NTNU – Trondheim
Norwegian University of
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Modular approach to offshore vessel design and configuration

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Marine Technology (2 year)
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Department of Marine Technology

Problem description

NTNU
Det skapende universitet

MSc thesis in Marine Systems Design
Stud. techn. Henrik Tvedt
"Modular approach to offshore vessel design and configuration"
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Background

As part of the SHIP-4C project, the System-Based Design method has been adapted to offshore support vessels. The functional breakdown structure has been adapted towards main types of OSVs, and key data has been collected from a number of existing STX OSV vessels.

Øystein Brekke and Henrik Tvedt have developed a preliminary product platform for OSV preliminary design in their pre-master project from the fall of 2011. The product platform is based on a System-Based Design method which uses a modular approach to preliminary design of OSVs.

Overall aim and focus

The overall aim of the MSc thesis is to provide a design approach for early design of OSV that enables flexibility, innovation and reduced resources and development time. In addition the thesis will study the configuration options for a vessel related to different operations with the intention of providing "configured to operation" options together with identification of requirements needed to perform multiple operations with the same configuration.

Scope and main activities

The candidate should presumably cover the following main points:

1. *Provide a summary of the theoretical and methodological foundation as well as current development for:*
    1. *Design aspects related to OSVs*
    2. *Product platforms*
    3. *System-Based Ship Design*
    4. *Modular theory*
    5. *Design evaluation and optimization*
2. *Study of OSV operations and modularization:*
    1. *Identify OSV operations and the related requirements (Crew, equipment, etc.)*
    2. *Develop an approach to develop and assess modules based on functional requirements which includes:*
        1. *Identification of modules related to specified missions*

        - ii. *Identification of similarities between operations*
        - iii. *Development a structure that is applicable for product platforms*
        - iv. *Evaluate module shapes relevant for OSV operations*

3. *Develop a flexible modular product platform which supports:*
    - a. *Concept design innovation and exploration*
    - b. *Iterative & sequential aspects to vessel design*
    - c. *Alternative vessel configurations*
    - d. *Design validation (stability, draught, displacement, etc.)*
    - e. *Comparison of design performance to publically available vessel designs*
4. *Discuss alternative design concepts and vessel arrangements based on the same detailed functional specification of the vessel (same areas, volumes, powering, etc.)*
5. *Evaluation of performance of design outputs*
    - a. *Selection of performance criteria*
    - b. *Compare the performance of the proposed design with publicly available design data for similar designs*
    - c. *Evaluation of the export of data to external software applications for purposes such as:*
        - i. *Damage stability*
        - ii. *Dynamic stability*
        - iii. *Resistance*
        - iv. *Design optimization*
6. *Discuss methods of evaluating configuration options related to OSV operations*
7. *Discuss, conclude, and propose a suggest future developments*

Modus operandi

At NTNU, Professor Stein Ove Erikstad will be the responsible advisor.

The work shall follow the guidelines given by NTNU for the MSc thesis. The work load shall be in accordance with 30 ECTS, corresponding to 100% of one semester.

Preface

This report is written as a MSc thesis at the Norwegian University of Science and Technology (NTNU) spring 2012. As a part of the SHIP-4C project, the System-Based Design method, developed by Kai Levander, has been adapted towards offshore support vessels. This method has identified a functional breakdown structure for main types of OSVs based on experience data for existing STX OSV vessels. Øyvind Vestbøstad (2011) has provided a preliminary method of 3D visualization and modelling. This thesis is based on the previously mentioned work and my pre-master thesis from fall 2011 which where a collaboration with the MSc student Øystein Brekke.

The overall aim of the MSc thesis is to provide a systematic approach for early design and concept evaluation of OSVs that enables flexibility, innovation and high responsiveness of the developed system. In addition the thesis will study the configuration options for a vessel related to different missions with the intention of providing “configured to operation” options.

The system developed in this thesis contains a relatively large degree of mathematical formulas and data. The author has tried to limit these in the thesis, and focused on explaining approaches, methodologies and assumptions behind this development.

I would like to direct my thanks to Professor in Marine Systems Design Stein Ove Erikstad as my advisor at the Department of Marine Technology (NTNU). He has provided me with valuable guidance based on his many years of experience in this field of work. I would also like to thank Vestbøstad for sharing initial work, experience and follow-up of my inquiries in relation with 3D visualization.

Bergen, June 8th 2012

Henrik Tvedt

Henrik Tvedt

Summary

The design process used in most vessel design approaches can be described as sequential and iterative, where the initial design is subject to constant improvements. The process development is thereby constrained by the decisions made in early stages of design. It becomes apparent that the more design knowledge which can be generated and evaluated in these stages, the better foundation the designer has to make the best decisions. System Based Ship design (SBSD) has introduced a bottom-up approach which generates a functional description based on the vessel missions for use in early stages of design. SBSD focuses on enabling creativity and innovation in vessel design by being able to evaluate alternative solutions. The increase and availability of computational processing capacity these days is a contributor to enabling more design aspects included in earlier design stages.

This thesis focuses on development of a system that is able to efficiently develop and evaluate Offshore Support Vessel designs and alternative designs in concept- and preliminary stages of design. Based on the functional description of OSVs from the SBSD methodology are modules related to vessels missions systematically identified and generated. Modular Product Platforms (MPPs) which contains rules for how these OSV modules can be combined have been developed to efficiently develop design alternatives for consideration. The main focuses have been to enable creativity, innovation and alternative solutions in an efficient manner in early stages of design. Due to the physical similarities that the OSVs share, MPPs have provided a good tool for efficient development of these vessels. The parametric ship description within the MPPs enables concept exploration and improvement with low effort and facilitates design evaluation and improvement. Automated 3D modelling based on the OSV MPPs provides a more intuitive design process and facilitates design evaluation to multiple vessel alternatives. The responsiveness and flexibility of the MPP and automated 3D modelling is believed to have benefits in a sales situation to efficiently develop design alternatives based on customer demands and providing a visual representation for discussion. This has the potential of reducing the time and resources involved in tendering/sales projects. MPPs can be used by design companies to more easily communicate which designs they can offer, and to explore vessel design parameters influence on performance.

Due to vessels complex hull shape, the modules' shapes and quantity positioned within the hull influence the performance of the output design form the MPPs. Control and manipulation of hull shape is found to be essential due to vessel characteristics. Sectioning of the hull shapes within the MPPs has provided a good method of enabling control and evaluation of the hull shape with minimum compromise to other design performances.

Databases containing vessel statistics have provided a good method of comparing key performance criteria of output design from the MPPs to existing vessels and thereby contribute to validation of the design. These vessel statistics will also support the designer in providing good initial input values for parameters that are found by iterations and design development. Search- and optimization algorithms can be used to find good configurations of the MPP parameters and support the designer with parameter options in future developments. The developed MPPs can be further developed to incorporate more aspects to OSV design, and by supporting and incorporating analysis and simulations from other software applications, based in the generated 3D model, a solid tool for OSV design can be established.

Re-configuration related to OSV operations can become a solution in competition for the most favourable contracts and to account for the fluctuating and seasonal market. Re-configuration alternatives can efficiently be launched and evaluated by the use of MPPs.

Although the developed system seems to efficiently develop design alternatives with good performance, it has yet to prove its applicability as a tool for use in the industry.

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Definitions

Block coefficient	Similar to box coefficient, but is limited to the submerged volumes of a vessel
Bollard pull	The pulling power of a vessel
Box coefficient	Ratio between the actual volume and the box volume of a shape.
Customer	A person interested in purchasing a vessel (often a ship owner)
Designer (in relation to product platform development)	Ship designer that operates the product platform
Interface	The connection across two system borders
Modular product platform	A product platform that uses component swapping to generate customized products
Modularization	Decomposition of a system into self-sufficient blocks
Module	Relative self-sufficient building block
Product platform	Scheme that contains rules for combining a set of components, modules or parts into customized products
Product platform designer	The creator of the product platforms architecture
Standardization	Establish standard components, modules, equipment and interfaces
System architecture	Description of the system structure, relations, interfaces and development
System designer (in relation to product platform development)	The developer of the product platform structure
x-direction	Longitudinal direction
y-direction	Transverse direction (from midship)
z-direction	Vertical direction

Abbreviations

3D	Three dimensional
A	Area
AHT(S)	Anchor Handling Tug (Supply) Vessel
B	Breadth
CAPEX	Capital Expenditures
COG	Centre of Gravity
DSV	Diving Support Vessel
GA	Genetic Algorithm General Arrangement
GT	Gross tonnage
GUI	Graphical User Interface
GV	Gross volume
H	Height
L	Length
LOA	Length over all
M	Mass
MDF	Modular Function Deployment
MPP	Modular Product Platform
OCV	Offshore Construction Vessel
OPEX	Operational Expenditures
OSV	Offshore Support Vessel
PL&C	Physical large and complex
PP	Product platform
PSV	Platform Support Vessel
RAO	Response Amplitude Operator
SBSD	System Based Ship Design
V	Volume
W	Weight

1 Introduction

Offshore oil and gas exploration and production has become an important industry in today's market. This industry uses various units, such as rigs, ships and platform in order to exploit marine resources. In the search for new resources, this activity moves into deeper waters and harsher environments. Offshore Support Vessels (OSVs) has been developed to support these units with their various activities. The design of these OSVs has become a large industry, which is characterized by its technological developments and high valued vessels. The competitive marked demands continuous improvement and shorter development time of these designs. The vessel design process can be seen as highly iterative and sequential, and was described by Evans' design spiral in 1959 (see Figure 3). The design process has evolved since then, much due to the increasing availability of computational power. "Modular theory" and "product platforms" are known terms used in today's company strategies. By using the computational power available, the design effort can be reduced and shifted into a focus on finding good and innovating solutions rather than just feasible.

This thesis has been divided into main 5 parts, aiming at improving approaches to early stages of design with respect to design knowledge, development, creativity and evaluation. The first part will introduce the reader to the theoretical foundation, methodologies and background for this thesis. The second part will focus on development of a strategic method of identification and generation of modules related to OSV design, which is step 1 & 2 in the design approach illustrated by Figure 1. This part is based on the System Based Ship Design (SBSD) methodology developed by Kai Levander. The third part describes the development of a product platform for the use in OSV design based on a parametric ship description, which is step 3 – 6 in the design approach. The product platform also includes automated visualization and 3D modelling based in the work of Øyvind Vestbøstad (2010). The output design of the product platform is assessed in the fourth part, which is step 7 in the design approach. It is discussed how the product platform supports iterative and project development aspects to OSV design. Part 5 introduces the reader to OSV configuration aspects related to operation, and how alternative configurations efficiently can be developed and evaluated based on the approaches used in part 2, 3 and 4.

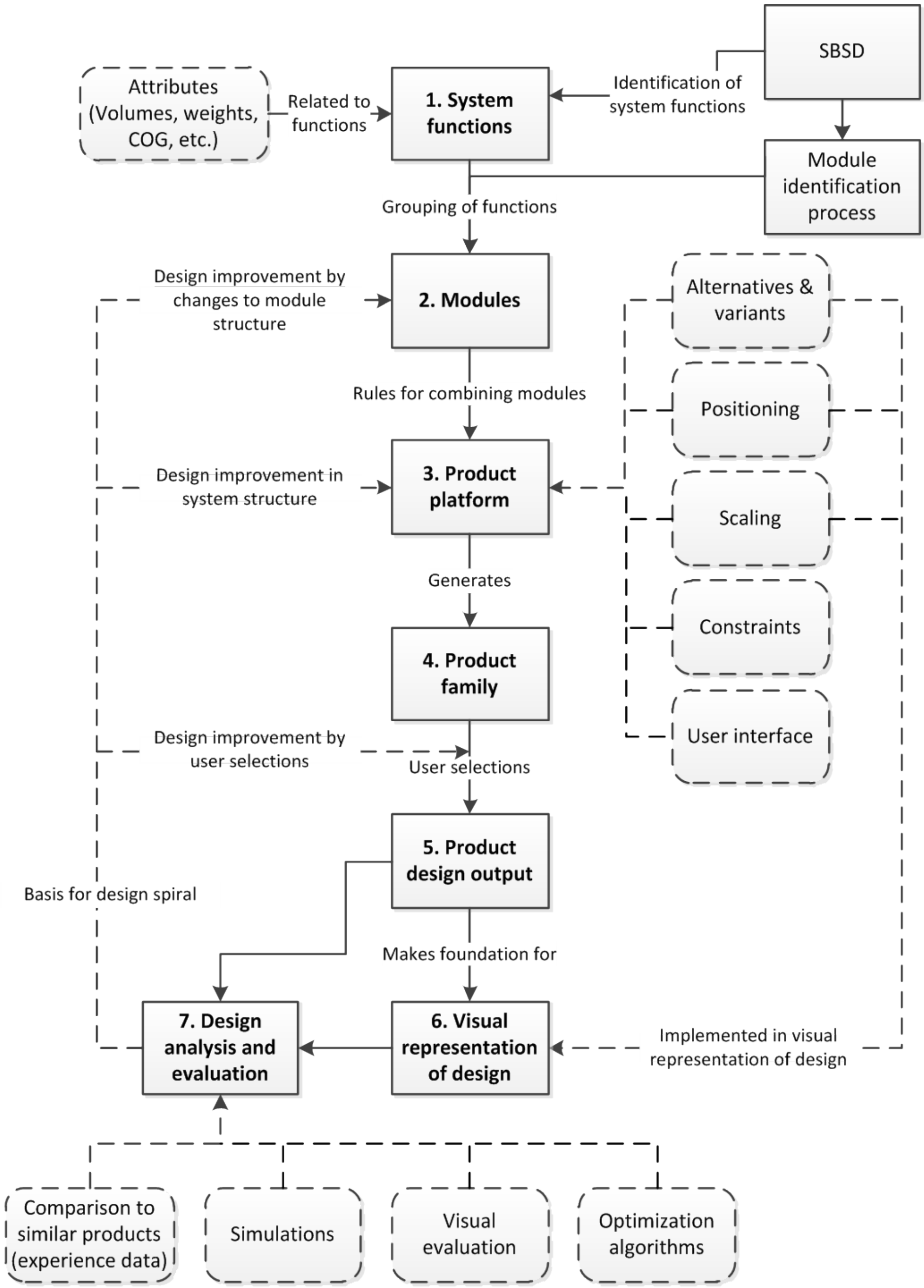


Figure 1 - Design approach

Part 1 Theoretical foundation

2 Design

The term “design” is a relative abstract term that is difficult to define. There are clear differences between a sculpture, a skyscraper, a computer program and a vessel, but they can all be characterized as designs. So what makes a design? Design is said to have a special nature, to involve procedures, to have a certain appeal to humans and to be “open ended” (Erichsen, 1999). “Open ended” means that there exists a multitude of design solutions, where there are no right or wrong solutions. Although there is not one correct solution, there exists better and worse design. What separates a good- from a bad design may not become apparent before the product has been in operation for several years or detected in the early stages of design. It is not always the amount of resources and time spent developing a design which determines the quality of the design.

It can be said that design engineers differs from other designers in the way that they develop their designs. This is a result of engineers being a scientific group that has a need for proven strategic methods of approaching problems. The development of the availability of large computing power in recent years has contributed to making engineering design methods more and more scientific. Some of these methodologies and their appliances related to ship design are explained and discussed in the following sub-chapters.

2.1 Ship design

The primary objective of the ship design process is to generate the information needed to build a ship within customer & regulatory requirements. The level of complexity involved with the ship design task makes this process “unique” compared to others, and are explained in the following sub-chapters.

2.1.1 Design phases

The total design task can often be categorized into different stages of activities. These stages will often have designated tasks for each stage and an increasing level of details. Society of Naval Architects and Marine Engineers (SNAME) categorize basic design into the following four categories (Lamb, 2004):

1. Concept design
2. Preliminary design
3. Contract design
4. Functional design

The ship design process has a nature that changes over time as the design is developed. The typical ship development process is also characterised with major milestones. These are aspects that make the ship design process especially eligible for a subdivision into phases.

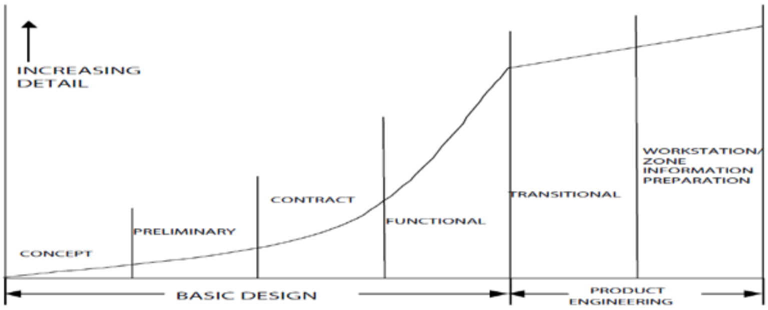


Figure 2 Design phases (Lamb, 2004)

2.1.2 Design evolution

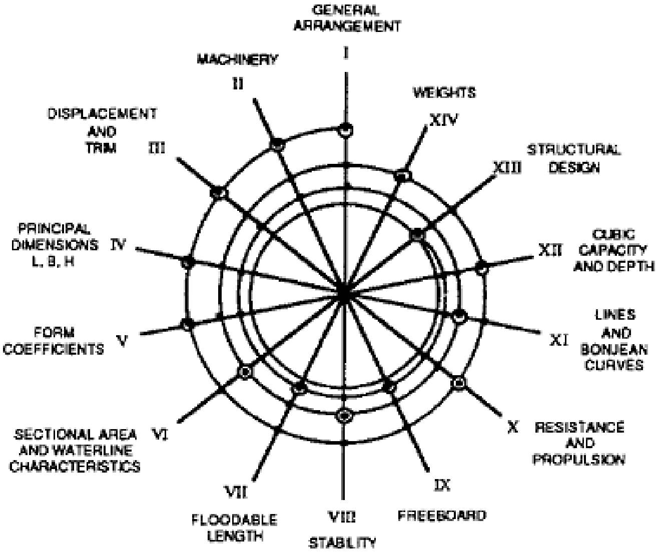


Figure 3 - Design spiral (Evans, 1959)

“The naval architect’s view of ship systems consists of a process that is traditionally viewed as a highly coupled collection of interrelated physical attributes” (Witcomb and Szatkowski, 2000). Because the various design aspects within ship design have such large influence on other design aspect, each design aspect cannot be developed individually. In 1959 J.H Evans introduced “The Design Spiral” to describe the iterative design process where the design aspects are repeated once others have been established. This provides the designer with a structured method of balancing all design aspects to achieve a valid design solution. Several variations have been developed since the introduction of the design spiral; the essence is the same, but with variations in the design aspects (the “spokes” in the spiral).

2.1.3 System Based Ship Design

Due to the large complexity of the ship design process and a need to support novel solutions a structured method of designing ships is needed. By defining each system related to the ship functions and the performance requirements this system are to perform, a framework can be established that can be called “System Based Ship Design” (SBSD). By transforming these systems, requirements or functions into simple algorithms, large amounts of calculations can be automated so that the designer can spend more time on improving and evaluating the design and finding alternative solutions.(Levander, 2009)

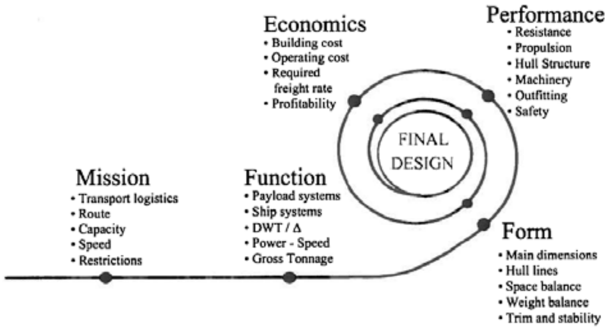


Figure 4 - Design spiral (Levander, 2009)

SBSD initially focuses on the vessel’s mission for then to generate a functional description of this mission. The design spiral used in the SBSD methodology is illustrated by Figure 4. The SBSD method supports a design process which aims at enabling creativity so that novel solutions can be found in early stage of design.

The methodology is found to be somewhat lacking the visualization aspect of the design which can provide the designer with information which can lead to a more efficient and intuitive design process. It is believed that modular approaches to visual representation of the design method can provide a manageable system that emphasizes novel solutions.

2.1.4 Library based approach to the initial design

“The issue in the initial design of complex ships, such as naval combatants and OSVs, is that the exploration should be as wide as possible so that all conceivable options are explored and the emergent requirements are ‘‘elucidated’’ from this comprehensive exploration. Importantly this exploration informs the dialogue between the requirement owner and the concept ship designer” (McDonald et al., 2010). Library based methods are able to describe large number of ship designs, from which the designer can filter out designs which meet the current design requirements, have been developed. One of the benefits with this approach is that the information in the library can maintained, so that new technologies, concepts and safety standards can be implemented. These libraries can be customized to organizations individual needs. (McDonald et al., 2010)

2.1.5 Building block synthesis

The architectural aspects of complex ship design can be integrated with the traditional numerical synthesis of weight and space, by the use of building block approach to initial ship design (Andrews, 2006).Building block approach can enable a more informed and information-rich preliminary design. It has been proven that building block approaches can provide the foundation for downstream design of complex entities as a whole. It enables designers to examine many more facets of the project, at the initial sizing stage, using sophisticated computer graphics tools. These approaches have been used with success for warship design, which are highly complex vessels. (Andrews, 1998) This methodology has been used in the development of PARAMARINE ship design system for the UK ministry of Defence naval ship design agency. The building block approach developed by D. J. Andrews can be summarized by Figure 5.

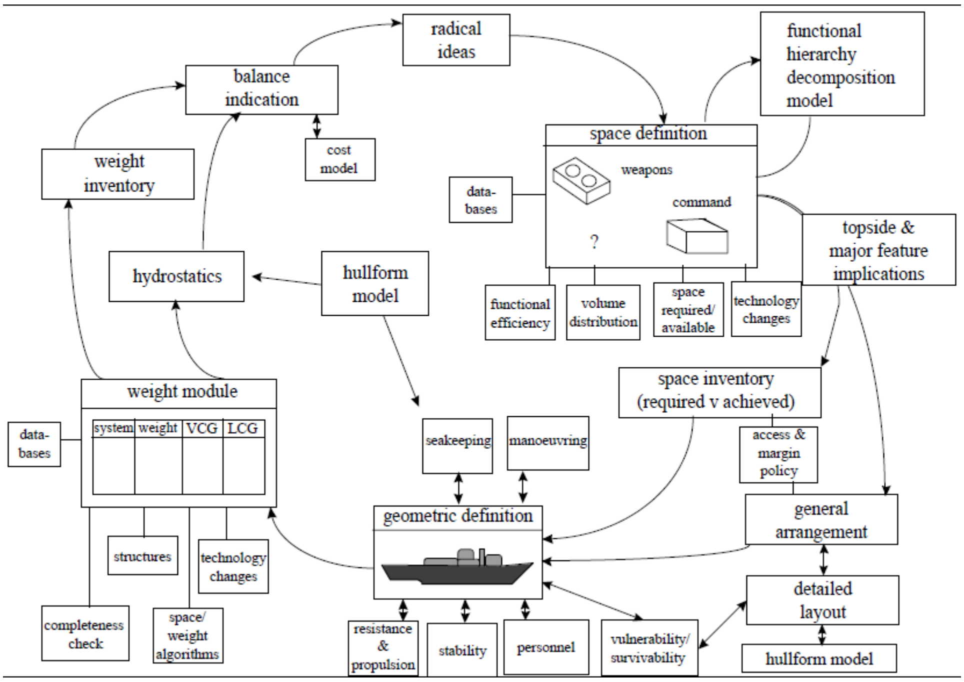


Figure 5 - Design building block approach applied to surface ship design synthesis (Andrews, 2006)

2.1.6 Parametric ship modelling

The ability to describe a vessel with a mathematical model, from which design variations are achieved from a given set of parameters, have great advantages in a competitive marked where preliminary design has to be performed in continually decreasing time spans (Abt et al., 2001). Parametric ship description allows the user to work with simpler representation of components , so that the designer easier can manipulate solutions to find configurations which satisfies the functional requirements (Bole and Forrest, 2005). “The ultimate goal of advanced modelling systems for future developments is to provide a complete generic model for the entire ship which includes production as well as lifecycle costs(Abt et al., 2001)”.

2.1.7 Offshore Support Vessels (OSV)

The general mission of the OSVs is, as the name implies, to support the offshore industry. The offshore industry requires certain specified missions which can be performed by various vessel types (see Table 1). The vessels can operate on spot marked (short term contracts), or be assigned to long term contracts. The market is subject to large and rapid variations; fluctuations in charter/day rates and seasonal variations due to the changing weather conditions are both factors that characterize this market. The high level of complexity and advanced in technology together with difficult operating conditions makes these vessels to become difficult design and engineering tasks. (SNAME, 2003)

Table 1 - OSV missions and vessel types (SNAME, 2003)

Main vessels types:

- Seismic vessels
- Anchor handlers (AHT(S))
- Platform supply vessels (PSV)
- Crewboats
- Multipurpose vessels (MPSV)
- Safety/standby vessels
- Combination vessels: (vessels that are able to perform OSV operation in combination with other operations)

Main specified missions:

- Seismic survey
- Rig and platform installation
  - Towing
  - Positioning
  - Laying of anchors and moorings
- Supplying rigs and platforms
  - Personnel
  - Equipment
  - Consumables
  - Stores, etc.
- Subsea operations
  - Diving
  - Subsea completion and ROV operation
  - Inspection and maintenance
- Safety standby
- Well intervention

The main focus of this thesis is limited to Platform Supply-, Anchor Handling-, and Multipurpose vessels and their related missions. Although this thesis is based on these three vessels, it is believed that the methodologies used are applicable to all advanced offshore work boats, including naval vessels.

2.1.8 Support design variation, creativity, innovation and evolution

"The only limit to our creativity in the design work is our imagination. But our creativity and imagination depend on the things we know, human beings cannot create from nothing" (Levander, 2009)

A design methodology should support the designer in exploring possibilities and making the best choices. The designer should not be restricted or limited to traditional solution. Methods to make use of technological innovations of design evolution are important to keep up with today's market. These are key aspects that have been emphasized in this thesis. Figure 6 illustrates three examples of innovating designs and applications within the current OSV market.

Novel application of hover crafts for offshore oil and gas applications.

Innovative and advanced OSV design.

Concept design for light workover/intervention.

Figure 6 - Examples of innovative offshore solutions and applications (OSJ, 2011)

2.2 Modularity and modularization in design(Brekke and Tvedt, 2011)

This thesis uses a large degree of modular theory in system development, and it is therefore important that the reader has some basic knowledge about this theory and motivations for using modularity. The interpretation of "modularization" differs from field of work, but the general idea is to divide large systems into smaller, self-sufficient parts. The way these parts are combined makes a final unique design. There are several clear benefits from modularization which can be used to ((Baldwin and Clark) pp. 175):

1. Make complexity manageable
2. Enable parallel work
3. Accommodate future uncertainty

By breaking the complexity down to self-sustainable building blocks, where each module has defined system borders and demands, the engineer is able to manage large and complex systems in a structured way. Each module is developed as an individual block, and it is the combination of these blocks that makes the end product. By using modularity it is possible to create good product architecture.

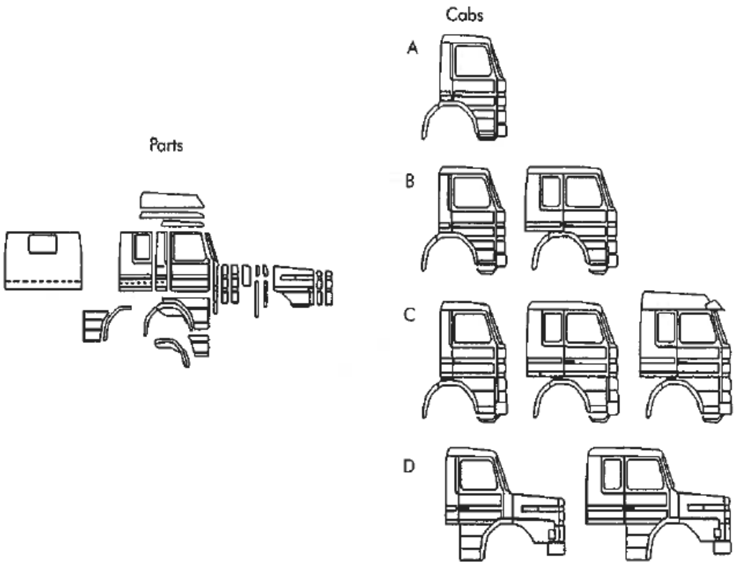


Figure 7 – Scanias modular truck cab (Ericsson and Erixon, 1999) pp.6

Modularization is related to several systems concepts and technologies that have been developed in recent years (Erikstad, 2009):

- Product platform technologies
- Product architecture
- Configuration-based design
- Mass customization
- Lean Manufacturing Principles

The systems and concepts listed above are developed and evaluated towards design of offshore vessels in part 2 and 3 of the thesis. Product platforms contain rules of how these modules are combined (constrained) can be developed based on the logical division of these modules.

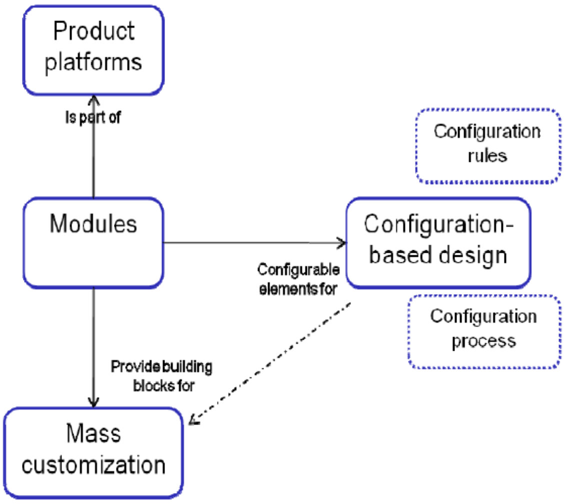


Figure 8 - Modularization in system concepts and technologies (Erikstad, 2009)

“One of a kind” products are high-risk and high cost projects compared to mass- or series produced products. By standardizing components, modules and interactions between modules it is possible to reduce uncertainties and the related risks. The risks involved in the design phase can be reduced by using well known components within the modules and known systems. In an operation phase old modules can easily be replaced by new modules given that standard interfaces are used on the modules. Scania’s truck cab is an example where the company can offer the customers a wide range of product alternatives while minimizing their ammount of parts and construction time(Ericsson and Erixon, 1999).

Modular Function Deployment (MDF) procedure is a structured, company-supported method with the objective of finding the optimal modular product design, taking the company’s specific needs into consideration. The MDF procedure is based on the following 5 steps ((Ericsson and Erixon, 1999) *pp29-41)*:

1. Define costumer requirements
2. Select technical solutions
3. Generate module concept
4. Evaluate Module concept
5. Optimize modules

In product life cycle design modular product architecture can be used to accommodate life cycle objectives such as functionality, manufacturability, assemblability, serviceability, reuseability, and recyclability (Gu and Sosale, 1999).

2.2.1 Integrated vs. modular design

Modularity in design has clear benefits in terms of handling complexity. As the modularization results in a structure in which relatively self-sufficient system is put together, it will cause some components having to be changed or moved so that self-sufficiency is achieved. These changes in location or geometry can lead to undesirable properties of the final design. The modular design approach relies on standardized interfaces between the connected modules. These standardized interfaces may cause component to be over specified resulting in additional weigh and volumes. As an example, the foundation for modular cranes requires dimensioning for the largest crane alternative.

Integrated designs have the possibility of generating more tailored solutions with better performance than a modular design. The problem with an integrated design process is that for large and complex systems, it often becomes inefficient due to the amount of information that has to be managed as a whole. This may result in a design process that focuses on finding a feasible solution rather than finding a good solution.

2.2.2 Modular design: Product variation or standardization

How modularization is applied to the development a product will impact the variety, and therefore the flexibility of the design. This can be result in two possible outcomes; product variation or standardization. Because modular theory is based on the use of standardized self-sufficient parts it means that the products that can be derived share more or less the same basic parts. Product variation must therefore be achieved by the composition of these modules. To achieve product variation a sufficient amount of configuration alternatives and options must be incorporated in the design development process.

2.2.3 Modularization of offshore vessels (Brekke and Tvedt, 2011)

Offshore vessels are highly complex systems that are built for the purpose to perform multiple tasks with precession in harsh environment. This can make the design phase a complex and resource demanding task. Offshore support vessels must be able to provide good sea keeping in all sea states, interact with offshore platforms and perform multiple precision tasks and this in addition to being heavily equipped. In addition these vessels require a large deck with high volume and weight capacity (often at the stern) while maintaining stability at all loading conditions. Often these vessels also have large tank capacities below deck and large engine rooms, ballast and payload tanks that complicate the design task even further. From a modularizations point of view there are several aspects that are interesting to investigate further in relation to offshore vessels in different phases during its life cycle:

1. Planning/design phase (designer)
    a. Reduce the design phase
    b. Produce multiple feasible design at an early design phase
    c. Allow for more creativity and flexibility
2. Construction phase (yard)
    a. Reduce build- and assembly time
    b. Increase yard capacity
3. Operation phase (owner)
    a. Easy service and upgrading
    b. Enable configurability

Part 2 and 3 in this thesis will explain and illustrate how these aspects to modularity can be identified for the used in design of offshore vessels. Modularisation in the production of OSVs has been more and more common the later years, but will not be included in this thesis. Part 5 will focus on enabling re-configuration of a vessel in operation by the use of modularization.

2.2.4 Modular management of complexity

As stated in previous chapters modularity can be used as a tool for managing complexity. Large and complex systems can consist of thousands, even millions of elements as a finished product. Working with this amount of information as a whole is not practical in an efficient design process. By developing a hierarchically description of the system which applies modular theory it is possible to describe which elements and level of detail is important to each stage of the design process. One level of the branching of the system will then belong to a certain phase in the design process. The hierarch (top level) will be the design objective. An incomplete example of such a system is illustrated in Figure 9.

By having a limited number of sub-nodes to each member in the system, the designer creates a manageable system. According to prof. S. O. Erikstad it is recommended to have 6-8, and no more than 10 sub-nodes, in order to support an efficient design process. In accordance to modular theory, the sub-systems should be relative self-sufficient with limited interactions to others.

As the project moves through the different stages of design, the focus of design are shifted into more detailed areas. The level of detail on the lowest level in the hierarchy of a complex system is often so comprehensive that it cannot be handled as a whole, but can be managed as individual sub-systems. These sub-systems are handled as individual systems, but integrated in the entire system according to the hierarchy.

Problems with this structure is that scientific design projects often quantify their design objectives based on detailed and specific requirements and functions that belong in a late stage of design. This may compromise the objectives in the earlier design phases, focusing on too detailed requirements. A solution to this is to group these detailed requirements and functions into building blocks or modules that are manageable at the correct stage of design. In this way the system is based on the more detail approaches that engineers tend to use, but managed according to the stage of design. This approach will often require the use of computers as there are large amounts of underlying data that have to be processed.

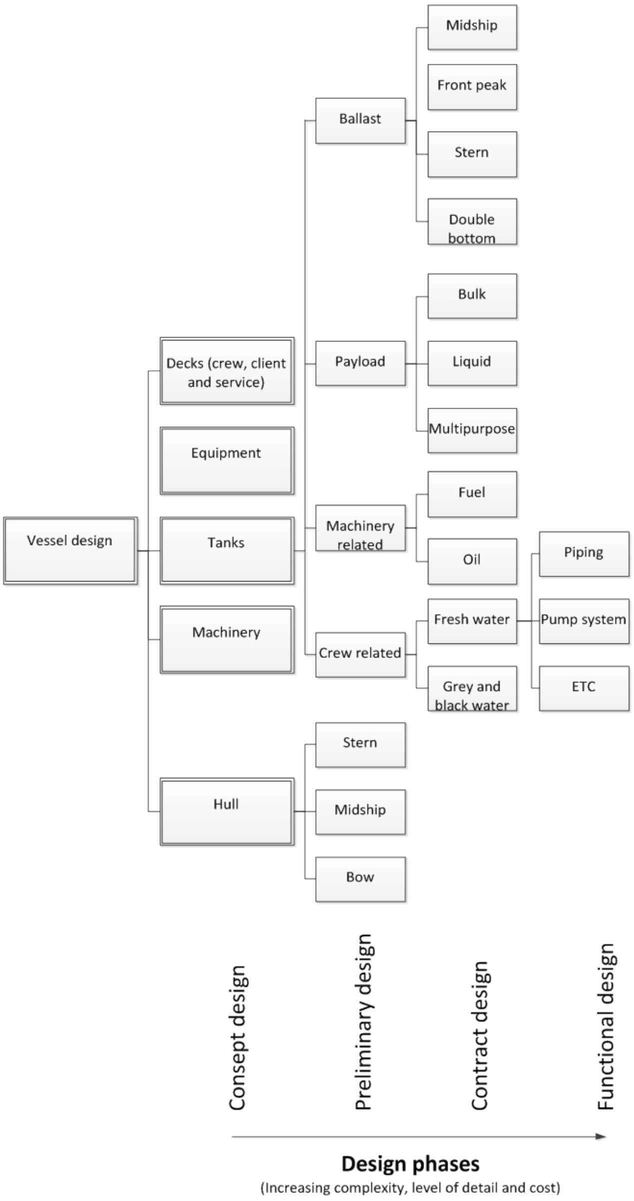


Figure 9 - Example of hierarchy description of a system based on stage of design

These approaches make the foundations for modular product platforms that contain a structure for combining these modules into derivative products. As we can interpret from the hierarchical structure of complex systems, such modular product platforms often are made for a specific step in the design process. Product platforms are explained in detail in later chapters.

2.3 Assessing requirements in design

The identification of product requirements is essential for a successful design. In OSV design different parts/actors will have different requirements to the. Each actor’s requirements set limits to acceptable solutions, and defines the design space. Within the design space, trade-offs have to be evaluated. The designer(s) must find a solution which benefits all parts. Figure 10 illustrates the 3-dimmentional design space between ship- owner’s, operator’s and builder’s requirements. A good project has to balance time, costs and performance. If for example the ship builder’s requirement to the design is to minimize build cost, the result might be a design which has undesirable performance in operation and may cause the ship builder to sell the vessel for a lower cost, reducing the earning potential.

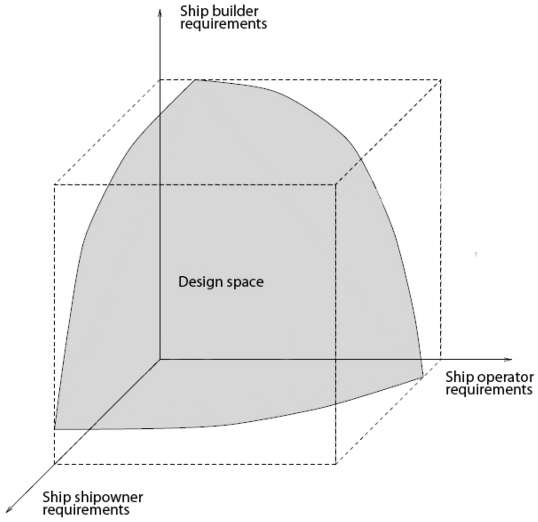


Figure 10 - 3-Dimmentional design space

Quality function deployment (QFD) is a well-known methodology “for conveniently organizing product, process, and production planning information and for processing customer requirements” (Prasad, 1998). “The most prominent strength of QFD is the focus on customer needs and the coherent translation of those needs into each phase of product development process” (Raharjo et al., 2010). The House of Quality is an extension of this methodology and is used for describing the customer requirement, the technical attribute, the relationship matrix, the correlation matrix, and the benchmarking information. This methodology is also used for assessing customer needs’ dynamics and risks.

Work breakdown structure (WBS) is a hierarchical method of breaking up systems into smaller sub-systems that can be managed by specific groups. WBS is a project-oriented structure which organizes and defines the activities within a project.

2.4 Physically large and complex systems

Physically large and complex (PL&C) systems differs from complex systems with having the added dimension of being physical large. Products that are large, one-offs, without prototype and with an individual manufacturing process, such as civil engineering constructions, large chemical process plants, ships and offshore facilities, are identified as such systems. (Andrews, 2011)

2.4.1 Art and science in design

The design of PL&C systems has earlier been regarded as an art form, but due to the dominance of computational-based tools and methods, the current design practices has evolved into a science rather than art. The issue of art and science in design can be seen to be explained in that the scientific approach assists the “art of designing” to enable creative ideas to be produced alongside obtaining rational decisions (Andrews, 2011). An explanation can be that these systems are often designed by engineers, which is a clear scientific discipline in need for structured and well proven methods of assessing problems.

2.5 Impact of computerization

Today’s availability of computer processing capacity makes it possible to manage and evaluate large amounts of data. This enables more aspects to take place in an earlier stage of design. Computer aided-design (CAD) has become part of the designer’s daily life, which has led to increased productivity and quality of design. CAD makes the foundation for development, evaluation and improvement of designs. Today there is no single tool for managing all aspects to vessel design, and the industry uses various applications managing the design problems. Because different disciplines within vessel design often use different software application, the same design might have to be modelled several times with various level of detail. By being able to use a single model, accessed and modified by multiple software applications has great benefits regarding productivity. This thesis will focus on systemizing the available information and calculations of OSV design, so that more aspects can efficiently be implemented in an early stage of design, with the purpose of being able to develop the best possible design.

2.6 Visualization of design

“Having a visual, geometric representation of a design process is crucial, for designers are spatial thinkers” (Brooks, 2010). Andrews concludes that computer graphical methods have changed the nature of PL&C systems, so that it can either can become more “black box” like or, preferably, use computer graphics to open up and early design synthesis to the use of simulation and visualization (Andrews, 2011). Existing ship design methodologies can easily be adapted to support visualization, such as Vestbøstad’s adaption of SBSD.

The required level of detail and accuracy of the visual representation of the design will vary with over time, much in accordance to the design phases (see Figure 2). Too much information in an early stage of design could limit the designer by being caught up in minor details. Sketches can provide valuable information for discussions, but should not be confused with prototypes related to more accurate design which are developed from later stages of design (Buxton, 2006).

2.7 Mass customization (Brekke and Tvedt, 2011)

Mass customization is a methodology that aims to provide a “tailored” solution to the customer while using modern mass production and still being able to have low production costs. The methodology accepts each customer as an individual and will provide them with the desired design at a relatively low cost. With mass customization a company can gain larger market share while keeping the cost of the production at a low level. Figure 11 illustrates that mass customization has its advantage at low to medium production volumes as

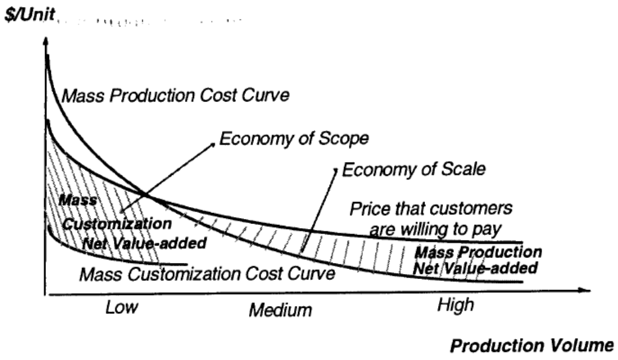


Figure 11 - Economic implications of mass customization (Jiao, 1998)

customers are willing to pay more to fulfil their special needs. In today's shipbuilding, mass customization is applied to some degree by presenting the customer with a list of manufacturers for each equipment or system. With a more structured application of the methodology, it is believed that the design phase and the cost of a vessel can be further reduced. In order to benefit of mass customization the company have to achieve product variety, economy of scale and quick responsiveness. (Jiao, 1998)

2.8 Product platforms

A product platform contains rules for the combination of predefined modules, components or parts. Meyer and Lenherd capture the essence of product platforms:

> *"A set of common components, modules, or parts from which a stream of derivative products can be efficiently developed and launched."(Meyer and Lenherd, 1997)*

The possible design alternatives and variants that can be derived from the product platform are known as a product family. This family is defined by the structure of the system and a product is selected by a user interaction with this system. The main motivation for using product platforms is the ability to provide tailored solutions to meet each customer's specific needs, while using known components, modules and parts. It can contribute to reduce development costs and lead-time while increasing product variety and customization.

There are two main alternatives to the structure of the product platform; a module based and a scale based product platform. A module based product family produces the family members by adding, substituting and/or removing one or more functional modules from the platform. A scale based product family on the other hand creates its family members by scaling each component from one or more scaling variables. Product platforms can also be a combination of the two. (Simpson et al., 2006)

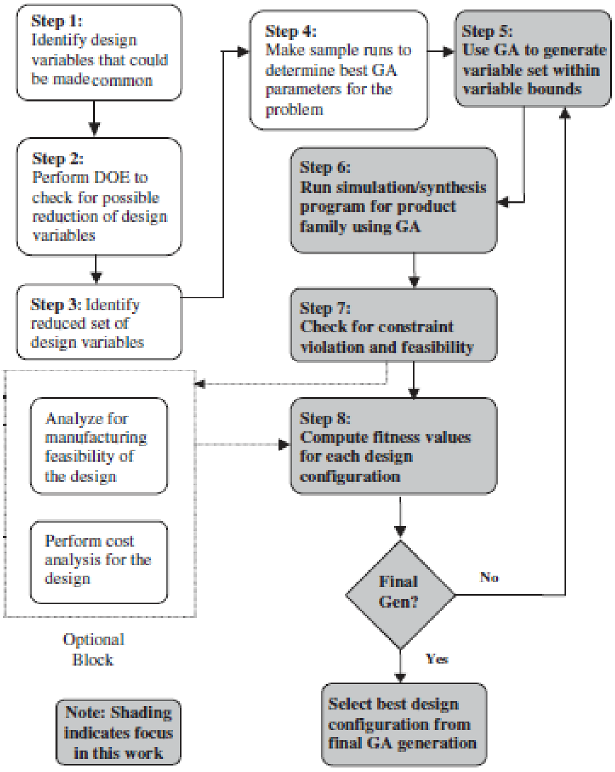


Figure 12 - Genetic algorithm-based methodology (Simpson and D'Souza, 2004)

3 Optimization & Design selections

3.1 Search algorithms

Search algorithms are algorithms for filtering items which meet specified criteria among a collection of items. These algorithms can assist a designer when working with large amounts of design alternatives, so that automated exploration product families or configuration of parameters can be made. This will improve the efficiency of the designer and allow for a larger range of concept designs to be identified, considered and evaluated against each other.

3.2 Genetic algorithms

Genetic algorithms are stochastic optimization methods based on the principles of natural evolution. The optimization process is carried out with a population of potential solutions for the problem, coded as chromosomes. A performance index is assigned to each chromosome. The population evolves toward better regions in the search space by means of genetic operators as selection, crossover and mutation. After several generations, the algorithm converges to the best individual, which represents an optimal solution to the problem. (Revollara et al., 2005)

Genetic algorithms have been proven as systematic and efficient methods of searching design space for the best solution. The increase in availability of computer resources the later years is a large driving force to GA's protrusion, due to the large amounts of calculations behind these methods. Optimization methods rely on a model of the system of which to optimize. (Day and Doctors, 2000) "The model must represent reality in a simple but meaningful manner"(Papalambros and Wilde).

3.3 Multiobjective optimization

For multi objective optimization problems there may not exist one solution that minimizes all the objective functions simultaneously. A concept known as "Pareto optimum solution" can be used for solving such problems. Pareto optimum solutions exist in the ranges where reducing one objective function causes increase in at least one other objective functions. Figure 13 illustrates two objective functions f_1 and f_2 with the minimum in the point P and Q. Pareto optimal solutions is found on the points on the line segment between these points (PQ). This means that all solutions between point P and Q is an "optimal" solution, and a trade-off between these solutions must be evaluated in order to select a solution. There exist multiple methods of multiobjective optimization, where most generate a set of Pareto optimal solutions and some additional criterion rule to select one of them. (Rao, 2009)

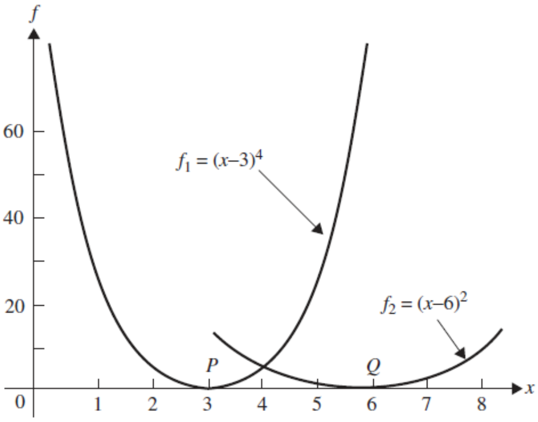


Figure 13 - Pareto optimal solutions (Rao, 2009)

Because Pareto optimality gives a set of solutions rather than a unique solution it can be used in the selection process of good feasible solutions rather than finding one optimum solution which may not exist. This set of solutions can also allow for individual decisions and requirements to be a part of the selection process of the best solution, which can be hard to capture in an optimization model.

Another disadvantage of Pareto based optimization, as well as other optimization algorithms, is that is lacks explanatory nature. This can cause problems when analysing how the best solution is found, and especially when the designer of the algorithms differs from the user.

While working with large amounts of solutions, Pareto based optimization can provide valuable information to which solutions that are most interesting and should be evaluated primarily. Although these solutions can prove "too optimal", meaning that they are impossible to implement in reality because the model suffer from basic flaws in the model, they can give indications to which areas of solutions that can be regarded as best solutions.

See chapter 0 for example of how multiobjective optimization in combination are used for the design of naval vessels.

3.4 Product platform optimization

Product platforms' structure makes them eligible for optimization by genetic algorithms. As the product platforms produces its design output from the selection/determination of a range of variables, multiobjective optimization can be used to determine the best setting of these variables in order to select the best individual. It is also possible to expand the scope of augmented GA to include multiple product platforms, and thereby increase the possibility to evaluate a variety of designs. (Simpson and D'Souza, 2004)

There are two basic optimization approaches for the selection of the best design variable settings (Simpson and D'Souza, 2004):

1. Single-stage: The product platform and resulting family is optimized simultaneously.
2. Two-stage: The product platform is designed during the first stage of the optimization, followed by instantiation of the individual products from the product platform during the second stage of the optimization.

Although it is possible to formulate product platforms as a multicriteria optimization problem, it has been experienced that the products within the product platform can degrade (Nelson(II) et al., 1999). It must therefore be evaluated whether formulating the product platform as an optimization problem will benefit the user by providing valuable solutions with minimum effort, or if the user is best off working with a product platform where a better solution can be found without knowing which solution that is the best, unless a thorough and comprehensive comparison study is performed.

The ability to get an "optimal design" by the click of a button can have great benefits when it comes to the responsiveness of the product platform. Drawbacks are as explained earlier that the user is left with little to no information of how this optimal design is selected.

An optimal design in reality will vary from person to person because of individual aspects. These individual aspects are hard, if not impossible to capture in an optimization algorithm of a complex system. The reduced product family resulting from the optimization selection process can cause an existing product platform to reduce its market scope, and thereby it's earning potential.

4 Royal Netherlands Navy (van Oers et al.)

The Royal Netherlands Navy is an example where modular methodology, parametric ship models and optimisation algorithms are actively used in the design processes of naval vessels. Their goal is to use the data processing capacity to reduce design time while maintaining the design responsibility with the designer and keeping track of capability and costs. They translate design requirements into feasible concept design and establish their capability. This is done by a space allocation routine integrated with an evolutionary algorithm that searches the design space for feasible ship designs. The design is feasible when is meet a set of designer defined requirements. From the collection of designs the designer can select a design based on reflection around different trade-offs. Figure 14 illustrates one feasible result from the space allocation algorithm and is based on a 2D sideview of a vessel.

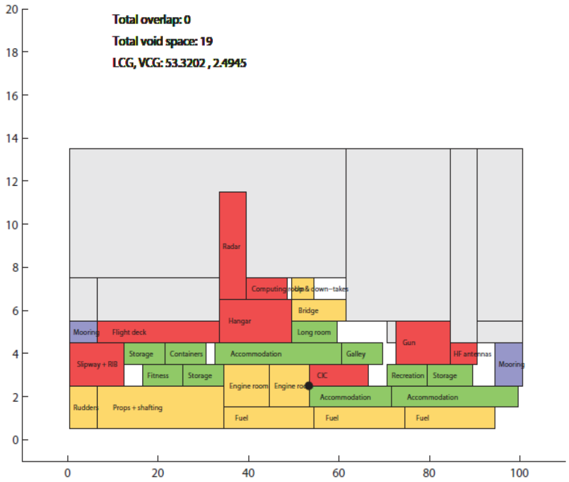


Figure 14 - Space allocation algorithm (van Oers et al.)

Delft University of Technology has in collaboration with Royal Netherlands Naval College have also explored the use of Pareto-based evolutionary algorithms to assist the designer during the selection process. This is done measuring predefined parameters and identifying those designs that best meet the designer's preferences. Figure 15 shows the Pareto-based evolutionary algorithm's selection process based on the feasible designs found by the space allocation algorithm. It was identified two main limitations to this selection process that can create black-box behaviour of the system(van Oers et al.):

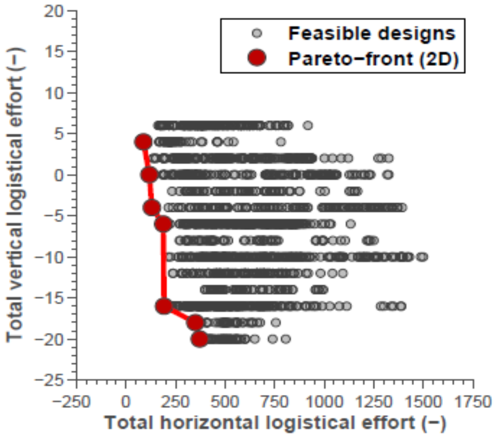


Figure 15 - Pareto-based selection process (van Oers et al.)

1. Pareto-based evolutionary algorithms lack explanatory nature
2. Best solution is excluded due to optimal design solutions may suffer from basic flaws due to constraints and system architecture.

Recent studies have developed a packing approach for the early stage design of service vessels (Oers, 2011). This approach uses a NSGA-II search algorithm in order to search for the best configuration of size, shape and positioning parameters for packaging modules into feasible 3D designs without human interaction. It was found that the number of feasible designs to consider during early stage of design could increase considerably compared to more traditional design approaches.

My opinion is that the packaging approach is a good method of generating large numbers of feasible designs for further evaluation. Because it uses no human interaction during the generation of the designs, the designs are limited to the parametric model of the system. This means that it may become hard to capture human judgement in the design solutions due to difficulties modelling these aspects, and limited possibilities to develop alternative designs by a designer that are not generated by the model. For others than the designer of the system, the design approach may become difficult to understand and seem black-box-like where they have little influence in the design process. A customer would have to choose from a given number of designs rather than being included in the design phase and able to contribute with own experiences and requirements. The design process of vessels is often subject to iterations and a design spiral process for continuous improvement. Aspects, such as vessel motions and hull resistance, may become hard to implement in a single model as these are generally evaluated at a later stage.

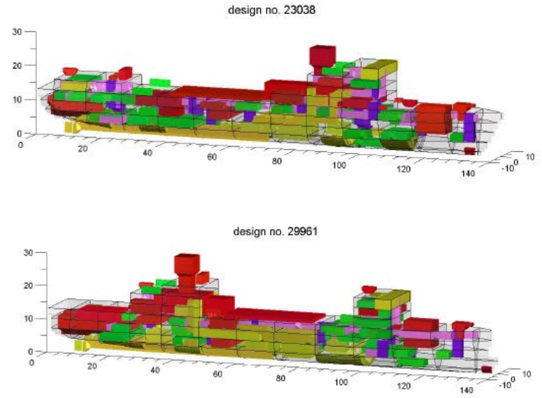


Figure 16 - Two feasible frigate configurations (Oers, 2011)

Part 2 Function management & modularization

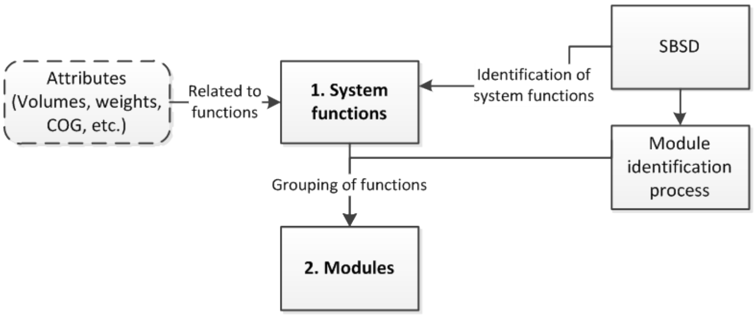


Figure 17 - Modularization of functions

Modules are the basis of modular product platforms (MPP) which contain rules for how these modules are positioned for the generation of a product family. This part will focus on how a system's functions and related attributes are identified and transformed into manageable modules for the purpose of being used in a modular system structure. SBSD and QFD methodologies have been actively used in this approach.

5 System functions

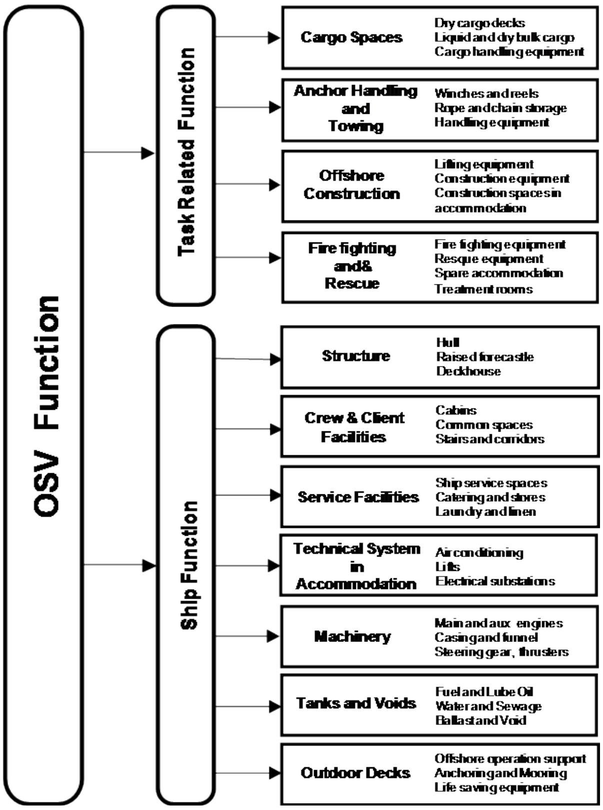


Figure 18 – OSV functions (Kai Levander)

A system will consist of a group of interacting elements or sub-systems. In order to describe the total system one needs to identify the functions that the system is to provide from the mission description. Examples of such functions will be carrying of payload and generation of power. The mission can often be linked to the customer demands while the functions are the solution to how a system is to fulfil its mission. When the system functions have been identified, the related attributes describing each functions performance requirements can be identified and quantified. The SBSD process provides a good framework for this process in relation to vessel design.

Figure 18 describes the functions related to offshore vessels according to the SBSD methodology developed by Kai Levander. This hierarchical description has similarities with the WBS, the main difference is that it describes multiple vessels. This description is a good foundation for a system where multiple vessels can be derived based on a template.

6 Modularization

The driving force for modular design is to simplify complexity according to the stage of design so that the designer has a manageable system to work with. Modularization in different stages of design is explained in chapter 2.2.4. The various functions and attributes identified in the previous chapter makes a foundation for the generation of modules specifically related to OSVs.

Another benefit of modularization is that the division of relative independent parts facilitates parallel work, meaning that each module can be regarded as an independent system that can be developed separate from the others. This means that several modules can be developed at the same time or outsourced, having the potential of reducing development time. In addition work can take place at the best suited place or by the best suited persons, for instance design of equipment modules by the equipment manufacturers.

6.1 Module system borders

How the system functions are assessed in the generation of modules have influence on the system structure. As the definition of a module is a relative self-sufficient part, the interactions across system borders should be kept at a minimum. Due to the complexity and spatial compactness of offshore vessel systems one might have to compromise the module to be self-sufficient in order to enable easy integration of modules.

As an example the system borders of equipment and systems that are installed in vessels may vary from you point of view. A deck crane for example can be viewed as simply the crane which is placed on the deck, the crane with foundation or the crane with foundation and all related systems such as hydraulics and control systems. This variety in system border means that a ship designer has to make clear deign decisions with regards to the implementation of these modules.

A wide system border may result in undesired implementation effort, resources and costs. If for example a crane module includes the hydraulic system, the implementation of this module will require much resources installing hydraulic piping within the hull. If standardized hydraulic interfaces where established, one could reduce the system border to the crane with foundation in order to reduce the integration effort.

A narrow system border can enable easy implementation, but will require preinstalled systems which will influence the size and weight of the vessel. If for example a vessel is supposed to be configured with multiple crane alternatives in a given location on deck, the foundation has to be able to support the crane with the largest weight and capacity, resulting in excess weight and space consumption for cranes with lower weight and capacities. To allow multiple crane locations on the deck, each location alternative has to be fitted with foundations, hydraulics and controls.

Using modularization for the purposes of enabling re-configuration in operation is explained in Part 5, but the general idea is to enable “configured-to-mission” options. From a re-configuration point of view the system borders will affect where one is located in the re-configuration pyramid introduced in chapter 20. From a ship builder’s perspective it is more related to the complexity of the build process and the vessel alternatives that a designer/design company is able to offer. It is believed that when the vessel is built and operational, the system borders will be narrower compared to the same system in the build process. The reason for this is that one will aim to be closer to the top of the re-configuration pyramid in order to achieve re-configurability. There will therefore be a difference between product platforms that only generate design alternatives and those which provide re-configuration alternatives.

6.2 Requirements management

A structured methodology is important in order to create good product structures and designs. Quality Function Deployment (QFD) is a well-known "method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process"(Akao and Mizuni, 1994).

Buhaug, Hagen and Langset (1999) have developed a method based on QFD which aims at improving flexibility and configuration of the product. This method divides requirements in three main categories (Buhaug et al., 1999):

A: Requirements for performance & function (E.g. performance, capabilities)
B: Requirements for integration (E.g. interaction with other modules, location)
C: Preferences of customers (E.g. material selection, noise)

Figure 19 illustrates the function of a thruster (A-requirements) related to the components as well as the interface between the units. Horizontal grouping within the matrix indicates that several units are affected by the same requirement. Vertical grouping indicates that one unit is affected by multiple requirements.

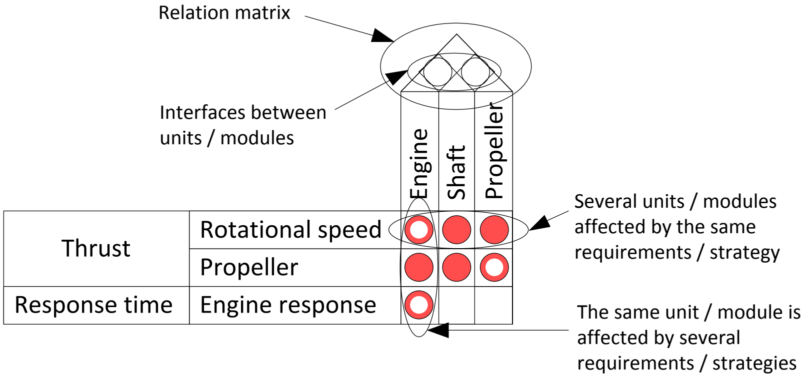


Figure 19 - Thruster example (Buhaug et al., 1999)

6.3 Relating functions to modules

Appliance of modular theory to the design and re-configuration of a product is a structured method of managing the complexity. By using modularization in design of OSV's one is able to focus on the main design aspects instead of minor details. Because the design process of OSV's have a tendency of starting with detailed functional requirements, a structured method of transforming these functional requirements into manageable modules are needed. The logical divisions of a vessel's modules have also been identified as one of the main limiting parameters in relation to the flexibility and capabilities of modular product platforms. One must be aware that control over independent functions are lost by grouping functional requirements together, one example of such losses of control can be the internal arrangement of a deck module.

This report uses a method that identifies vessels functions and then has them categorized into ship related- and task related functions according to the SBSD approach. The ship related functions are associated with the general functions of a vessel while the task related functions are associated with the type of operation the vessel is to perform, also known as the mission. When the functions are identified, this report uses the method of Buhaug et al.,1999, to evaluate and relate functions to modules. This method was initially developed to be used on a more detailed level and for improvements to product structures, but has been modified to support a modular approach to vessel design.

The ship related functions are then grouped / assigned to modules that make the basic vessel. These modules are mainly generated and positioned prior to the operation modules indicating that they form a basic vessel without any operational related capabilities.

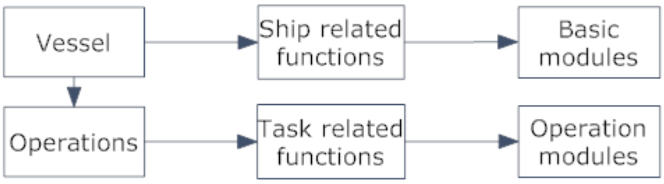
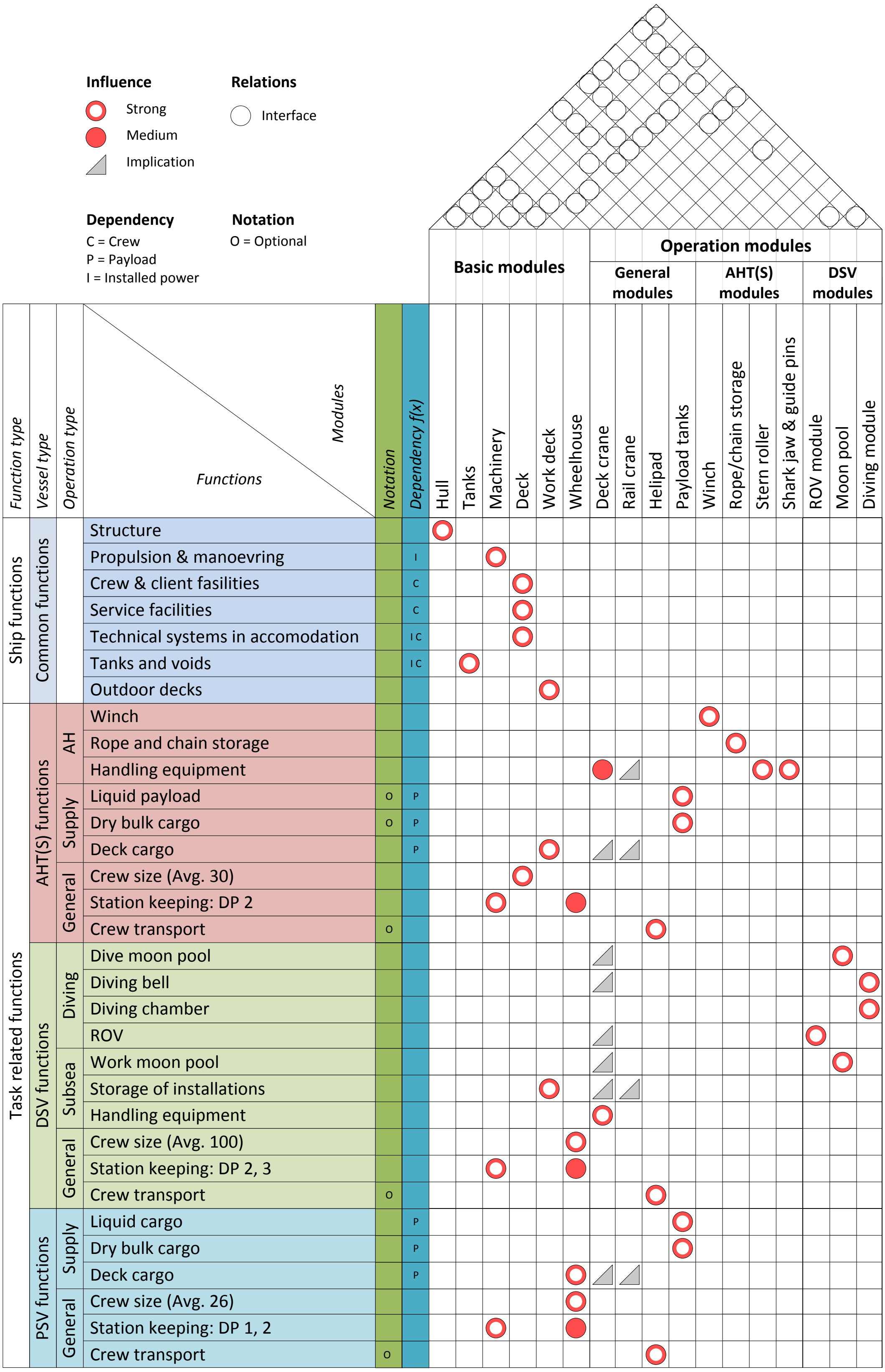


Figure 20 - Module generation

The task related functions are also assigned to modules analog to the procedure for the ship related functions. These modules are constrained by the basic vessel and will in general have fewer relations to other modules; this can be seen in the relation matrix in Figure 21. It must be noted that some operational modules, such as moon pool, will influence the positioning rules of some of the basic modules and will therefore have to be incorporated within the structure of the basic vessel. Task related modules that are added to the basic vessel with minimal influence on the basic modules, such as cranes, will have large opportunities for re-configurations. Task related modules that can be added to the basic vessel with minimal influence on other modules are later referred to as “external modules”, with the implication that they can be added to the initial configuration.

Figure 21 illustrates the developed House of Quality used for identifying requirements related to each vessel type, and then be related to one or more modules. Figure 21 also describes the interfaces between the modules which are used in the structure of product platform development. The figure indicates which parameters the functions are dependent on, as well as which functions that are optional. In addition alternative modules and module variants can be introduced in order to increase the flexibility of the modularization process. These module alternatives and variants can have variations in geometry, functions, location and constraints, making the combination of modules eligible for diversity and design selections.

It must be noted that AHT(S), PSV and DSV are the vessels included in this example. The modules of PSV can be found in the general modules. The reason for this is that this vessel can be described with modules that are common to other vessel. Other construction vessels are not a part of this study because of the large variety found in construction vessel functions.



Influence
◎ Strong
● Medium
◢ Implication

Relations
○ Interface

Dependency
C = Crew
P = Payload
I = Installed power

Notation
O = Optional

						Basic modules						Operation modules										
												General modules				AHT(S) modules				DSV modules		
Function type	Vessel type	Operation type	Functions / Modules	Notation	Dependency f(x)	Hull	Tanks	Machinery	Deck	Work deck	Wheelhouse	Deck crane	Rail crane	Helipad	Payload tanks	Winch	Rope/chain storage	Stern roller	Shark jaw & guide pins	ROV module	Moon pool	Diving module
Ship functions	Common functions		Structure			◎																
			Propulsion & manoevring		I			◎														
			Crew & client fasilities		C				◎													
			Service facilities		C				◎													
			Technical systems in accomodation		I C				◎													
			Tanks and voids		I C		◎															
			Outdoor decks							◎												
Task related functions	AHT(S) functions	AH	Winch													◎						
			Rope and chain storage														◎					
			Handling equipment									●	◢					◎	◎			
		Supply	Liquid payload	O	P										◎							
			Dry bulk cargo	O	P										◎							
			Deck cargo		P					◎		◢	◢									
		General	Crew size (Avg. 30)						◎													
			Station keeping: DP 2					◎			●											
			Crew transport	O										◎								
	DSV functions	Diving	Dive moon pool									◢									◎	
			Diving bell									◢										◎
			Diving chamber																			◎
			ROV									◢								◎		
		Subsea	Work moon pool									◢									◎	
			Storage of installations							◎		◢	◢									
			Handling equipment									◎										
		General	Crew size (Avg. 100)								◎											
			Station keeping: DP 2, 3					◎			●											
			Crew transport	O										◎								
	PSV functions	Supply	Liquid cargo		P										◎							
			Dry bulk cargo		P										◎							
			Deck cargo		P						◎	◢	◢									
		General	Crew size (Avg. 26)								◎											
			Station keeping: DP 1, 2					◎			●											
			Crew transport	O										◎								

Figure 21 – HOQ: Module identification based on functional requirements

6.3.1 Labelling of functions

The method of relating the identified functions to modules also needs a structured method of managing the large amounts of data and calculations related to each function in a database. By labelling each function according to which module it is related to, the properties for each module can easily be calculated automatically. This is in practise done by summing all values in the database if assigned by the correct label. Volumes and weights are typical values that can be calculated based on the labelling approach. The main advantages with this approach are that more general formulas can be used to reduce complexity and increase transparency of the system. Advantages and disadvantages with this approach are listed below:

Advantages	**Disadvantages**
Foundation for more automatic calculations	Functions without or miss spelled labels will be excluded
Reduces computing complexity of systems	Most applicable for (large) modules assigned with multiple functions
Supports easy implementation of new, or changes to existing functions	
Increase user understanding of systems	
Functions can easily be moved between the individual modules	

Example:

If we consider a system consisting of 10 functions (F_i), with volumes (V_i) and weights (W_i) as appurtenant data as Table 2 illustrates. Each function is assigned to one of four available modules (M_j). The general formula for calculating the volume of the functions assigned to a module follows:

$$V_{M_j} = \sum_{i=1,j}^{n} V_i$$

This means that the volume of module 1 (M_1) is calculated as: $V_{M_1} = V_5 + V_7$,

For module 2: $V_{M_2} = V_1 + V_4 + V_6 + V_8 + V_{10}$, and so on.

Function	**Volume**	**Weight**	**Label**
F_1	V_1	W_1	M_2
F_2	V_2	W_2	M_4
F_3	V_3	W_3	M_4
F_4	V_4	W_4	M_2
F_5	V_5	W_5	M_1
F_6	V_6	W_6	M_2
F_7	V_7	W_7	M_1
F_8	V_8	W_8	M_2
F_9	V_9	W_9	M_4
F_{10}	V_{10}	W_{10}	M_2

Table 2 – Example data

As we can imagine, this method quickly becomes inefficient and difficult to follow when working with large amounts of data. If we introduce labelling of the functions, we can use the more general formula to calculate the volume assigned to each module. This means that the volumes of a given range of data can be summarized if they fulfil a given criteria. The criteria in this case are that we only want to summarize volumes with a given label, e.g. M_2 to summarize all volumes assigned to module 2. All calculations can now be automated so that changes and implementation of new functions requires minimum changes to the system structure.

6.4 Non-modular components and modular suitability

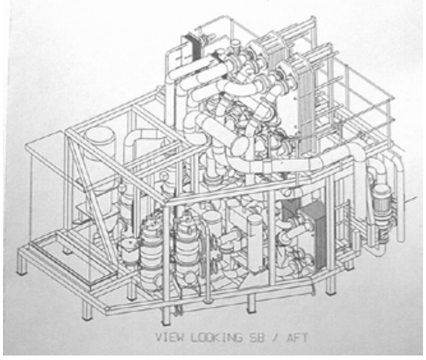


Figure 22 - Complex module (Hagen, 2011)

In concept design, as described in previous chapters, it might be beneficial to work with complete modular systems. Modularity in a concept stage is often made available by simplifications of the system, for the purpose of exploring possibilities and support creativity. As the project develops, the more detailed design is needed. During this project development it might become apparent that not all components and systems can be described as independent building blocks. These are typical systems and components that cross module borders. Piping and electrical wiring are typical systems that are difficult to modularize due to the degree of extent inside the vessel and the accuracy requirements for these systems. How to handle these non-modular components must be established. Standardized interfaces could be established between the modules for these systems, but generic interfaces for all module configurations are difficult to achieve. A solution might be to allow these systems and components to be implemented after the module configuration are established. This may be achieved by adding designated zones (empty space at given locations) to modules for implementation of these systems at a later stage. In a 3-D model, such systems can be integrated inside other modules, and thoroughly checked against the existing module systems.

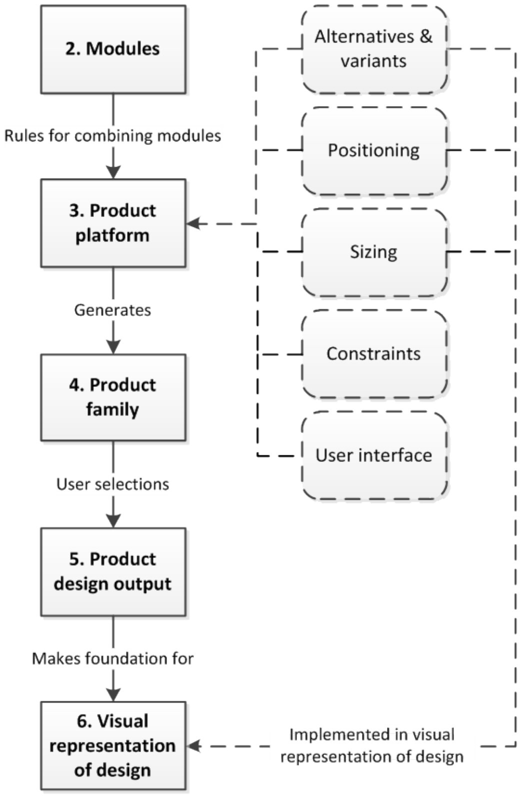
Equipment alternatives, such as cranes, thrusters, winches, moonpool, etc., are handled as separate modules in this context. But it is noteworthy that these equipment modules often require power supply or structural reinforcement which will affect surrounding modules. This must be accounted for in later stages of design.

Hardly any modules in such a large and complex system as a vessel is can be placed randomly without some influence on the system. And although large parts of the system can be described as modules, for obvious reasons, the modules require some sets of rules for where they can and cannot be positioned. This applies to both local and global references. Global references can for example be front wheelhouse, or engine room and tanks in the lower part of the vessel. Local preferences for the modules positioning relations may be used to separate accommodation from the engine room to meet noise requirements, or connect main deck with A-deck. Zones can be introduced to describe the area where modules are allowed to be positioned, and thereby constraining the modules to these zones.

6.5 Conclusion & findings

SBSD have provided a good framework for concept design of OSVs. The method of using the house of quality to generate modules has provided a structured method for managing functional requirements. It also provides detailed and transparent information about functions and modules that are required for each vessel type’s mission, and which modules that interact. When working with large amounts of functional requirements, labelling of these requirements according to which module they are assigned to will contribute to a non-complex and understandable system structure. These approaches form a basis for the construction of the product platform structure developed in part 3.

Part 3 Product platform development & visualization



Part 3 looks at how the modules generated from Part 2 will be systematized in order to generate a product family, known as a product platform. The basic of such a modular description of OSVs was identified by the House of Quality. A parametric ship description can be created, so that specific designs are derived from a variety of user choices in the form of a systematic selection and input parameter process. This means that the user of the product platform in practice is selecting a desired product from the product family generated by the product platform. The fact that the possible design options are determined by the product platform structure means that there are large numbers of requirements to system development. It must be created a generic product platform that incorporates the largest possible range of customer and designer requirements. Visualization of the preliminary design output has been shown to have a number of advantages and challenges that are discussed later in this part.

The essence of the description of product platforms is captured by the following phrase:

> *"A set of common components, modules, or parts from which a stream of derivative products can be efficiently developed and launched." (Meyer and Lenherd, 1997)*

Efficiency in the derivation of products is the key to product platforms. The fact that large amounts of information are to be processed by the product platforms and efficiently developed into a selected product, demands a good system structure. The product platform is subject to several aspects that are discussed in the following chapters. As a product platform uses common components, modules and parts to create a product family, it is subject to large amount of data that must be structured. The product platform architecture must be created in a structured way in order to be used in an efficient way by the user. Input values, how the output designs are visualized, level of complexity and which software that are used, are examples of aspects that impacts the structure of the product platform. This chapter aims to evaluate different aspects of development and use of product platforms in design of offshore vessels. Both aspects form a ship owner (the buyer) and ship builder/designer (the seller) are evaluated as these will have different requirements to the product platform.

7 Modular Product Platform Development

A product platform which contains rules for combining the identified OSV modules are developed and discussed in the following chapters. How modularization is applied, and integrated in the system development are essential for the functionality of the product platform and the performances of the output designs. In correlation to the SBDS methodology this approach does not need pre-defined main dimensions, hull lines or standard layouts, but used as a tool in concept exploration and acquiring design knowledge.

7.1 Requirements to the product platform

A product platform is constructed to a specific purpose and makes each product platform unique. Product platforms can be used for various purposes, and these purposes are important when the product platforms structures are developed. Another aspect to the structure is the operators of the product platform. Operators form different backgrounds will have different requirements to the product platform (PP). Examples of such requirements are listed below:

1. Designer
    - A flexible PP that is able to produce the desired design and design changes
    - A structured PP that is understandable
2. Owner
    - A PP that captures customer needs
    - A PP that has good visual representation of the design
3. Operator (in operation)
    - A PP that provides designs that have good performance in operation
    - A PP that incorporates re-configurability in operation
4. Builder
    - Produces design that is “easy” to build, in order to achieve low build costs
    - A PP that can produce various drawings for build purposes
5. Salesman
    - An intuitive PP that easily can produce desired design changes without knowledge of detailed calculations.

Chapter 2.3 discussed the differences between the actors’ requirements to the design output. Due to the differences in interests between the actors in the market, it is found to be favourable for the product platform to provide evaluation of the performances of the design output as well as comparison to alternative solutions. Because requirements can vary from person to person it is selected to develop an open structure with limited constraints in order to meet a larger target group.

7.2 Software development and selection

As there are no existing complete tools for creating product platforms for offshore vessels, or ships at all, the product platform must be developed. How the product platform is best created and visualized is independent from company to company. The product platform must be tailored to each user’s specific needs and is intended to incorporate large amount of company specific data. This report will discuss two main ways of developing product platforms; dedicated- and interconnect software.

7.2.1 Dedicated software

Dedicated software is software created for managing a specific task, in this context a modular product platform with visualization of design output. Dedicated software will require software development of applications that can design a vessel based on given input parameters, and return a visual representation of this design. The software must incorporate databases, calculations, user interface and 3D modelling. Some of the advantages and disadvantages are listed below:

Advantages

- Better performance achievable
- Customized user interface

Disadvantages

- Software development needed
- Resource demanding to develop
- Little insight to system structure by user
- Changes to structure is difficult to achieve

If such a tool is developed it can become a unique design tool for the OSV industry. It is believed that the levels of complexity of product platforms for offshore vessel makes dedicated software development difficult and can make the user (ship designer) feel less in control. Due to the effort developing this software, it should not be part of a design process. If a commercial solution is developed, it will still require large degree of adaptions to the individual user.

7.2.2 Interconnect software

The fact that today's ship building uses numerous software applications that have limited interactions between each other can cause a single design to be modelled several times in the same project. If for example a company uses one software for structural analysis, one for hydrostatics and hydrodynamic calculations and one for piping, the result might be that the vessel must be modelled 3 times if there is no interaction (exchange of data) between each independent software. The results are that the efficiency of the project is reduced and inaccuracies might appear in calculations and design due to loss of data and simplifications from other software.

By interconnecting different software and making it possible to work together, sending information back and forward can lead to a more efficient design process. One of the benefits with interconnect software is that one can tailor the product platform to fit a company's existing software solutions, reducing training and supporting an easy integration in the company. Another benefit with interconnect software is that well tried existing software is being used so that there is no need for resource demanding software development. By being able to use the best suited software for each design task, without rework can prove itself to become a valuable design tool in the future. Benefits with this solution are summarized below:

- Freedom in software selection
- Best suited software for each task of the design
- Minimal training (due to use of familiar solutions)
- Easy to adapt to existing solutions
- Easier access to system structure: Changes to system structure is easier, and the user can get better understanding of the structure.
- Continuous improvement to initial design

In order to interconnect different software one must create the interactions between the individual software if they do not exist. In order to enable these interactions one must understand the computer language of each software application and how the information must be communicated. It is recommended that all interconnected software uses the same database to store and retrieve information in order to have control over the large amounts of data. When creating a product platform for the OSV industry, it is believed that interconnect software has large benefits compared to dedicated software development.

7.3 Approach

The development of the product platform requires a structured and systemized approach. This report uses SBSD as a method of identifying detailed ship- and task related functions. These functions are then used as the basis for a modular product platform. The modular product platform contains rules for combining defined modules, including module alternatives and variants, based on user decisions. The user of the product platform, are presented with an interface to the product platform that supports a structured design process which focuses on concept exploration and including customer requirements. Large amounts of simple calculations are made on the basis on a set of input parameters in order to increase the efficiency of the design and concept exploration phase. The configuration and generation of the modules are used as the basis for 3D visualization of the output design.

7.3.1 Identification of functions

In correlation to the SBSD approach are the OSV's functions divided into ship- and task related functions. Ship functions are basic functions that are common for all OSV's, such as machinery, tanks and crew facilities. Task related functions are associated with the operations that a vessel is to perform, and are therefore connected to the different vessel types within the OSV term. See chapter 5 for description of the division and identification of these functions. Figure 21 on page 22 illustrates how the functions are related to the modules, the interactions between the modules and which modules that are related to the different vessel types in the product platform.

7.3.2 Function attributes

The identified functions can be described by certain properties, or attributes. These attributes must be identified and quantified in order to generate the description of the vessel design. The following three main attributes are used to describe the functional requirements:

- Volume
- Weight
- Area

For modules with given shapes, such as most task related modules the following main attributes are used (Volume and area requirement are calculated from the dimensions):

- Length
- Breadth
- Height
- Weight
- COG

To be able to establish the total volume and weight of the vessel, the areas, volumes and weights for both the ship- and task related functions must be estimated. A requirement's attributes will often have the same parameter dependency. Three main categories of dependencies are identified for the attributes:

- Constant: Constant for all vessel types and user input.
- Selection dependent: Functions properties are implemented based on discrete input parameters. E.g. the volume of an anchor winch is 0 for all vessel types except AHT(S). This is also used to implement alternative mathematical models related to the different vessel types.
- Mathematical models: Properties are functions of numeric and/or discrete input parameters. In the parametric description of the product platform, mathematical models, also known as sizing models, can be developed for the calculation of these attributes based on one or more input parameters. The parameters of the engine room can for instance be expressed as $\frac{\text{Volume}}{\text{Installed Power}}$, $\frac{\text{Area}}{\text{Installed Power}}$ & $\frac{\text{Weight}}{\text{Installed Power}}$, with installed power as input parameter. These mathematical models can be developed based on experience data of similar successful designs.

The establishment of the area- and volumes requirements of each functional requirement is the basis for the sizing of the vessel. It is the configuration of these volumes which determines the output design and design alternatives. Weight calculations are calculated similar to the volume calculations. Weight calculations are used in the validation of the design. Stability, trim, pitch, draught and freeboard are examples of design properties that are derived from the weight calculations.

7.3.3 Modularization

Due to the large number of requirements that are related to OSV design it can be beneficial to group certain functions into modules, with the related attributes. This generation of modules is explained more in detail in Part 2, and Figure 21 describes the modular configuration of the product platform. The attributes for each module is calculated by adding up the attributes for all functions assigned to each module. COG values for each module must be estimated in order to calculate the global COG of the vessel. This thesis assumes homogeneous weight distribution for most modules.

It has been noticed that the ship functions often allow the grouping into large modules. These modules can be called main- or basic modules, which are required for all vessels. Task related functions will mainly be retained as smaller modules or implemented in one of the existing main modules, called operation modules. This is a consequence of a structure that uses basic modules that are common for all vessel types, and then adding modules related to the selected vessel type. The reason is that smaller modules are easier to add to the basic modules without influencing large parts of the design. Large operational modules such as the moon pool module will have a large influence on the basic modules, and thereby increase the system complexity.

For the purposes of constructing an efficient product platform it has been a needed to differentiate the modules in the following categories:

- Hull module(s)/sections: The watertight body
- Internal modules: Modules that are placed within the confinement of the hull. Consist of all basic modules, and certain task related modules.

- External modules: Modules that can be added to the initial configuration with minimal influence on the other modules. Consist mainly of task related modules.

7.3.4 Generation of the product family

The variation within the product family defines the flexibility and performance of the product platform. The product family is generated by the configuration of established modules, and are established through various discrete, continuous and combinatorial parameters. These parameters can either be made available as user input, or integrated in the system structure where more expertise is required in order to make changes. The following parameters have been used to generate the various designs available within the modular product platform:

- Shape- & size parameters
    - Alternative modules enable large variations in designs:
        - Alternative modules enable large variations in design. E.g. alternative bow shapes, or crane alternatives.
        - Alternative task modules enable the possibility to generate designs for given tasks. The product platform can incorporate different vessels requirements, e.g. that an AHTS require an anchor winch module.
    - Variable modular attachment of functions:
        - Makes it possible to adjust size of modules. E.g. so that modules can be sized in order to better fit the hull.
        - Functions can be moved across the modules (in all stages in the process) so that better modular structure can be achieved.
    - Scaling:
        - Modules can be scaled in one or more dimensions in order to meet a given criteria. Based on the volume- and area requirement of a module, the length of the module can be calculated based on desired (vessel) breadth and (deck) height as input parameters. See chapter 7.3.6 for detailed description of how modules are scaled in the product platform.
        - Hull shape can be scaled to fit the configuration of modules
    - Sizing models:
        - Based on one or more input parameters mathematical models can determine the size of modules. The size and weight of the machinery can for example be calculated based on required propulsion power as input.
    - Fixed shape and size:
        - Modules which has predetermined dimensions. E.g. equipment from a manufacturer such as cranes, anchor handling equipment, thrusters, etc.
- Positioning parameters
    - Combinatorial which defines the sequence the modules are positioned in. E.g. engine module(s) are positioned after the tank module(s).
    - Continuous parameters allow modules to be positioned within a defined coordinate system. E.g. a crane’s position on the work deck.
    - Discrete which allows predefined positions to be selected. E.g. a crane having a set of predefined positions which can be selected.

The system also requires overlap rules which constraints modules from being positioned inside each other. This can be managed based on the combinatorial rules and module dimensions.

This system structure is similar to the packaging approach developed by B.J. van Oers, where a NSGA-II search algorithm where used to search for configurations that meets a set of design requirements (Oers, 2011). Here the main goal where (similar to this thesis), to reduce the effort required to generate and evaluate multiple feasible ship design alternatives in early stages of design. Search algorithms like these can be used to find designs from the product family with specified properties, or which meets a set of requirements, so that the designer can eliminate infeasible designs from an evaluation process. In order to benefit from search algorithms, all design changes must be accomplished solely by value changes of input parameters (Oers, 2011).

7.3.5 Input parameters

The input parameters are the interaction between the user and the design selections. These input parameters are the main source of design changes to the output design. These design changes must be incorporated within the product platform structure so that the desirable design changes are available from one or more input selections. From a designers point of view it is desirable that one input parameter is connected to one design change. If an input parameter influence multiple design changes it is difficult to produce the desired design changes. As the design of vessels is based on an iteration process, where a design is produced, evaluated and changed in order to meet given requirements, the input parameters have to capture this aspect of the design process. The input parameters have to provide:

- User interaction
- Design changes
- Support iteration and design improvement

The parameters generating the product family from chapter 7.3.4 is naturally selected as input parameters because the configuration of these input parameters generates the design output from the product platform. Although these parameters define the product family, it can be necessary to exclude some of these parameters from the user inputs. If the user of the product platform lacks competence that certain parameters require, or if the stage of design don't require the level of detail that certain parameters involves, the parameters can be excluded from the user interface.

The product platform is a good tool for concept exploration because the automated calculations enable generation of multiple design alternatives with minimum effort. Concept evaluation requires large freedom in design variations which has to be incorporated in the system structure and made available through the input parameters.

The input parameters have to support the iteration aspects of the design process. For instance the product platform is generated so that a preliminary value of the installed machinery power has to be selected. The product platform then returns a suggested value based on a database of similar designs and the gross tonnage of the preliminary input. Furthermore the 3D model of output design can be exported to external software which may return new values of installed power based on resistance calculations which then have to be implemented in the product platform.

7.3.6 Scaling of 3D models

The product platform uses scaling of a large variety of irregular shapes. The product platform applies scaling which is independent from axis to axis, meaning that the shapes can have different scaling in all 3 dimensions (x-, y- and z-direction).

Box volume is referred to as the volume of a rectangular prism that encloses the irregular shape and is indicated by the blue lines in Figure 23. By assuming that the relation between the actual volume and the box volume of the shape, we get the following expression for the box-coefficient (notation 1 and 2 indicates before and after scaling):

$$\frac{V_1}{V_{1,box}} = \frac{V_2}{V_{2,box}} = C_{box}$$

The cube volume can be calculated by the extreme values in x-, y- and z-direction giving us *V=L*B*H*. The new dimensions of the cube can be expressed as the initial value times a scaling factor (S) related to that dimension. This gives us the following expression:

$$\frac{V_1}{L_1 \cdot B_1 \cdot H_1} = \frac{V_2}{(L_1 \cdot S_x) \cdot (B_1 \cdot S_y) \cdot (H_1 \cdot S_z)} = \frac{V_2}{L_2 \cdot B_2 \cdot H_2}$$

As the initial volumes, initial dimensions and new dimensions are known (or calculated), the new actual volume can be found by the following expression:

$$V_2 = \frac{V_1}{L_1 \cdot B_1 \cdot H_1} \cdot L_2 \cdot B_2 \cdot H_2 = \frac{V_1}{L_1 \cdot B_1 \cdot H_1} \cdot (L_1 \cdot S_x \cdot B_1 \cdot S_y \cdot H_1 \cdot S_z) = V_1 \cdot (S_x \cdot S_y \cdot S_z)$$

Or if we use the relation between actual and box volume:

$$V_2 = C_{Box} \cdot L_2 \cdot B_2 \cdot H_2 = C_{Box} \cdot (L_1 \cdot S_x) \cdot (B_1 \cdot S_y) \cdot (H_1 \cdot S_z)$$

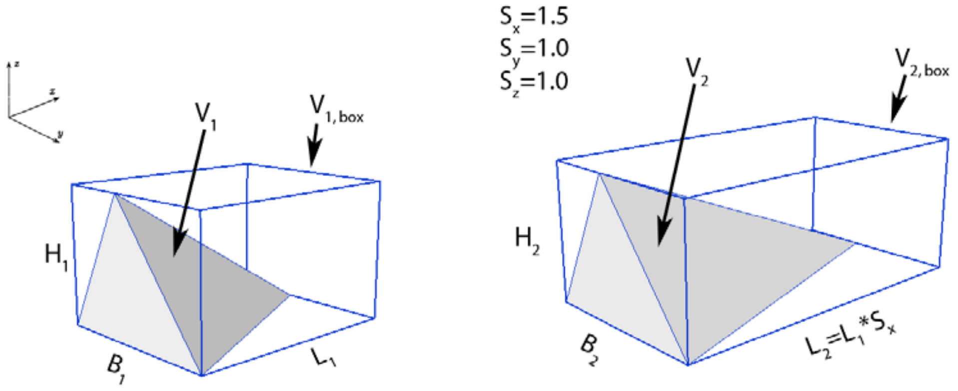


Figure 23- Scaling of irregular shapes

When working with 3D models that are scaled in one or more dimensions, these correlations enables accurate calculations with minimum effort in order to calculate the new volume of a scaled object.

The initial 3D model can be used to establish the box-coefficient and initial dimensions that are implemented in a database.

7.3.7 Establishment of module dimensions

Due to the fact that volumes are related to modules, it is the modules shape and placement that determines the main dimensions. The dimensions of the basic modules are constrained in two dimensions by input parameters and enables automated calculations in the third dimension.

Basic volume calculations are used for determining the unknown dimension of the modules where a box coefficient related to each module has been introduced to account for variable shapes: $V_m = L_m \cdot B_m \cdot H_m \cdot C_{Box,m}$ gives: $L_\mathrm{m} = \dfrac{V_\mathrm{m}}{B_m \cdot H_m \cdot C_{Box,m}}$

The required volume of the module is calculated by summarizing the volumes of all requirements (*i*) related to a given module (*m):* $V_\mathrm{m} = \sum_{i=1}^{n} V_{m,i}$

As $B_m = I\text{nput parameter}$ and $H_m = \text{Input parameter}$ the only unknown are the length of the module when a box-coefficient have been established. The previous chapters explain that 3D models of the modules contribute to simple and accurate calculations of the box-coefficients.

Vessel breadth is selected as a user input in order to manipulate the main dimensions of the design. As a majority of basic modules can be expressed by the breadth of the vessel and makes this a suitable input parameter. The heights of the basic modules are often a result of requirements such as draught, freeboard and deck heights. These aspects make the length of the modules suitable as the open dimension.

7.3.8 Vessel main dimensions

Due to the modular structure of the product platform it is the modules dimensions and positioning that determines the total dimensions of the vessel. The breadth and deck heights of the vessel are selected as input parameters due to reasons explained in chapter 7.3.7. The module dimensions are established based on the volume requirement, deck assignment and number of modules in breadth. Based on each module individual length requirement and locational configuration, the required length of each deck can be calculated. The structure developed in this report is based on two main length requirements; one below main deck and one above. The reason for the system to operate with two length requirements is to manage the various requirements. By doing so it is possible to separate the modules below work deck from the other modules in order to simplify the structure of the product platform. This is not a total division as several requirements have impact on the modules above and below main deck. The largest length requirement is the limiting parameter for the design, which the modules and hull must be adjusted to.

The length requirement below main deck is dependent on, apart from deck height and beam, length and configuration of tanks-, payload tanks-, stern equipment-, moon pool, and engine modules. The length requirement above main deck is mainly dependent on the required work deck length, equipment on deck, and largest super structure module.

As these length requirements rarely are the same, adjustments to the design configuration can be made to improve the space utilization of the vessel (minimize void) and increase the vessel performances. If the module configurations are to be kept constant, a larger requirement below main deck means that a larger super structure which can accommodate more crew or a larger work deck which can increase cargo capacity may be installed. If there is a larger required length above work deck, larger payload tanks or engine alternatives may be chosen.

Summary of the establishment of main dimensions:

- Breadth as user input: Breadth of all basic modules expressed by this parameter
- Deck height as user inputs: User must specify the height of each deck.
- Length is calculated based on the module configuration: By adding up all length requirements assigned to a given deck, the required length of each deck can be established. The deck with the larges required length is the determining factor for the length of the vessel (hull shape, which has variations in length requirement of each deck, must be accounted for).

7.3.9 System Based Design & Visualization in the product platform

System Based Design provides a structured methodology for identifying and managing all factors that influence the design. In addition it provides a method for using statistical data's to both support the designer in making design choices, and to automate calculations.

The methodology however lacks a good visualization of the design and design changes which can provide a designer with valuable information. By utilizing modular theory to manage the complexity of the design approach, in combination with a 3D modelling software, it is possible to develop a visual representation of the design. This means that the SBSD framework has to implement or be able communicate with a 3D modelling software. Methods of using the SBSD as a framework for design calculation, for then to generate a 3D model that are based on these calculations have been developed (Vestbøstad, 2011). Based on the SBSD calculations, commands can be formulated and communicated to a 3D modelling software so that a 3D model is created.

Modular product platforms that manage the configuration of modules can be developed based on the SBSD framework, to quickly develop and launch designs and design alternatives with large diversity based on a range of input parameters. The SBSD and QFD methodologies are used as a foundation for the identification and generation of modules in the product platform. The product platform contains rules for combining these modules and makes calculations related to these combinations.

7.3.10 User interface

The user interface is the main interaction between the user and the product platform. This is where the user makes desired design selections related to the output design(s). These design options are made available through various input parameters and are supported by design performance information. The computer based interface is known as a graphical user interface (GUI) where information and user options are made available through graphics and visual indicators. Chapter 7.3.5 identifies the input parameters the main source of design changes. In addition to enabling design changes, the product platform also needs to provide the user with information to make his/her design decisions. In this report it has been suggested to provide the user with the following information and options related to the design:

- Input parameters:
    - Primary input parameters: Main user decisions.
    - Secondary input parameters: Some parameters are related to the iteration process of the design. Initial input as a first guess are required from the user or provided by mathematical models in the system structure.
- Performance information:
    - Vessel dimensions & weights
    - Ship performances: Stability, trim, draft, freeboard, etc.
    - Payload & operational performances (Bollard pull, etc.)
- Visualization:
    - 3D model of design.
    - Alternative views: Views such as exploded view can be pre-programmed and made available on demand.
    - Selected geometry & systems: Selected geometry and systems can be available on demand.
- Validation & support:
    - Comparison of key characteristics to similar vessels: Based on database of existing designs built after year 2000.
    - Satisfaction of rules and regulations: Stability and freeboard regulations.
    - Export of 3D model: The generated 3D models are eligible for design analysis, simulations and evaluation in independent software solutions. These results can be implemented as input parameters to achieve a more accurate design.

7.4 Implementing vessel databases in design

Information about previous built vessels can provide valuable information that can assist the design process. This information can be used to atomize calculations or provide information of how the current design compares to others. Benefits with such databases are that they can be continuously updated to support evolution and improvement of designs.

Online subscriptions give access to large databases containing key features, such as DWT, design speed, LWT and machinery, of existing vessels. These online databases often contain powerful queries filters, so that relevant data can be exported. A database containing a range of vessel data for about 1100 AHT(S), 920 PSV & 50 DSV has been created based on information available at sea-web (IHS). It was selected to only use vessel data for vessels built after year 2000 to avoid using out-dated data, and still having a fair amount of data to base further analysis on. This information has been used to provide the user of the product platform with information about main vessel characteristics for similar designs based on mathematical functions, and thereby being able to compare the design performances in a fast and efficient manner. Mathematical models where developed based on regression statistics, and are explained in the following chapter. For input parameters that are only available by an iteration process, this database can provide a preliminary input or a good first guess. The Norwegian ship building- and design cluster in Sunnmøre, on the western coast of Norway, have become market leading in especially offshore vessels. In a reason article does Gunvor Ulstein, the group managing director and chief executive of Ulstein Group, state that this industry has 40 years of advance to the competitors (Stensvold, 2012). Due to competitive and technological advantages in the Norwegian market, it was selected to pay especially attention to Norwegian built and registered vessels. Plots for some of the key data for Norwegian built or registered vessels have been included in appendix XII. Plots of a selection of key data for the world fleet can be found in appendix XI.

Design offices and ship offices have more detailed information of their previous built vessels available. How accessible and systemized these databases are can vary a lot from company to company. This information can be used to develop mathematical functions that can be implemented and used to atomize the calculations in the product platform. These mathematical functions are often dependent on the input parameters available in the user interface. This thesis uses vessel data that form the work of Kai Levander that is based on experience data form STX OSV to automate these calculations. This vessel data contains much more detailed information than the database created from publicly available data, and is based on detailed functional requirements of the vessels.

One method of determining these mathematical functions are to use a set of data located in a database, to calculate regression statics. When the function and the input parameters are determined, it can be implemented in the product platform. By using this method for determining the mathematical functions within a product platform creates a more generic and flexible product platform. When the user of the product platform receives more statistics, it is only necessary to update the database for the new function to be automatically calculated and implemented in the product platform. A product platform that is based on a database of experience data will become more and more accurate over time as the number of data increases over time, reducing uncertainties. It can also easily be implemented in a company as the company only have to develop its own database of experience data to generate these mathematical functions. A problem with this experience data structure is that new companies will have low amount of experience data and will have difficulties creating accurate calculations, thereby generating uncertainties in the design solutions.

The following two chapters explain how regression statics are used to generate mathematical functions based on a database. MS Excel has been used to develop a database of OSV statistics and for the calculations of regression statistics.

7.4.1 Linear functions (regression statics)

By using the least squares method to calculate a straight line between the best suited data one is able to calculate the array that describes the line. The least square method seeks to minimize the mean squared error. A straight line is described based on the slope and the y-intercept as shown by the following formula:

$$y = cx + b$$

Regression statics terms:

Statistics	Description
c	Slope
b	y-intercept
se	Standard error values
x	x-value
y	y-value
$\overline{x}$	Average value for x-values
$\overline{y}$	Average value for x-values

Using the "LINEST" command in excel to return regression statics based on data-sets:

MS excel will return a 2x2 matrix containing regression statics when 2x2 cells are marked, a syntax is entered and ctrl+shift+enter is typed.

MS excel returns the regression static illustrated in the 2x2 matrix below for the following syntax: LINEST((Y-range);(X-range);TRUE;TRUE)

	A	**B**
1	C	b
2	se_c	se_b

The accuracy of the line calculated by LINEST depends on the degree of scatter in the data. The more linear the data, the more accurate the LINEST model. LINEST uses the method of least squares for determining the best fit for the data. When there is only one independent x-variable, the calculations for c and b are based on the following formulas:

$$c = \frac{\sum (x-\overline{x})(y-\overline{y})}{\sum (x-\overline{x})^2} \qquad \text{and} \qquad b = \overline{y} - c\overline{x}$$

7.4.2 Non-linear functions (regression statics)

In order to describe a non-linear line based on a linear approach one has to rewrite the non-linear function into a linear. The same least squares method is used as described in linear functions. One problem with this method is that constants are lost in this process, resulting in functions starting in origo (if x=0 then y=0).

The non-linear power function: $y = cx^b$

Rule 1. $\ln(x*y) = \ln(x) + \ln(y)$ gives $\ln(y) = \ln(c) + \ln(x^b)$

Rule 2. $\ln(x^y) = y*ln(x)$ gives

The linear function $\ln(y) = \ln(c) + b * \ln(x)$

MS Excel will return the following 2x2 matrix for the command “LINEST(LN(Y-range);LN(X-range);TRUE;TRUE)”:

	A	B
1	B	ln(c)
2	se_b	$se_{\ln(c)}$

This means that the non-linear power function can be described as:

$$y = e^{B1} x^{A1} = e^{\ln(c)} x^b = cx^b \qquad \text{with} \qquad e^{\ln(c)} = c$$

Figure 24 illustrates bollard pull plotted against gross tonnage of vessels selected from a database containing information of anchor handlers built after 2000. Regression statics are used for developing functions as a function of gross illustrated by the trend lines. The scatter in these results have to be carefully evaluated.

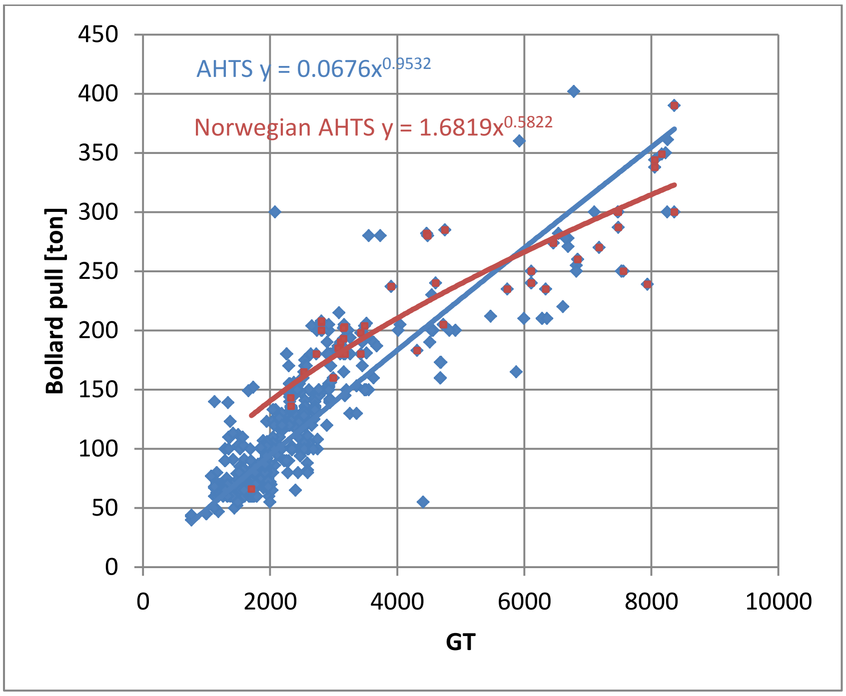


Figure 24 - Example of regression statics

7.4.3 Dealing with uncertainties

When using statistical data to create mathematical functions, there will almost always be a margin of error due to the scatter in the values. This margin of error will also be inflicted to the design output when basing calculations on these functions. Confidence intervals can be estimated and used to indicate the reliability of the statistical data. The total uncertainty of the design can be estimated by adding up the uncertainties of all independent properties. This total uncertainty may for instance be used to select designs with low level of uncertainty, or to prepare all parts for the worst and best scenario which can be expected when proceeding into more detailed design. When signing contracts, this margin of error can be used to allow for some deviation to the estimated build price and design performance, so that no parties are suffering, and breaches of contract can be avoided. Due to OSVs being "one-of-a-kind" vessels and statistical few, it has been experienced that the scatter in these results will be more than most other vessels, such as container-, bulk- and tank vessels.

7.5 Hull shape

The product platforms intention is to be implemented as a supplement to the existing hull shapes of a company. This means that the product platform must be able to have a structured method of incorporation an existing hull shape and make desired changes in order to produce a valid design. The modular structure of the product platform has consequences for the approaches to hull determination and integration and is discussed in the following chapters.

7.5.1 Hull determination and modularity

As explained earlier the vessels functions are grouped together generating boxes or modules. These boxes then have to be positioned and situated within a hull. When applying modular theory to ship design there is two main approaches to the determination of the hull:

1. The modules are placed first, then the hull is created around these modules, or
2. The hull is selected and defined prior to the configuration of the modules

The first approach supports a good internal module arrangement as the modules can be positioned in the best location and the geometry of the modules can be "optimized" for each other and internal arrangement. The hull is drawn around these modules, or an existing is scaled to fit. A problem with this is that the hull shape aspects are put aside and comes in second order. This has consequences for the vessel characteristics such as motions, manoeuvrability and resistance.

The second approach is the opposite of the first, and can be called a hull focused design process, supporting the vessel motions, manoeuvrability and resistance. The modules then have to be "squeezed" into the predefined hull shape, restricting the location and geometry of the modules.

A third method which combines the two methods is suggested here to support the hull shape and minimum void space. The main reason for this is that design performances when using the two other methods were undesirable when using small number of modules. The main idea is to shape the modules after the hull by sectioning of an existing hull. These modules do now have given dimensions and box-coefficients that enable them to be scaled in proportion to the volumes that are assigned to each module within a set of constraints. Motivations and how the hull is sectioned and used for creating modules are explained in chapter 7.5.4. By using this method one is able to achieve good hull shapes as well as good vessel configuration. This hybrid method is also expected to improve space utilization by minimizing void spaces.

The third method can also be used for exploring various hull shapes or hull sections within a modular product platform. As the method is based on the grouping of volumes into modules, these volumes can be assigned to a module with an alternative shape, and will mainly just require updated box coefficients (and 3D models) to be implemented. It must be noted that some hull geometries, such as twin hulls, might require changes to calculations and system structure. Such large design changes can be made available by using multiple product platforms, where the structure and calculations within the product platforms corresponds to the design output of each product platform.

The third method is found to be restricting with regards to the positioning of the modules as each module has a predefined place as a result of its shape. This may be solved by using multiple hull shapes, or product platforms that use different hull modules, which have different positioning rules.

7.5.2 Manipulation of hull geometry

For several reasons it is beneficial for the product platform to allow for changes to the hull shape based on one or more input parameters. Examples of such reasons might be improvement of design performance (resistance, stability, motions etc.), or larger design variety so that a larger customer range can be achieved (multiple bow shapes, variable position of super structure, etc.). Whether to section or manage the hull as a whole must be discussed. In this context, “hull modules” refers to both hull sections and complete hulls. There are multiple methods of achieving these changes to the hull geometry:

- Shape and size variation:
    - Alternative hull modules can allow for complex changes to the hull geometry. Discrete input parameters will allow a user to select form a set of predefined modules from a database in order to achieve the desired hull shape. Sectional hull shape (see chapter 7.5.4), in combination with alternative sections, will allow changes to independent parts of the hull. Alternative modules within the hull will not cause complex changes to the geometry of the hull (unless a module is related to a given hull shape), but might result in a different sizing of the hull. Selections of alternative hull modules will influence the internal configuration of modules which may require alternative modules, positioning or scaling of internal modules to be implemented. Complete hulls can be related to a given set of modules which are implemented on selection.
    - Scaling of modules will allow changes to the size of modules (see chapter 7.3.6 for description of how modules are scaled in the product platform). Continuous input parameters such as breadth, depth and freeboard can be used to alter the hull dimensions. Due to a system structure where volume and area requirements of each module are predetermined (based on grouping of functions), it is selected to keep length of modules as a calculated value based on breadth- and height inputs and the volume and area requirements. This means that a lower breadth- or height input will result in a longer vessel, as long as the positions of the modules are not altered. Scaling can also be to fit a hull shape around a configuration of modules so that the surface of the hull is outside the surface of the modules. Scaling of complete hull will allow the hull shape to fit a configuration of modules. Scaling of individual hull sections will allow the designer to achieve desired hull geometry.
- Positional variation:
    - Sectional hull shapes will allow for some degree of positional variation of the hull modules. For instance a moon pool module can be placed between two midship modules, where the fore midship module must be moved forward compared to a configuration without moon pool.

Sectional hull shapes enables two main features with regards to hull shape:

1. Alternative hull shape sections (E.g. alternative bow shapes)
2. Independent and conditional scaling of each hull section (E.g. constant L/B ratio of bow and stern shapes)

The first feature enables the product platform to incorporate alternative hull sections in order to produce multiple hull shape alternatives. The basic idea is to only change a minimum of the hull, and thereby the related internal modules, at the same time produce designs with large variety. This can be used by companies that are able to offer vessels with large variety of hull shapes. The trend today is that highly regarded design companies are developing bow shapes specialized for certain conditions while still offer the more traditional designs. An example of such a company is Ulstein, a company that has developed the X-bow design, but still must provide the more traditional P- A- and S- designs.

Another appliance of the first feature is to remove or add sections of the hull in order to meet certain task related functional requirements. An anchor handler will for example require a different stern finish due to the stern roller. The features of a moon pool also require changes to the hull, and might be solved with dedicated hull- and internal modules that are inserted as a midship section (see chapter 20.2 for illustration of moon pool).

The second feature enables the designer to change the dimensions of certain sections of the hull. This is especially important due to the fact that the hull is scaled to meet a certain breadth. When the hull is scaled it changes certain characteristic, especially stability, sea behaviour and resistance. The bow- and stern sections of the hull are areas of high importance, and giving the designer control over how these sections are scaled will increase the flexibility and moreover the quality of the design. This will especially support easy changes to the hull in relation to hydrodynamic testing. It must be noted that when a hull section is scaled, then all internal modules are changed and must be handled by the product platform. In practise this means that the volume of the hull section is calculated and related to the internal modules in this section, the excess required volume of these modules is handled by "buffer modules" located midship. This also means that if the volume demand of the internal modules is lower than the volume in the hull section, they will not be able to fill the hull and create void spaces.

With the parametric ship description in the product platform, the designer is able to develop various hull shapes rapidly for further evaluation. With this ability in early stages of design, larger amount of hull shapes and vessel configuration can be considered.

7.5.3 Integration of hull shape in product platforms

Chapter 7.5.1 identifies two main approaches and suggests a third method which uses sectioning of the hull to achieve desired hull shape and generation of internal modules. These approaches will also have consequences for how the hull is implemented in a product platform.

As the first approach has focus on the internal modules, the modules are placed prior to the hull shape. The hull shape will then either be a result of drawing lines around the modules or finding a hull that fits or scaled to fit. In the product platform the hull is determined by a summation of the internal modules dimensions in x-, y-, and z- direction and positions. Problems with this approach is that a hull shapes often have very complex geometry (or lines), especially in stern and bow regions, and makes it difficult to achieve a good hull shape without large voids. This will depend on the modules size and shape which are discussed in chapter 7.6.1.

The second approach uses an existing hull shape and modules are scaled or positioned to fit inside this hull. The shape, positioning and scaling of the modules determines the space utilization within the hull. This approach focuses on finding positioning and scaling of modules in order to find a feasible design under a given set of constraints.

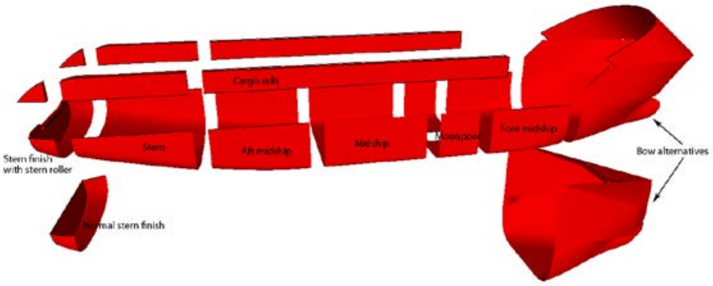
The third method hull shapes are used for creating internal modules, and then these modules are scaled to meet the volume requirements. This enables hull sections related to these modules to be scaled in proportion to the modules. The positioning and scaling of these modules are also subject to multiple constraints and variables that the product platform must incorporate. This structure requires incorporation of larger amounts of data from 3D models.

7.5.4 Sectional hull shape

The hull is normally as a single unit, but by breaking the hull shape into smaller sections, it will have several benefits in a flexible parametric ship design process. The main reason for implementing sectional hull shapes in the system structure is to allow for easy concept generation and exploration of hull shapes. Although the sections are based on one or more existing hull shapes, the designers are not locked to a given hull shape that have to fit a configuration of internal modules. Sectional hull shape in the product platform will have several benefits and disadvantages that are discussed below:

Motivation for sectional hull:

- More control of hull shape as it is possible to scale independent sections of hull (e.g. constant aspect ratio when scaling bow and stern section). This means that it is possible to generate desired vessel characteristics.



- Easy implementation of changes at later stages of design. Resource demanding analysis which requires changes to hull shape can be implemented with minimal influence on system structure.
- Ability to swap independent sections for new design variants (e.g. bow shape)
- Task related modules can be implemented on selection (e.g. moon pool can implemented midship as a module on selection)
- More control of volumes and modular affiliation of independent functions
- More accurate scaling and modelling of internal modules. Modules can be shaped after the hull in order to minimize voids and inaccuracies.
- Hull section connected to a given module enables equal scaling of hull section and internal module related to that section so that the system structure can be simplified.
- Modules that where related to the midship have the same hull shape, and can therefore be positioned in alternative orders.

Disadvantages with sectional hull:

- Increases the complexity of the product platform. Mainly due to increase in number of modules managed by the product platform.
- May decrease user understanding of product platform architecture. This is mainly due to the increase in complexity.
- Increases effort of implementing product platform in a company. More work is needed to generate hull sections and internal modules and implementing them in a system structure.
- When modules are linked to a given hull section, the modules also linked to a given position, which can restrain concept evaluation as there are little options for position alternatives. Alternative internal module positions can be enabled by alternative modules or even multiple product platforms which enable alternative positioning.

7.6 Internal modules

Modules that are placed inside the hull are referred to as internal modules. These modules consist mainly of all basic modules, but also include some of the task related modules such as payload tanks and moon pool.

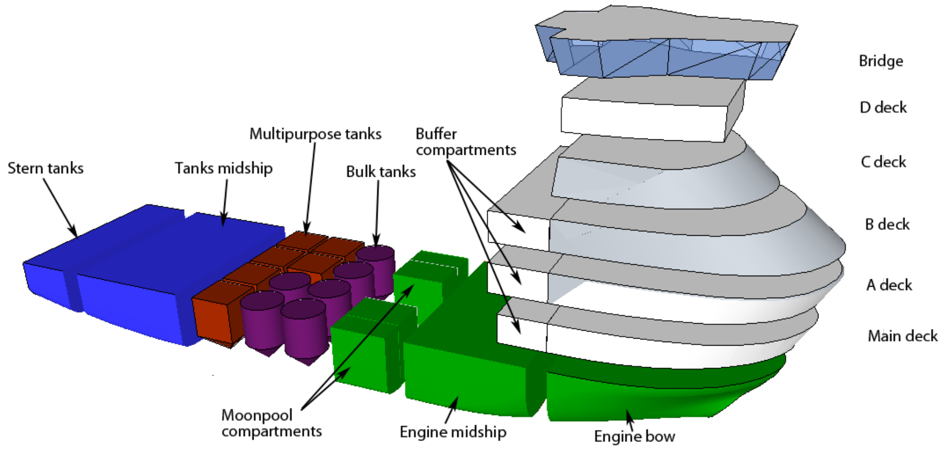


Figure 25 - Internal modules generated from existing hull shape

7.6.1 Module shapes, size & quantities

The internal modules are confined by the hull shape, and will require complex management in the system structure. Modules with various complexity of geometry are can be positioned within a hull shape. The shape of the internal modules has been divided into three categories:

1. Box-modules (rectangular shape)
2. Modules with simple shapes
3. Modules with complex geometry

Based on the product platforms it has been evaluated how the modular geometry influence the system structure, the diversity of the product family and design performances. The results are shown in Table 3 and Table 4.

Table 3 - Module geometry's influence on system structure

		Module Shape and size complexity				Module Positioning complexity				System overall complexity
		Alternatives	Scaling	Sizing models	Functions modular attachment	Combinatorial	Continious	Discrete	Overlapping	
Module geometry complexity	Low (Box)	Low	Low	Medium	Medium	High	Low	Low	High	**Medium**
	Medium (Simple geometry)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	**Medium**
	High (Fitted to hull)	High	Medium	Medium	Medium	Low	High	High	High	**High**

The results indicate that modules with high complexity in geometry require large amounts of alternative modules to enable positional diversity. This is due to the fact that modules with such highly complex geometry often have a given position or sequence in the design, and require a complex structure for implementing alternative modules with different positional relations. Although modules with rectangular shapes are not complex, the large amounts of modules that are required to produce a design with acceptable performance will increase the overall complexity of the system.

Table 4 - Module geometry's influence on design diversity and accuracy

		Accuracy of design	Product family diversity	
		Number of modules for accurate design	**Positional diversity mainly achieved by**	**Shape and size diversity mainly achieved by**
Module geometry complexity	Low (Box)	High	Positional variation	Scaling & positional variation
	Medium (Simple geometry)	Medium	Both pos. & modular	All
	High (Fitted to hull)	Low	Alternative modules	Alternative modules & scaling

The analysis also showed how the diversity of the product family was achieved. High design performances, where achieved by a low number of modules with highly complex module geometries or a high number of box shaped modules. This is mainly due to the modules relation to the complex geometry of OSV hull shapes, where large amounts of void spaces are generated when using large and box-modules. Modules with complex geometry can be generated based on a hull shape, which has the potential of minimizing void spaces.

Due to the small number (and large size) of modules within the hull, it was selected to initially develop modules that were shaped to the hull in order to achieve the required level of accuracy in the design. The main motivation for this was to reduce the amount of unused space between internal modules and the hull. The results from the project thesis, which were based on main modules with a medium complex shape, showed somewhat worse and inaccurate design performance compared to similar vessel. (Brekke and Tvedt, 2011). To achieve better and more realistic design performance, the modules where generated from an existing hull shape, and connected to the hull shape of its origin. Limitations regarding positioning of these modules were found to have negative impact on the concept evaluation. To enable position alternatives, modules with different shapes, related to other positions had to be implemented in the system structure, which increased the system complexity. Another consequence of the modules shaped to the hull, were that alternative hull shapes also required internal modules with that shaped. This increased the complexity of the system structure even further.

In order to decrease the complexity of the system structure, multiple product platforms are developed, which have limited positional alternatives of the main modules. The positional diversity of the design family is achieved when comparing the product platforms to each other. The product platforms are based on the same functional requirements that generate volume-, area- and weight requirements related to each module, which means that these calculations are identical between the product platforms. The differences are in how these modules are sized, positioned, shaped and constrained within the structure of each product platform as well as rules for which 3D models of the modules to select. The developed system combines multiple product platforms in order to generate a design family with large diversity and accurate performance, without a highly complex system structure.

7.6.2 Example of system complexity variations due to level of detail in visual representation

There are multiple methods of modelling different modules, but the main importance is that the product platform is consistent with and able to handle the 3D model of the module. How the 3D model illustrates the design solution influences the structure of the product platform. Payload tanks have for instance several aspects that are of importance when modelled, such as shape, cargo type, integration in the vessel, etc. Three different methods are proposed for modelling the payload tanks, with respectably increasing level of detail and complexity in the product platform:

1. Single module. The required volume of all payload tanks are calculated and assigned to a single module, similar to the machinery-, deck- and tank modules. Alternatively they can be assigned to an existing module such as the existing tank module.
    - Allows simple integration in the product platform.
    - Difficult to calculate exact volume as the payload tanks often have odd shapes, and spacing.
    - Do not differentiate the different types of tanks.
2. Sectional module with given tanks modelled.
    - Sections need to be scaled to the breadth of the vessel, and will change the dimensions and the shape of the tanks. Rules of how the tank modules are scaled in length with variable breadth are required. Typical issues are whether the tank modules should have a constant length or scaled in order to achieve the same L/B relation of the internal tanks.
    - This method requires various sections for various types of tanks and can result in increased volume if the whole breadth of tanks isn't needed.
    - Partially simple integration in the product platform as sections are added to one meets the required volume.
    - The volumes of the tanks are a function of breadth, tank height and number of sections.
3. Individual tank modules where the hull is shaped after the entire collection of tanks.
    - Allows variable tank spacing.

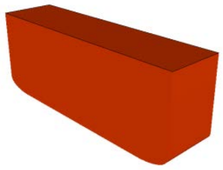


Figure 26 – Alt. 1 Single module

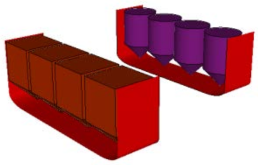


Figure 27 – Alt. 2 Sectional module

- Enables various tank types in breadth with multipurpose and bulk tanks in the 2nd row as Figure 28 illustrates.
- Enables conditional constraints. E.g. if the breadth of the vessel is smaller than a given breadth, the tanks can be limited to 3 tanks in the breadth as Figure 29 illustrates.
- Complex integration in the product platform as all constraint, positions of each tanks, tank types, spacing, dimensioning and hull shape must be established and structured.
- Support good visual representation of payload tanks.
- Number of tanks can be calculated based on the required volume as input.

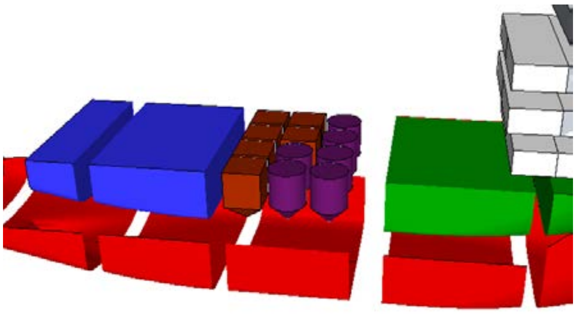


Figure 28 – Alt. 3 Individual tank modules (4 per row)

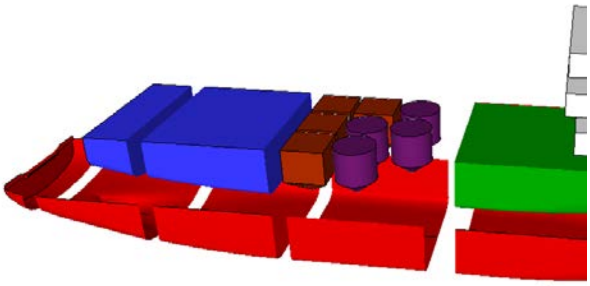


Figure 29 - Alt. 3 Individual tank modules (3 per row)

7.7 External modules

External modules are defined here as modules that have little influence when added to the other modules. These are typical task related modules that is implemented on selection. Common for these modules are that they have limited interaction between other modules (1-2 interacting modules), are not situated inside complex shapes such as the hull, and does often have complex shapes which makes them difficult to integrate with surrounding modules. Deck equipment such as cranes, well intervention systems, and A-frames are examples of such modules. Also modules that are situated in the vicinity of or added to the superstructure, such as ROV garage, helipad and diving modules are part of this category.

7.8 Weight implementation

The weight of the design resulting from the design synthesis has consequences for several properties that are essential for the feasibility and performance of the design. Properties than can be derived from weight and COG are:

- Weights: LWT, DWT & Δ=DWT+LWT
- Stability: GM, KM, GZ-curves
- Centres of buoyancy and gravity: KB, KG
- Inertia: Second moment of area for calculation of KM. Moment of inertia is related to the vessel motions and generation of RAO.
- Heel- & trim angles
- Bending moment and shear forces

In the product platform, the weight is implemented and calculated similar to the volume requirements. The main difference is that a COG values related to the weight must be calculated in order to find a feasible design and observe the influence of design changes. Similar to the volume calculations are the weight of each module calculated based on each function's weight requirement. The total weight of the vessel is the sum of each module weight, but is in reality the sum of all functions' weight requirement because of grouping of functions for generation of modules.

7.8.1 Calculation of COG

The designs centre of gravity is essential for a good and valid vessel design. For most internal modules it is assumed homogeneous weight distribution. It is assumed that the centroid, the geometric centre, is equal to the centre of mass for these modules. The centroid can, in most 3D software, easily be retrieved from a 3D model. A database containing information of each modules centroid must be established. Due to scaling of these 3D models in the assembled design, the correct centred must be calculated. The correct centroid is calculated using the scaling and the shape of each module, and is similar to the scaling calculations in chapter 7.3.6. For other modules such as equipment modules is it intended that COG values is provided by the manufacturer. Modules such as the engine module is expected to have more concentration of mass in the bottom due to the floor mounted engine and systems. DWT such as deck load and tanks must also be included in these calculations when considering loading conditions.

The global COG is calculated based on each modules weight, position and an individual COG. The individual module's COG is referred to the modules local coordinate system and is related to a global user defined coordinate system by including the module's position in this global coordinate system. By expressing each module's COG to a global coordinate system, and account for each module's weight contribution, we get the following formula:

$$COG = \frac{\sum_{i=1}^{N} W_i \cdot (COG_i + Position_i)}{\sum_{i=1}^{N} W_i}$$

These calculations must be made in all three dimensions, x-, y- and z- direction.

7.8.2 Calculation of moments of inertia

The vessels inertia has consequences for the stability and movements of the vessel and is therefore of interest in order to validate the feasibility of the design. Based on each modules individual moment of inertia, it is possible to calculate the vessels global moment of inertia. The second area moment of the vessels water plane area and is related to the initial stability of the vessel.

7.8.3 Draught calculations

From the weight calculations, the weight displacement is established. Archimedes law establishes that any floating object displaces its own weight of the fluid it is floating in. The volume displacement of the vessel is found by dividing the weight displacement with the density of the liquid (sea water).

$$\Delta = \nabla \cdot \rho \qquad \text{or} \qquad \nabla = {}^{\Delta}\!/_{\rho}$$

The submerged volume can also be expressed by the length, breadth, draught and a block coefficient according to the following formula: $\nabla = L_{WL}BT \cdot C_b$

The draught of the vessel can then be calculated with the following formula: $T = \dfrac{\nabla}{L_{WL}B \cdot C_b}$

A vessel's geometry often causes the block coefficient to vary with the draught. By establishing a mathematical function of a vessels volume displacement as a function of draught, the draught can be calculated with the calculated volume displacement of the vessel. As the modular product platform use a combination of different hull sections which can be scaled independently, there need to be calculated a mathematical function for each section. These functions then need to be adjusted according to the scaling of the related hull section. An expression of the vessels volume displacement as a function of draught can then be established by the summation of the functions of all hull sections. In this thesis it has been chosen to express all hull sections' volume displacement as quadratic functions ($\nabla_i = a_i \cdot T^2 + b_i \cdot T + c_i$). The reason for this is that the sum of all quadratic functions also results in a quadratic function($\nabla = \sum_{i=1}^{N} a_i \cdot T^2 + b_i \cdot T + c_i$). For linear functions a=0. As the volume displacements are known , the formula can be written as: $a \cdot T^2 + b \cdot T + (c + \nabla) = 0$

By solving the second order quadratic function we get the following two possible solutions:

$$T_1 = \frac{-b + \sqrt{b^2 - 4a(c+\nabla)}}{2a} \quad \text{and} \quad T_2 = \frac{-b - \sqrt{b^2 - 4a(c+\nabla)}}{2a}$$

These are the two values for draft that meets the criteria for the summation of all hull sections for a given displacement. The draught which gives a feasible solution is selected as the draught. T_1 is shown to give the correct values for the quadratic function used in the product platform.

Appendix X illustrates an example of the submerged volume as a function of draught for two hull section and one scaled hull section. Appendix X also illustrates the total mathematical function for all hull modules, and how it differs from the function for a square box.

When the draught of the vessel has been established as described in the previous chapter, the block coefficient can be calculated by the following formula: $C_b = \dfrac{\nabla}{L_{WL}BT}$

Due to vessels hull geometry does the block coefficient change with a change in draft. An example of how the C_b changes with draught for a given vessel from the product platform is illustrated and explained in appendix X.

8 Visualization of product platforms

The principle that is used for visualization is two interconnected software application where calculation and development of the product platform architecture are made in an independent software, MS Excel. This software is also used as a database for 3D model properties and vessel statistics. The relevant information for a visual representation of the design is then sent to a 2D or 3D modelling program. In order to visualize the product platform a 3D or 2D modelling program needs to receive instruction of how to draw the design output from the product platform. This means that the program needs to receive a number of commands in a given programming language. The creator of the product platform needs to possess some level of programming skills and knowledge of which commands to give. The main method of 3D visualization in this report is based on Vestbøstad's work from 2011 where SBSD is used identify functions, then volume-, area- and weight requirements related to these functions are calculated. Information from these calculations is then used to calculate commands exported to an independent 3D software application. In this report the commands given to the visualization program are limited to assembly scaling and positioning. This means that the visualization program needs to receive 3 main input commands:

1. Model to retrieve and where to find it
2. Scaling of the model 3 dimensions
3. Position of the model in 3 dimensions

The product platform incorporates information from the model database. This information includes main dimensions, box-coefficient, placement of local coordinate system, centre of gravity, inertia, name, type of model and constraints. The model database includes models of all modules available in the product platform. From the required volume of a module and the 3D model's box-coefficient, the dimensions of the module can be established. The ratio between the calculated dimensions and the 3D model's dimensions is used as a command for scaling the existing model in order to generate 3D models with correct size. The positioning of these modules are calculated in the product platform based on the dimensions and composition of the modules.

It is notable that the selected method of visualization impacts the architecture of the product platform. This meaning that the more knowledge the creator of the product platform has about available input commands that can be given to the visualization program, the better the architecture of the product platform can be created. It is also possible that the visualization program receives other commands from the product platform, such as drawing geometry or extruding volumes as long as this is included in the calculations to produce an accurate visual representation of the design.

8.1 Visualization supporting the design phase

As visual representation of a design and design changes creates awareness and validation of the design, the visual representation of the design will support an intuitive design phase. With visual representation in the design phase the designer will easily detect infeasible designs and make the correct changes.

Another way of using the visual illustration of the design is two way interactions between product platform and visualization program where information from the design visualization are sent back to the product platform, and then again used in the illustration, creating an iteration process. Examples of information that are useful to send back into the product platform are volumes, areas box-coefficients. This iteration process is a part of the design spiral to get closer and closer to a final design. At the current stage, the 3D model properties are implemented in the product platform database manually.

8.2 Level of detail in design

A range of drawings, models (and animations) are often used to illustrate vessel designs where the level of detail of these illustrations can vary a lot. Examples of drawings used in ship design are general arrangement, tank plan, section drawing, midship drawing and more. The level of detail is dependent on the purpose of the illustration and is primarily dependent of stage of design and for which person they are meant for. Figure 30 shows an illustration of the correlation between the level of detail in design and the stages in the build process.

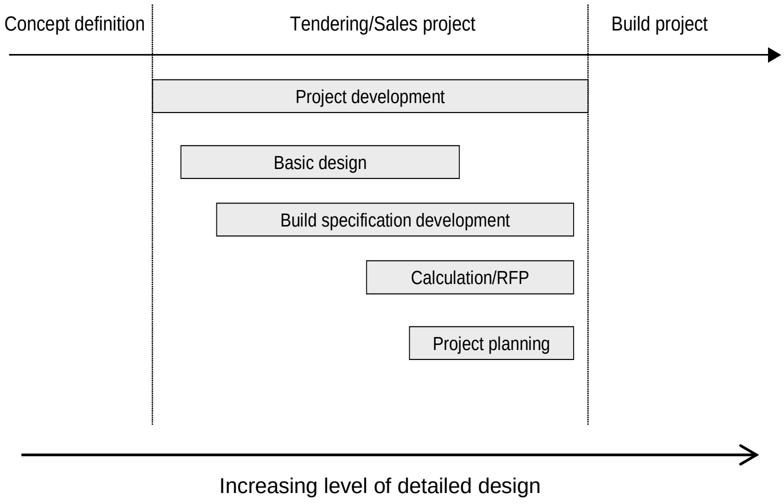


Figure 30 - Project development process (Hagen, 2011)

In early stages of design the required level of detailed design is low. In a concept phase the main focus are to explore and evaluate different designs in order to provide the customer the best suited solution. As the visualisation of concept design are primarily meant to establish main parameters and configuration, the required level of detail is low. In early design phases to much detailed information can become overwhelming and create a non-desired focus on detailed aspects of the design instead of evaluating the all-over-design. The concept design still has to provide accurate performances to be used in further project development.

Another reason for low level of detail in early design phases is that detailed design and engineering is time- and resource consuming. When evaluating several design concepts, it is not practical or necessary to do detailed design. As design decisions are made, the need for more and more detailed design are needed, and as a result the detail and complexity of the design will increase as a function of time.

The level of detail in the illustration of design solutions should therefore be thoroughly evaluated and set in proportion to the intention of the visual representation. If the intention of the illustration is to evaluate concept designs, the level of detail should be low. Illustration for production on the other hand generally required high level of detail.

8.3 2D and 3D systems

Before developing the system architecture it is beneficial to have decided whether the design is to be presented in 2D, 3D, or a combination of both. 3D representation of the design requires control over all parameters of the design and will require a more complex architecture than 2D visualization. This thesis distinguishes between the dimensions of the product platform architecture and the dimensions of the visual representation of the design.

3D visualization is a good method of illustrating correlation between different design requirements and global design changes. Product platforms with 3D visualization generally require a more complex system architecture compared to 2D. In concept design illustration of global designs by 3D visualization are often required. Due to a low level of detail in concept design, 3D visualization of a system can be implemented relatively easy.

A product platform that is constructed on the basis of 2D thinking will require more input from designers as there are less automated calculations within the system architecture. As there is less automated calculation in a 2D architecture there are more requirements of validation of the output designs. The fact that there is a lower number of constraints, dependencies and inputs compared to a 3D system architecture will make it more suited for an optimization model.

2D visualisation of an output design from a product platform will sometimes require an architecture that is based on a 3D structure. General arrangements (GA) are typical 2D visualisations that require global control of all parameters to the design. GA illustrates internal compartments of each deck and requires control of the global design. As such 2D visualisation often requires a 3D system architecture it can easily be combined with 3D visualization.

It can be concluded that 3D system architecture supports an intuitive design process with few input from a designer and supports automated calculation as well as automated generation of the 3D visualisation.

8.4 Accuracy of the visualization

As calculations are performed in the product platform it can be discussed how important the accuracy of the visual representation of the output design is. It can be argued that concept designs do not require a high level of accuracy of the visual representation. As described earlier is the level of detail dependent on the stage of design and will have a natural increase as the design phases elapses. It can therefore be imagined that the required accuracy of the visualization is proportional to the level of detail of the design.

The visual representation of the design is used in a design iteration process, the required level of accuracy of the visualization increases as the design process progresses. As the accuracy of a design is only as accurate as the least accurate parameter, the accuracy of the visualization should be no less than the accuracy within the product platform. The accuracy of the 3D model will highly determine the possibilities for further design evaluation based on this 3D model. As it is possible to implement a relatively complex and accurate hull shape in early stages of concept development, it is recommended to do so in order to facilitate an efficient project development process.

8.5 Communication between product platform and the 3D modelling program

The product platform contains information and calculations beyond what is relevant for the visualization, the relevant information must be collected and systemized for then to be exported and received by the visualization program. Appendix IX illustrates a process explanation of the visualization tool developed by Vestbøstad. The method of visualizing the product platform in this thesis uses the same basic setup where an input file is generated for a Google SketchUp plugin.

VBA scripts have been developed to export a coded area in the Excel spread sheet to a separate text file (see appendix V for script). The Spread sheet contains in principle three different product platforms, or rules for combining the modules, and has therefore incorporated three export scripts which and linked to separate buttons. An example of the exported text file is attached in appendix I. Vestbøstad's Ruby script to transverse the exported file generated from Excel has been used to import, scale and position 3D-models of the modules (see appendix II for script). It has also been used Vestbøstad's Java script to actively call a catcher to update the 3D model if new data has been exported from Excel. A script has also been developed for rendering and exporting 2D and 3D drawings of the 3D model in SketchUp (see appendix 0 for script). These drawings can be imported in the spread sheet by a VBA script which imports, scales and positions the drawings.

8.6 Variable views

As a product platform increases in complexity and number of components/modules, the standard assembled view of the output design might become insufficient in providing the required information. The basic template can be expanded to incorporate means of visualizing the design so that design information can be communicated better to the user.

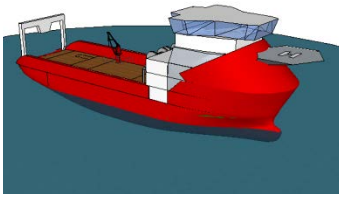


Figure 31 - Initial view

8.6.1 Exploded view (module spacing)

Within the product platform the modules are selected, scaled and then positioned. The positioning of the modules is a result of each modules relation to other modules. For example the A deck is positioned above Main deck, B-deck positioned above A-deck and so on. These relations means that if a module is re-positioned or have a change in dimensions, and then all modules that are related to that module are affected. If we introduce spacing between these modules we are able to generate various views of the design. This spacing means that the initial configuration is generated by zero spacing as the modules are connected and is illustrated by Figure 31. This initial view illustrates the actual design, but do not illustrate the composition of the various modules.

If we not introduce a module spacing of a given distance in x- and z-direction (forward and upward), the modules will be positioned apart and will represent an exploded view of the design. With the exploded view the individual modules can clearly be identified and will give more insight to the structure of the product platform as well as the design. Figure 32 illustrates an exploded view of the same design as Figure 31 with a module spacing of 2 meters.

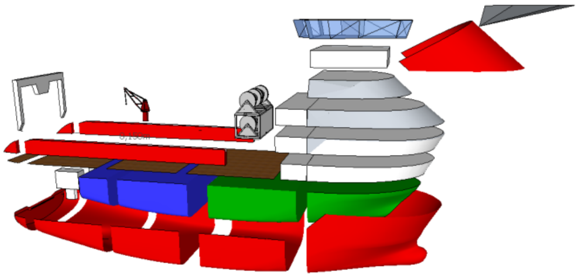
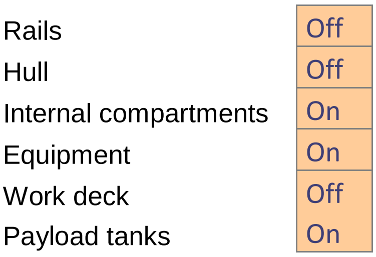


Figure 32 - Exploded view (2m spacing in x- and z-direction)

8.6.2 Geometry selection

The option to view selected geometry modules can provide the user with valuable information and enable a more flexible and transparent MPP. This option is beneficial in both the product platform development for identifying errors in the structure, as well as assisting the operator and the customer in the designing.

Different departments, customers and operators will have different needs to the required information from the 3D model. Being able to



Rails	Off
Hull	Off
Internal compartments	On
Equipment	On
Work deck	Off
Payload tanks	On

Figure 33 - View options

automate the selection of geometry and module types will support an efficient work process that can reduce the design phase even further. This option will be the foundation for the generation of automated drawings and models.

Another appliance of this option will be to export only the necessary geometry to external software applications. It is for example not necessary to export all the geometry to do hydrodynamic analysis of the hull shape. This will minimize the information exported to external software, and can reduce analysis duration or time used deleting unwanted information. Figure 36 illustrates the design when only hull is selected.

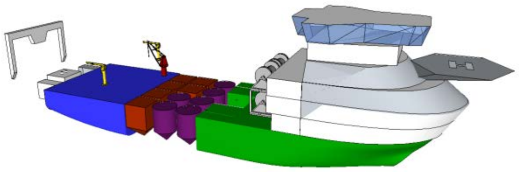


Figure 34 - View internal compartments & equipment

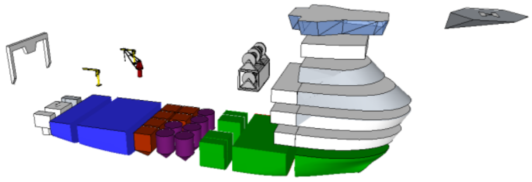


Figure 35 - Exploded view of selected geometry

By categorizing the modules, then making the product platform able to only collect the modules that are selected, one is able to exclude undesired module categories. Figure 33 shows the categories that are implemented in the product platform. Figure 34, 35 and 36 illustrates some of the view options that have been implemented in the MPP.

Figure 36 – View of hull geometry

8.6.3 Drawings

Drawings are an important method of describing and visualizing vessels designs. The method of automated 3D visualization in combinations with geometry selection and exploded view can be used as a foundation for the automation of drawings. It is believed that automation of drawings can contribute to increase the efficiency of the design phase, and may prove its value in a sales situation. Defined 2D and 3D views can be created to automatically generate general arrangements (GA) and other drawings. A Ruby script has been developed to render and export 2D drawings with parallel projection and 3D isometric views of the 3D model. This script defines edge and line styles of the exported drawings. These drawings have been implemented in the MS Excel product platform by a VBA script to generate a preliminary GA of the vessel. See appendix III for Ruby rendering & export script, appendix IV for the VBA import script and appendix VI for an example of a preliminary GA illustrated in Excel.

Various disciplines and system may require specialised software for 3D modelling and creation of drawings. It is therefore important that the software applications are able to communicate with each other. Different software solutions will have different Appendix VIII illustrates bottom and side view of the hull geometry generated in AutoCAD based on the initial 3D model.

9 Alternative design concepts and vessel arrangements based on the same functional specification of the vessel

The ability to evaluate multiple design alternatives against each other is beneficial on many levels, including concept development and selection. Based on the same basic functional requirements of the vessel, is it possible to develop alternative designs by different module compositions and configurations. These alternative design concepts can be available as separate product platforms, which contains different rules for combining and selecting modules, and as changes to input parameters discussed in chapter 7.3.4. Due to the parametric model of the ship, alternative configurations of these parameters will make way for easy concept exploration. It must be noted that the validity of these configurations of input parameters have to be evaluated further to enable feasible design. To avoid largely complex systems it is recommend enabling large design variations in separate product platforms, while medium and small variations can be made possible in a single product platform.

One of the simplest design changes is available by changing the breadth of the vessel. Due to the modules area and volume requirements and given deck heights, the change in breadth will determine the length of the vessel. The designer can play around with these parameters until a desirable L/B is found. Other examples would be to choose an alternative bow shape, or changing the position of the wheelhouse (which are described in the following chapter).

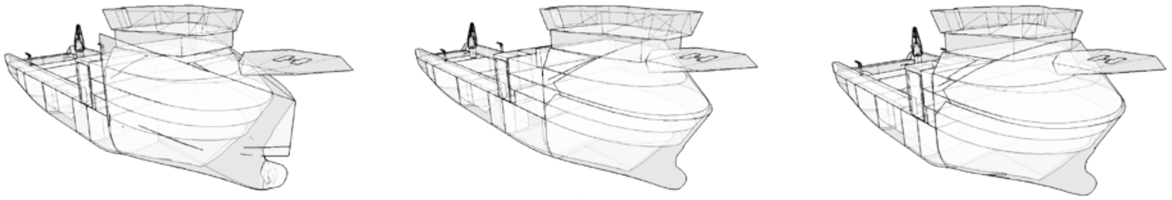

Alternative bow
Slim vessel (L/B=6)
Bulky vessel (L/B=2.7)

Figure 37 - Alternative vessel configurations

When the alternative vessel configurations have been established, they can be used for further evaluation. A structured selection process is required when a large group of alternative vessel alternatives have been established. Based on given performance criteria vessels can be compared against each other.

The current OSV product platform is able to produce vessels with a largely variety with minimal effort. Although still in development stage, the output designs have good design performance compared to similar vessels. The designs are valid for a large range of input parameters which means that it is very suitable for concept evaluation.

9.1 Example: Alternative superstructure positions

Figure 38 illustrates 3 vessels with 3 different positions of superstructure. All designs have the same basic functional specification, except the left one which does not have the alternative of an A-frame or anchor winch. Alternative positions of superstructure can be selected in the product platform which will inflict relatively large variations in designs. Different wheelhouse modules and positional composition is associated with each position alternative. In addition some modules have different module positions associated with each wheelhouse position alternative.

All three wheelhouse position alternatives are available for all vessel types available in the product platform. Modules that are not available for a given wheelhouse position are indicated in the user interface, but have to be manually turned off. This means that certain vessel missions are not available for all wheelhouse positions.

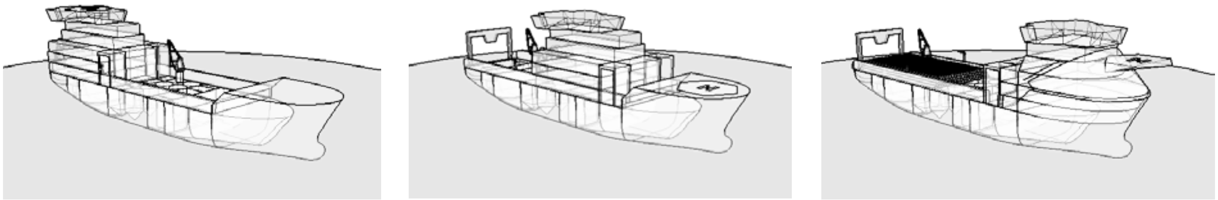


Figure 38 - Alternative superstructure configurations

10 Second stage of design

When a concept design has been selected, the project commence into a more detailed stage of design. The concept stage generated main modules as well as equipment selections based on the identification and grouping of system function. Logically the next stage of design will be to determine the internal arrangement of these modules. The modules of interest are the modules that can be divided into sub-system or sub-modules, and can often be recognized by consisting of multiple functions. This will support a hierarchical design approach.

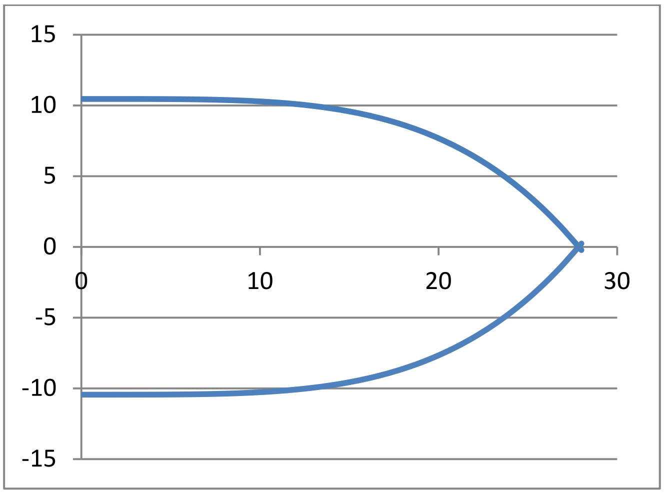


Figure 39 - A-deck described as a function

By describing the shape of a module as a mathematical function, it is possible to generate sub-modules based on the functions related to the module. The generated modules are constrained by the shape function as well as a positioning- and scaling algorithm. An example of how A-deck can be created is presented in this thesis. The A-deck module and a 3D model have been established from the earlier design phase. Further on a function describing a 2D top view of the deck module can be developed, illustrated in Figure 39, based on the geometry of the established 3D model. By retrieving information from the database for all functions that have been assigned to this module, the attributes related to this module can be systemized. In this case each function has been regarded as an individual sub-module, but could also be grouped together. Each function now has an area requirement which the new modules have to fulfil. The dimensions of each module are generated by the desired position and the shape function which limits these dimensions. The modules dimensions are thus dependent on position, area requirement and a set of

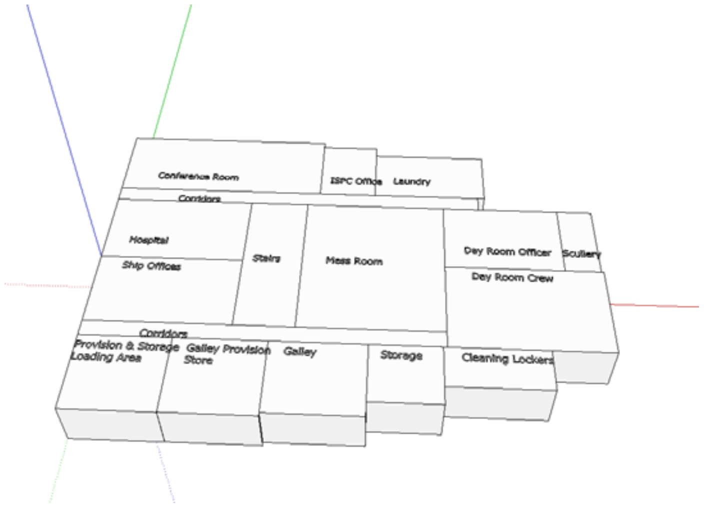


Figure 40 - Generated modules constrained by shape function

rules for dimensioning. The result is illustrated by Figure 40. The designer has to make adjustments to the output design, but the solution gives a good method of finding rough design solutions.

The benefits with this approach is that modules can easily be moved around, so that a different solutions can be found and explored in order to establish the best suited solution. Further an optimizing algorithm can be applied in order to find an optimal configuration toward a goal function. When a configuration of sub-modules has been established, this configuration can be implemented in the existing 3D model. In that way the initial 3D model can be continuously updated in accordance to the project development, with increasing level of detail.

11 Loading conditions

In order to produce a valid design, it has to meet certain classification requirements. These regulations include various loading conditions of the vessel. The initial output of the product platform produces a lightship without any consumables, payload, passengers, etc. The product platform has therefore been expanded to include user specified deadweight loading conditions. These include user specified:

- Deck load: A deck load with centre of gravity can be specified.
- Payload tanks: Payload tanks filling percentage and cargo density can be specified.
- General tanks: Filling percentage can be specified
- Ballast tanks: Filling percentage can be specified

The design has to prove valid for all loading conditions. Ballast water is an undesired load to carry because of the increase of the vessels weight without generating income. By exploring various vessel configurations, the necessity of ballast water can be minimized for various loading conditions. A summary of relevant regulations for OSV that must be included in the stability booklet have been included in appendix VII. Future developments can generate automated reports based on these loading conditions in order to validate the design.

12 Product platform operators

An important aspect to the user-friendliness of the product platform is the intended operators. Different operators will have consequences both for the system structure and the user interface. There have been identified the following possible users of the product platform:

- Sales department
- Ship designer/engineer
- Ship owner
- Ship yard/builder
- Ship operator
- Internet based (open)

The initial product platform has been developed for a sales situation. It has been developed to contribute to an efficient dialog and concept evaluation between a ship designer or sales department and a ship owner. In addition it can be used as a tool for parametric evaluation of the hull. The input parameters and output information will require some level of expertise from a ship designer. To support creativity in an early stage of design, the focus has been to enable possibilities rather than limiting the design to just feasible designs. This configuration will require qualified judgement from the operator, but comparison data of similar vessels are provided to support this aspect.

13 Constraints

Constraints can be used for setting limits to parameters, calculations or systems. It is selected to keep a system structure that uses a small amount of constraints in order to not limit the designer in a design exploration stage. This means that all design solutions that can be derived from the system is not feasible. It has been chosen to provide the user with information about vessel performance, such as GM, draught and freeboard, so that the designer knows if the design satisfies these requirements. Constraints have been used to prevent modules form overlapping and in the making of positioning rules.

14 Issues and experience from current system configuration

Google SketchUp, which is used for generation of 3D models and assembly of the 3D modules, is a basic 3D modelling software which provides the user with a simple and intuitive design tool. The fact that the software required minimal training and knowledge about 3D modelling combined with the availability of assistance, training, extensions and information available online, makes this initially a user-friendly software. The fact that the software has 30 million users according to the software's web sites means that there is much information and help publicly available from users online at various forums, blogs etc. The ability to change the line styles get a more sketch-like 3D design is easily available and can be programmed into scripts for automated drawings.

While developing the product platform, which required more and more attributes and details, the 3D software was found to be lacking several features that are available at competitive software such as ProEngineer, Autodesk Inventor, etc.:

- Volume of module: No information about the volume of a 3D model available. A script is available online for these calculations, but requires large computer resources for large models with complex shapes. The product platform uses information about the models' volume to calculate the box-coefficients which are then used for dimension- and model scaling calculations.
- COG or centroid of module: No information about centre of gravity or centroid (geometric centre) available. Script is available online, but requires large computer resources and has inaccuracy for large models with complex shapes.
- Inertia: No information about inertia available. Stability calculations and future hydro dynamic analysis requires this information in order to calculate key aspects to vessel design. No solution for this problem, and simplified formulas based modules shapes where used in the product platform.
- Program crash. Program crashes when importing/exporting 3D geometry. Export and importation of 3D geometry where found to be essential for design evaluation and improvement. As Google SketchUp is unavailable to perform hydro static and dynamic analysis, this must be done in other software solutions. A solution to this problem was to

export geometry as a single component, rather than as an assembly, as well as limiting the amount of exported/imported geometry.

- Unsupported file formats. The free version of Google SketchUp has limited supported file formats. The Pro version has a larger range of supported formats, but is found to be lacking the formats used in common ship design- and analysis applications. It is therefore recommended that a 3D modelling software that is more compatible with formats used in the line of work in order to increase productivity of the system.

Microsoft Excel has been used as a database for ship database, 3D model data properties database, calculations and user interface:

- Transparency: Due to the development of system, where the system has been reconfigured several times in the process, the structure has become comprehensive and difficult to follow. Re-structuring of the system would be recommended.
- Re-structuring the system: May become difficult because of the current complexity of the system.
- All aspects to vessel design not implemented in the current stage: Analysis and simulations in external software is required to prove the validity of the design. The product platform is developed to support implementation of results from external analysis, such as vessel characteristics and structural integrity.
- Detailed configuration (within modules): The product platforms do not take the internal configuration of the main modules into consideration. These configurations must be developed at a later stage of design within the boundaries of the established modules.

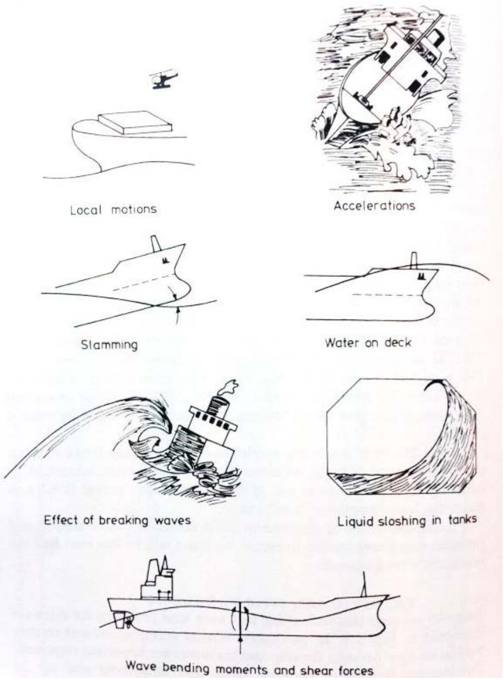
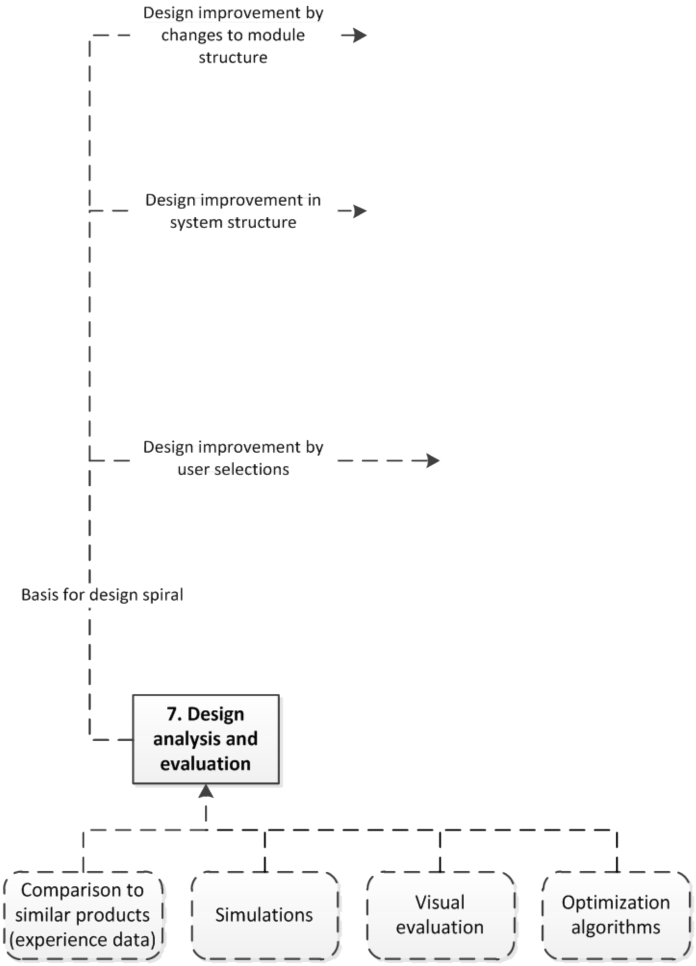


Figure 41 - Example of vessel characteristics (Faltinsen, 1999)

Scheme of simplified system architecture is found in appendix XIV. Appendix XV illustrates how the system supports iteration aspects to design.

Part 4 Design evaluation and improvement



The initial design output(s) from the MPP is not meant as a final design solution, but rather makes the foundation for a design spiral with constant improvement by iterations. These design improvement can be based on multiple methods of analysing and evaluating the design, including comparison to similar products, simulations, visual evaluation, optimization and more detailed calculations.

The product platform now has the benefit of the immediately available 3D model, and comparison of key performance criteria of similar vessels which are developed from a database of vessels.

Design aspects which can be hard to capture in a parametric ship model, such as structural integrity and ship motions, have been intended to be performed in external software applications. The findings and design changes from these applications can then be implemented as changes to input parameters, changes to system- or modular structure.

Changes to design output can be made through changes to input parameters, changes to the system structure or changes to modular structure. Changes to system and modular structure will alter the product family of the product platform.

Important aspects to design decisions are how to measure design performance and what to design for. These aspects can often be prone to subjective opinions and requirements which will require a flexible system structure that can meet a large range of demands.

15 Measurement of design performance

For further improvement of design it is essential to have a basis of determining what separates the good from the bad solutions. The performance of the design is measurable, and it is important to know which performance criteria to measure and how. Within ship design there are multiple design performances that are of interest, which also are subject to trade-off as explained in previous chapters. Areas of importance are listed below:

- Resistance
- Hull structure
- Machinery
- Safety
- Trim & stability
- Payload capacity
- Building & operational costs
- Vessel characteristics

16 Visual evaluation

The visual representation of the design output facilitates instant visual evaluation of the design. Simple flaws and necessary changes can easily be detected and corrected, whether this involves changes in system structure or changes in user input.

While constructing the MPP's structure, the visual validation of calculations, constraints, input, etc., has great benefits for the system designer. Figure 42 illustrated a basic flaw in the system structure where the well intervention system and moon pool of an OCV conflicts with the superstructure.

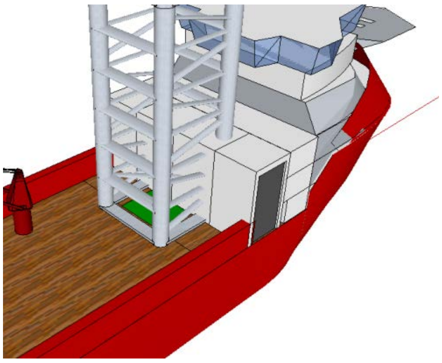


Figure 42 - Basic flaw in the system structure

16.1 Visualisation in a sales situation

Regardless of which parties that participate and who initiates the build process of a vessel, there is often a sales situation where one part can be regarded the buyer and the latter the seller. In this sales situation the parts have to come to an agreement about the contractual specification and design.

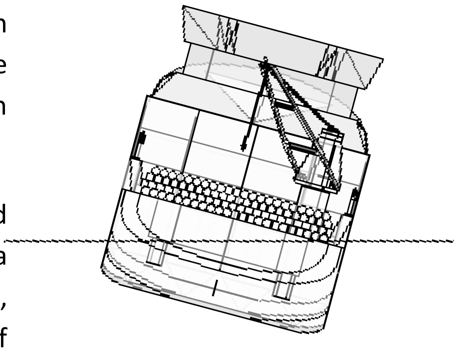


Figure 43 - Trim angle influenced by deck vessel configuration (infeasible design)

Today's situation may require several meetings and interactions before a contract can be signed. This is often a result that the calculations require more resources and time, than what's available at these meetings. By the automation of the calculations, and the visualization of the design that are based on these calculations, it is believed that modular product platforms have large benefits. The fact that a visual design is available instantaneously during all steps of the design process makes the interaction between the parties easy, as well as misunderstandings can be eliminated. As the calculations are automated and supported by visualization, there is no need for calculations and conceptual design to be made back at the office. This supports an efficient sales process with less meetings, interactions and misunderstandings.

It is believed that modular product platforms have the potential if large benefits in a sales situation of offshore vessels. This firstly because of reducing the design phase in an industry where day rates can exceed 300.000 NOK.

17 Comparison to similar designs

How the design compares to other vessels with similar task requirements is essential to the validation of the design. Based on the gross tonnage of the design, the product platform does provide comparison data for similar vessels. The comparison can return the following scenarios:

1. Design output has performance outside range of similar designs
    a. Design output has worse performance than similar designs
    b. Design output has better performance than similar designs
2. Design output has performance in range of similar designs
    a. Design output has worse performance than similar designs
    b. Design output has better performance than similar designs

If the product platform returns a design which the performance is outside the range of similar vessels, there is reason to believe that there are faults within the system structure or some of the parameters within the structure. Another reason which the design can be outside the range of performance of similar vessels, are if the design deviates largely from the existing designs. This may occur when new concepts are developed or unorthodox hull shapes are used. In this case the comparison can determine whether (and where) the new design has competitive advantages compared to existing vessels.

If the design outputs performance is in range of similar vessels, it can be used to validate and evaluate the design. A vessel design with worse performance is than its competitors is not favourable, and changes ought to be made to the design. By an iteration process the design output can be made better and better until it reaches desired performance.

18 Export of 3D model

Due to the various software applications used in ship design, the possibilities to import the developed 3D model in external sternal software applications is beneficial. These benefits include:

- Similar models for all analysis: Results concur with models used in other applications
- Avoid re-modelling: Minimal resources can be used modelling the vessel

Software used in ship design analysis does often have specialised file-extensions compared to traditional 3D tools. It is recommended to use a 3D application for modelling the product platform that supports these file-extensions. The current configurations that use Google SketchUp for 3D modelling has limited support of such file formats, and have caused problems with doing external analysis. It is therefore suggested that a different 3D application that has better support of ship design analysis is used in future developments.

19 Optimization

The best design may become difficult to achieve for large and complex systems and product platforms with a large product family. A design problem can be formulated so that the computational power available these days can assist the designer in finding the best, or a set of good suited solutions which fulfils all design requirements.

In modular vessel design and in combination with modular product platforms this can be seen as a vessel configuration problem, where the position and dimensions of the modules are optimized towards an objective functions under a set of constraints and input values. The constraints set limits to how the modules can be positions and dimensioned. Examples of such constrains can be that modules cannot have a breadth larger than the hull, engine modules confined to the lower part of the vessel, or stability requirements.

The optimization can be formulated as either as a 2D- or a 3D problem. 3D problems have to position, dimension, and constrain the modules in all three dimensions which can become a complex and difficult task.

Due to the fact that the optimal solution is highly subjective, and the fact that all aspects to vessel design are difficult to capture in a single model, it is believed that these methods should support the designer with valuable information about good solutions rather than restricting the designer to a number of fixed solutions.

19.1 Objective functions

In order to find an optimal solution, one needs to establish what to optimize for. Mathematical optimization relies on one or more functions that are subject to minimization or maximization. The optimal solution is prone to subjective opinions, and will vary from the various actors in the OSV market. For a ship builder it may for instance be desirable to minimize build costs for a vessel with given functional requirements, and for a ship operator to minimize operational costs for the same vessel. At the same time the ship builder must provide a desirable product, which has competitive advantages compared to the competitors, in order to generate the largest income. These interests do not often coincide, and decisions and trade-offs are needed in the design process. Figure 44 illustrates a 3D Pareto optimal surface which visualizes the trade-off problem where the different actors have different interests in the design solution. Pareto sets can be generated, based multiple objective functions, in order to assist and make the designer conscious of these trade-offs. The most important objective functions are identified and discussed here.

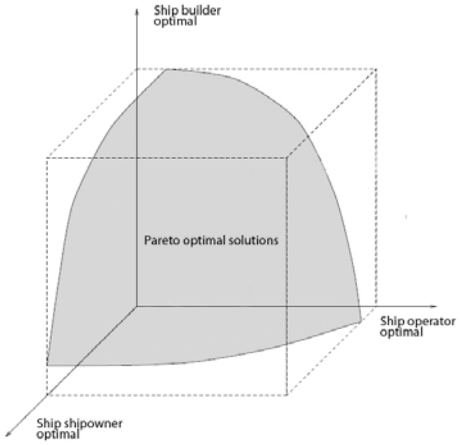


Figure 44 - 3 Dimensional optimization surface

Minimize volume:

> The volume of a vessel can be linked to the dimensions of the output design. By minimizing the volume of the output design of the product platform, it is possible to produce a vessel

with the smallest size. Each module are positioned and scaled so that the total volume consumed by all modules is kept at the minimum.

$$\min V(x_1, x_2, \ldots x_m) = \sum_{i=0}^{N} V_i(x_1, x_2, \ldots x_m)$$

V = Volume
x = Variable
i = Module

Minimize void spaces:

Minimizing of void spaces is an alternative solution to minimizing the volume. Minimizing void spaces is a good solution for positioning modules when the volumes of each module is constant. This can for instance generate positions and dimensions of internal modules so that the modules can best be fitted within the hull minimum excess space. The void space can in this case be calculated as the difference between enclosed volume of the hull and the sum of the volumes of internal modules. The output design will be a compact and space efficient design.

$$\min V(x_1, x_2, \ldots x_m) = V_{hull}(V_i) - \sum_{i=0}^{N} V_i(x_1, x_2, \ldots x_m)$$

V = Volume
x = Variable
i = Module

Minimize walk distances:

By measuring the activity movements of the crew within the vessel during a given time period (for instance a year), it is possible to map the interactions between the individual modules. The sum of all interactions (walks) between two modules times the distance between these modules will return a distance (per year) which the crew moves within the vessel. This distance can be related to the crew's efficiency in operation. By minimizing this distance the optimal position of each module can be established with regards to the crew's efficiency in operation.

$$\min D_{total}(x_1, x_2, \ldots x_m) = \sum_{i=1}^{N} \sum_{j=1}^{N|j>1} D_{i,j}(x_1, x_2, \ldots x_m) \cdot N_{i,j}$$

D = Distance
x = Variable
i = First module
j = Second module
N = Number of interactions

Minimize weight:

A vessels weight is often closely linked to the vessels build costs, and by minimizing weight one can thereby minimize build costs. The vessels weight also determines its volume displacement, thus the wetted surface of the hull. The wetted surface has direct impact on the vessels resistance and thereby the installed power and fuel consumption. A large part of

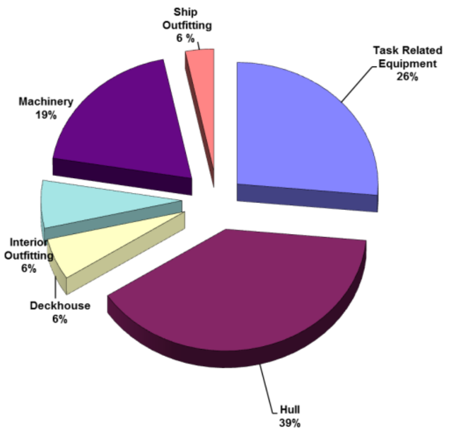


Figure 45 - Example of LWT distribution for OSV

a vessels weight can be related to steel structure which indicates how much steel which has to be bought and processed by the yard.

The method of minimizing the vessels weight will be analogous to the method of minimizing the volume of the vessel. The main difference is that modules with higher weight/volume ration will be prioritised.

$$\min W(x_1, x_2, \ldots x_m) = \sum_{i=0}^{N} W_i(x_1, x_2, \ldots x_m)$$

W = Weight
x = Variable
i = Module

19.2 Conclusions

The ship model makes a good foundation for design evaluation and improvement. At the current stage of development, the product platform provides comparison data of similar vessels, angle of heel, stability, draught, freeboard and a 3D model.

The comparison data is based on the gross tonnage (GT) of the vessel which is compared to a database of vessels. This provides the user with suggested values for the input parameters as well as describing how the output design performs in comparison to others. The reliability of this method is dependent on the accuracy of the calculated GT of the vessel. As the GT is a function of input parameters, and the comparison data may result in changes to these input parameters which leads to different comparison values, iterations are required to achieve a valid design. To enable creativity, flexibility and innovation in design, it is decided to provide the user with this information rather than restricting the model to produce a design which is similar to the existing. The accuracy of these suggested performance values is highly dependent on the vessels in the database. Out-dated vessels in the database may cause suggested design performance values to be worse in comparison to state of the art designs. The fact that OSV vessels often are one of-a-kind vessels, makes it difficult to provide statistical data with a high reliability for a given design. These uncertainties aside, it appears that the product platform produces designs that easily are comparable with existing vessels. This might be a result of the fact that the system is based on statistical data provided by Kai Levander and SBSD for description of functional requirements which are based on vessels statistics form STX OSV.

The automated 3D model is fully functional and provides valuable visual information for both system development and parameter selections. A preliminary GA is also generated automated based on the 3D model. It is believed that the responsiveness of a parametric system with automated visualisation will have great benefits in a sales situation where the parties can quickly develop a preliminary design.

The product platform also provides a good foundation for further design improvement. The automated 3D model can easily be exported in software applications for specialized analysis. Due to the fact that multiple designs and design changes are easily implemented in the system with automated generation of 3D model, it is believed that it is possible to analyse and explore much more alternatives than in traditional design. More analysis at an early stage of design provides more information that can be used for selecting the most suitable design solution.

Optimization of the parametric ship model can be used to find an “optimal” design or a range of designs. Genetic algorithms can be used to explore configurations of the input parameters, in order to identify the most favourable designs. It is believed that providing the user with suggestions to design solutions has more benefits than limiting the user to a set of optimal designs. This is both because there exist aspects that are difficult to capture in a single ship model, and to invite the designer into the design process.

Part 5 Operational design

20 Configurability

Within offshore activities it's apparent that some types of contracts are seasonable dependent, mainly meaning that weather conditions only allows the work to be performed in limited periods of the year. This means that vessels purpose built for these tasks have limited periods of the year where they are able to utilize this vessel configuration. Most offshore vessels have the ability to perform multiple tasks to increase its operational timespan, but it can be discussed whether a vessel are to be configured for all types of intended operation from birth, or if a vessel can be re-configured from operation to operation.

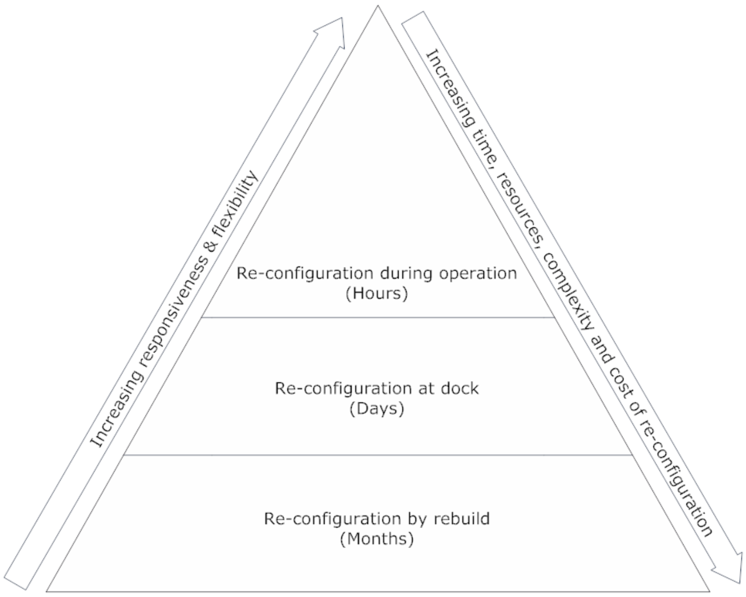


Figure 46 - Re-configuration pyramid

This thesis introduces three levels of re-configurations which is characterized by the resources, time, complexity, cost, responsiveness and flexibility involved with re-configuring a vessel.

Re-configuration during operation is level 1 and means that a vessel does not need to return to shore in order to be prepared for the next task or operation. This level of re-configuration has large benefits with the responsiveness of the vessel as no time is lost due to undesired transit. Large re-configurations is difficult in this level as offshore sea states results in undesired vessel motions and the fact that the vessel must be able to perform these re-configurations with its own resources. This also means that the systems and equipment that are being installed have to be on-board the vessel resulting in space consumption and additional weight (reduced payload and cargo space). It is expected that these re-configurations have a time span less than a day and is limited to hours.

Level 2 is re-configuration at dock where a vessel will have the re-builds performed in more controlled surroundings as it is more sheltered form wind and waves. External equipment such as quay cranes and welding equipment can be used to increase the extent of the re-configurations. These re-configurations can be done in correlations with the change of crew, re-fuelling and other scheduled tasks which involves the vessel returning to shore. These kinds of re-configurations have a timespan over days rather than hours or months.

Re-configuration by level 3 involves major changes to the vessel where the vessel is taken out of operation over a longer period of time (months). Re-configuration at this level can be characterized by large structural changes which may require the vessel to be put into a slipway or dry-dock. Re-configuration at this level enables the vessel to change its operational area partially or entirely meaning that the vessel can be rebuilt into a different vessel type.

It is believed that the ability to re-configure a vessel with the least amount of effort can contribute to enhanced flexibility, creating opportunities for a wider range of contracts. By being configured to operation rather than configured for several operations at the same time, the vessel will have opportunities for increased performance as it is not consisting of large amount of unnecessary systems and equipment. The vessel then needs to be re-configured for new operations when there is a change in seasonal demand, meaning that the owner needs to possess the required equipment and systems. A consequence of this re-configuration is the cost and resources involved with the rebuild as well as the fact that the vessel is not operational when re-configuring.

20.1 Economic aspects to configurability

It is not apparent which solution is most favourable from a ship-owners perspective, and there are several aspects to a re-configuration strategy that have to be thoroughly evaluated. As the main reason for owning ships are to generate profit, independent if the vessels are operated by the ship owner or chartered to a third-party, the economic aspects of re-configuration solutions become important.

If we look at yearly profit it is clear that it is dependent on generated income and the related expenses. For a ship owner the aim should be to maximize profit rather than maximizing income or minimizing expenses in order to have the best performance of the fleet.

$$Yearly\ profit = Yearly\ income - Yearly\ expenses$$

If we divide yearly expenses into capital- and operational expenditures we get:

$$Yearly\ expenses = OPEX + CAPEX$$

OPEX can further be divided into the expenditures shown in the equation below. Within OPEX it is believed that large degree of re-configuration, especially with regards to rebuild, will increase manning because of increased yard activities as well as direct costs of the re-configurations. The OPEX costs in re-configuration are related to the additional work of installing equipment and systems. To limit the increase of OPEX it recommended that rebuild and re-configuration at dock is combined with maintenance and repair.

$$\begin{aligned} OPEX \approx\ & Manning + Stores\ \&\ Consumables + Maintenance\ \&\ Repair + Administration \\ & + Re - configuration -\ \&\ upgrade\ work \end{aligned}$$

If a re-configuration strategy is selected, the vessel is less equipped when built and results in lower interest because of the lower vessel value. Because the ship owner needs to purchase the systems and equipment for future contracts, there will also be involved capital expenditures. The subdivision of CAPEX is shown below.

$$CAPEX \approx Interests + Depresiations + Re - configurations\ systems\ and\ equipment$$

The yearly income of a vessel is dependent on the vessel's contracts over a year as shown below.

$$Yearly\ vessel\ income = \sum_{i=0}^{n} Income\ contract_1 + Income\ contract_2 + \cdots + Income\ contract_n$$

As a ship-owner often has a fleet of vessels, the income of the entire fleet must be calculated:

$$Yearly\ income = \sum_{j=0}^{m} Yearly\ income\ vessel_1 + Yearly\ income\ vessel_2 + \cdots + Yearly\ income\ vessel_n$$

The income of each contract is often the product of a charter rate and the duration of the contract as shown below. The charter rate is dependent on the type of vessel needed to perform the operation consequently the type of operation. The duration of the contract is constrained by the operational window (the periods of the year when it is possible to perform the operation) and the amount of work involved. Vessels with high efficiency compared to similar vessels will have the ability to achieve a higher charter rate because of the possibility of lower operation duration.

$$Contract_i = Charter\ rate_i * Duration_i$$

In order to argue for a re-build strategy it must be concluded that a higher profit during the fleet's lifecycle is achievable. It is believed that frequent re-configuration will increase a vessel's lifetime as the vessel is frequent upgraded, inspected and maintained and means an increased generated income over the vessels lifecycle. A negative consequence of re-configuring a vessel is the fact the vessel is not able to operate while doing the re-configuring resulting in lower operation time and generated income in these periods. For re-configuration to be beneficial the positive effects needs to exceed the negative summarized below:

Lost profit due to lost operating time + Cost of re-configuring <Profit from higher operation efficiency + Profit from increased lifetime + Reduced interest costs + Profit from new available contracts

In order to keep the negative effects of lost operational time and large costs of re-build it is expected that frequent re-builds are not desired and should be used for enabling the vessel to compete for a larger variety of contracts. Of course a vessel can be rebuilt during its lifetime, but the author's opinion is that a vessel should not depend on resource demanding work in order to compete for contracts. Modularity is a method of reducing re-configuration time and resources and is discussed in the next chapter.

20.2 Modularity enabling configurability

By applying modular methodology to enable re-configuring of vessels it is possible to reduce time and resources involved. In this report the systems, equipment and structural changes that are related to a given operation are grouped into one or more re-configuration (or operation) modules. This report differentiates Part 5, which aims to enable configurability by modularization, and Part 2 which describes a method of generating modules based on functional requirements for the use in MPPs in part 4.

This report differentiates between re-configuration modules, that are associated with interchangeable modules that aim at specific operations/tasks when the vessel is put into operation, and modules used for design purposes. Basic modules are modules required for all vessel types, and are not associated with a specific operation. Operational modules are related to the design, construction and operation of vessels, while the re-configuration modules are only related to configurability in operation. Design modules are those operation modules that are selected during the design phase to be permanently installed and part of all operations.

It is expected that structural integrity will be difficult to achieve for hull modules that has large impact on a vessels design and must therefore be thoroughly evaluated. The "puzzle" example of the moon pool module shows an extreme method of sectional modularity and is meant as a way of thinking rather than a real situation. The general idea is to use standardized interfaces in order to reduce amount of work involved with re-builds and prepare for future opportunities.

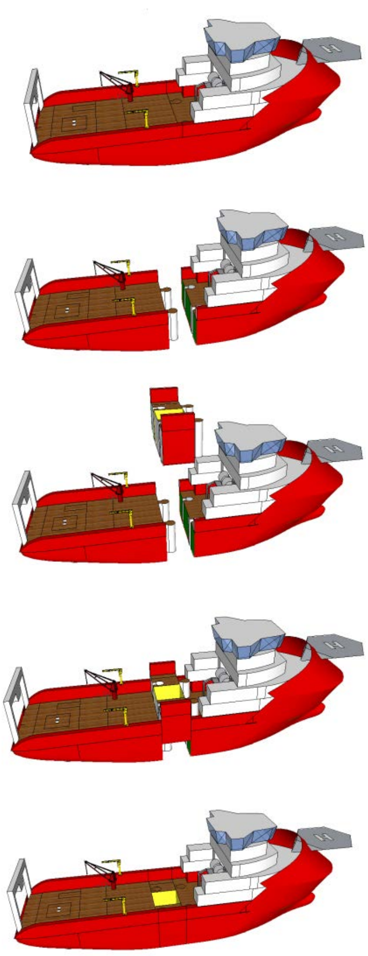


Figure 47 - Modular moon pool

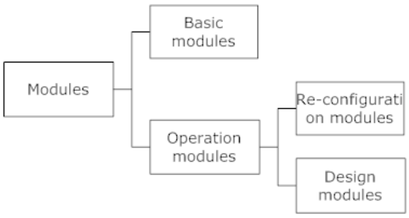


Figure 48 - Module categorization

20.2.1 Component swapping

Another appliance of modularity in re-configuration is to standardize deck equipment, deck systems and interfaces. Component swapping will enable a set of modules to be paired with the same basic module. An example of this can be a set of deck cranes that can be mounted to the same foundation on deck, and will in this way enable to match the crane capacity to the demanded capacity of the operation.

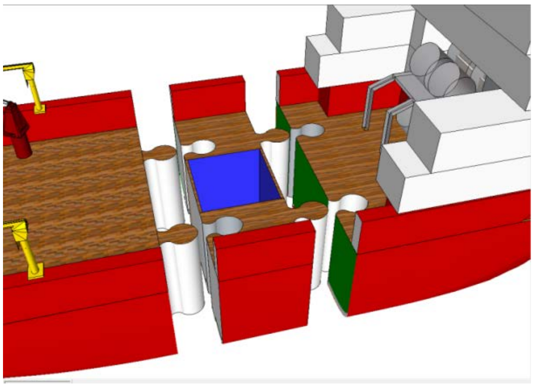


Figure 49 - Moon pool module

By using component swapping one is able to have a vessel value that is in relation to the operation it is to perform, and might thereby reduce the cost of the vessel for "simple" operations. The equipment that are not in use can be taken off and are thereby not subject to wear, and could be maintained ashore or used on an alternative vessel. A ship owner must invest the re-configuration modules related to operations, but with good fleet and module logistics one is thereby able to reduce capital expenses as over specification are avoided. A lower operational cost will also be expected as there are lower maintenance costs of equipment and systems that are not in use.

Component swapping of re-configuration modules will also have competitive advantages as a vessel will have increased flexibility, thereby being able to compete for more and more favourable contracts, resulting in more generated income.

20.2.2 Bus modularity

To further expand the flexibility of a vessel it is also possible to use bus modularity to enable reconfigurable placements of equipment. E.g. if standard fundaments and interfaces, such as hydraulics and controls, are used on a deck equipment of an OSV one can be able to change the position of the deck equipment to have the best configured work deck arrangement towards a specific operation. For instance a crane can have multiple position alternatives on deck, which will give flexibility towards work deck arrangement and number of installed cranes.

20.2.3 Conclusion

Modularity is a method for achieving configurability towards different offshore operations. The main reason for re-configuration is to achieve a more flexible vessel that can target the most favourable contracts. Re-configurability must be motivated by economic benefits where profit is the main driver in this industry. Cost-benefit analysis is a method of assessing this strategy, but can be difficult to calculate as there are large uncertainties involved when trying to predict the future.

Chapter 6.1 identifies that there are differences with regards to the system borders of modules related to different modules. When a vessel is in operation, the time spent re-configuring a vessel must be minimized. A result of this will be re-configuration modules that affect the hull and structure as little as possible and thereby having preinstalled systems, foundations, hydraulics, etc., which can then result in additional weight and volumes of the vessel.

21 Re-configuration evaluation by MPP’s

Enabling re-configurability requires detailed development, planning and evaluation. Modular product platforms can assist this process by efficiently developing and launching multiple configuration alternatives. The benefits with a MPP are that multiple alternatives can be developed after each customer’s needs and evaluated rapidly. Each configuration alternative must be evaluated individually for all loading conditions, which may become time consuming using traditional methods of design. It is belied that by using modular product platform, the time and resources required to develop and evaluate configuration alternatives can be reduced. In addition is it possible to develop and evaluate multiple alternative solutions based on the same re-configuration options.

Epilogue

22 Conclusions & findings

This MSc thesis focuses on development of a structured and efficient approach for concept- and preliminary development and evaluation of offshore support vessel designs. The responsiveness and flexibility of the design where emphasized in order to meet today's competitive marked. A modular product platform which efficiently creates OSV designs has been developed based on these terms. The product platform creates automatically a 3D model which can be used for further design evaluation and improvement.

The method of visualization where found to have large impact on the architecture of the product platform. Using QFD combined with SBSD has provided a structured method of relating the functions to modules. The House of Quality has proven to be a structured method of describing functions, modules and relations. This structure has also been successfully been implemented in the product platform. Using vessel statistics to validate the design provides good information in a design process, and will support the designer in design decisions. Scaling of modules within a MPP changes the shape of the output design. Ship characteristics are largely dependent on the hull shape, and will therefore be subject to variations due to scaling. It is therefore important to enable manipulation of the hull shape within a MPP, which can be achieved by sectioning of the hull and relating given modules to given sections. Although the current MPP does not incorporate all aspects to OSV design, it is able to support a design spiral process where adaption can be made based on the described methods of design evaluation.

Using modules with complex geometry in a product platform will create a more realistic design which concurs more with existing vessel design performances. The information from a 3D hull model can be used to generate these complex shaped modules, so that the accuracy of the output design can be increased (compared to box modules). Modules created based on predefined (complex) geometry, such as hull shape, will more or less have a fixed location that will limit the diversity of the product family. Locational diversity of modules can be created by having alternative modules which are linked to other locations, or functional assignment to alternative modules. The alternative modules can either be made available in a single product platform, or by having multiple product platforms that implement different modules and positional requirements. Using multiple product platforms is a contributor to reducing the overall system complexity and transparency. MPP's with square shaped modules will have more flexibility with regards to the positioning of the modules, but require a high number of modules in order to achieve good design performance.

MPP's enables an efficient parametric concept exploration process where detailed calculations are managed in an efficient manner in order to focus on the important (and more global) design changes in early stages of design. The level of detail in the methods engineers use to make design decisions makes modular approaches to early design very applicable.

The issue of whether to re-configure or not, is highly dependent on economic feasibility. Modularisation and standardization of module interfaces can contribute to this development. Modular product platforms, proven by the work in this thesis, provide a structured method of developing alternative configurations for OSV designs. The developed product platform can provide a basis for re-configuration concept evaluation and development. The method of identifying modules based on functional requirements related to OSV explained in chapter 6.3 and illustrated by Figure 21, can also be used as a basis for evaluating which operational modules which are most applicable for re-configuration alternatives of OSVs.

The current developed MPPs seems to provide designs with good performance compared to similar vessel design, but still have to prove its applicability in a real-world situation. Companies within the OSV market have stated their interest and recognize the value of these developments. It is believed that such tools will become part of future sales processes and a part of marketing strategies.

23 Future developments

The developed design approach for OSVs requires further development to be used as a finished tool by companies. The following improvements are proposed:

- Implement external analysis, such as structural & hydrodynamic. Google SketchUp has limited support of such file-formats, and another 3D application might be preferable to increase the system productivity. New scripts have to be developed in order to read the exported commands from excel and new 3D models of modules and hull must be created in order to adapt the system to an alternative 3D application.
- Improve user interface and rewrite the MPP system to a more transparent structure. After working with the system over time, the increase in size of the system has made the difficult to follow.
- Expand product platform to manage more alternatives, such as engine selection, vessel type and equipment.
- Implement more accurate calculations of:
    - Heel and trim: Visualization only support up to 15 degree heel angle.
    - Moments of inertia and second moment of area.
- Investigate the practical applicability in a real-life OSV design environment.
- Evaluate vessel data in the databases. Out-dated vessels and vessels with poor performance are undesired when producing innovating designs.
- Implement uncertainties of vessel statistics.
- Implement database of detailed vessel statistics. Simple mathematical functions which are determined using STX OSV statistics have been used to determine the attributes of functions. By implementing a database with these data, the mathematical functions can be automatically updated with new vessel statistics and experience.
- Further development of re-configurability related to operations. Economic aspects to the feasibility (profitability) of these developments must be investigated.

References

ABT, C., BADE, S. D., BIRK, L. & HARRIES, S. 2001. PARAMETRIC HULL FORM DESIGN – A STEP TOWARDS ONE WEEK SHIP DESIGN. 9.

AKAO, Y. & MIZUNI, S. 1994. *QFD, the Customer-Driven Approach to Quality Planning and Deployment*.

ANDREWS, D. J. 1998. A comprehensive methodology for the design of ships (and other complex systems). 27.

ANDREWS, D. J. 2006. Simulation and the design building block approach in the design of ships and other complex systems. 28.

ANDREWS, D. J. 2011. Art and science in the design of physically large and complex systems. 23.

BALDWIN, C. & CLARK, K. *Modularity in design of complex engineering systems,* Harvard, Boston.

BOLE, M. & FORREST, C. 2005. Early Stage Integrated Parametric Ship Design. 14.

BREKKE, Ø. & TVEDT, H. 2011. Project thesis: System-Based Design of Offshore Support Vessel.

BROOKS, F. P. 2010. *The design of design - essays from a computer scientist,* Boston.

BUHAUG, Ø., HAGEN, A. & LANGSET, J. G. 1999. *Kravhåndtering*, Marintek.

BUXTON, B. 2006. What Sketches (and Prototypes) Are and Are Not.

DAY, A. H. & DOCTORS, L. J. 2000. The survival of the fittest - evolutionary tools for hydrodynamic design of ship hull form. 16.

ERICHSEN, S. 1999. *Elements and techniques of marine design,* Trondheim, MTS.

ERICSSON, A. & ERIXON, G. 1999. *Controlling Design Variants: Modular Product Platforms,* Dearborn / Michigan, Society of Manufacturing Engineers.

ERIKSTAD, S. O. 2009. Modularisation in Shipbuilding and Modular Production. 58.

EVANS, J. H. 1959. BASIC DESIGN CONCEPTS. *Journal of the American Society for Naval Engineers,* 71**,** 671-678.

FALTINSEN, O. M. 1999. *Sea loads on ships and offshore structures,* Cambridge, UK, Cambridge University Press.

GU, P. & SOSALE, S. 1999. Product modularization for life cycle engineering. 15.

HAGEN, A. 2011. Shipbuilding (TMR 4125).

IHS Sea-web.

JIAO, J. 1998. Design for mass customization by developing product family architecture. Hong Kong: Hong Kong University of Science and Technology.

LAMB, T. 2004. Ship Design and Construction, Volumes 1-2. Society of Naval Architects and Marine Engineers (SNAME).

LEVANDER, K. 2009. *System Based Ship Design*.

MCDONALD, T. P., ANDREWS, D. J. & PAWLING, R. G. 2010. A demonstration of an advanced library based approach to the initial design exploration of different hullform configurations

15.

MEYER & LENHERD 1997. Unknown.

NELSON(II), S. A., PARKINSON, M. B. & PAPALAMBROS, P. Y. 1999. MULTICRITERIA OPTIMIZATION IN PRODUCT PLATFORM DESIGN. s**,** 8.

OERS, B. V. 2011. *A packin approach for the early stage design of service vessels.* PhD.

OSJ 2011. Offshore Support Journal. 124.

PAPALAMBROS, P. Y. & WILDE, D. J. *Principles of Optimal Design - Modeling and Computation,* Cambridge, Cambridge University Press.

PRASAD, B. 1998. Review of QFD and Related Deployment Techniques. 14.

RAHARJO, H., XIE, M. & BROMBACHER, A. C. 2010. A systematic methodology to deal with the dynamics of customer needs in Quality Function Deployment. 10.

RAO, S. S. 2009. *Engineering Optimization: Theory and practice,* New Jersey, JOHN WILEY & SONS, INC.

REVOLLARA, S., LAMANNAA, R. & VEGAB, P. 2005. Algorithmic Synthesis and Integrated Design for Activated Sludge Processes Using Genetic Algorithms.

SIMPSON & D'SOUZA 2004. Assessing variable levels of product platform commonality within product family using a multiobjective genetic algorithm. USA.

SIMPSON, SIDDIQUE & JIAO 2006. Product platform and product family design. USA.

SNAME 2003. *Ship Design and Construction*, The Society of Naval Architects and Marine Engineers.

STENSVOLD, T. 2012. *Norsk skipsbygging har 40 års forsprang* [Online]. Available: http://www.tu.no/industri/2012/05/09/norsk-skipsbygging-har-40-ars-forsprang [Accessed May 2012].

VAN OERS, B., STAPERSMA, D. & HOPMAN, H. Issues when selecting naval ship configurations from a Pareto-optimal set. Delft University of technology.

VERISTAR Rules for the Classification of Steel Ships. *In:* VERITAS, B. (ed.).

VESTBØSTAD, Ø. 2011. MSc Thesis System Based Ship design.

WITCOMB, C. A. & SZATKOWSKI, J. J. 2000. CONCEPT LEVEL NAVAL SURFACE COMBATANT DESIGN IN THE AXIOMATIC APPROACH TO DESIGN FRAMEWORK.

Appendices

I. Example of file exported from Excel, which are used as input for 3D model generation

The columns, from left represents: x-position, y-position, z-position, scaling in x-direction, scaling in y-direction, scaling in z-direction and name of model. The model named “none” implies that module is not selected.

```
0   0   0   1   2,3   1,0625   Hull_Stern01
0   0   0   0   0   0   none
15   0   0   0,81885717820304   2,3   1,0625   Hull_midship_aft
37,3948947559914   0   0   1   2,3   1,0625   Hull_midship_moonpool
43,3948947559914   0   0   0,372248963525871   2,3   1,0625   Hull_midship_fore
15   0   0   1,16824632502943   2,3   1,0625   none
49,4048542721166   0   0   1   2,3   1,05235602094241   Hull_Bow01
0   0   0   0   2,3   1,29573170731707   none
25,8948947559914   0   0   1,91666666666667   2,3   1,0625   Hull_midship
49,3048542721166   0   20,1   0,802884825582779   0,784090909090909   1   Internal_deck_D
49,3048542721166   0   23   0   0,784090909090909   0   Internal_deck_E
49,3048542721166   0   8,5   0,99   2,29   1   Internal_deck_main_bow01
46,8829467258897   0   8,5   0,484381509245377   2,29   1   Internal_deck_midship
49,3048542721166   0   11,4   0,99   2,29   1   Internal_deck_A_bow01
46,3824029977538   0   11,4   0,584490254872563   2,29   1   Internal_deck_midship
49,3048542721166   0   14,3   0,99   2,29   1   Internal_deck_B_bow01
46,3142485749652   0   14,3   0,598121139430285   2,29   1   Internal_deck_midship
49,3048542721166   0   17,2   0,788090360052185   2,27571428571429   1   Internal_deck_C_bow01
0   0   17,2   0   0   0   None
15   0   0,5   1   2,299   1   Internal_stern
15   0   0,5   0,81885717820304   2,299   1   Internal_midship_aft
37,3948947559914   0   0,5   1   2,299   1   Internal_moonpool_sides
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43,3948947559914   0   0,5   0,363410692260253   2,299   1   Internal_midship_fore
49,2621603825332   0   0,5   0,947   2,28   1   Internal_bow01
0   0   0   0   0   0   none
49,3048542721166   0   23   0,849658922632486   0,940909090909091   1,03448275862069   Bridge
-2   0   8,51   2,03474887690925   3,69523139187049   1   none
73,0648542721166   0   13,8069109947644   0,947   2,28   0,7   stxbow
0   0   8,51   0,5824111822947   2,3   1   Deck_stern_shape
0   0   8,51   1   2,3   1   Deck_stern
15   0   8,51   0,913182790572151   2,3   1   Deck_midship
37,3948947559914   7,25   8,51   1   1,41666666666667   1   Deck_moonpool
37,3948947559914   -7,25   8,51   1   1,41666666666667   1   Deck_moonpool
43,3948947559914   0   8,51   0,2450644069534   2,3   1   Deck_midship
0   11,5   8,5   0,5824111822947   1   1,35009310986965   Rail_stern_shape_port
0   -11,5   8,5   0,5824111822947   1   1,35009310986965   Rail_stern_shape_starboard
0   11,5   8,5   1   1   1,35009310986965   Rail_stern_port
0   -11,5   8,5   1   1   1,35009310986965   Rail_stern_starboard
15   11,5   8,5   1,47127481810499   1   1,35009310986965   Rail_midship_port
15   -11,5   8,5   1,47127481810499   1   1,35009310986965   Rail_midship_starboard
4   0   4,9   1,25   0,704   0,514285714285714   retractable_thruster
0   0   0   1   0,8625   1,42857142857143   None
19,2517764988769   11   11,4   1   1   1   Eq_railcrane01
0   0   0   1   1   1   None
19,2517764988769   -11   11,4   1   1   1   Eq_railcrane01
63,8590672721166   0   20,8413109947644   0,5   0,5   0,5   Eq_helipad
9,62588824943845   7,5   8,5   1   1   1   Eq_crane0101
0   0   0   1   1   1   None
0   0   0   1   1   1   None
0   0   0   1   1   1   None
0   0   0   1   1   1   None
0   0   0   1   1   1   None
0   0   0   1   1   1   None
46,3142485749652   0   0   0   0,7   0,6   None
0   0   0   1   1   1   None
2   0   8,5   0   0   0   None
0   0   8,5   0,5824111822947   2,3   1,0625   Hull_finish_Normalstern
41,3142485749652   -9   8,5   1   1   1   Eq_rov_garage
41,3142485749652   9   8,5   1   1   1   Eq_rov_garage
41,3142485749652   0   8,5   1   2,6   1   Eq_diving_module
40,3948947559914   0   8,5   0   1   0,777777777777778   None
28,5198947559914   8,625   0,5   1,05   1,05   1,05333333333333   Eq_tanks_multipurpose
28,5198947559914   2,875   0,5   1,05   1,05   1,05333333333333   Eq_tanks_multipurpose
28,5198947559914   -2,875   0,5   1,05   1,05   1,05333333333333   Eq_tanks_multipurpose
28,5198947559914   -8,625   0,5   1,05   1,05   1,05333333333333   Eq_tanks_multipurpose
34,2698947559914   8,625   0,5   1,05   1,05   1,05333333333333   Eq_tanks_bulk
34,2698947559914   2,875   0,5   1,05   1,05   1,05333333333333   Eq_tanks_bulk
34,2698947559914   -2,875   0,5   1,05   1,05   1,05333333333333   Eq_tanks_bulk
```

```
34,2698947559914  -8,625  0,5  1,05  1,05  1,05333333333333  Eq_tanks_bulk
40,0198947559914  0  0,5  0  0  0  None
40,0198947559914  0  0,5  0  0  0  None
40,0198947559914  0  0,5  0  0  0  None
40,0198947559914  0  0,5  0  0  0  None
2  0  8,5  3,23948947559914  2,05278592375367  2,05278592375367  none
47,6631655596668  0,122710925558687  8,17019132724709  1  1  1  Stab_COG
37,5430021360583  0  2,93570330744387  1  1  1  Stab_COB
47,6631655596668  0  9,75342691282766  1  1  1  Stab_Mt
0  0  0  1  1  1  None
```

II. Ruby script for retrieving, scaling and positioning of modules based in input file. (Vestbøstad, 2011)

```ruby
# First we pull in the standard API hooks.
require 'sketchup.rb'

# Show the Ruby Console at startup so we can
# see any programming errors we may make.
Sketchup.send_action "showRubyPanel:"

# Add a menu item to launch our plugin.
UI.menu("PlugIns").add_item("Build modules") {

  # Call our new method.
  draw_geometry

  view = Sketchup.active_model.active_view
  new_view = view.zoom_extents
}


def draw_geometry
  # Convert factor for mm per inch.
  mmperinch = 0.0254

  # Get handles to our model and the Entities collection it contains.
  model = Sketchup.active_model
  entities = model.entities

  # Clear the workspace
  entities.clear!


  File.open("C:/OSV_design/Output_excel.txt") do |file|


    while content = file.gets

        # This line ensures that dots are used for decimals
        content.gsub!(',','.')

        parts = content.split

        filename = parts[6]

        posx = (parts[0].to_f/mmperinch)
        posy = (parts[1].to_f/mmperinch)
        posz = (parts[2].to_f/mmperinch)

        scalex = parts[3].to_f
        scaley = parts[4].to_f
        scalez = parts[5].to_f

        parts_def = Sketchup.active_model.definitions.load("C:/OSV_design/Module_folder/#{filename}.skp")


        parts_location = Geom::Point3d.new posx,posy,posz
        transform = Geom::Transformation.new parts_location
        entities = Sketchup.active_model.active_entities
        instance = entities.add_instance parts_def, transform

        t = Geom::Transformation.scaling parts_location, scalex, scaley, scalez
        status = instance.transform! t

    end

  end


end
```

III. Ruby script for rendering 3D model and exporting top-, side-, front-, stern, and isometric view

```
# Create the WebDialog instance
my_dialog = UI::WebDialog.new("Selection Info", false, "Selection Info", 200,
200, 200, 200, true)

# Attach an action callback
my_dialog.add_action_callback("get_data") do |web_dialog,action_name|
if action_name=="pull_selection_count"
total_selected = Sketchup.active_model.selection.length
js_command = "passFromRubyToJavascript("+ total_selected.to_s + ")"
web_dialog.execute_script(js_command)
end

if action_name=="draw_geometry"
draw_geometry

#Cange rendering options
Sketchup.active_model.rendering_options['DisplaySketchAxes']=true
Sketchup.active_model.rendering_options['DrawSilhouettes']=true
Sketchup.active_model.rendering_options['ModelTransparency']=true
Sketchup.active_model.rendering_options['RenderMode']=1
Sketchup.active_model.rendering_options['Texture']=false

#Writes 2D top view
view = Sketchup.active_model.active_view
Sketchup.active_model.active_view.camera.perspective = false
Sketchup.active_model.active_view.camera= [0,0,1000], [0,0,0], [1,0,0]#eye,
target up-vector
new_view = view.zoom_extents

 keys = {
   :filename => "c:/OSV_design/2Dtop.png",
   :width => 640,
   :height => 480,
   :antialias => false,
   :compression => 0.9,
   :transparent => true
 }
 model = Sketchup.active_model
 view = model.active_view
 view.write_image keys

#Writes 2D stb view
view = Sketchup.active_model.active_view
Sketchup.active_model.active_view.camera.perspective = false
Sketchup.active_model.active_view.camera= [100,-100,0], [100,0,0], [0,0,1]
new_view = view.zoom_extents

 keys = {
   :filename => "c:/OSV_design/2Dstb.png",
   :width => 940,
   :height => 480,
   :antialias => false,
   :compression => 0.8,
   :transparent => true
 }
 model = Sketchup.active_model
 view = model.active_view
 view.write_image keys

#Writes 2D front view
view = Sketchup.active_model.active_view
Sketchup.active_model.active_view.camera.perspective = false
Sketchup.active_model.active_view.camera= [20000,0,0], [0,0,0], [0,0,1]
new_view = view.zoom_extents

 keys = {
   :filename => "c:/OSV_design/2Dfront.png",
   :width => 640,
```

```
   :height => 480,
   :antialias => false,
   :compression => 0.9,
   :transparent => true
 }
 model = Sketchup.active_model
 view = model.active_view
 view.write_image keys

#Writes 2D stern view
view = Sketchup.active_model.active_view
Sketchup.active_model.active_view.camera.perspective = false
Sketchup.active_model.active_view.camera= [-20000,0,0], [0,0,0], [0,0,1]
new_view = view.zoom_extents

 keys = {
   :filename => "c:/OSV_design/2Dstern.png",
   :width => 640,
   :height => 480,
   :antialias => false,
   :compression => 0.9,
   :transparent => true
 }
 model = Sketchup.active_model
 view = model.active_view
 view.write_image keys


#Writes 3D iso view
view = Sketchup.active_model.active_view
Sketchup.active_model.active_view.camera.perspective = true
Sketchup.active_model.active_view.camera= [10000,-10000,5000], [0,0,0], [0,0,1]
new_view = view.zoom_extents

 keys = {
   :filename => "c:/OSV_design/3Diso.png",
   :width => 940,
   :height => 480,
   :antialias => false,
   :compression => 0.75,
   :transparent => true
 }
 model = Sketchup.active_model
 view = model.active_view
 view.write_image keys

#Cange rendering options
Sketchup.active_model.rendering_options['DisplaySketchAxes']=true
Sketchup.active_model.rendering_options['DrawSilhouettes']=false
Sketchup.active_model.rendering_options['ModelTransparency']=false
Sketchup.active_model.rendering_options['RenderMode']=2
Sketchup.active_model.rendering_options['Texture']=true

#Writes coloured 3D iso view
view = Sketchup.active_model.active_view
Sketchup.active_model.active_view.camera.perspective = true
Sketchup.active_model.active_view.camera= [10000,-10000,5000], [0,0,0], [0,0,1]
new_view = view.zoom_extents

 keys = {
   :filename => "c:/OSV_design/3Disocolour.png",
   :width => 940,
   :height => 480,
   :antialias => false,
   :compression => 0.75,
   :transparent => true
 }
 model = Sketchup.active_model
 view = model.active_view
 view.write_image keys
end

end

# Find and show our html file
html_path = Sketchup.find_support_file "selectionInfo.html" ,"Plugins"
my_dialog.set_file(html_path)
my_dialog.show()
```

IV. VBA script for retrieving, scaling and positioning of rendered drawings

```
Module14 - 1

Sub Insert_GA()
'
' Insert_GA Macro
'
ActiveSheet.Shapes.SelectAll
Selection.Delete
'
    ActiveSheet.Buttons.Add(76,5#, 129,75#, 127,5#, 67,5#).Select
    Selection.OnAction = "Insert GA"
    Selection.Characters.Text = "Update GA"
    With Selection.Characters(Start:=1, Length:=9).Font
        .Name = "Arial"
        .FontStyle = "Normal"
        .Size = 10
        .Strikethrough = False
        .Superscript = False
        .Subscript = False
        .OutlineFont = False
        .Shadow = False
        .Underline = xlUnderlineStyleNone
        .ColorIndex = xlAutomatic
    End With
    Range("F13").Select
    ActiveSheet.Pictures.Insert("C:\OSV_design\2Dstb.png").Select
    Selection.ShapeRange.ScaleWidth 0,7#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 0,7#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.IncrementLeft 35,#
    Selection.ShapeRange.IncrementTop -65,#

    ActiveSheet.Pictures.Insert("C:\OSV_design\2Dfront.png").Select
    Selection.ShapeRange.ScaleWidth 0,53#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 0,53#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.IncrementLeft 405,#
    Selection.ShapeRange.IncrementTop -27,#

    ActiveSheet.Pictures.Insert("C:\OSV_design\2Dtop.png").Select
    Selection.ShapeRange.IncrementRotation 90
    Selection.ShapeRange.ScaleWidth 1,#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 1,#, msoFalse, _
        msoScaleFromBottomRight
    Selection.ShapeRange.IncrementLeft -30,#
    Selection.ShapeRange.IncrementTop 10,#

    ActiveSheet.Pictures.Insert("C:\OSV_design\2Dstern.png").Select
    Selection.ShapeRange.ScaleWidth 0,54#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 0,54#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.IncrementLeft 400
    Selection.ShapeRange.IncrementTop 140,#

    ActiveSheet.Pictures.Insert("C:\OSV_design\3Diso.png").Select
    Selection.ShapeRange.ScaleWidth 0,6#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.ScaleHeight 0,6#, msoFalse, msoScaleFromTopLeft
    Selection.ShapeRange.IncrementLeft 50,#
    Selection.ShapeRange.IncrementTop 270,#
    Range("M31").Select
End Sub
```

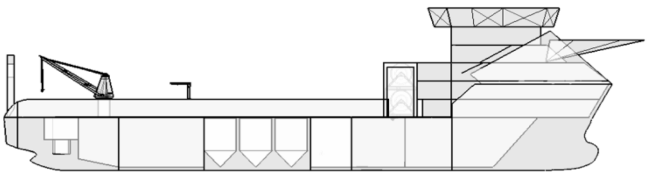
V. VBA script for exporting initial view of design

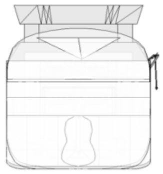
```
Attribute VB_Name = "Module7"
Public Sub export(FName As String, _
    Sep As String, SelectionOnly As Boolean, _
    AppendData As Boolean)

Dim WholeLine As String
Dim FNum As Integer
Dim RowNdx As Long
Dim ColNdx As Integer
Dim StartRow As Long
Dim EndRow As Long
Dim StartCol As Integer
Dim EndCol As Integer
Dim CellValue As String


Application.ScreenUpdating = False
On Error GoTo EndMacro:
FNum = FreeFile


    With ActiveSheet.Range("exportarea")
        StartRow = .Cells(1).Row
        StartCol = .Cells(1).Column
        EndRow = .Cells(.Cells.Count).Row
        EndCol = .Cells(.Cells.Count).Column
    End With


If AppendData = True Then
    Open FName For Append Access Write As #FNum
Else
    Open FName For Output Access Write As #FNum
End If

For RowNdx = StartRow To EndRow
    WholeLine = ""
    For ColNdx = StartCol To EndCol
        If Cells(RowNdx, ColNdx).Value = "" Then
            CellValue = Empty
        Else
           CellValue = Cells(RowNdx, ColNdx).Value
        End If
        WholeLine = WholeLine & CellValue & Sep
    Next ColNdx
    WholeLine = Left(WholeLine, Len(WholeLine) - Len(Sep))
    Print #FNum, WholeLine
Next RowNdx

EndMacro:
On Error GoTo 0
Application.ScreenUpdating = True
Close #FNum

End Sub



Sub lagreExport()
    export FName:="C:\OSV_design\output_excel.txt", Sep:="  ", _
       SelectionOnly:=True, AppendData:=False
End Sub
```

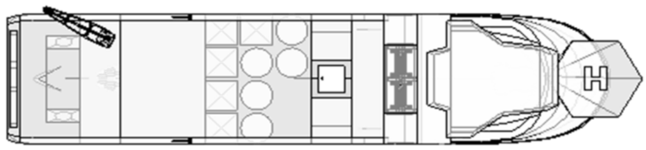
Scripts for export of alternative views and alternative module configuration are based on this script, but will export different ranges of cells in MS excel.

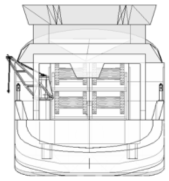
VI. Preliminary GA in excel (Side-, top-, front-, stern- & isometric view)

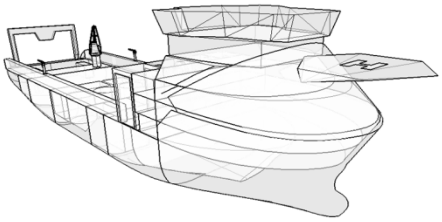
An illustration of the automated rendered 3D model implemented in MS Excel:











VII. Loading conditions (Veristar)

Part B Hull and Stability
Chapter 3 Stability
Appendix 2 Trim and Stability Booklet
1 Trim and stability booklet

1.2 Loading conditions

1.2.1 General

The standard loading conditions to be included in the trim and stability booklet are:

- lightship condition
- ship in ballast in the departure condition, without cargo but with full stores and fuel
- ship in ballast in the arrival condition, without cargo and with 10% stores and fuel remaining.

Further loading cases may be included when deemed necessary or useful.

When a tropical freeboard is to be assigned to the ship, the corresponding loading conditions are also to be included.

1.2.2 Ships carrying cargo on deck

In addition to the loading conditions indicated in [1.2.1] to [1.2.13], in the case of cargo carried on deck the following cases are to be considered:

- ship in the fully loaded departure condition having cargo homogeneously distributed in the holds and a cargo specified in extension and weight on deck, with full stores and fuel
- ship in the fully loaded arrival condition having cargo homogeneously distributed in holds and a cargo specified in extension and weight on deck, with 10% stores and fuel.

1.2.11 Tugs and fire-fighting ships

In addition to the standard loading conditions defined in [1.2.1], for ships with one of the service notations **tug** and **fire fighting ship** the following loading cases are to be included in the trim and stability booklet:

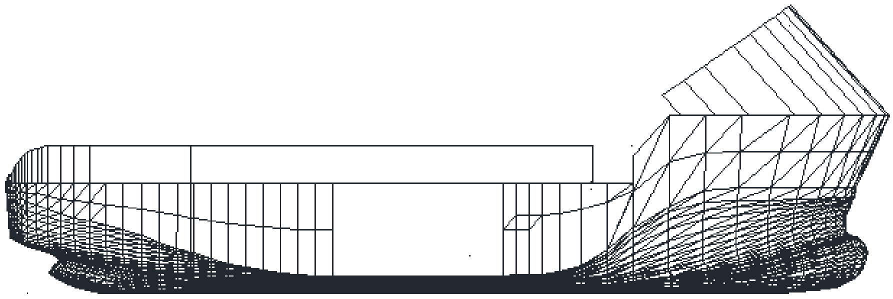
- ship in the departure condition at the waterline corresponding to the maximum assigned immersion, with full stores, provisions and consumables
- same conditions as above, but with 10% stores and consumables.

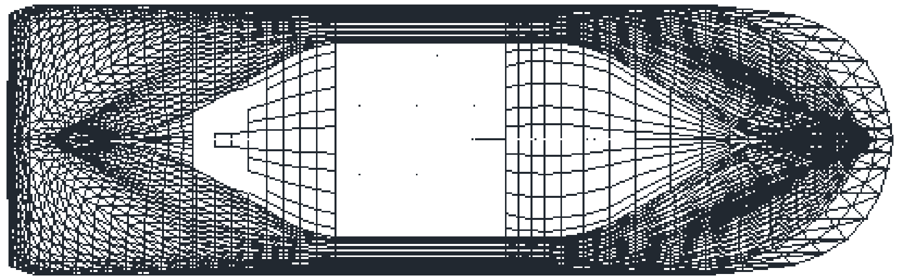
1.2.12 Supply vessels

In addition to the standard loading conditions specified in [1.2.1], for ships with the service notation **supply vessel** the following loading cases are to be included in the trim and stability booklet:

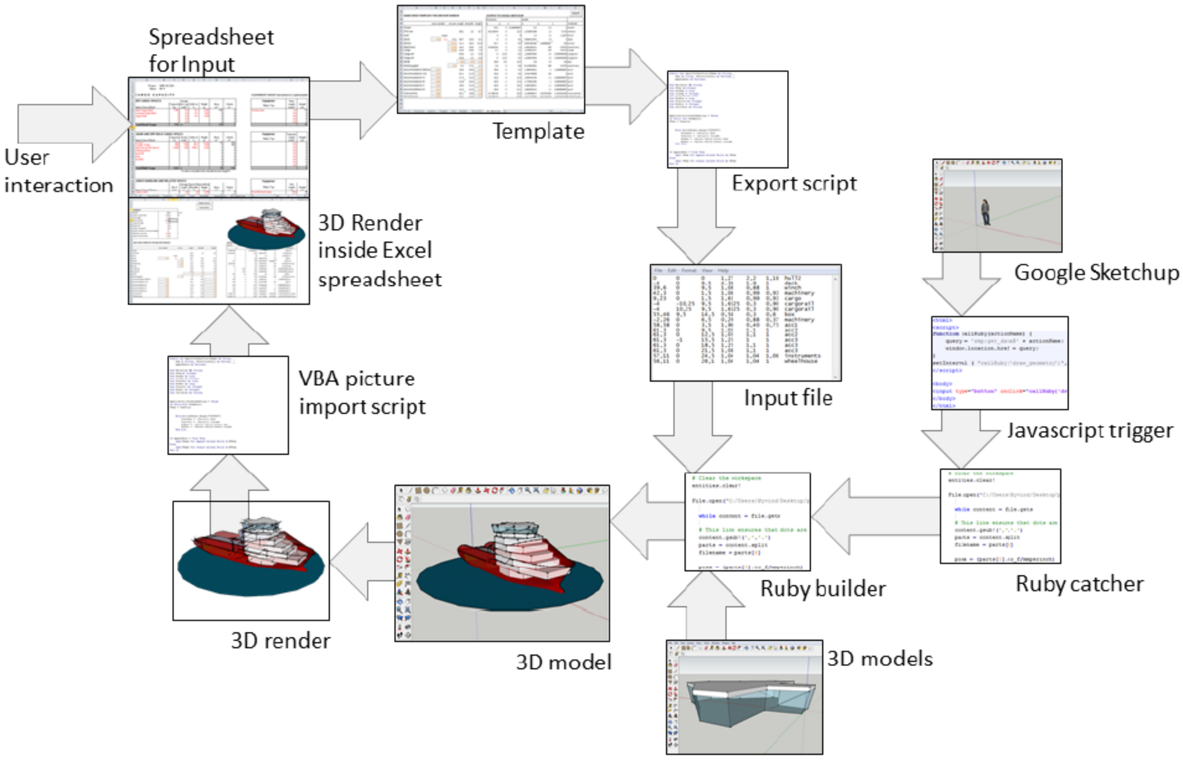
- ship in the fully loaded departure condition having under deck cargo, if any, and cargo specified by position and weight on deck, with full stores and fuel, corresponding to the worst service condition in which all the relevant stability criteria are met
- ship in the fully loaded arrival condition with cargo as specified above, but with 10 per cent stores and fuel.

VIII. Exported model (AutoCad model)



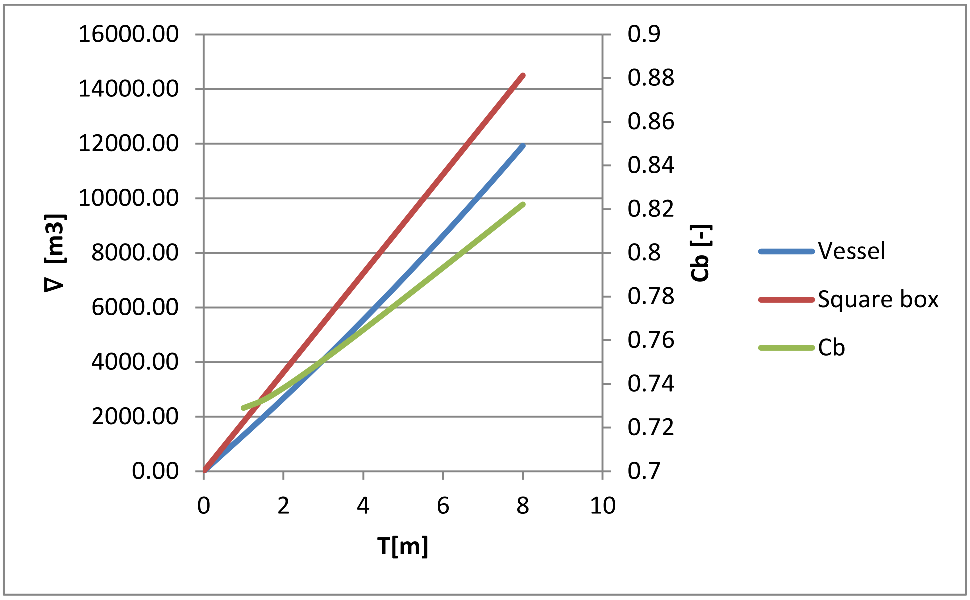


IX. Prototype of visualization tool (Vestbøstad, 2011)

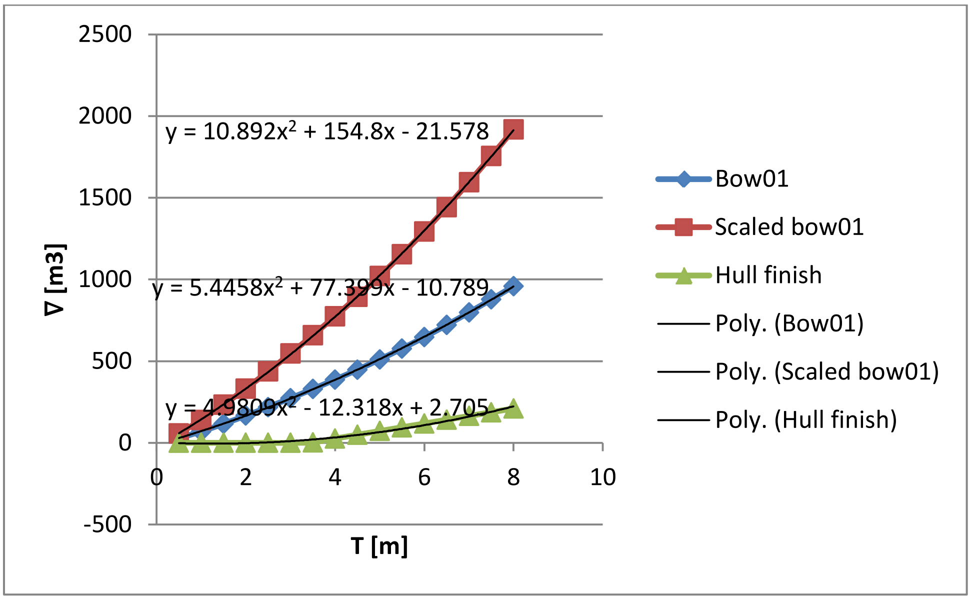


X. Displacement as a function of draught

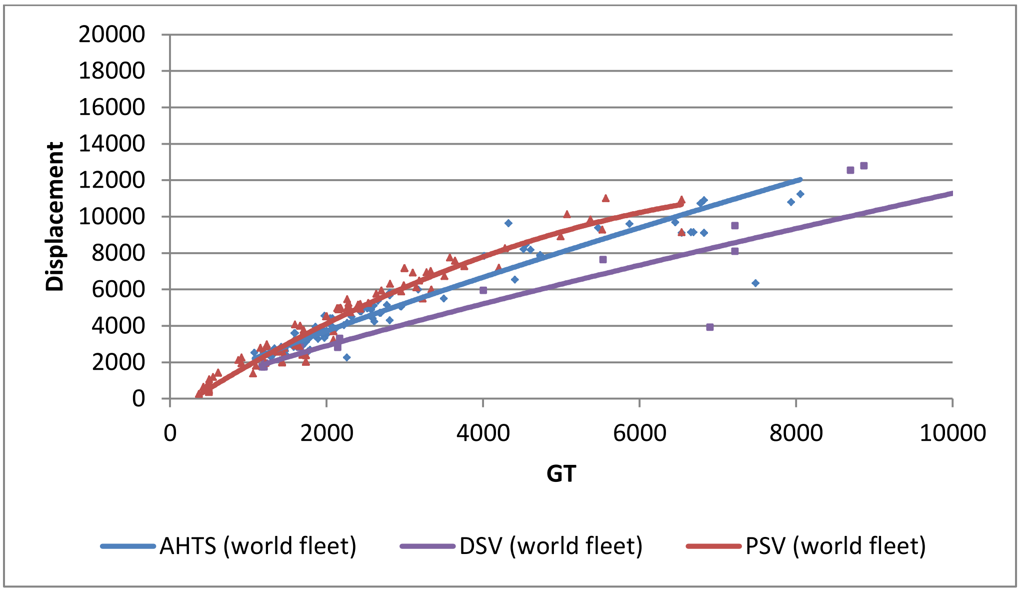
The hull shape's displacement will be dependent on draught. The vessels displacement as a function of draught can be calculated based on the hull modules specific displacement. Based on this function and a function for a square box, the block coefficient (C_b) can be determined:

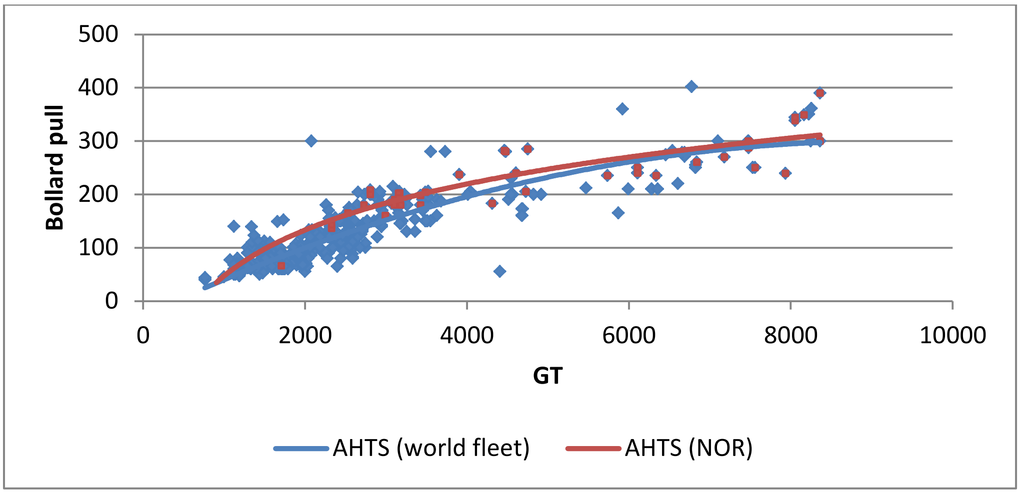


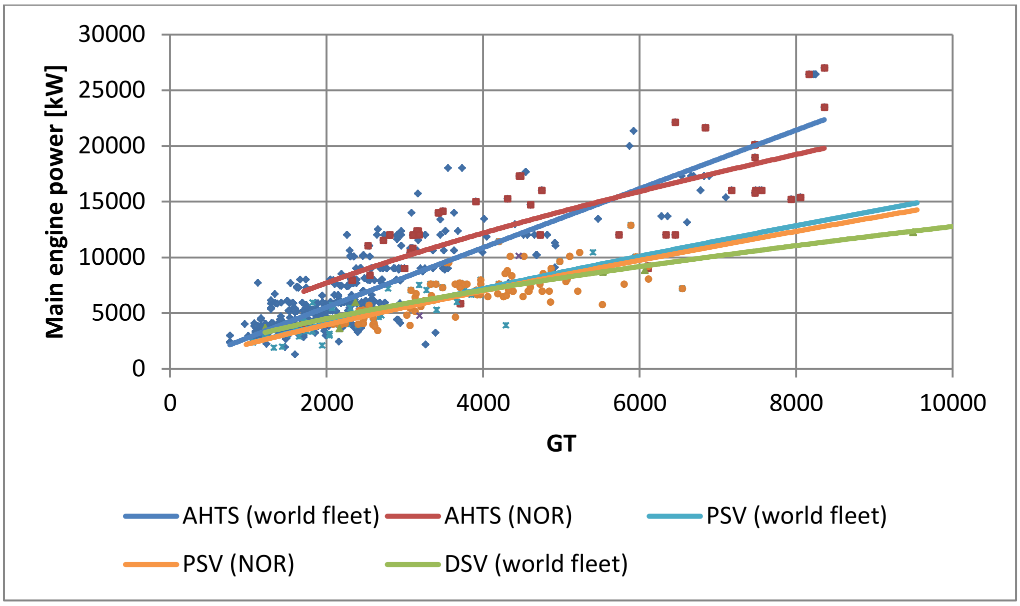
These calculations are based on each hull module's specific displacement as a function of draught. By scaling modules, the properties of these functions changes. Mathematical functions can be developed for each hull module and summarized to establish a function of the entire vessel. Example of a stern-, bow- and scaled bow module are illustrated below. These functions will vary with scaling of modules and module selections. The mathematical function is generated automatically in the product platform.



XI. Key data for world fleet built after year 2000



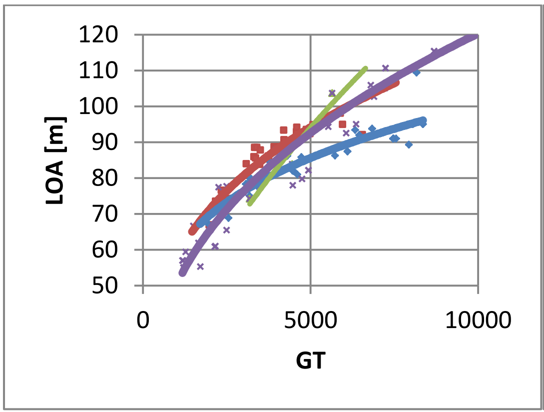


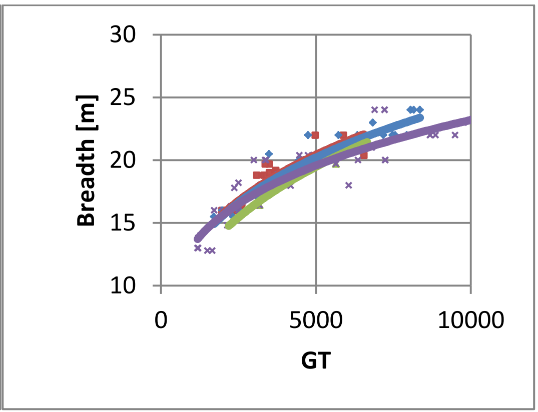


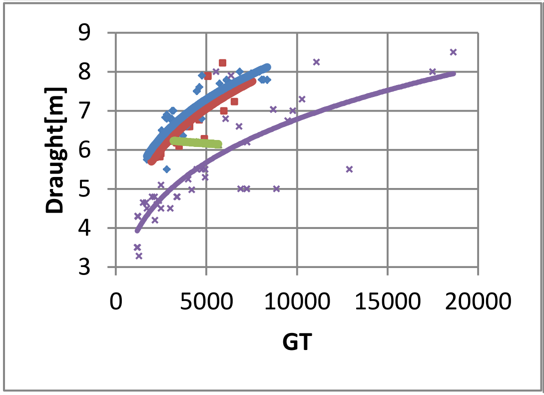
XII. Key data for Norwegian built or registered vessels built after year 2000

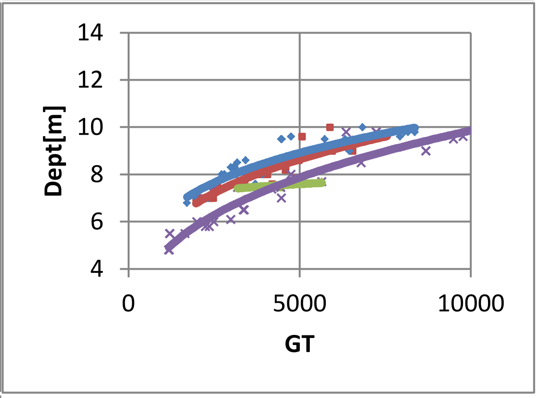
PSV (NOR)
AHTS (NOR)
DSV (NOR)
DSV world fleet

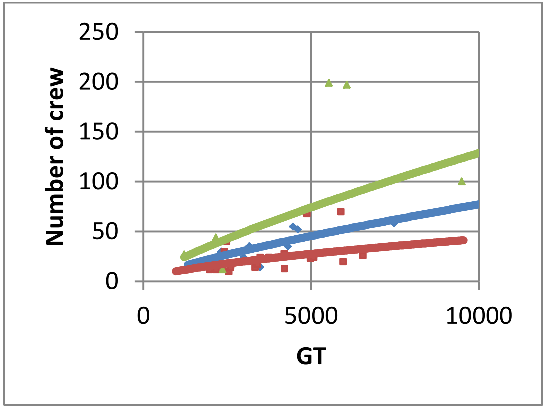
Due to lack of statistical data, the world fleet of DSV have been included.





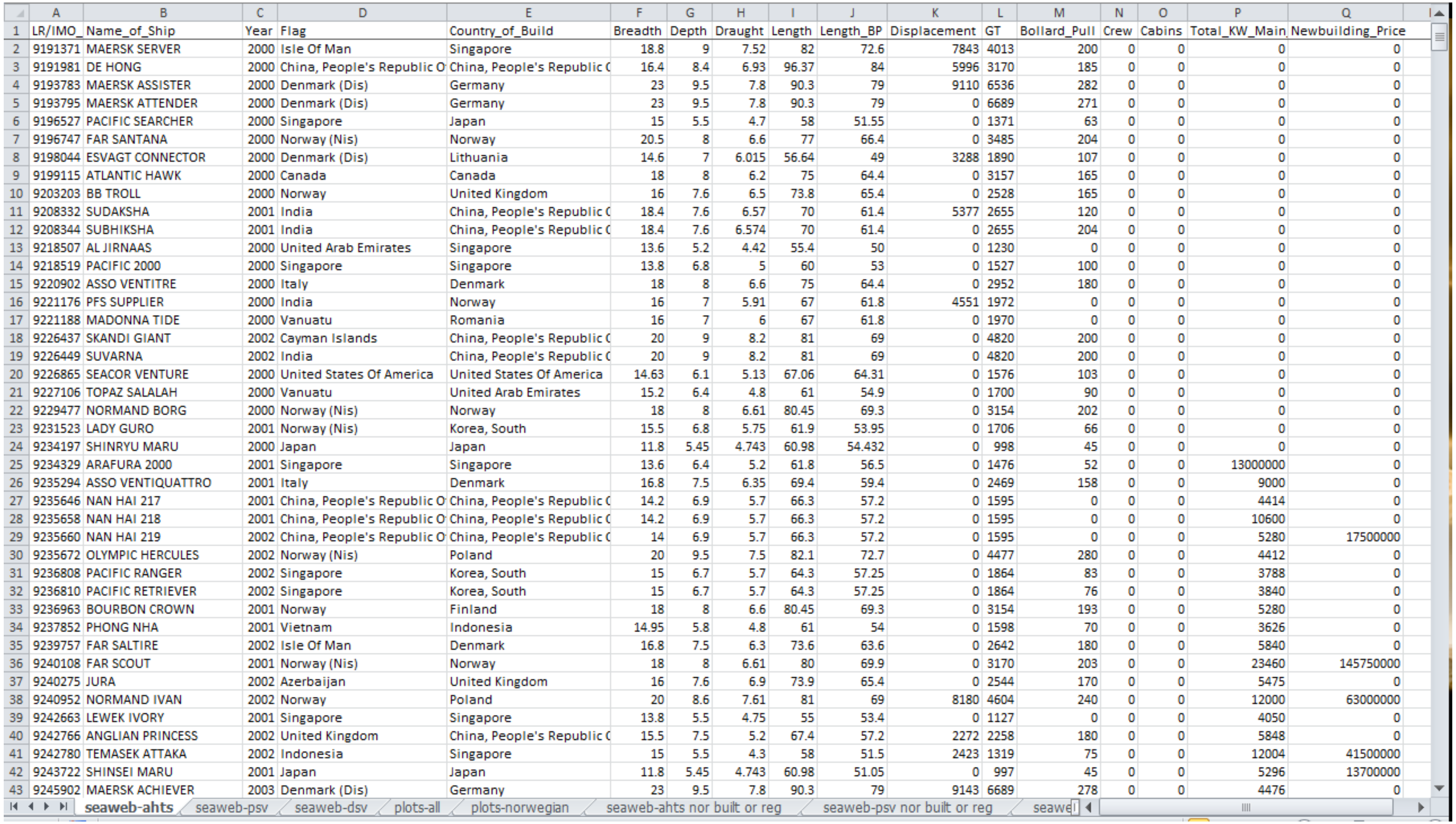






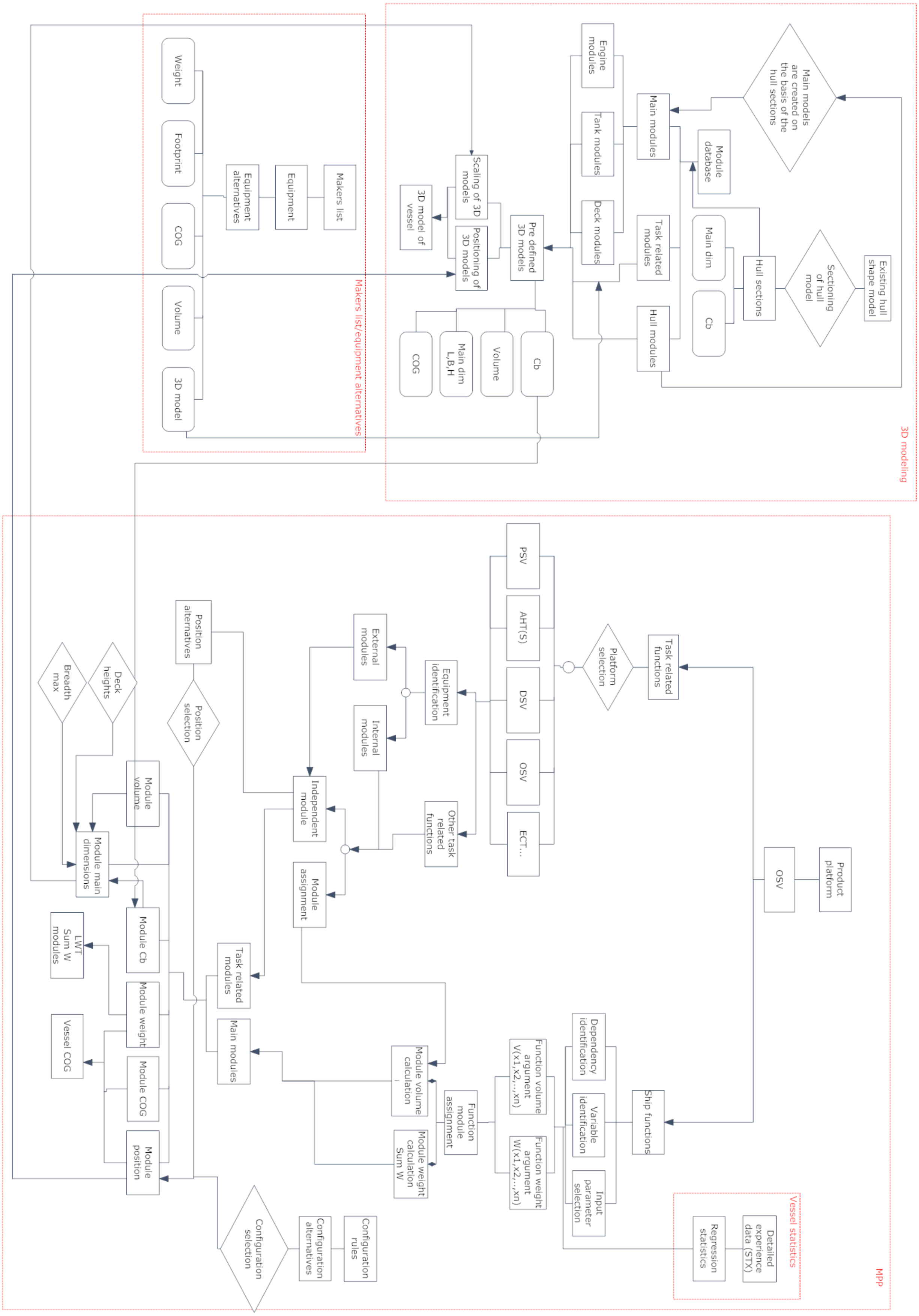
Low level of statistical data and large scatter in number of crew makes these statistics unreliable, but illustrates the differences to vessel types.

XIII. Example of vessel statistics database

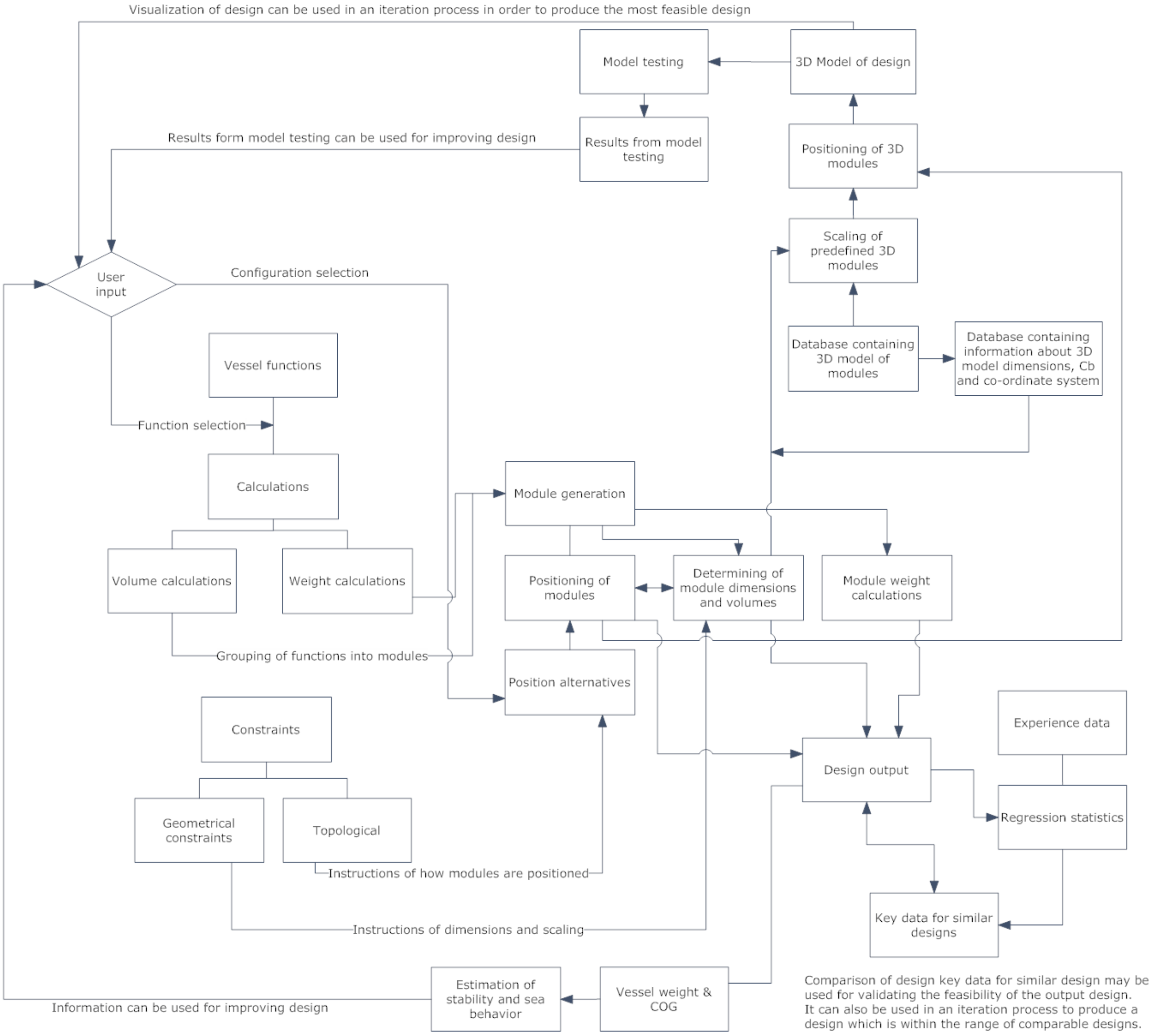


1	LR/IMO_	Name_of_Ship	Year	Flag	Country_of_Build	Breadth	Depth	Draught	Length	Length_BP	Displacement	GT	Bollard_Pull	Crew	Cabins	Total_KW_Main	Newbuilding_Price
2	9191371	MAERSK SERVER	2000	Isle Of Man	Singapore	18.8	9	7.52	82	72.6	7843	4013	200	0	0	0	0
3	9191981	DE HONG	2000	China, People's Republic O	China, People's Republic (	16.4	8.4	6.93	96.37	84	5996	3170	185	0	0	0	0
4	9193783	MAERSK ASSISTER	2000	Denmark (Dis)	Germany	23	9.5	7.8	90.3	79	9110	6536	282	0	0	0	0
5	9193795	MAERSK ATTENDER	2000	Denmark (Dis)	Germany	23	9.5	7.8	90.3	79	0	6689	271	0	0	0	0
6	9196527	PACIFIC SEARCHER	2000	Singapore	Japan	15	5.5	4.7	58	51.55	0	1371	63	0	0	0	0
7	9196747	FAR SANTANA	2000	Norway (Nis)	Norway	20.5	8	6.6	77	66.4	0	3485	204	0	0	0	0
8	9198044	ESVAGT CONNECTOR	2000	Denmark (Dis)	Lithuania	14.6	7	6.015	56.64	49	3288	1890	107	0	0	0	0
9	9199115	ATLANTIC HAWK	2000	Canada	Canada	18	8	6.2	75	64.4	0	3157	165	0	0	0	0
10	9203203	BB TROLL	2000	Norway	United Kingdom	16	7.6	6.5	73.8	65.4	0	2528	165	0	0	0	0
11	9208332	SUDAKSHA	2001	India	China, People's Republic (	18.4	7.6	6.57	70	61.4	5377	2655	120	0	0	0	0
12	9208344	SUBHIKSHA	2001	India	China, People's Republic (	18.4	7.6	6.574	70	61.4	0	2655	204	0	0	0	0
13	9218507	AL JIRNAAS	2000	United Arab Emirates	Singapore	13.6	5.2	4.42	55.4	50	0	1230	0	0	0	0	0
14	9218519	PACIFIC 2000	2000	Singapore	Singapore	13.8	6.8	5	60	53	0	1527	100	0	0	0	0
15	9220902	ASSO VENTITRE	2000	Italy	Denmark	18	8	6.6	75	64.4	0	2952	180	0	0	0	0
16	9221176	PFS SUPPLIER	2000	India	Norway	16	7	5.91	67	61.8	4551	1972	0	0	0	0	0
17	9221188	MADONNA TIDE	2000	Vanuatu	Romania	16	7	6	67	61.8	0	1970	0	0	0	0	0
18	9226437	SKANDI GIANT	2002	Cayman Islands	China, People's Republic (	20	9	8.2	81	69	0	4820	200	0	0	0	0
19	9226449	SUVARNA	2002	India	China, People's Republic (	20	9	8.2	81	69	0	4820	200	0	0	0	0
20	9226865	SEACOR VENTURE	2000	United States Of America	United States Of America	14.63	6.1	5.13	67.06	64.31	0	1576	103	0	0	0	0
21	9227106	TOPAZ SALALAH	2000	Vanuatu	United Arab Emirates	15.2	6.4	4.8	61	54.9	0	1700	90	0	0	0	0
22	9229477	NORMAND BORG	2000	Norway (Nis)	Norway	18	8	6.61	80.45	69.3	0	3154	202	0	0	0	0
23	9231523	LADY GURO	2001	Norway (Nis)	Korea, South	15.5	6.8	5.75	61.9	53.95	0	1706	66	0	0	0	0
24	9234197	SHINRYU MARU	2000	Japan	Japan	11.8	5.45	4.743	60.98	54.432	0	998	45	0	0	0	0
25	9234329	ARAFURA 2000	2001	Singapore	Singapore	13.6	6.4	5.2	61.8	56.5	0	1476	52	0	0	13000000	0
26	9235294	ASSO VENTIQUATTRO	2001	Italy	Denmark	16.8	7.5	6.35	69.4	59.4	0	2469	158	0	0	9000	0
27	9235646	NAN HAI 217	2001	China, People's Republic O	China, People's Republic (	14.2	6.9	5.7	66.3	57.2	0	1595	0	0	0	4414	0
28	9235658	NAN HAI 218	2001	China, People's Republic O	China, People's Republic (	14.2	6.9	5.7	66.3	57.2	0	1595	0	0	0	10600	0
29	9235660	NAN HAI 219	2002	China, People's Republic O	China, People's Republic (	14	6.9	5.7	66.3	57.2	0	1595	0	0	0	5280	17500000
30	9235672	OLYMPIC HERCULES	2002	Norway (Nis)	Poland	20	9.5	7.5	82.1	72.7	0	4477	280	0	0	4412	0
31	9236808	PACIFIC RANGER	2002	Singapore	Korea, South	15	6.7	5.7	64.3	57.25	0	1864	83	0	0	3788	0
32	9236810	PACIFIC RETRIEVER	2002	Singapore	Korea, South	15	6.7	5.7	64.3	57.25	0	1864	76	0	0	3840	0
33	9236963	BOURBON CROWN	2001	Norway	Finland	18	8	6.6	80.45	69.3	0	3154	193	0	0	5280	0
34	9237852	PHONG NHA	2001	Vietnam	Indonesia	14.95	5.8	4.8	61	54	0	1598	70	0	0	3626	0
35	9239757	FAR SALTIRE	2002	Isle Of Man	Denmark	16.8	7.5	6.3	73.6	63.6	0	2642	180	0	0	5840	0
36	9240108	FAR SCOUT	2001	Norway (Nis)	Norway	18	8	6.61	80	69.9	0	3170	203	0	0	23460	145750000
37	9240275	JURA	2002	Azerbaijan	United Kingdom	16	7.6	6.9	73.9	65.4	0	2544	170	0	0	5475	0
38	9240952	NORMAND IVAN	2002	Norway	Poland	20	8.6	7.61	81	69	8180	4604	240	0	0	12000	63000000
39	9242663	LEWEK IVORY	2001	Singapore	Singapore	13.8	5.5	4.75	55	53.4	0	1127	0	0	0	4050	0
40	9242766	ANGLIAN PRINCESS	2002	United Kingdom	China, People's Republic (	15.5	7.5	5.2	67.4	57.2	2272	2258	180	0	0	5848	0
41	9242780	TEMASEK ATTAKA	2002	Indonesia	Singapore	15	5.5	4.3	58	51.5	2423	1319	75	0	0	12004	41500000
42	9243722	SHINSEI MARU	2001	Japan	Japan	11.8	5.45	4.743	60.98	51.05	0	997	45	0	0	5296	13700000
43	9245902	MAERSK ACHIEVER	2003	Denmark (Dis)	Germany	23	9.5	7.8	90.3	79	9143	6689	278	0	0	4476	0

XIV. Simplified system architecture



XV. System architecture for supporting design evaluation & iterations



XVI. Digital/CD

List of available files available from digital attachments:

1. Scripts:
    a. Ruby script for assembly, scaling and positioning of 3D models based on the exported file from Excel (Vestbøstad, 2011)
    b. Ruby script for rendering the 3D Google SketchUp model. Generates 3D and 2D images of the model.
    c. JavaScript for automatic updating of 3D model in Google SketchUp (Vestbøstad, 2011)
    d. VBA export scripts for exporting a range of cells in MS Excel used for input of script a.:
        i. VBA script for Export initial design
        ii. VBA script for Export exploded and selected geometry
        iii. VBA script for Export alternative module configurations
    e. VBA import script for importing the rendered 3D and 2D model in MS Excel
    f. Ruby script for calculating volume of 3D models (publicly available script: http://www.cad-addict.com/2008/11/sketchup-plugins-volume-calculator.html)
    g. Ruby script for calculating centroid of 3D models (publicly available script: http://www.alexschreyer.net/projects/centroid-and-area-properties-plugin-for-sketchup/)
2. Excel sheet containing:
    a. User interface
    b. Parametric ship description
    c. Calculations
    d. Constraints
    e. VBA scripts
    f. OSV database (separate file)
3. Others:
    a. Demo video
    b. Installation instructions
    c. 3D models of modules
    d. Rendered images from 3D model