delve deeply into the subject matter, enabling a thorough analysis to discern the influence of detailed or undetailed drawings and plans on the production process. By addressing these research objectives, the thesis endeavours to contribute to the existing academic knowledge and provide valuable insights into enhancing the ship design-production interface.

4.2 Interview with Ulstein

The main objective of this study is to enhance understanding of the concept of series production, specifically as it pertains to shipbuilding. As a means of achieving this goal, it was an ideal time to conduct an unstructured interview with Per Olaf Brett, a representative of the Ulstein Group, whose name is synonymous with shipbuilding and who serves as my co-supervisor in this study. This interview was held over Teams on the 24th of May. The interview provided me with valuable information that enabled me to gain a deeper understanding of series production within the shipbuilding industry. The interview with Per Olav, my interviewee, who has extensive experience in this field as a long-term professional at Ulstein, provided me with valuable insight into the intricacies and nuances of series production in shipbuilding.

The interview provided me with the opportunity to discuss some questions regarding what I have found in my data. Those questions were:

- *Why do the second and third ships in a series take more time to build than ship number one?* As a result of the learning phase during the building process, ship number two takes more time than ship number one. This is because they will gain experience while building the first ship. In addition, they tried to fix some mistakes made during the first ship's construction. It is normal for CAPEX (Capital expenditures) and building time for ship number two to increase in some cases (there are some cases in Ulstein where the second ship takes less time than the first), but not for ship number three.

- *What is the most appropriate number of ships in a series production for a shipyard if they want to make money from it? (Repeat production effect*)

  There is no accurate answer to the most appropriate number of ships in series production for a shipyard.

- *Does it make more sense for the shipyard to build only one ship rather than two or three if it always takes time to build the second and third ships?*

  Building sister ships for shipyears is always economically beneficial.

5 Data Analysis

5.1 Data Collection and Processing

5.1.1 *Data Collection:*

It is the purpose of this chapter to present the data that has been used for this project. Initially, there was a plan to obtain data from Ulstein Company, but by the end, it became clear that we could not obtain any data from them due to their privacy policies and policies regarding their system. Based on Marco's advice, I investigated some data for shipbuilding in SeaWeb, one of the open-source databases for most of the world's ships.

Sea-web™: The ultimate marine online database:

Global maritime industry information is provided by SeaWeb, the ultimate marine online database. Ship owners, operators, maritime professionals, and researchers can benefit from SeaWeb's extensive features and vast database of vessel data (SeaWeb™ 2023).

The vast amount of information about vessels that SeaWeb contains is one of its key strengths. As well as covering a wide range of maritime sectors, it covers a large amount of information regarding merchant vessels, offshore installations and ports. In addition, users are able to access detailed information about the technical specifications of ships, the ownership, the classification, and historical data, which enables them to make better decisions regarding the selection of vessels, the analysis of the market, and the assessment of risks. The SeaWeb provides an array of accurate and reliable data for the purpose of tracking the movement of a specific vessel or conducting market research on the different types of vessels available (SeaWeb™ 2023).

5.1.2 *Data Processing*

There were three main companies for which the data was collected: Ulstein and Vard from Norway and Damen from the Netherlands. The Norwegian shipbuilding industry is represented by Ulstein and Vard, and the European shipbuilding industry is represented by Damen, a high skilled shipbuilding company. It was these companies that provided the majority of the data collected for this study. The following Table 1 summarises the characteristics of the Excel files collected,

Table 1: Characteristics of the collected Excel files

File Name	File Size	Rows x Columns	Time Span	File Downloaded
Ulstein	359KB	138 x 14	August 2000 - July 2022	27.04.2023
Vard	480KB	83 x 14	April 2012 - April 2022	05.05.2023
Damen	317KB	40 x 14	June 2005 - August 2014	05.05.2023

Data selection was limited to the categories of OSVs (Offshore Support Vessels) and PSVs (Platform Supply Vessels). It was decided to select these types of vessels based on their prominence in Norway, where they are widely used. Norway is recognised for its expertise in the construction and manufacture of OSVs and PSVs. Data collection was specifically targeted to these types of vessels in order to gain a comprehensive understanding of the Norwegian shipbuilding industry's primary focus and strengths. Having focused on OSVs and PSVs, the data analysis will provide valuable and detailed information about Norway's renowned shipbuilding industry.

Table 2: The number of ships and serial production of each shipbuilding company

Shipbuilding Company	Country	nr. of ships	nr. of Series Production of ships
Ulstein	Norway	59	12
Vard	Norway	14	3
Damen	The Netherlands	15	3

Table 2 displays the number of ships that have been selected for the purpose of this study. These ships are all being manufactured in series production. In the study of the analysis, a total of twelve distinct Ulstein series were scrutinised across five different designs. Additionally, the study encompassed an investigation of three different Vard series applied to three distinct designs. Furthermore, the examination also incorporated varying Damen series implemented in three different designs.

A focus was placed on how long it would take to build the ship according to the available data during each phase of the production process in this study. The dates for building a ship were very limited in SeaWeb. The dates included those when the ship was on order/not commenced when the keel was laid, when it was launched, and when it was put into service/commissioning. Due to the lack of available data, certain assumptions had to be made in the course of the analysis. The initial assumption involved estimating the building time by considering the time interval between the launch date and the date of keel laying. Based on (Semini, Per Olaf Brett, Arnulf Hagen, Kolsvik, Alfnes and Strandhagen 2018), the production steps are as follows: steel block construction, block outfitting, ship assembly, dock outfitting, lunch, quay outfitting, commissioning and testing, and delivery. The second assumption pertained to the duration of commissioning and testing activities, which was estimated based on the time span between the in-service date and the launch date. These assumptions were necessary due to the limited information at hand, enabling the establishment of reasonable approximations for the respective timeframes. The following Table 3 shows an example of how data appears in SeaWeb for the four dates mentioned above.

Table 3: An example of the dates for the ship construction in SeaWeb

2012-05-31	In Service/Commission
2009-08-26	Launched
2008-12-30	Keel Laid
2007-09-09	On Order/Not Commenced

Ulstein

The Ulstein Verft shipyard in Norway is an internationally recognised shipyard that specialises in shipbuilding and offshore construction. In the maritime industry, Ulstein Verft has established itself as a leading player over the course of over 100 years. In addition to offshore support vessels, expedition cruise ships, and specialised work-boats, the shipyard specialises in the construction of advanced and innovative vessels. With its state-of-the-art facilities and skilled workforce, Ulstein Verft demonstrates its commitment to quality, efficiency, and sustainability (Ulstein 2023).

With a total of twelve serial production numbers studied throughout the study, Ulstein has the highest number of serial production numbers that have been examined. It is considered that those series are made up of five designs in total. PX105, PX121, SX124, SX175 and SX195 are the designs. In some cases, these series have been completely constructed overseas, while in others, they have been built with a combination of work being done abroad in China, for example, and the remainder being done in Norway.

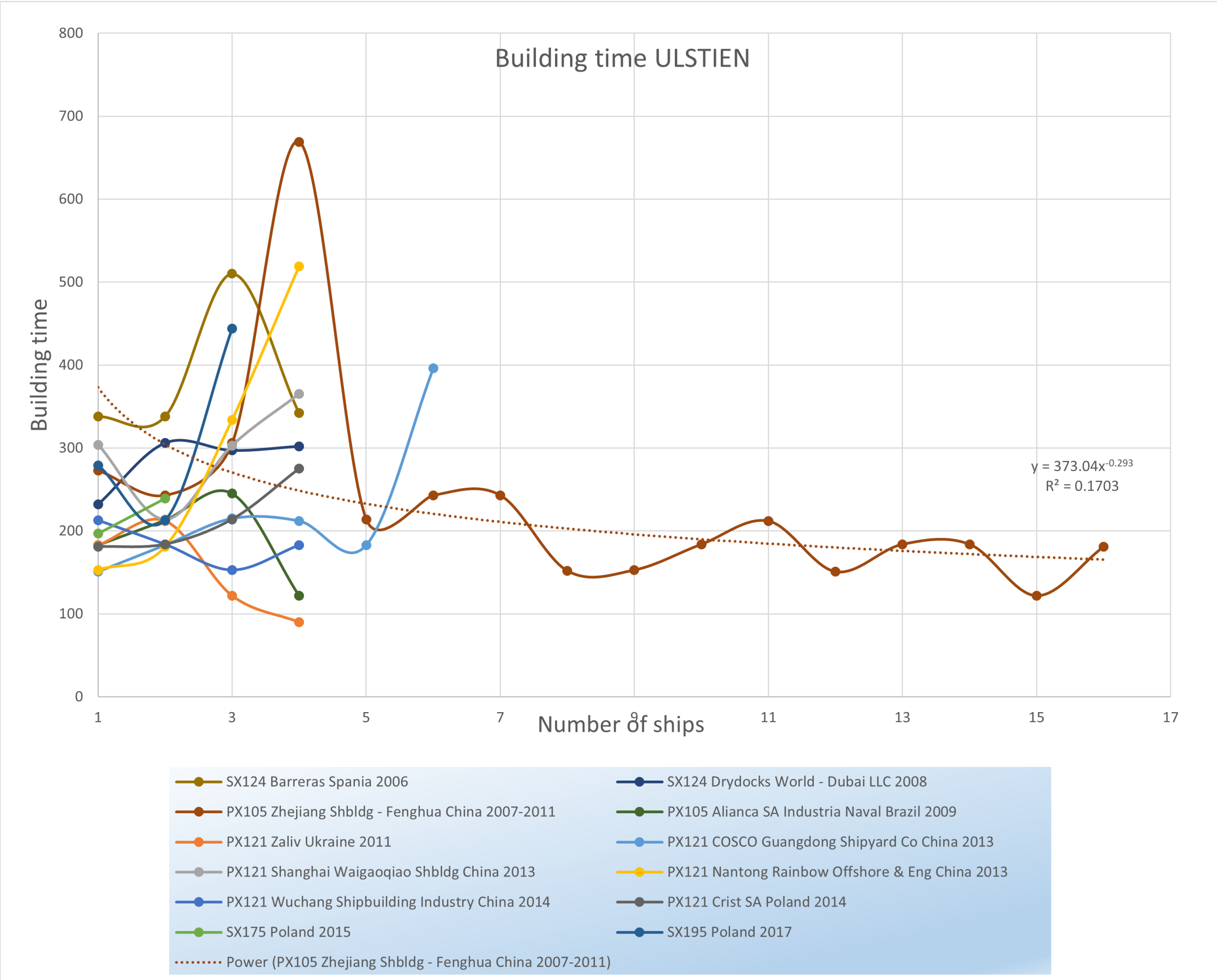


Figure 11: Building time graph for the twelve series production in Ulstein

On Figure 11, the building time of the series production specifically selected for this study is displayed as a graph, providing a visual representation of the length of time required for construction. Based on the research conducted, the graph serves as an extremely useful tool for analysing and understanding the duration of the selected series. It is shown in Figure 11 how many hours it takes to build each ship in series production, showing the time it took to construct each ship.

It has been shown that most of the second ships in each series takes a longer time to build than the first ship in each series. Most of the series shown in the figure above show that the third ship in a series takes longer time to build than the first and second ships, as well as demonstrating that in some cases, the fourth ship in a series will take less time to build than the third and second ships.

As a result of a close examination of the longest series shown in Figure 11, a discernible pattern emerges, which indicates progress in the reduction of construction time up until a threshold is reached, after which no further reduction in construction time can be observed. As a result, this has to be a normal result in a long-run series production, according to (Erichsen 1994, Semini, Per Olaf Brett, Strandhagen and Vatn 2022 & A.Hagen and S.O.Erikstad 2014)

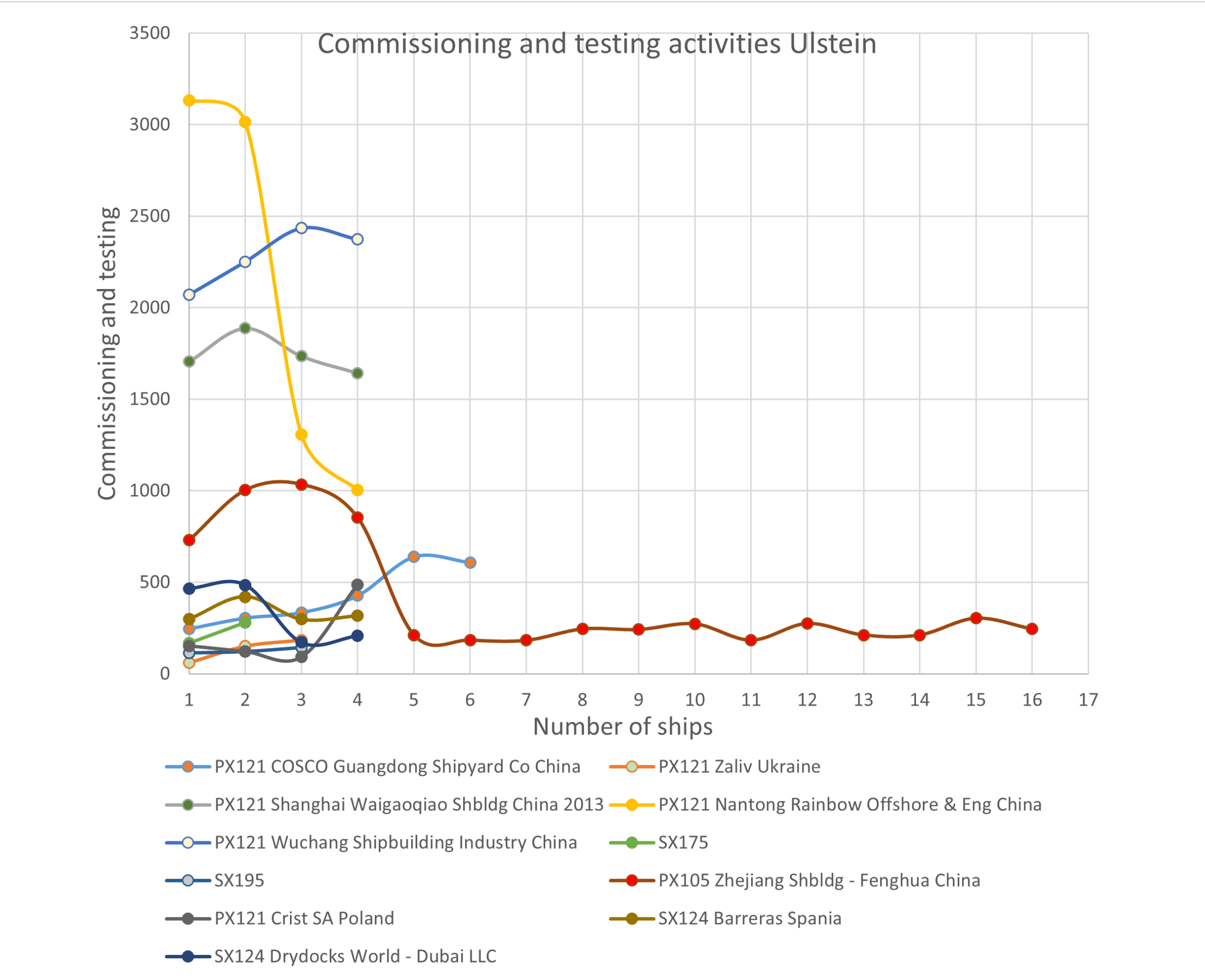


Figure 12: Commissioning and testing activities time graph for the twelve series production in Ulstein

Figure 12 shows and represents the duration of the commissioning and testing phase carried out in Ulstein for the twelve series production units. As I observe the data, certain series appear to exhibit a substantial amount of time during this phase; however, the reasoning behind such extensive durations remains unclear to me, causing me to exclude these series. Following the removal of the aforementioned series from the graphical representation, the resultant Figure 13 presented below accurately reflects the analysed data.

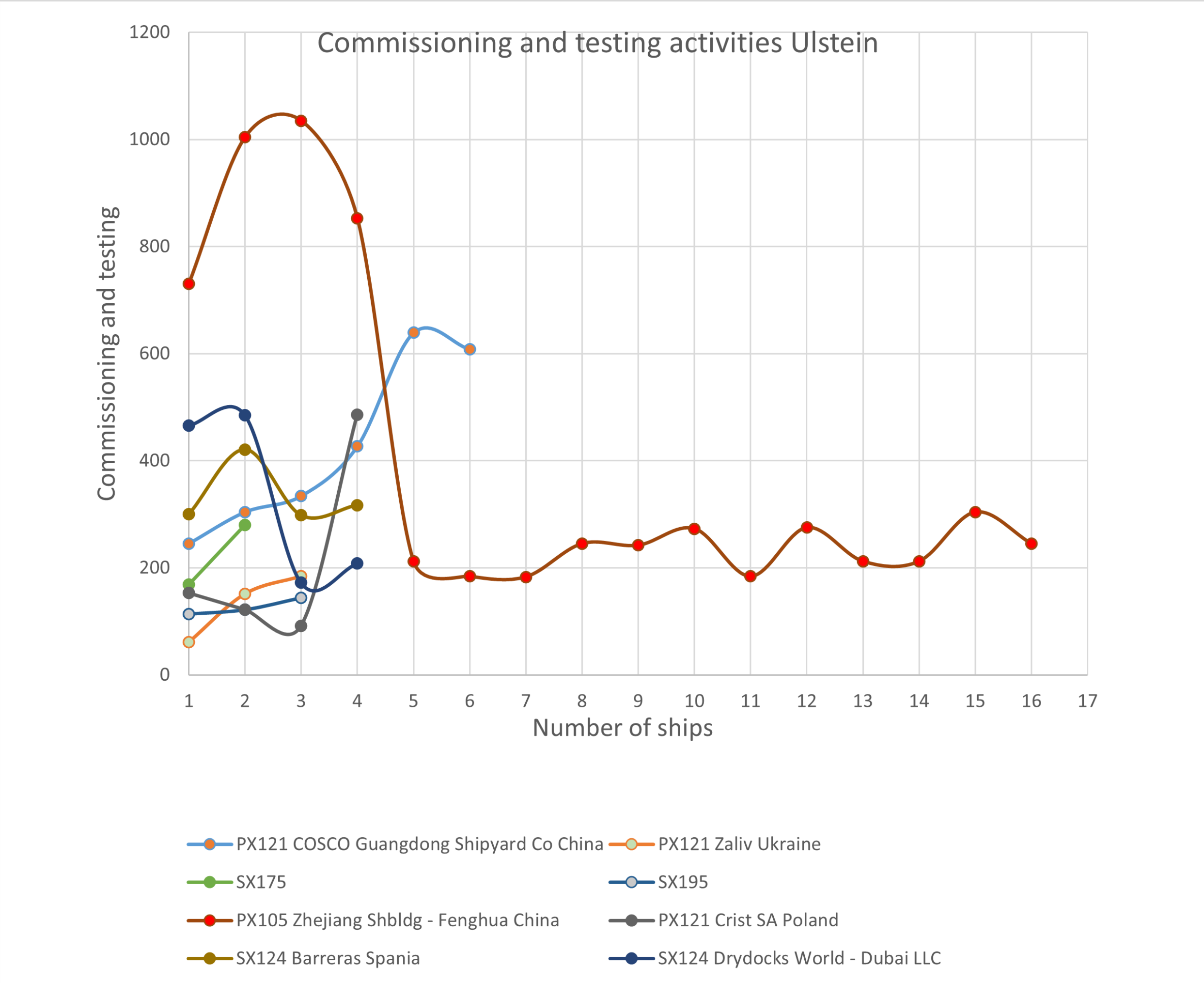


Figure 13: Commissioning and testing activities time graph in Ulstein

Through an examination of Figure 13, it becomes evident that the second and third ships underwent a more protracted commissioning and testing period compared to the initial ship. Furthermore, an observation of the longest series depicted in the figure reveals a declining trend in temporal requirements as the number of ships increases.

Vard

Vard Shipyard is a prominent shipyard in Norway that specialises in shipbuilding and offshore construction. With a long and distinguished history, Vard Shipyard has established itself as a leader in the maritime industry. The shipyard builds various vessels, including offshore support vessels, fishing vessels, luxury yachts, and specialised naval vessels. With its state-of-the-art facilities and highly skilled workforce, Vard Shipyard can deliver cutting-edge, technologically advanced ships to its clients worldwide (Vard 2023).

In the study of Vard, we focused our research on the same temporal domain of vessels that were examined in the Ulstein study as well. Most of the vessels scrutinised were offshore supply vessels (OSV) and platform supply vessels (PSV). Consequently, our inquiry yielded the identification of three series productions comprising two distinct designs, namely Vard 108 and Vard 9 60. Every vessel examined for Vard during our study was constructed outside of Norway.

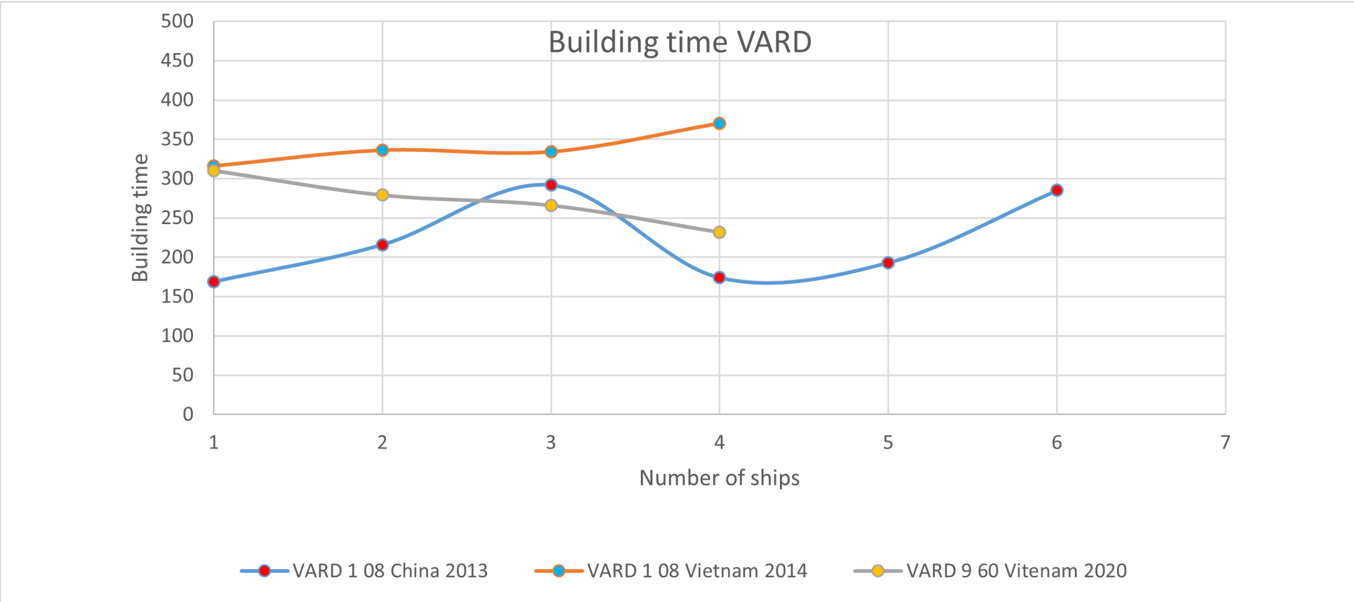


Figure 14: Building time graph for the three series production in Vard

It has also been shown in Figure 14 for Vard that most of the second ships in each series take longer to build than the first ship in each series. It has also been shown for Vard that most of the second ships in each series take longer to build than the first ship in each series. As for the third ship was quite different from what was found for Ulstein, where the third ship took a long time in one series of three. Furthermore, Vard 9 60 - the most recent series production built-in 2020 - shows superior repeatability when compared to the previous series productions. It is likely that there has been a change in their production methodology or that they have learned from previous series, which has contributed to the improvement of repeatability.

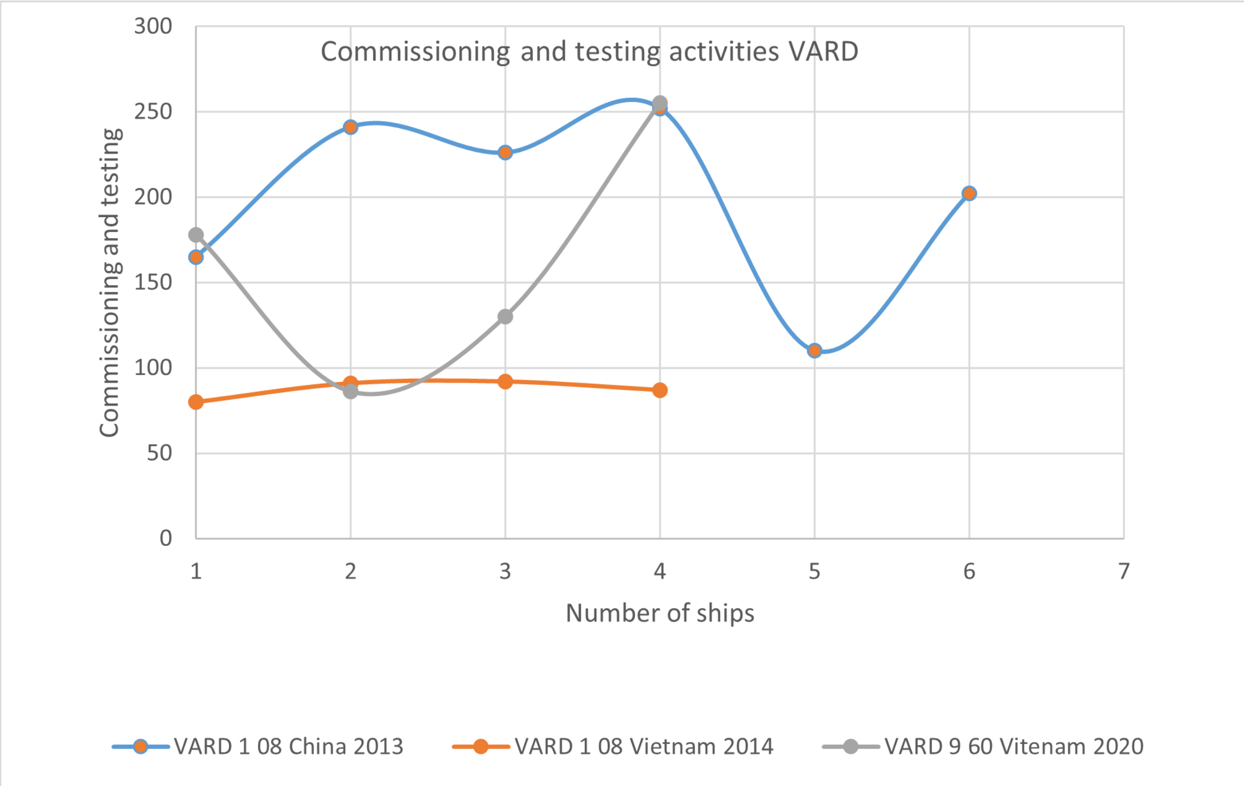


Figure 15: Commissioning and testing activities time graph in Vard

Upon examining the commissioning and testing duration in Figure 15 across three series productions within Vard, it becomes evident that the second ship in the 2013 and 2014 series incurred a longer timeframe compared to the first ship. However, in the most recent 2020 series, an inverse pattern emerges, as the commissioning and testing duration for the second ship demonstrates a reduction in contrast to the first ship.

Damen

It is a well-known and globally recognized shipbuilding company with a rich history that spans over nine decades; Damen Shipyards is one of that company. With its diverse portfolio of vessel types and comprehensive shipbuilding services, Damen has evolved into one of the leading players in the maritime industry. Innovating, providing quality craftsmanship, and exceeding customer expectations are the shipyard's hallmarks. A wide range of Damen's vessels are available worldwide, including offshore support vessels, dredgers, naval ships, ferries, and yachts (Damen 2023).

Our comprehensive study deliberately incorporated Damen Shipyard as the most recent addition to our research investigation. Our rationale behind this decision stemmed from recognising that including a European shipyard would contribute valuable insights to our comparative analysis, particularly in discerning potential disparities in series production practices between European shipyards and those in Norway. By including Damen Shipyard in our study, we aimed to expand the breadth of our research scope, facilitating a comprehensive evaluation of building methodologies within the European shipbuilding landscape. Through this approach, we sought to enhance the scholarly understanding of the nuances and variances in series production techniques and outcomes across European geographical contexts.

In this study, we conducted an in-depth analysis of three series production for Damen Shipyard. These series encompassed OSV (Offshore Support Vessel) and PSV (Platform Supply Vessel) vessels, sharing a common scope. Consequently, we arrived at three distinct designs: the Damen PSV 7216, Damen PSV 4500, and Damen PSV 3300. The majority of the vessels investigated fell within these design categories. Most vessels were built with a combination of work being done abroad in Brazil, for example, and the remainder being done in The Netherlands.

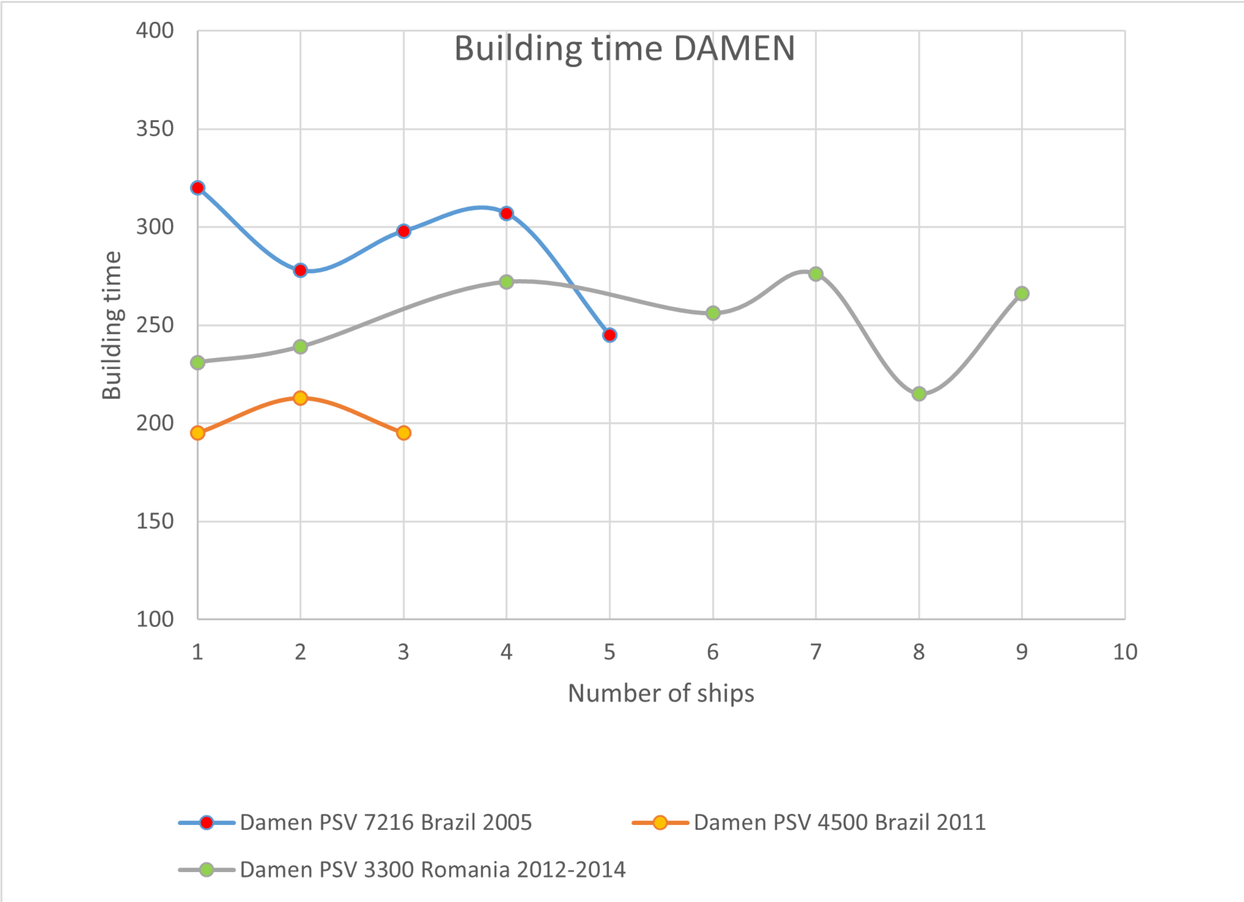


Figure 16: Building time graph for the three series production in Damen

Figure 16 shows that the second ship in series production took longer than the first ship, Ulstein and Vard. However, in some cases, it was easier to observe repeat production effects in the third ship. As can be seen, the building time difference for the Damen series was not as high as the building time difference for Vard and Ulstein.

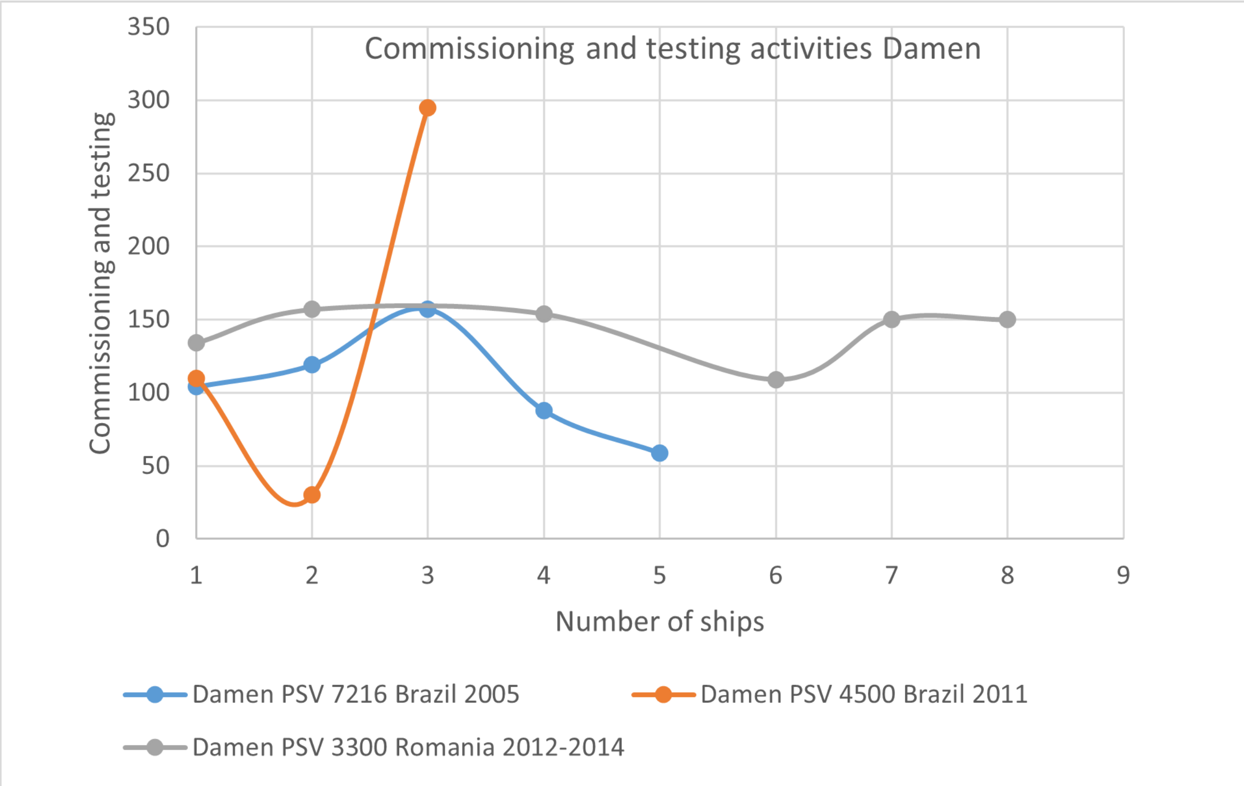


Figure 17: Commissioning and testing activities time graph in Damen

Upon examining the commissioning and testing duration in Figure 17 across three series productions within Damen, it becomes evident that the second ship in the 2005 and 2012 series incurred a longer timeframe compared to the first ship. However, in the 2012 series, an inverse pattern emerges, as the commissioning and testing duration for the second ship reduces in contrast to the first ship. However, this reduction was by more than 50%, which puts in doubt the validity of the data, while for the third ship, there was a huge jump with an almost 200% increase in the commissioning and testing time which may confirm that the possibility of data inaccuracy is high.

6 Results and Discussion

During the process of reviewing the SeaWeb shipbuilding data covering Ulstein, Vard and Damen, a deep sense of scholarly enchantment was evoked by the detailed examination of various aspects, including but not limited to building time, commissioning and testing time, and market trends. Numerous intriguing insights into the intricate world of shipbuilding resulted in a heightened appreciation of the intricacies and complexities of this multifaceted field. The research conducted for our study centred around an extensive data-set encompassing the construction timelines of numerous ships belonging to diverse series.

Based on the findings obtained through our comprehensive investigation, the following conclusions can be drawn: construction of the first vessel during the shipbuilding process typically takes less time than construction of subsequent vessels. This phenomenon is caused by a number of factors, such as the need to develop prototypes and refine construction procedures during the construction of the first ship. Based on the prototype, subsequent vessels are constructed in series production, requiring less trial and error; however, they still encounter challenges that prolong the construction process.

Compared to the first ship, building the second takes longer. This is primarily due to the fact that the first vessel serves as a prototype for subsequent vessels. During this process, any design flaws or construction issues will be identified and addressed before production begins. A considerable amount of experimentation and trial and error were also required during the construction of the first vessel in order to maximise the use of resources and materials. Using the lessons learned from the development of the first ship, it is possible to streamline subsequent vessel production and improve the efficiency of the production process. A second ship may also encounter specific challenges unique to the vessel-building process. It may be necessary to make adjustments to the production schedule, equipment, or infrastructure in order to accommodate the upcoming ship. Additional time may also be required for modifications or customisation to meet the customer's specific needs.

The production of the third vessel in the series will also take longer than the production of the second ship. The reason for this may be the introduction of changes or improvements to the product design, the need for further customisation, or the necessity for further modifications to the production process in order to achieve maximum efficiency. As a result, it can be observed that ship construction time is affected by a variety of factors that are unique to each vessel, even in the case of series productions.

Based on the data, commissioning and testing durations for the first, second, and third ships were consistent with the corresponding building times. In particular, it was observed that the first ship consistently required less time for commissioning and testing than the second ship, while the duration for the third ship varied. The reason for this is the learning effect or learning curve that occurs during series production, as well as the improved processes during production.

My results and Ulstein's answers seem to indicate that we almost agree with the conclusion that ship number two takes longer than ship number one, but when it comes to ship number three, there is a substantial difference between the two. According to Ulstein, in series production, there will likely be a reduction in the building time for ship number three. However, the thing I found is that in most series, the time it takes to build ship number three is longer than the time it takes to build ship numbers one and two in a series. In light of this notable contrast, it is necessary to study more series productions for different shipyards in more detail.

OSVs are closely related to market trends, which is easy to see, which is why they are closely related. In order to illustrate this relationship between building series of OSVs and PSVs and market trends, such as oil and gas, I attempted to create a model. The model, shown in Figure 18, illustrates the relationship between high demand for OSV vessels and the oil price.

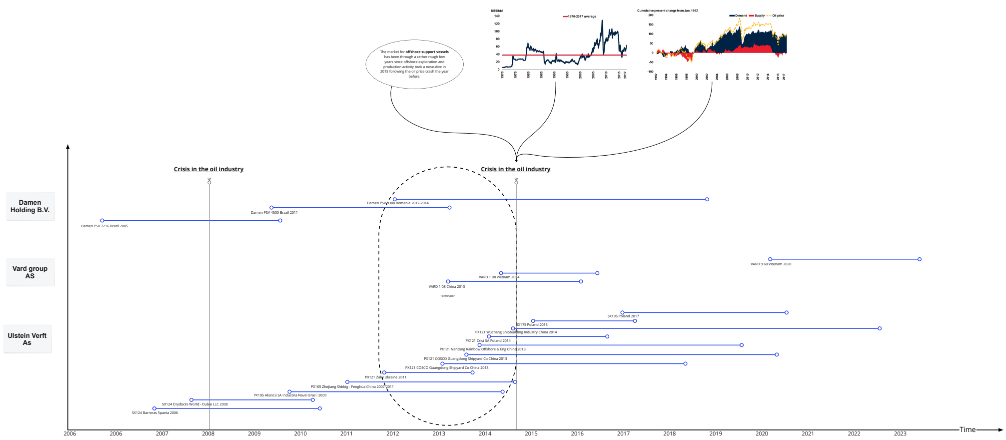


Figure 18: Series production building timeline model.

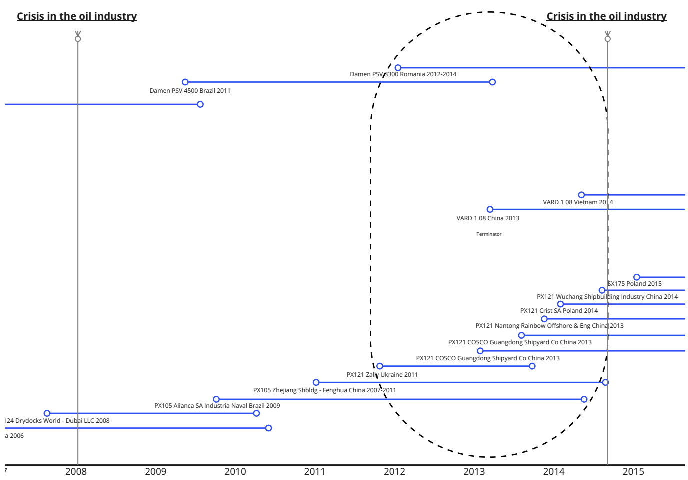
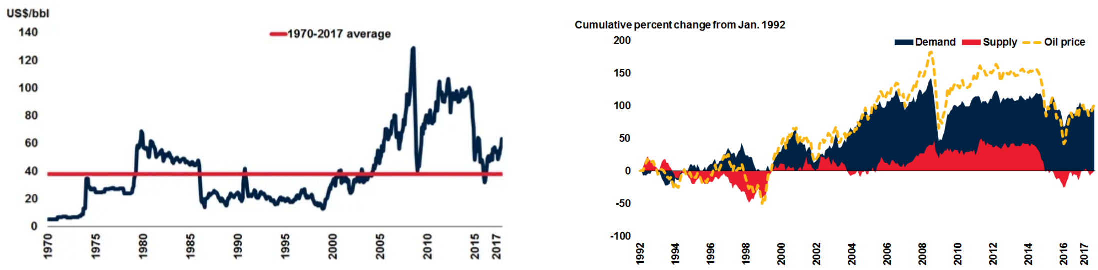


Figure 19: A snapshot between 2009-2015 for the series production building timeline model.

In order to examine the interplay between different series associated with Ulstein, Vard, and Damen companies, a comprehensive investigation was conducted using building data sourced from SeaWeb. This analysis revealed, as shown in the Figure 19 above, a marked increase in demand for OSV vessels during the period of elevated oil prices spanning from 2012 to 2014. In contrast, a significant decline in the demand for the building of OSV vessels was observed after the oil crisis in 2009 and towards the end of 2014. Based on this juxtaposition of data, it is evident that there is a correlation between fluctuations in oil prices and the propensity for the building of OSV vessels. Figure 20 shows oil prices charts between 1992-2017 (STOCKER, BAFFES and VORISEK 2023 & Skjong 2023).



(a) Real oil prices between 1992-2017 (b) Oil price decomposition between 1992-2017

Figure 20: Oil prices chart between 1992-2017 shows a massive drop in oil prices over the past three decades (STOCKER, BAFFES and VORISEK 2023).

Upcoming years are expected to see a new marked trend and a high demand for Service Operation Vessels (SOVs) vessels as the Offshore Wind Industry, which has been growing steadily, is expected to have a strong trend and high demand in the near future (H-BLIX 2023). There is a growing need for specialised vessels to be able to assist in the construction, installation, and maintenance of offshore wind farms in order to cope with the rapid growth of offshore wind farms worldwide. Due to the unique requirements of the offshore wind industry in terms of providing a versatile platform for various activities, SOVs have emerged as a solution to address these requirements (H-BLIX 2023). Figure 21 in below shows the expected high demand for SOVs in the Offshore Wind Industry.

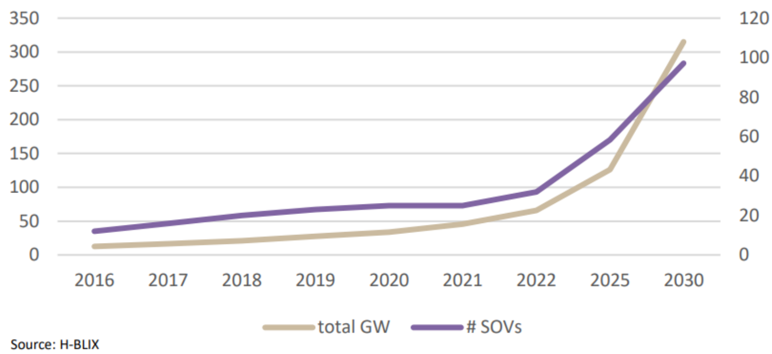


Figure 21: High demand is expected for SOVs (H-BLIX 2023).

It is expected that there will be a high demand for SOV vessels due to this new trend in the offshore wind industry. Therefore, Norwegian shipyards should expect an increase in series production. According to Figure 26 in the appendices, Vard and Ulstein have received increased orders for SOV vessels for the offshore wind turbine industry (Giske 2023).

Ship series production is inherently complex and subject to numerous factors that can influence its efficiency. To maintain a competitive edge in the shipbuilding industry, reducing the factors that may negatively affect series production is imperative. One effective approach entails allocating additional time during the initial design phase to develop highly precise drawings and plans meticulously. This strategic investment enables the reduction of potential modifications and errors in the aforementioned technical documentation, thereby fostering enhanced production efficiency.

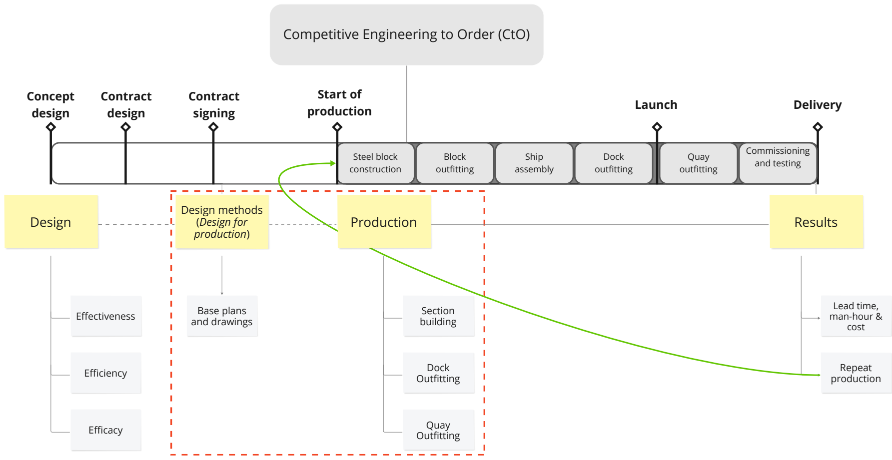


Figure 22: Favourable scenario for the building of series production.

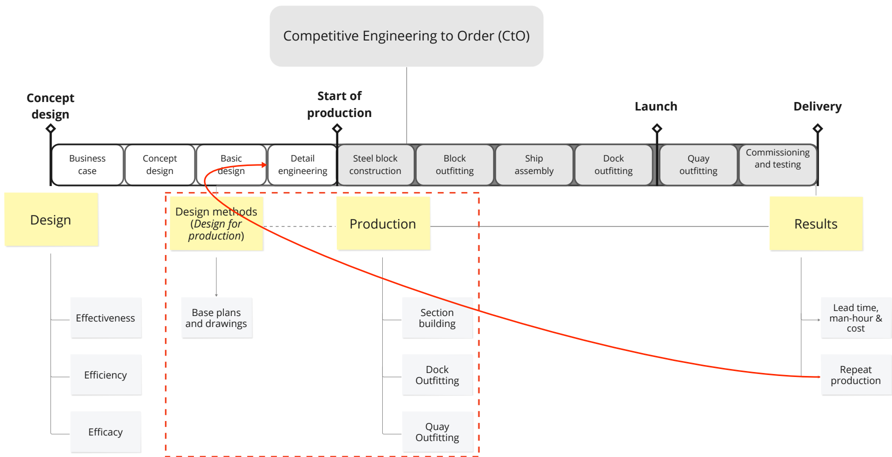


Figure 23: Unfavourable scenario for the building of series production.

The figures presented in this study, Figure 22 and Figure 23 above, depict an optimal configuration for series production in which the subsequent vessels within the series undergo uninterrupted production without the need to revisit the design stage. Figure 22 illustrates a favourable scenario characterised by seamless progression, wherein each successive ship in the series commences production directly. Conversely, Figure 23 showcases one of the least desirable scenarios, exemplifying a situation where modifications to the ship's design and drawings occur prior to the construction of another vessel within the series.

7 Conclusion and Further Work

7.1 Conclusion

Over the past few decades, the shipbuilding industry has become increasingly competitive. In constructing large and complex structures, especially ship hulls, low-cost countries like Turkey and India compete with high-cost countries like Norway. Oil and gas prices fell from 2015 to 2018, and the Corona pandemic in 2020 affected Norwegian ship design and production. Consequently, Norwegian shipyards are losing many vessel-building contracts to lower-cost countries. Norwegian shipbuilding industries must seek solutions to increase their competitiveness in the shipbuilding market.

The ship design process starts from the customer's ideas, and then after much work, finding and optimising the best solution that meets the customer's needs while finding the balance between effectiveness, efficiency, and efficacy, the phase ends with the ship's drawings and plans.
Drawings and plans are the essential links between ship design and ship production. That is why it is important to have detailed drawings and plans from the beginning. This will save time and work in the ship production phase.

Ship production in Norway is based on building ship hulls or sections abroad and getting them to Norway for outfitting. The dependence of the Norwegian shipbuilding industry on hull manufacturing abroad requires a lot of communication and details between workers in foreign countries. This is because they are usually less qualified and experienced than workers here in Norway, who do not need detailed drawings and plans to do good work.

Effective communication between foreign shipyards and Norwegian designers is essential for increasing productivity between a ship's design and production phases. More time spent during the early stages of ship design will lead to an efficient design and more detailed drawings. Shipbuilding may become more competitive as a result.

My master thesis will focus on the factors and stages that occur between design methods and production phases, as shown in Figure 24 below.

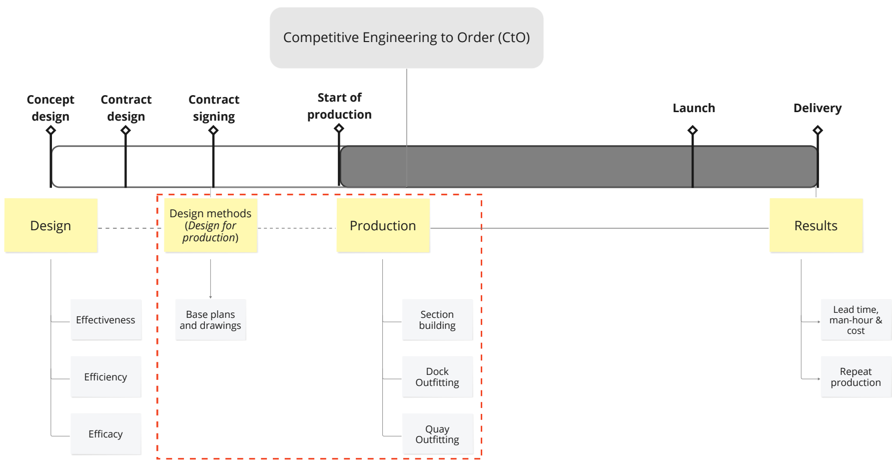


Figure 24: Masters thesis area of focus.

Figure 24 illustrates a sequential flow from the design phase to the design methods phase (design for production), enabling the translation of design results into drawings and fabrication plans. A competitive engineering-to-order (CtO) model encompasses the entire product life cycle, yielding tangible outcomes that inform subsequent stages of production. It provides a valuable foundation of experience for future instances of repeat production by analysing crucial factors and providing an academically-oriented framework that enhances decision-making and operational efficiency.

As a result of our detailed analysis of SeaWeb shipbuilding data, specifically focusing on Ulstein, Vard, and Damen, we gained insight into several aspects related to ship construction, such as construction time, commissioning and testing durations, and market trends. Research has shown that building the first vessel in a series generally takes less time than building the second and third vessels and subsequent vessels due to the necessity of developing prototypes and refining construction procedures. Nonetheless, our findings differed from Ulstein's responses, as we observed that the construction time for the third ship in a series is often longer than expected, contrary to Ulstein's expectations.

7.2 Further Work

The shipping industry encompasses numerous factors that exert influence, presenting challenges in comprehending the intricate relationship between ship design and the subsequent phases of ship production. As encountered in the course of this thesis, these challenges highlight the need for continued investigation and deeper exploration. Further work and meticulous examination remain imperative to understand this relationship comprehensively, unveiling underlying complexities and shedding light on the interplay between ship design and production phases. By undertaking additional inquiries, a more refined understanding can be achieved, providing valuable insights for industry stakeholders and facilitating informed decision-making processes.

Further work is necessary to clarify this notable discrepancy, which encompasses a wide range of series productions conducted by different shipyards, in order to gain a comprehensive understanding of shipbuilding dynamics. Taking into account the divergent outcomes discovered so far, it becomes apparent that in-depth scrutiny of supplementary series productions assumes paramount significance as a result of the divergent outcomes discovered so far. Through this meticulous approach, it will be possible to analyse ship construction timelines thoroughly, thereby facilitating the identification of underlying factors that are contributing to variations in the building durations for distinct ships within a series as a whole. A more nuanced understanding of shipbuilding processes can be achieved through extensive research and the expansion of the study's scope, thereby assisting shipyards in optimising production efficiency and minimising construction duration.

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Appendix

A Series production building timeline model.

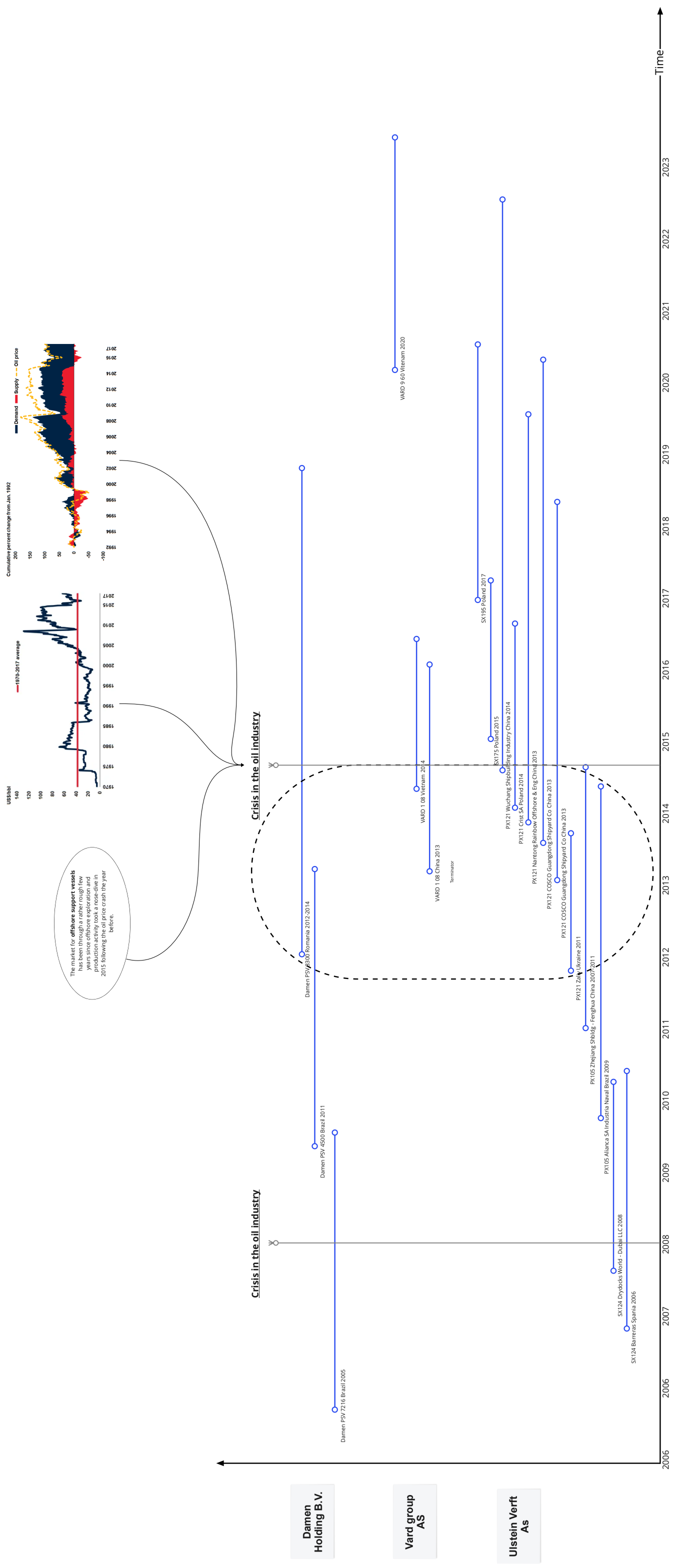

Figure 25: Series production building timeline model.

B Norwegian Ship orders June 2023 (Maritimt Magasin)

ORDRELISTE FOR NORSKE VERFT

BNR.	VERFT	STED	NAVN	REDERI	TYPE	DIVERSE	LEV.
49	Stadyard	Raudeberg	PR Jari	Kalsøybas	SC15		07.2025
219	Trosvik Maritime	Brevik	Reach Remote 1	Reach Subsea	UT 5208 USV		12.2023
220	Trosvik Maritime	Brevik	Reach Remote 2	Reach Subsea	UT 5208 USV		12.2023
318	Ulstein Verft	Ulsteinvik	Olympic TBN	Olympic Shipping	ULSTEIN SX222		05.2024
319	Ulstein Verft	Ulsteinvik	Olympic TBN	Olympic Shipping	ULSTEIN SX222		07.2024
24	Umoe Mandal	Mandal	TBN	World Maritime Offshore	Springer 25		01.06.2023
25	Umoe Mandal	Mandal	TBN	World Maritime Offshore	Springer 25		01.09.2023
962	Vard	Norge	NCT Offshore	TBN	VARD 9 01		12.2024
965	Vard	Norge	Edda TBN	Edda Wind	VARD 4 25		03.2025
966	Vard	Norge	Edda TBN	Edda Wind	VARD 4 25		03.2025
	Vard	Norge	Grampian TBN	North Star Renewables	VARD 4 22		2025
	Vard	Norge	Grampian TBN	North Star Renewables	VARD 4 22		2025
	Vard	Norge	Grampian TBN	North Star Renewables	VARD 4 22	Opsjon	2026
	Vard	Norge	Grampian TBN	North Star Renewables	VARD 4 22	Opsjon	2026
	Vard	Norge	Edda TBN	Edda Wind	VARD 4 25	Opsjon	2025
	Vard	Norge	Edda TBN	Edda Wind	VARD 4 25	Opsjon	2025
922	Vard Brattvaag	Brattvåg	Calypso	Van Oord	VARD 9 02		2023
930	Vard Brattvaag	Brattvåg	Sørkapp	Nergård Havfiske	VARD 8 02		12.2023
931	Vard Brattvaag	Brattvåg	Berlin	Deutsche Fischfang-Union	VARD 8 03		03.2024
947	Vard Brattvaag	Brattvåg	Rem Power	Rem Offshore	VARD 4 19		06.2023
949	Vard Brattvaag	Brattvåg	Norwind Gale	Norwind Offshore	VARD 4 19		09.06.2023
951	Vard Brattvaag	Brattvåg	Norwind Hurricane	Norwind Offshore	VARD 4 19		03.2024
952	Vard Brattvaag	Brattvåg	Norwind Helm	Norwind Offshore	VARD 4 19		2024
961	Vard Brattvaag	Brattvåg	TBN	Prysmian Group	VARD 9 04		03.2025
884	Vard Langsten	Tomrefjord	REV Ocean	Rosellinis Four-10	VARD 6 16	Forsk. & ekspedisjonsskip	2023
910	Vard Langsten	Tomrefjord	Jan Mayen	Forsvarsmateriell/Kystvakten	Kystvakt		05.2023
911	Vard Langsten	Tomrefjord	Bjørnøya	Forsvarsmateriell/Kystvakten	Kystvakt		2023
912	Vard Langsten	Tomrefjord	Hopen	Forsvarsmateriell/Kystvakten	Kystvakt		03.2024
	Vard Søviknes	Søvik	Somnio	Somnio	Yacht	222,00m På vent	03.2024
60	Viknaslipen	Rørvik	TBN	SinkabergHansen	Passasjerbåt	11,00m	05.2023
61	Viknaslipen	Rørvik	Stamsundværing	Stamsundværing	MD-1499-FV	Fiskebåt	05.2023
39	Westcon	Ølensvåg	Jan Mayen	Rimfrost	NVC 338 WP		2023
41	Westcon	Ølensvåg	Ecofive	Bluewild	ULSTEIN FX101	Fiskebåt	12.2023
42	Westcon	Ølensvåg	Trønderbas	Trønderbas	Pelagisk Tråler/Snurper		2024
212	Aas Mek Verksted	Vestnes	Ronja Mistral	Sølvtrans	AAS 3002 ST		30.08.2023
213	Aas Mek Verksted	Vestnes	Ronja Evolution	Sølvtrans	AAS 3002 ST		01.2024
214	Aas Mek Verksted	Vestnes	Ronja Vita	Sølvtrans	AAS 3002 ST		03.2024

Kilde: Norsk Skipsfarts Forum/Oddgeir Refvik

Rød tekst: endringer fra forrige liste — Endringer kan sendes på e-mail: liste@maritimt.com — Oppdatert: 13.05.23

Maritimt Magasin 06/2023 — maritimt.com

Figure 26: Norwegian Ship orders June 2023 (Maritimt Magasin) Giske 2023

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