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3D Reuse in PLM for Conceptual Ship Design

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3D Reuse in PLM for Conceptual Ship Design

Introduction
PLM is a management strategy that has shown result in the industry for mass production. The process involves looking at the product lifecycle as one, concept design, production, disposal etc. However, to use this in such a highly scalable process such as shipbuilding, little research has been conducted. Recent work have been developed at NTNU in Ålesund combining PLM and ship design, which will be the starting point of this work.
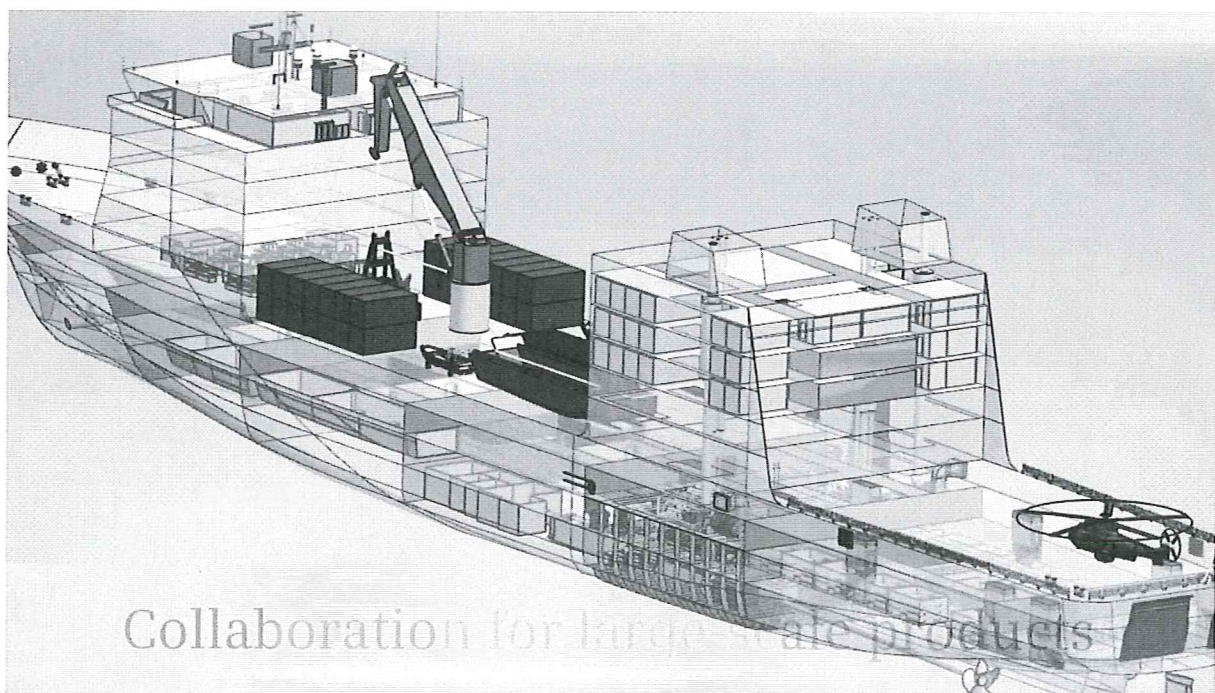

Figure 1 – 3D assembly of vessel in Siemens NX (from: Siemens PLM Advertising Movie)

Motivation
In the conceptual design stage, the traditional approach for ship designer has been using 2D drawings. However later in the process these 2D drawings are turned into 3D assemblies. With building up the 3D model from the start, much time can be saved in the detail design phase. Also, incorporating the reuse philosophy of PLM the time used for building the assembly can be minimized.

Scope
The scope of the project is at the conceptual phase of design looking at how to setup the combination of reuse library, 3D CAD- and PLM software. How to deal with taxonomy issues in library, changes in models/assemblies and deal with interfaces.

Objectives
The objective of the thesis is to create a 3D reuse library example using the PLM tools (Siemens NX and Teamcenter), and look on how to combine 2D and 3d drawings with re-using common objects of the library. It will be done in cooperation with Ulstein Group, where investigations of exactly how 3D tools is used in shipbuilding, will be conducted.

Research questions:

- How can we combine 2D and3D drawings using PLM tools?
- How efficiently deal with changes in 3D component(s) when re-using it for different systems/ stages?
- How to incorporate component into library using different taxonomy?
- How to deal with interfaces when using the library?

Milestones:
Tasks:

1. Review of PLM tools and Shipbuiding (1 Jan – 30 Jan)
2. Study PLM tool selected (NX) – (!5 Jan – 15 March)
3. Taxonomy for creating and re-using 3D models in Ship Design (1 Feb – 30 March)
4. Methodology for efficient re-use of 3D models (16 March – 15 April)
5. Study of the methodology (16 March – 30 April)
6. Study of the interfaces (1st April – 1st May)
7. Results and Discussion (15 April – 15th May)
8. Writing (1st Feb – 30th May)

In addition to the specified tasks, a conference paper will be handled at the end of the research.

Deliveries:
Preliminary Thesis (30th March)
Final Thesis + Article (3rd June)

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Abstract

Today 3D CAD tools have become more and more used in design processes, allowing amongst other better visualization of product, computer analysis of design, etc. Even so, in ship design, 3d-design is still combined with 2D drawings in the conceptual stage. At this point, developing the design in full 3D is not justifiable, since shipbuilding companies almost consistently use a no-cure no-pay principle at this stage. Using 3D vessel models and - software is just too complex and time-consuming. This, in its turn, causes situations where a lot of rework has to be done, because these drawings must be turned into 3D models in the subsequent stages. A method is needed to support the process and reduce the time it takes. PLM is a holistic business approach which promotes amongst others reuse of information. And the question arises; can PLM reuse simplify the 3D design process for use in conceptual ship design?

The main goal of this thesis is to create a framework where a virtual prototype can be built from existing components. The way the author wants to achieve this is by creating a library using PLM tools, where the components can be easily stored and reused in other projects. To do this a PLM reuse framework was adapted to maritime requirements. Additionally, the interfaces between vessel model and library were identified and a method to handle them found. Then these methods were applied to a case, with two different vessels, one of them where all components were designed to requirements and one where components from the previous vessel was reused.

From the cases, discussions were made about the challenges discovered and ways to improve the models. The discussions lead to a conclusion that while there are still elements to handle, PLM shows promise in providing a tool to reuse vessel components in the conceptual design stage. This thesis could only look into a few of the aspects in 3D reuse in ship design in one step of the lifecycle. PLM is about integrating data from all the stages and processes together, and the 3D components should be combined with data from these processes connecting the models with e.g. specifications, manuals, BOMs etc. When that is done the full benefits of PLM will be revealed.

Preface

This dissertation is part of a Master of Science degree at Ship Design programme at Norwegian University of Science and Technology in Aalesund. It focuses upon maritime reuse using the product lifecycle management philosophy and software as a basis. The main supervisor was Henrique Murilo Gaspar at NTNU and bi supervisor Greta Levišauskaitė at Ulstein Design and Solutions.

The subject was chosen due to a great interest in conceptual ship design and due to investigating methods to improve this domain. The thesis was partly done at Ulstein to gain knowledge on the subject.

Acknowledgements

Many people helped me make this thesis to what it is, and firstly I would like to thank my supervisor Henrique Murilo Gaspar, for helping me along the path. For helping to transform my thesis when Teamcenter, originally a key software in the thesis, did not work. And always giving me the time I needed, to ask and discuss my thesis.

All the employees at Ulstein Design and Solution, especially Greta Levišauskaitė, who helped me whenever I needed it when I was at Ulstein and shared her thesis with me. Additionally, Bernt-Aage Ulstein, Frode Sollid, Per Olav Brett and Berit Cecilie Skeide for providing me with useful feedback which helped me set the thesis focus. And all the rest at Ulstein which made me feel welcome and helped me in my studies.

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Abbreviations

4GD	Fourth Generation Design
BIM	Building Information Model
BOM	Bill of Material
CAD	Computer Aided Design
CAE	Computer Aided Engineering
EC	Engineering Change
ECR	Engineering Change Request
FEA	Finite Element Analysis
GA	General Arrangement
KPI	Key Performance Indicators
LCA	Lifecycle Cost Assessment
LOD	Level Of Detail
MIM	Marine Information Modelling
NX	Siemens NX software
PDM	Product Data Management
PLM	Product Lifecycle Management
PSV	Platform Supply Vessel

1 Introduction

1.1 Background

Ship building is an industry with heavy competition. As the traditional maritime shipbuilding industry has migrated from Nordics and Europe due to high salaries, strategies must be developed to keep what is left, design and building of advanced ships (see figure 1-1). To do this, shipbuilding and offshore engineering companies make great investments, both in computer aided tools and IT solutions for faster and better manufacturing. A typical company have several databases to store all information generated through the process (Technia Transcat 2016).

Still, shipyards are struggling to meet deadlines and liquidated damages are a common word within the industry. Now on top of this the oil prices have bottomed and well-paying customers, has become just the opposite. Therefore, to stay competitive and not lose the rest of the remaining market, an evolution in the companies is needed (ibid).

NEWBUILD BY CONSTRUCTION PLACE

Number of vessels

SUBSEA (64) PSV (331) AHTS (48)
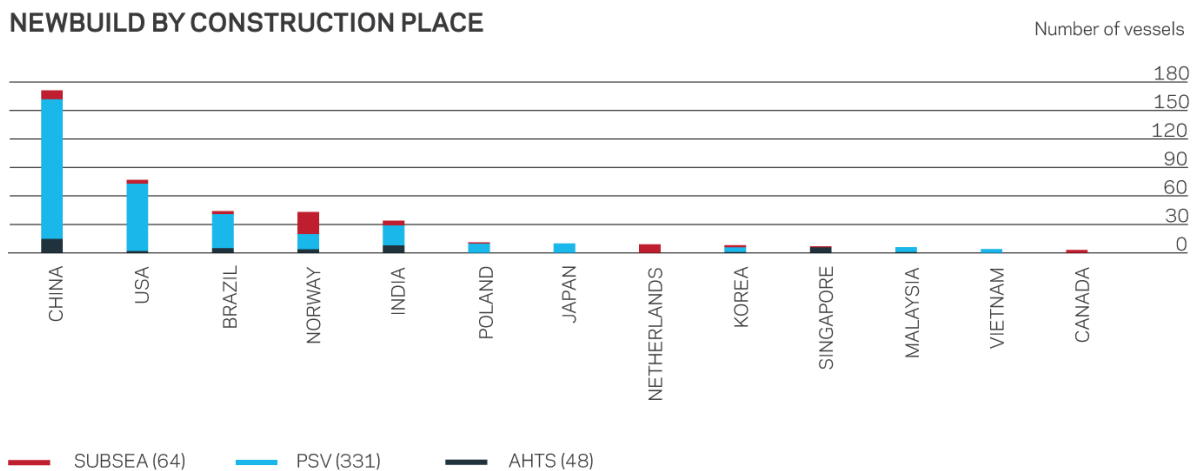
Figure 1-1 – Newbuilding in offshore market by country of shipyard (Farstad 2013).

From 1970 to 2015 product started to change, many revolutions in different business areas and both development and lifetime was reduced drastically. A new business paradigm had occurred, but with all the changes, how could companies continue to be competitive? (Stark 2015)

PLM is a holistic business approach, which promotes reuse of information, standardization, and strategic use of IT tools to increase innovation. It enables all parties involved to work jointly, with the latest information, no matter where they are. This is done by creating an product information backbone, which integrates people, data, processes and business systems through

1

the product whole lifespan, from conceptual stage to disposal (PLM Techology Guide 2008; Stark 2015).

> *The PLM paradigm emerged in 2001. The reasoning behind it was that the specialists in a department are the best equipped to carry out activities of that function. However, in time, departments didn't only do what they had now-how about. Each department would decide everything about their operations, e.g. organizing activities, data and computer systems. With time this departmental approach led to contradictory versions of same data, information silos, duplicate activities etc.*

<div align="right">(Stark 2015)</div>

From a scalability standpoint, shipbuilding is a very daunting design- and engineering challenge. According to Gaspar et al. (2012), vessels are a complicated and specific product and has an equally complex value chain. The uniqueness and complexity of a vessel makes standard PLM approach impractical and adaption of the techniques is needed. This thesis is part of a joint corporation between NTNU Aalesund and Ulstein Group, to adapt PLM to the need of ship design and -building. Others participants of this project include: Elisabeth Masdal Hovden, Greta Levišauskaitė and Ruta Masteikaite.

3D CAD tools have become more and more popular nowadays, but in ship design it is still combined with 2D drawings in the conceptual design stage. The complexity of 3D ship models and -software makes it a very time consuming process. At this point, developing the concept design in full 3D usually is not justifiable since shipbuilding companies almost consistently use a no-cure no-pay principle in conceptual ship design. This causes the situation were a lot of rework has to be done. Concept department create 2D drawings of the vessel, and if contract is won, these drawings are turned into 3D models (Sollid 2017). PLM tools gives a way to simplify this process through data re-usage. When designing the concept, old models can easily be re-used since all data is stored within the common and easily searchable database. The integration between PDM and CAD application creates a handy tool to handle indexing of the data generated in the process (Masteikaite 2016). However, since neither of these are typically created for shipbuilding purposes, which is design and manufacturing of large-scale products, certain challenges arise (Levišauskaitė 2016).

1.2 Objectives/research questions

The main goal of this research is to simplify the 3D design process for the use in conceptual ship design with PLM tools. The way the author wants to achieve this is by creating an example library using PLM tools, where the component can be stored and reused in other projects easily. Several aspects will be studied towards giving the library better application for a ship design company needs:

- Incorporate a suitable taxonomy for better indexing and searching
- Develop some sample models to populate the system
- Test storing entire assemblies into library for reuse
- Develop a method to extract 2D drawings from the 3D model.

Through this process, challenges will be captured and the author will have a special focus on the interfaces, e.g. search input/library output etc. In order to do this the author needs to get a grasp of how vessels are designed and therefore several field-trips to Ulstein was conducted, where the ship design process was observed. Simultaneously, the author will explore NX capabilities towards developing the library and note any challenges.

At the end, the researcher will conduct a case-study using traditional approach and the new suggested method, to test the performance of the product. Last, the results of the case-study will be analyzed, discussed and conclusion drawn towards finding answers to the research questions listed in the next section.

The research questions are developed symbiotically with the objectives, and is derived from the main scientific goals. Answering and/or discussing these, will be the research goal of this thesis and underlying in the report as a whole. They are as follows:

- How can we combine 2D- and 3D drawings using PLM tools?
- How to *efficiently* deal with changes in 3D components when re-using it for different systems/stages?
- How to incorporate component into library using taxonomy?
- How to deal with interfaces when using library?

1.3 Scope

The scope of this thesis lay somewhere within the boundaries of PLM, 3D and taxonomies as figure 1-2 shows used in a conceptual ship design context. The processes developed in this area

will have effects on the downstream value chain, but this will not be the focus of this dissertation. Since the ship design process will be explored at offices at Ulstein Group, the user-cases should have some inspiration from their challenges.

PLM in the context of shipbuilding is at a early stage. When addressing the empirical research, this will be done via the PLM computer tool Siemens NX, as both Ulstein and NTNU uses this software. Therefore, the user-cases used to test performances will have some terminology from these applications.

3D design has a vast area of application, therefore, when studying this field, the scope needs a narrow field. Via the constraints of PLM and conceptual ship design, the author limits this area into showing some background on 3D design and computer aided design (CAD). Also, some state of the art on virtual prototyping, CAD and library reuse is presented.

When studying and incorporating the taxonomy, this will be done via NX functionality. However, when doing the case-study, a sample divisions will be needed to test performances of the method developed. Some insight into the science of the field will be required. The standard approach within the maritime industry, SFI group system, will be explored. Additionally, 3D CAD taxonomy has generated the requirements for new divisions of components and the author will give this some focus.
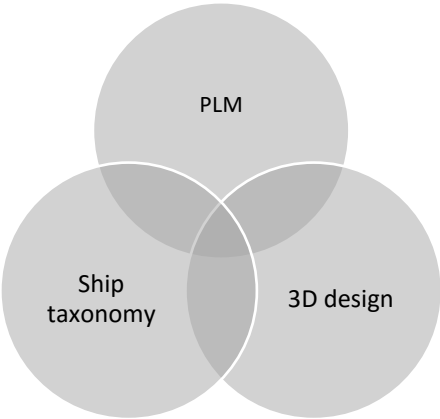
Figure 1-2 - Scope shown through "Venn diagram"

1.4 Structure of thesis

Chapter two explores what other researchers in this field have done earlier. This follows what is presented in the scope; first PLM, 3D design and Ship Taxonomy. The section about PLM

will introduce the philosophy, reuse with the principles and combining it with ship design. 3D design chapter will present CAD modelling, fourth-generation design and virtual prototyping. Ship taxonomy will talk about ship design process and different taxonomies developed for ship.

Chapter three present the methodology of solving the problem presented into section. Showing chosen research design and -approach and why it was selected. Further it describes the method used to solve the objectives (RQs) and the research process as it was conducted. The next section will deal with interfaces as identified. Finally, a short case is presented to give readers an introduction into the topic.

Chapter four contains a more advanced case, taking into account more element of the virtual prototyping and reuse within the ship design context. First the case will be presented, next the traditional 2D way is presented and challenges using this approach shown. Then a section where interfaces are identified and handled. This is then tested in a user case with two ship, where the first created from the beginning then and then design element are recycled to developed the other.

Chapter five comprises a discussion of the main case and the challenges using the suggested reuse models and interfaces. The discussion are structured using the research questions as a basis.

2   State of the art literature review

This chapter will give a short summary of the theoretical background and state of the art on the main domains defined in the scope, which is; PLM, 3D design and ship taxonomy. Evaluations will be made on the basis of usage in a conceptual-, ship design and shipbuilding context. In the final section, the state of the art will be summarized, critiqued and the novelty of this work defended.

2.1   PLM

Since this thesis will be based on the PLM framework, this expression should be defined and explored.

2.1.1 PLM definition
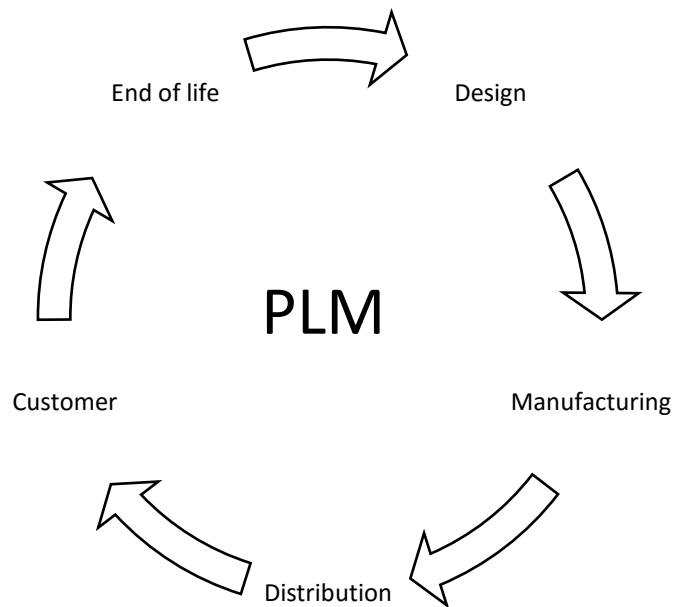
Figure 2-1 - PLM lifecycle five phases (Adapted from Axis Technologies, 2015)

> *Product Lifecycle Management (PLM) is the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of. At the highest level, the objective of PLM is to increase product revenues, reduce product-related costs, maximize the value of the product portfolio, and maximize the value of current and future products for both customers and shareholders*

> (Stark 2015)

Explained simply, PLM is a business approach that promises to increase revenue for shareowners. This is achieved by integrating the whole lifecycle as seen in figure 2-1 into one process, from first design to decommission. The potential of such an implementation is less re-work, easier reuse of information, shorter time-to-market and better cooperation between employees and departments (Stark 2015).

"The scope of PLM as a holistic business process is extensive and does not only include the management documents and BOM's but analysis results, specifications, quality standards, engineering requirements, manufacturing procedure, product performance information, etc. as

well" (Saakvuori & Immonen 2008). According to (CIMdata 2016) "*it is important to note that PLM is not a definition of a piece, or pieces, of technology"*. PLM is a holistic business approach, where handling all information about a product through the whole value chain is key, but equally or more important are the processes. PLM has to do with everyone in the workplace, by creating a database for the product(s) that holds all information through the whole lifecycle it totally changes the way of working. It can be the designer, drawing 3D assemblies in the conceptual stage or the service worker logging a warranty call from a customer. All information is stored in the same system making it available for those who need it. According to Stark (2015), the typical scenario of today is that each department has their own database(s), which lead to different versions of the same data and information silos. This ends up in work being done twice, redundant functionality developed, automation that only works for some processes. Companies also got ineffective fixes and excessive product recalls. In the end this lead to lower revenues and higher product costs, this is what PLM seeks to solve.

2.1.2 Data reuse in PLM context

(El Hani et al. 2012) has investigated product data reuse in project development from a user perspective. They have developed a framework with several step to improve data reuse, tested its performances in several user cases and discussed the challenges.

From the research, two reuse processes are proposed; one unplanned (ad hoc) reuse (user driven) and one planned reuse (business driven) and suggest certain steps to follow when using each of the models. Steps shown in table 2-1 is suggested.

Table 2-1 – Steps for unplanned reuse in PLM (El Hani et al., 2012)

1	Define reuse criteria	User defines the criteria of reuse data based on customer requirements/specification and own experience.
2	Search in knowledge domain	User performs search within the existing data library
3	Choose data to reuse	User chooses which data to reuse and how to reuse it (described in next three subsequent steps)
3a	Full reuse	Use "as is" with no changes, link to library must be kept

3b	Evolve data with link	Alter the source data and create link to new variant in library
3c	Evolve without link	Change data only on current product/project (not to be further reused), link to library must be broken.
4	Reuse data ready	Development of reuse model(s) towards defined requirement is finished
5	Measure reusability	Evaluate data reuse performances towards quality, time and cost.
6	Maintain reuse library	if 3a or 3b step were utilized, maintaining links is important. Also, if changes to block models from common library are to be made, an impact analysis should be made with input from all users of the data in question

Planned reuse (business driven) is usually reuse of large scale, e.g. the maritime company developing a vessel family. This type of reuse is typically engaged from management, and is generally about trying to reduce cost. El Hani et al. suggest steps shown in table 2-2, to be taken.

Table 2-2 – Planned reuse (business driven) approach (ibid, 2012)

1	Purpose of reuse	Why should the data be reused e.g. cost reduction, shorten time-to-market, increase company capacity etc.
2	Feasibility studies	Based on available data and chosen criteria, evaluate feasibility of reuse. This consist of allocated individuals analyzing the data towards selected criterion/requirements (KPI's). Company should run a simulation of reusing the data to capture potential impacts. Other concerns to be studied is the availability of data and policy of reusing it. An example could be; a naval architect is assigned to

		evaluate reusing a vessel towards a specification given from a ship-owner, runs a simulation and finds that data cannot be reused "as is".
3	Reuse amount	Make decisions from feasibility studies on how much can be re-used. This can vary from no changes to existing data (full reuse), adaptation needed (partial reuse) to not reusing anything (no reuse)
4	Choose data to reuse	(same as step 3 in unplanned reuse)
4a	Full reuse	(same as step 3a in unplanned reuse)
4b	Evolve data with link	(same as step 3b in unplanned reuse)
4c	Evolve without link	(same as step 3c in unplanned reuse)
5	Reuse data ready	(same as step 4 in unplanned reuse)
6	Measure reusability	(same as step 5 in unplanned reuse)
7	Maintain reuse library	(same as step 6 in unplanned reuse)

The model was tested in several data reuse user-cases to capture limitations. The author lists the following challenges of the data reuse model after verification in table 2-3.

Table 2-3 – Challenges with PLM reuse captured in user cases

Project budgets	Development cost, usually companies has project budgets. This creates the situation were the "first" re-use project of a new type generates large costs (and may be limited from the budget). Re-use data are usable for all projects but current economic models do not support this. Companies should bring re-use cost up to an enterprise level, not included in single projects.

No reuse framework	A reuse strategy of this scale may not be implemented within the company. Often data sharing for reuse application happens only between peers. The models require an enterprise framework to support it and will have a level of cultural-impact if implemented.
Identifying similar work processes	The PLM tools available today support the data sharing, but cannot recognize similar work processes. This leads to a situation where the company might still do duplicate work, if the employees do not capture these processes.
Administrating links	With partial reuse, administrating the object links become a complex task as some relations should be kept and others not. A solution may be to duplicate data under new name, adapt the links (delete/add links if needed) and break ties with previous part.
Configurations and variants	One of PLM main benefits is the linkage between product portfolio-, BOM and enterprises knowledge management. Knowing and practicing this was one of the key elements of differencing between product configurations and -variants. Variants are more complex and difficult to implement, and should only be used in product families.
Different data systems	Data is owned by different system, user need to make sure that when adapting data, all links are maintained within all systems.
Data formats	Using data created by another software. During the last years, the number of data formats has grown quickly and user may experience format issues.
Projects own data	Project/program-based economy lead to a certain project "owning the data". Other project usually cannot change data without the approval of this project. To rectify this, a governance model of the reuse data should be established,

transferring control of data from the projects to enterprise level.

2.1.3 PLM applied to conceptual ship design.

Figure 2-4 present a simplified vessel value chain, from first idea to decommission. Through PLM methods, a way of dealing with this huge amount of data generated in the vessel products life cycle can be provided. There are several ways of achieving this; information indexing, database management, product decomposition and –analysis and project management (Andrade et al. 2015).

"PLM can be divided into 6 elements; Database is related to indexation tools and document management, Modelling and Simulation tools is composed by all the software used to design the vessel and virtual prototyping, Value Chain Processes are related to the management of the processes within the Ships VC, Product Hierarchy management is establishing the classification of all the ship systems and components, Product Management administrates all the information related to every component and Project Management connects every process to the entire vessel life-cycle".

(Andrade et al. 2015)

| Conceptual design | Basic and detailed design | Construction and assembly | Commisioning and testing | Operation | Decommisioning |
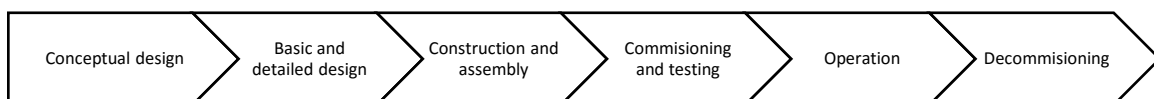
Figure 2-2 – Simplified ship value chain (Adapted from Andrade et al. 2015)

(Masteikaite 2016) has created PLM framework and compared its performances in two engineering change management cases within a maritime company. She suggests PLM in shipbuilding domain during this process to (at least[1]) contain the following advantages and drawbacks (list adapted to fit thesis scope):

- PDM application. Data digitalization and management, structuring, the flow and usage in both case studies was facilitated by the PDM capabilities provided by the software.

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[1] She concluded that more benefits/drawbacks could also be revealed after repeated similar tasks.

- Process management support. EC process was facilitated by the process mapping, creation and utilization of robust workflow, a grouping of EC process activities into steps and assigning people to perform them as specific tasks.
- Integrated IT solutions. The ability to use a single PLM software and single database to perform all processes (data implementation and EC) was provided. The CAD software has Teamcenter integration which accelerated data transfer and opening straight from the single interface.
- Facilitated collaboration. The addition of participants (such as customer, allied partners, suppliers, different department employees) to objects, processes and workflows, integrated mail system and ability to leave comments and additional information on any object in Teamcenter enhanced the collaboration when solving problems in both case studies.
- Data and knowledge re-use. The usage of data, ECR and ECN objects from the Engine Room case in the second case study allowed for the data and knowledge re-use.
- CAD integration. Using of CAD software in both case studies facilitated the creation of the product architecture, easier information visualization, decision-making and fast 2D document creation. Automatic updates on 3D and 2D files were also an advantage provided by the CAD software and Teamcenter integration.
- Supported information visualization and interpretation. Powerful visualization tools provided fast file viewing and editing in one environment without needing to use separate IT solutions.

Noted disadvantages of PLM:

- PLM software installation. According to Ulstein specialists and the experience gained during Teamcenter's installation process in NTNU it can be concluded that the installation of the new software requires high time and monetary investments.
- CAD software. Similarly, regardless the obvious benefits of using Siemens NX CAD software which has Teamcenter's integration, this can result in high investment cost to installation and training processes.
- Changes in business processes. Ulstein aims to research on possible improvements of their existing business approaches and processes, nevertheless, the evaluation of ROI is still very unclear and hard to determine. PLM implementation and application requires making significant changes in their current business since.

The framework and engineering cases was done in cooperation with Ulstein Group, and should to great extent encompass different ship consultants implementing PLM. The work included developing a general PLM framework usable for all companies implementing the philosophy and use-testing it in two case studies. The user-cases were both engineering changes; the first a specific part of the vessel, the engine room case and a ship case were the large-scale effects were explored. Through the whole process, Masteikaite used the 3D CAD- and PDM applications Siemens NX and Teamcenter to facilitate and track the process. She concluded that using PLM for engineering change cases is an area of promise, but that other processes should be explored.

The benefits are very much in line with what Stark suggest as possible benefits, even if this work evolved around PLM computer tools and Stark focus on the general principles. When looking towards El Hani et al. studies, the drawbacks/challenges are very different. However, this can be explained by the different focus, where the El Hani et al. focuses only on reuse, while Masteikaite studies of reuse is within a high-level framework.

2.2 3D design

In this section the state of the art in 3D design will be studied both generally and more specifically on areas of interest to the thesis. While 3D design is a huge domain with numerous applications, this thesis will focus on the engineering aspect. This is mostly done through computer aided design (CAD) software and further exploration of this field is needed.

2.2.1 Computer aided design (CAD)

CAD is any design activity, were computers are used to develop, analyze or modify an engineering design. Implementing CAD has several benefits; it increases the productivity of designers due to the software helping visualize the products. Additionally, it allows computer aided engineering analysis of the design and makes it easier to include design errors control measures. Finally, it provides better drawings and designs and allows for easier standardization and can create databases useful for the manufacturing like BOMs, dimensions etc. (Narayan et al. 2008; Kwon et al. 2015). An example could be that of the design of a vessel; the concept developers creates the design by using CAD tools, the marketing department can further show this to the customer for sales argumentation (visualization). Next the structural engineers can use this design within their FEA software (CAE analysis), evaluating structure stresses, displacement etc. Finally, all data generated could be used for a vessel family or sister vessel

(standardization). There is various computer aided design methods: 3D wireframe which is an extension of 2D drawings were each line must manually be inserted into the drawing. 3D solid modelling which is the method most used today. This has two under-categories; parametric- and direct (explicit) modelling. Parametric approach of 3D modelling (see figure 2-3) has become the industry standard for mechanical CAD tools (Ushakov 2008).

> *CAD (Computer Aided Design) system is inevitable in design practices. It is desired to have an application that supports the entire lifecycle of initial design, configuration design, detail design manufacturing and disassembly. Parametric modelling allows re-use of existing products and rapid design modification based on results of engineering analysis*

> (Shin & Kwak 1999)

According to (Verroust et al. 1992), parametric modelling consists of two approaches, an algebraic and an AI method. Using this method enables a designer to *"easily design a part by providing a small number of values of specified parameters instead of the full, enumerated description"* (Verroust et al. 1992). Constrains (e.g. geometrical) between features, dimensions, and assemblies can be governed by rules within these models. This means that the model only requires a set of parameters, rather than a complete, were every single part would require an x- , y- and z coordinate for each feature. The number of constrains are therefore be significantly lower than a non-parametric model.
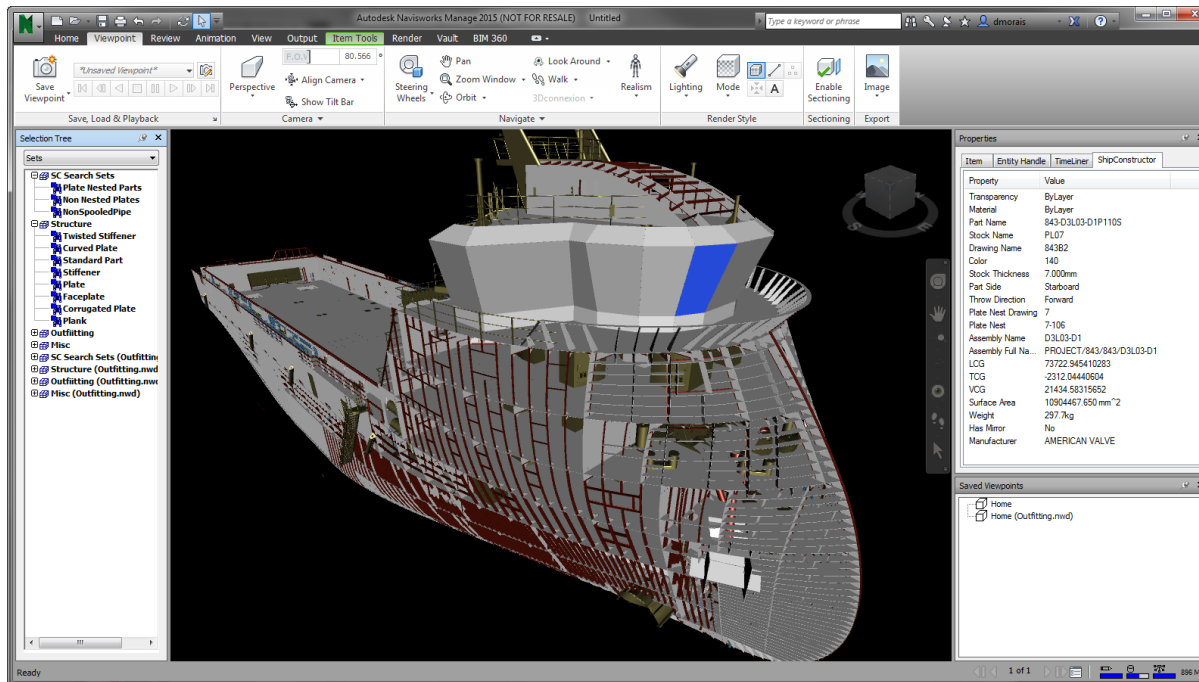
Figure 2-3 – Vessel designed in 3D CAD environment (Morais 2014)

2.2.2 Fourth generation design (4GD) approach

Behrens et al. (2014) define a large-scale product as:

> *A product by which man encounters his technical, organizational and economic limits with the methods and tools available at the time of observation, in the context of product creation. Significant for large scale products is a disproportionate increase in effort, e.g. construction, manufacturing or transport, for the augmentation of a characteristic feature of the product.*

Levišauskaitė (2016) consider a vessel as such a product due to amount of data, complexity of the ship product model and complex requirements. This creates challenges both in engineering and construction when designing and building the vessel. Structure dimensions, amount of components etc. may change rapidly during the process.

Ship designers have commonly used an approach where the assembly consist of several sub-assemblies and on the lowest level, the actual components. However, this methodology creates numerous constrains which creates a very rigid model, with little flexibility (Levišauskaitė, 2016; XF, et al., 2001).

15

(Levišauskaitė 2016) evaluates a new approach, called 4GD (Fourth-generation design). Through her thesis, she wanted to see if this new "framework" could overcome some of the drawback of traditional approach (3rd generation CAD) and further improve exchange and 3D re-use. She concludes that due to the "flat structure" of 4GD where components and assemblies are geometrically constrained towards a global coordinate system rather than the traditional links, as described above, improved exchange of parts significantly. The 3D re-use capability of the computer tool was also improved, with the use of design elements[2]. These could also be configured into "effectivity structures", where location data of all elements is stored. This can then be re-used for another design, e.g. a cargo hold is set to an effectivity structure and can be placed inside a new design, with all elements, configurations and geometrical positions intact.

2.2.3 Use of libraries in 3D design

According to (Kwon et al. 2015) in the design phase, companies build up equipment catalogues for easier data reuse. However, the level of detail (LOD) of the components are so high, that shipyards often cannot use them, and therefore have to simplify the data (Kwon et al. 2015). The reason this situation arises is that the suppliers is not willing to share all their 3D CAD data, due to intellectual properties. Not doing this, shipyard cannot delete unnecessary details or features. For shipyards, the most important features of the 3D models are the ports, e.g. exhaust port, and correct geometrical dimensions to detect collision between equipment. To make 3D models which has the needed LOD for the shipyards, subcontractor(s) are hired to simplify the data still keeping the important information. This process requires time and add an additional expense for the shipyard. The model data result may also vary from modeler to modeler.

Kwon et al. 2015 suggests a computer feature-based 3D CAD simplification tool. This tool will use six criteria to simplify the model; feature volume, ports, outer boundaries, assembly constraints, internal features and adjacent features. A list off what each criterion consists of is listed in table 2-4.

Table 2-4 – Criterion used in simplification tool.

Feature volume	Not within thesis scope

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[2] *"Design element object is an independently managed entity which contains its unique geometric and locating data. Different types of design element can be specified as shape, reuse and promissory type to sort the parts according to different properties and characteristics"* (Levišauskaitė, 2016).

Ports	Interfaces between components, e.g. an engine exhaust port
Outer boundaries	Outside boundary should be correct (dimensions etc.), used for collision control between equipment, pipes etc.
Assembly constraint	Simplification of constraints; e.g. a coincidence- instead of both contact and infer axis constraints
Internal features	Hidden features, with neither interface- or collision application
Adjacent features	Features/equipment in direct contact with model

Their conclusions are that 3D CAD models needs simplification. However, using both their own and other simplification tools human intervention was needed to evaluate if the feature removed was superfluous.

2.2.4 Virtual prototyping within 3D CAD domain

(Andrade et al. 2015) suggest an implementation of virtual prototyping in naval architecture. In the conceptual stage this can be used to provide preliminary data, through simulations of resistance, sea-keeping behaviors, structural resistance etc. From a marketing point-of-view, the model can be used as a visual tool to present the product to the customer. In the conceptual phase, they recommend that the ship database to consist of similar vessel and previous project data and information, lessening work amount for the development team. Andrade et al. further studies the benefits in the downstream processes of the ship value chain, but as this is not within the scope of this thesis it will not be discussed.

Digital mock-up (DMU) is a tool under the PLM umbrella, where a model of the product is created digitally. The foundation of the model is a 3D CAD assembly where all components is added. Several designers can use the model at the same time, even from other companies if shared with them, making it a collaborative platform. Since everybody work on the same model all participants have the latest information. Another benefit is that the DMU creates a handy platform for further computer simulations. This enables the company to replace the use of physical models, especially expensive ones, to do testing and training (Riascos et al. 2015).
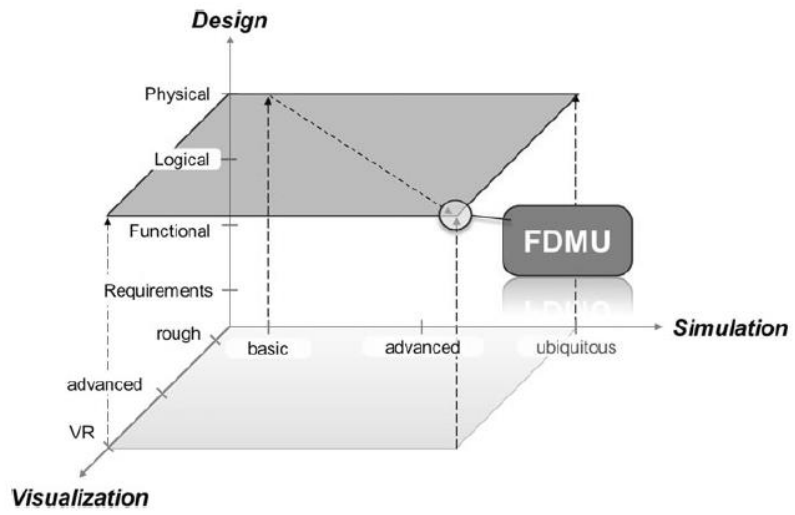
Figure 2-4 – Functional digital mock-up (Riascos et al. 2015).

2.3 Ship taxonomy

"Taxonomy is the classification and naming of things such as animals and plants in groups within a larger system, according to their similarities and differences" (Clue Norge 2017). Explained briefly, one put certain attributes to a "thing", e.g. size, names, color, price, manufacturer etc. In this section the shipbuilding industry standard taxonomy; SFI group system and some alternatives will be explored. Additionally, ship design process will be presented and where 3D and components library fits into it.

2.3.1 Ship Design

The ship design process start with the sales department capture a customer request for the build of a new ship or a tender, a company that offers a contract for a ship designed purposely to the mission (Sollid 2017). The preparation stages of the design is often called initial design and consist of three stages; concept, preliminary and contract design. The process is iterative and the designer will balance depending attributes and features of the design as shown in figure 2-5 (Eyre 2007).
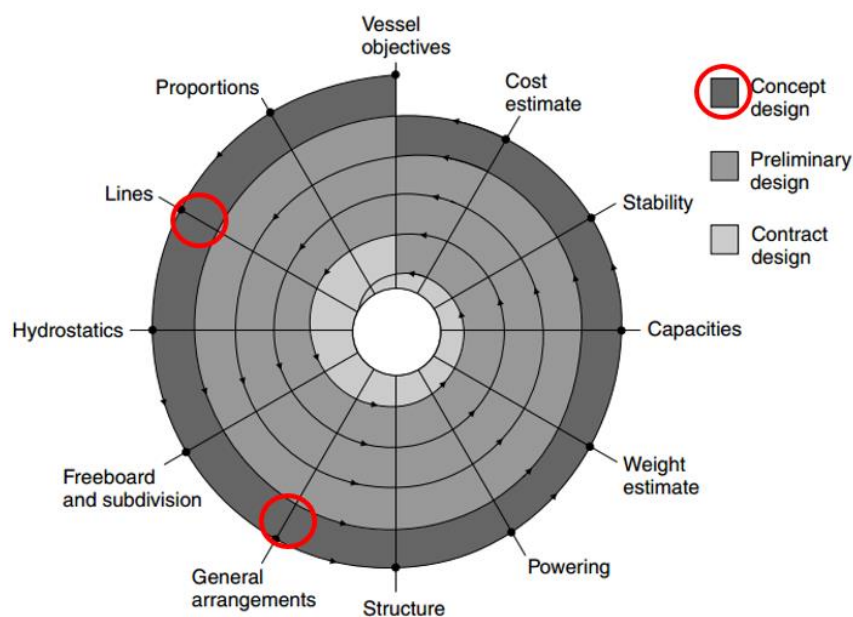
Figure 2-5 – Design spiral and where 3D fits (Eyre 2007).

The product of the process should provide information to the customer to able to do a techno-economic assessment of the design.

(Levander 2012) suggest that the traditional design spiral limits creativity. He suggests, using what he calls system based ship design approach (SBSD), that the spiral start from the mission of the vessel it is supposed to carry out. The input data necessary should be divided into absolute and preferences that describe goals. This allows designer to find an optimum solution with fewer loops in the spiral. Vessel is divided into systems and subsystems, giving the designer a checklist and via factors the system are turned into areas and/or volumes. Via design criteria, solution is considered against other existing successful design

(Brett & Ulstein 2010) want to further extend the SBSD method. They suggest a more holistic approach where both upstream- and downstream activities (see figure 2-5) be part of the considerations when developing a new design.
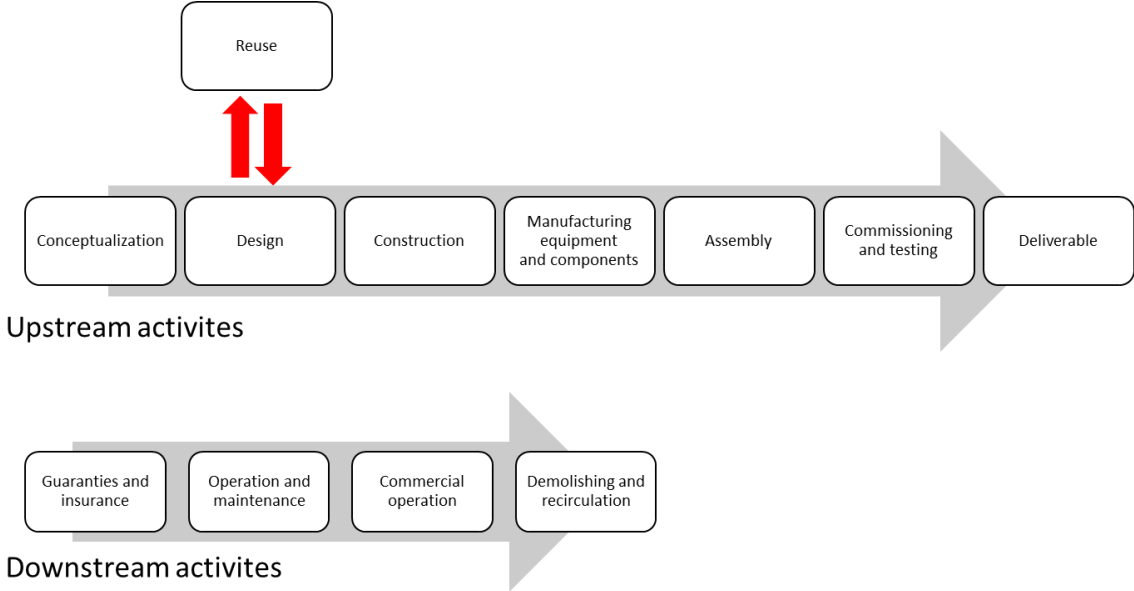
Figure 2-6: Up- and downstream activities in ship value chain and where reuse library fit in. (adapted from (Brett & Ulstein 2010))

They propose a critical thinking based ship design, to integrate all activities to provide the best ship, e.g. analyzing market, benchmarking design. By using heuristic methods, the design company can learn the preferences of ship owners. Ship design companies needs to intervene more in the business process of ship-building and Brett and Ulstein also stress the need for a clear dialogue with project stakeholders and decision makers upstream. There is also a need for extending ship design process to include the downstream activities, when the ship is operating and how it works as a part of vessel fleet.

2.3.2 SFI group system

A common approach for maritime companies is to use the SFI grouping systems taxonomy when creating a division for systems and components on their ships. This taxonomy is based on the functional aspect where, the ship is grouped into main group, group, sub group (see figure 2-6) (Xantic 2001). After the group numbers, each component is given a unique ID based on the company standard. This typically a digit code, e.g. 001 for first component in the subgroup, 002 for the second etc. A general arrangement for project 3517, would look like this: 3517-101-001.
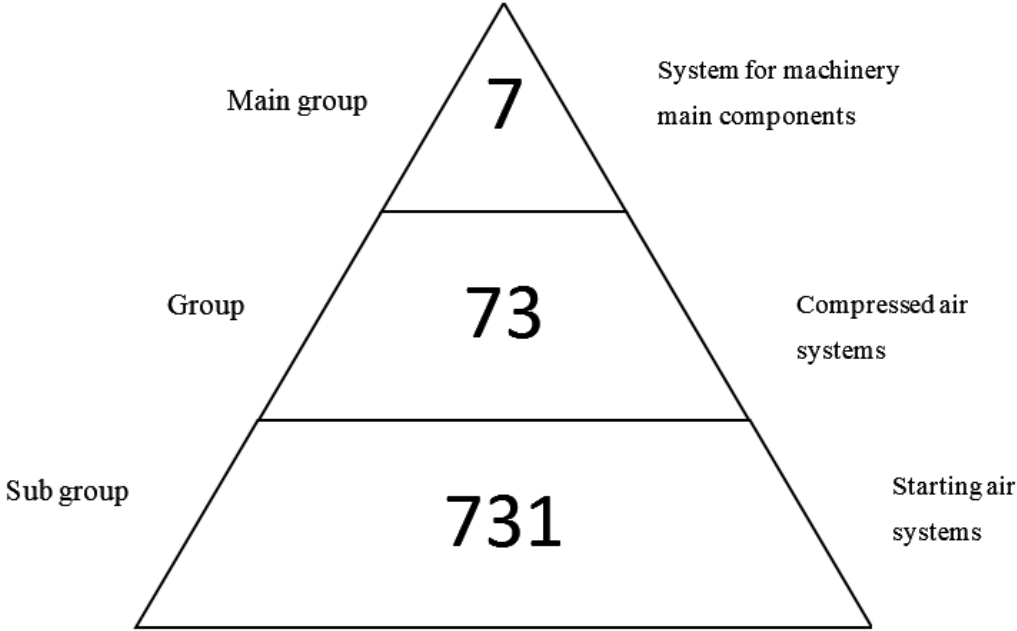
Figure 2-7 – Example of a SFI grouping system subdivision (adapted from (Xantic 2001))

2.3.3 Native NX supported taxonomies

In her thesis, (Levišauskaitė 2016) discusses the three taxonomies supported natively in Siemens NX 4GD module; functional, modular and spatial. In short, functional taxonomy divides components after their function (HVAC, piping, propulsion systems etc.). Modular division of a ship is broken down into modules (hull, superstructure etc.), sub-systems (bow, stern etc.), systems (thrusters, ballast) and components (propeller, motor etc.). Spatial uses divisions into zones e.g. decks, rooms etc. She suggests that traditional 3D CAD modelling (3rd generation) is very dependent on the taxonomy and should be decided before vessel model is created.
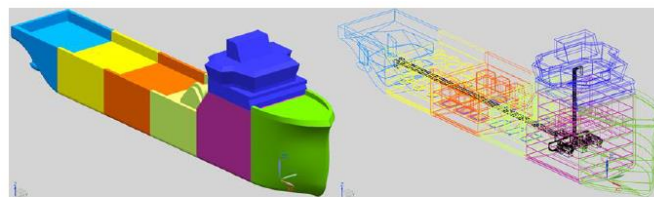
Figure 4.21. PSV (modular organizational breakdown)
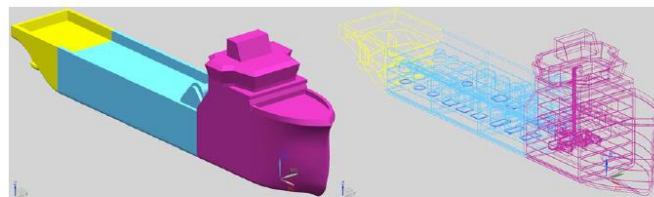
Figure 4.22. PSV (physical organizational breakdown)
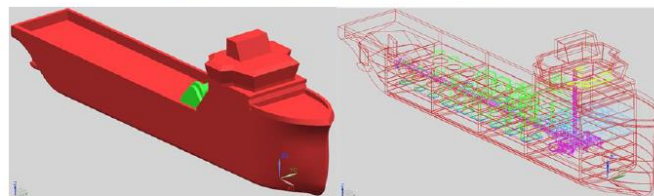
Figure 4.23. PSV (functional organizational breakdown)

Figure 2-8 - Different breakdowns of a sample PSV/AHTS (Levišauskaitė, 2016)

2.4 Summarizing the state-of-the-art

This sub-section will present a critical summary of the work introduced in the state-of-the-art chapter and assumptions and conclusion drawn from the reviews. The first chapter defines what PLM is, using the principles to reuse data gathered and combines it with ship design by adapting it with vessel lifecycle terms. The second section present the 3D modelling standard for mechanical businesses, some possible future solutions for 3D and virtual prototyping and using 3D libraries in ship building context. Next, third section contains ship design and concept design, SFI the standard for shipbuilding taxonomy and native NX taxonomies.

The need for 3D reuse in conceptual ship design comes mainly from reducing amount of re-work and improve analysis capabilities. In the concept phase 2D drawing are made of the arrangement of the drawing, which is later turned into 3D models; rendering to present customer, stability model etc. Additionally, if contract is won, 3D models are made from the 2D drawings in basic- and/or detail design. This means that the job has to be several times. Creating a simplified 3D model in concept design, which can either be used or exported to provide these purposes, seems like a good idea.

Using PLM tools to facilitate the work should be beneficial amongst other due to "jungle" of software used in ship design. Using the PLM both general arrangement and hull design from the design spiral can be done in one software. This means that one step in which a mistake can occur, exporting hull lines, is eliminated. This is just one example of where the PLM tools can serve more than one purpose.

Another feature with PLM is that it centralizes data in one database, this has many benefits and one that improve 3D reuse is that all CAD data can be stored here. However, with a vessel there are numerous of complex parts, can PLM which was deal with it? There are frameworks that deal with using PLM for maritime application and reuse in PLM. However, these have not been combined to provide a framework for PLM reuse in maritime application.

To make a library work some sort of taxonomy is needed, in the maritime industry the standard today is SFI. However, with 3D CAD software allow large assemblies of components and not necessarily in a functional aspect which SFI builds upon. Both modular- and physical can be useful taxonomies when setting boundaries for the reuse components.

From studying state-of-the-art, I have concluded that developing a reuse framework for 3D components in conceptual ship design using PLM is a novel domain of research. Projects trying to implement 3D into conceptual ship design often fails due to the amount of time needed and complexity of the process. Still, the ship design companies are searching for a way to deal with these issues since the benefits of introducing 3D through the whole design process is many. For this reason, reusing 3D components can be a way of promoting that approach.

3 Methodology

3.1 Assumptions/constrains

For developing the methodology and case-study some assumptions have been made. Additionally, the author has set some constrains to limit the research due to the dissertation being written in one semester. These assumptions and constraints will be presented in this section.

3.1.1 Conceptual ship design at Ulstein

This thesis focuses on the conceptual ship design phase, were the product is a simplified ship model to present the customer. To understand today's process of concept design, the work is done in cooperation with Ulstein Design and Solutions to study the approach. Therefore, both cases and research will be inspired by their way of working, giving work internal validity.

3.1.2 PLM fixed platform

The dissertation uses a PLM platform as a foundation, as both Ulstein and NTNU uses a 3D software which is included in a PLM package.

3.1.3 Taxonomy

The industry standard taxonomy in ship building is SFI group system, therefore author sees it a necessity to support this.

However, since it discovered that SFI is old in a CAD context, it should not be the only division. Therefore, author has chosen modular taxonomy as the second division of library.

3.1.4 Virtual prototyping only

Concept ship design includes several processes to assess vessel behavior, presentation to customer etc. This thesis will only investigate the virtual prototyping of the ship, meaning general arrangement (GA) in 3D.

3.1.5 3D models used

Models used in the cases was mostly made by author with simplifications. In main case two of the models were downloaded from GrabCAD.com and was made by users Lewi Uberg (mooring winches) and Lois (ship crane).

3.2 Research design

Action-based design was chosen, as the product of this thesis will be an intervention strategy, using a PLM based 3D reuse library to overcome some of the bottlenecks of the 2D approach. The author sought to understand the problems with the current approach (2D) and suggest a new method using 3D PLM reuse library.

(University of South Calefornia 2017) suggests that action-based research design has the following advantages:

- Adaptive research design that suits use in work situations
- Pragmatic and solution driven outcomes,
- It has the potential to increase the amount practitioner learn consciously from his experience

And disadvantages that must be overcome:

- Researcher both advocate for change and research the topic in question
- Advocating for change requires buy-in from participants.

(List adapted to fit this thesis)

Advocate for change and research topic, this dissertation is a work done for Ulstein, which is implement PLM. Therefore, it is not the researcher who advocate for the change.

Buy-in from participants, Ulstein employees have been very forthcoming in being observed and having discussion about the topic. However, they are very busy, and if participant had little time observer saved time by going directly to the question he had rather than take the full discussion about the process. Additionally, in some cases the author scheduled a meeting when suitable for employee to make sure he/she had time for the discussion.

3.3 Research approach

Since this research is about creating an intervention in an area where the researcher has limited knowledge and the research is of cyclic nature, the author uses mainly quantitative work. Ideas may be developed and dropped quickly, and the author therefore suggest that a qualitative approach is too time consuming and could limit the results of the thesis. Additionally, following strength of quantitative research approach show the suitability for this work (Adapted from (University of South Calefornia 2017).

1. Allows greater accuracy of results

2. Process can be easily replicated

These aspects were important to the research as Ulstein may use some of the ideas developed in their future processes.

Disadvantages of selected approach (ibid):

1. Quantitative work rarely considers human significance, e.g. employees might not want to use the new suggested proposal.
2. Unnatural environment may give results that may not be applicable for the process in question for real world purposes.

Since this thesis was part of a research project, the first aspect was somewhat addressed by another participant. In her thesis Hovden "A systems engineering approach to evaluate PLM during upstream ship design process", evaluate PLM processes in a company. Even if her focus is not to evaluate if engineers want to use a structured reuse method, but rather the overall PLM approach, the author think this aspect is satisfactory handled

Second weakness will be handled by the case-study, further described in chapter 3.7.

3.4 Research methods

This dissertation is based on the action-based research design. This method was chosen, since the thesis presents an intervention in ship design processes. Data was collected via field trips to Ulstein. The author then made a proposal for a 3D library approach. This was then tested in the selected PLM tool with a simple engine room case and possible improvements was listed in a table. These improvements were then used in a full-scale vessel case, presenting two existing PSVs to increase realism. Figure 3-1 show the different stages of the thesis.
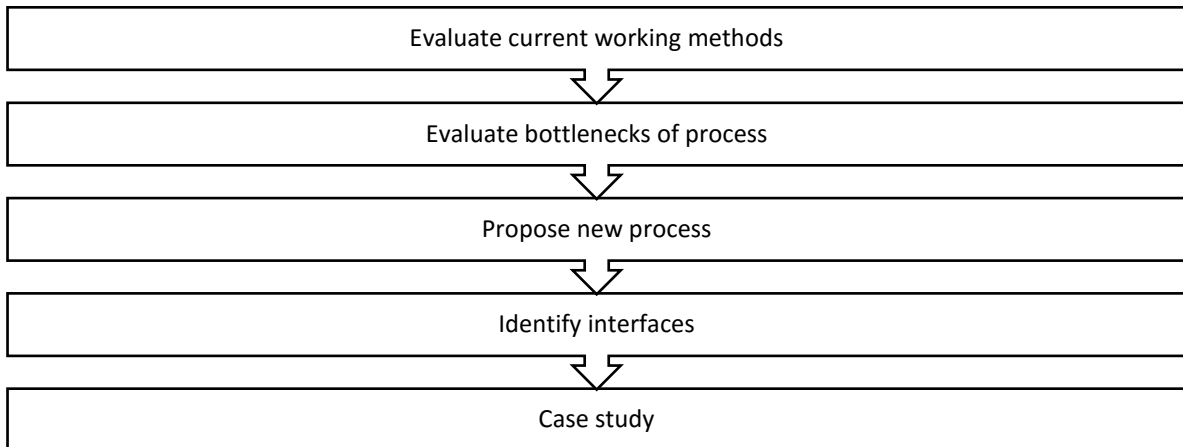
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┌─────────────────────────────────────────────────────────┐
│            Evaluate current working methods               │
└─────────────────────────────────────────────────────────┘
                            ⇓
┌─────────────────────────────────────────────────────────┐
│              Evaluate bottlenecks of process              │
└─────────────────────────────────────────────────────────┘
                            ⇓
┌─────────────────────────────────────────────────────────┐
│                   Propose new process                     │
└─────────────────────────────────────────────────────────┘
                            ⇓
┌─────────────────────────────────────────────────────────┐
│                   Identify interfaces                     │
└─────────────────────────────────────────────────────────┘
                            ⇓
┌─────────────────────────────────────────────────────────┐
│                        Case study                         │
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Figure 3-1 – Stages of thesis development

3.4.1 Evaluate current working method

Author was given some documents showing Ulstein's process of developing a concept design. From this the user derived the relevant steps for this research and created a flow chart of the process. Then the researcher went to employees experienced in the process in question and observed it being done in a real context. When the observation was conducted, the researcher redid the flow chart with the new input. After this, description of the steps was developed using information from observations.

3.4.2 Evaluate advantages and bottlenecks

At Ulstein the researcher was given a presentation about the 2D process, showing some of the problems with today's concept design. This was then filtered, finding advantages and bottlenecks in line with assumptions shown in chapter 3.1. Additionally, author make some assumptions of other steps where he thought the component library could help overcome some of the problems of 2D concept design. Finally, the steps where the 3D components fits were identified and summarized in a flow chart.

3.4.3 Propose new process

First researcher will make a proposal for a simplified 3D process which uses the component library. To validate proposals, discussions were made with a 3D designer who uses the PLM software in question. This process will be an adapted version of (El Hani et al. 2012) proposal

for unplanned PLM reuse. Secondly, the proposed method will be applied to a simple user case. During this, limitations of the process and use of library was identified. This will lead to new input for main case study. This case will explore a more holistic concept ship design process and researcher will present a new method dealing with the whole virtual prototype.

3.4.4 Interfaces

When using the library, user must deal with several interfaces. These was identified from the flowchart of the process. After being identified, author investigated in NX for a way to handle them. This method was then tested in the case studies and improvements made.

3.5 Research process

In this section a simplified version of the process in question, both currently used 2D approach and new 3D PLM proposal, to present the problem and suggested solution.

3.5.1 Evaluate current process

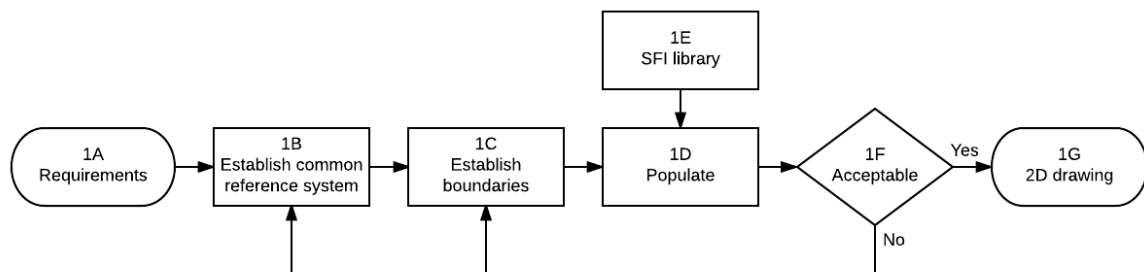This explains a simplified approach of creating 2D drawing (figure 3-2) and is used to find common input and outputs.

Figure 3-2 – Simplified 2D approach for creating a given drawing

1A: designer is allocated to draw a certain 2D drawing with a given set of requirements.

1B: next a reference system using "framelines" is established, this is used to relate current drawing to the rest of the vessel.

1C: in this step the designer creates 2D lines to show the limits (bulkhead and deck) of the compartment being designed. This must at least be shown in;

- Plan view
- Profile view

- Section view, if compartment has limited spaces or difficult geometry and designer needs to make sure there is enough room.

1D: now that the boundaries are established, the compartment in question is populated with necessary equipment. This may be found from;

- Company 2D SFI library
- Another project

1E: companies usually have a library for 2D drawing of equipment, which is structured after the SFI group system.

1F: does compartment fulfil given requirements?

Yes: go to step 1G

No: go back to either boundary- or population stage, or redo impacted steps.

1G: the drawing is now complete and stored under respective project

3.5.2 Evaluate bottlenecks of process

Advantages of the 2D process:

- Process is fast, allowing company to design several concept designs at the same time.
- If change is needed, this can be done quickly.
- 2D SFI library is easy to maintain, with no link administration.
- Reference system is a useful tool in design process.

Disadvantages:

- Boundaries is not stored in library
- Designer must draw the same drawing in two-, sometimes three views
- SFI library is not easily searchable

Processes where 3D component library can assist:

Boundaries are only stored under projects and if these should be reused, designer must remember the project where it is stored and copy it into new project. New library can store these as assemblies, which can store compartment, modules etc., allowing easy searchability and quick reuse of good designs or solutions.

2D SFI library is not searchable in an easy way, leaving designer to use a lot of time to find the correct drawings. PLM software allows easy searchability of parts and assembly stored.

Additionally, the drawing stored in library usually is arrangement drawings from supplier containing information about product which is not necessary for design process. 3D equipment does not have this information within drawing, allowing direct use.

When 2D process is complete the drawing is only stored under project library. If company has a vast number of projects, finding the layouts can be a difficult task. 3D library can store the good solutions under several taxonomies, not only project, e.g. can be a midship module which is stored under project, but also in a structural taxonomy.

Figure 3-3 show the suggested places to use the 3D library, red arrows are new interfaces with current approach.
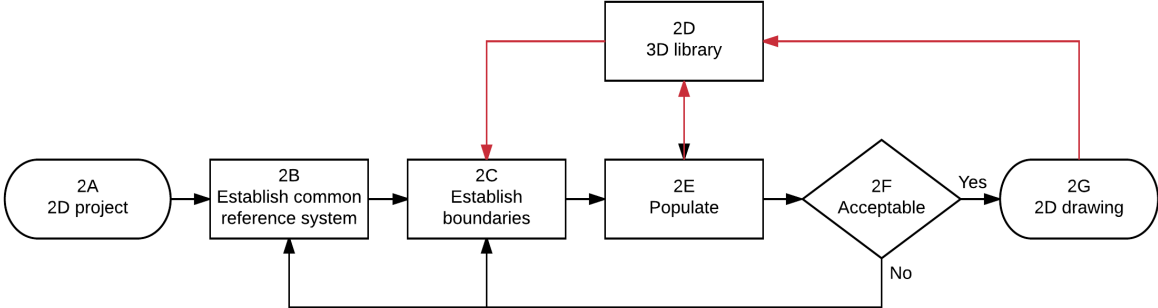

Figure 3-3 – Author suggestions where 3D component library fit in a 2D process

Author propose that new library still stores equipment models. Additionally, it can include layouts, meaning assemblies containing both boundary and relevant equipment. When process is complete, designer can choose to add link to their layout within the library under respective taxonomy. This way, the information is stored and easily searchable if it were to be used for another project.

3.5.3 Propose new processes

"No reuse" approach

When creating a totally new concept designer can use a "no reuse" approach. Author consider this when no existing boundaries or layouts is reused. However, in nearly all cases use designer will use existing equipment. Author suggest the approach using 3D library in this to be as shown in figure 3-4. Note that while there is little reuse (only equipment) in these cases, they give new component for partial- or full reuse cases, and is therefore necessary for library.
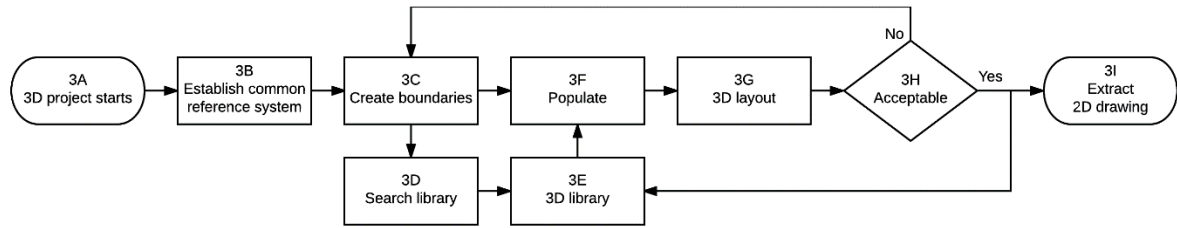
Figure 3-4 – Suggested approach for a "unique" new ship, where only equipment is reused

3A: designer is given a project with a set of requirements.

3B: the reference system is very useful in the 2D process and the author suggest that it be used in the 3D method as well. This allows easier positioning of bulkheads and is helpful if later changes and position is needed.

3C: designer now starts to create boundaries, meaning decks, walls etc.

3D: Search library, now the designer will define search criteria and search the library. In this case when looking for equipment, author suggest main taxonomy to be SFI.

3E: this step includes selecting desired equipment.

3F: Populate, in this step the desired equipment is loaded into assembly and positioned, this is done via drag-and-drop for library and positioned with constraints.

3G: designer is now completed with the 3D layout

3H: check, does model fulfill given requirement?

Yes: designer should consider to store layout in library (El Hani 2012, propose that time, cost and quality as criteria) and if stored maintain necessary links. When this is done go to step 3I.

No: go to boundaries and redo subsequent impacted steps.

3I: necessary 2D drawing are extracted from the 3D model.

Full- or partial reuse method

If company want to reuse existing layout(s), e.g. a module, the following method as shown in 3-5 is suggested:
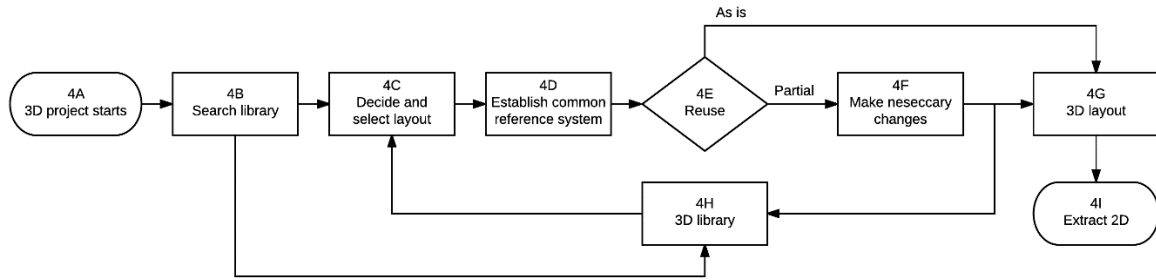
Figure 3-5 – Suggested 3D process for engine room case, reusing existing layouts

4A: Same as 3A

4B: designer defines search criteria in library using desired taxonomy. This can e.g. be searching to find an existing engine room layout.

4C: in this steps designer should choose which layout(s) to use, this can be a tank arrangement, midship module etc. and load them into current assembly.

4D: same as in step 3B

4E: which reuse strategy should be used?

As is: designer uses layout as is, link to library should be established.

Partial: designer makes necessary changes to layout, no link is needed.

4F: in this step designer evolves layout to fulfil the given requirements, this can include both changes to boundaries and/or "population". Additionally, considers[3] whether to store the new layout in library.

4G: the 3D layout is now complete.

4I: now drawing(s) can be extracted from the 3D assembly in necessary views.

---

[3] Criteria explained in step 3H

3.6 How to deal with interfaces in process

In this section, interfaces will be identified from the flowchart and researcher will try to find a good way of dealing with them.

3.6.1 Library search interface

When employee uses component library to find a certain 3D model, finding the model should be as easy as possible.
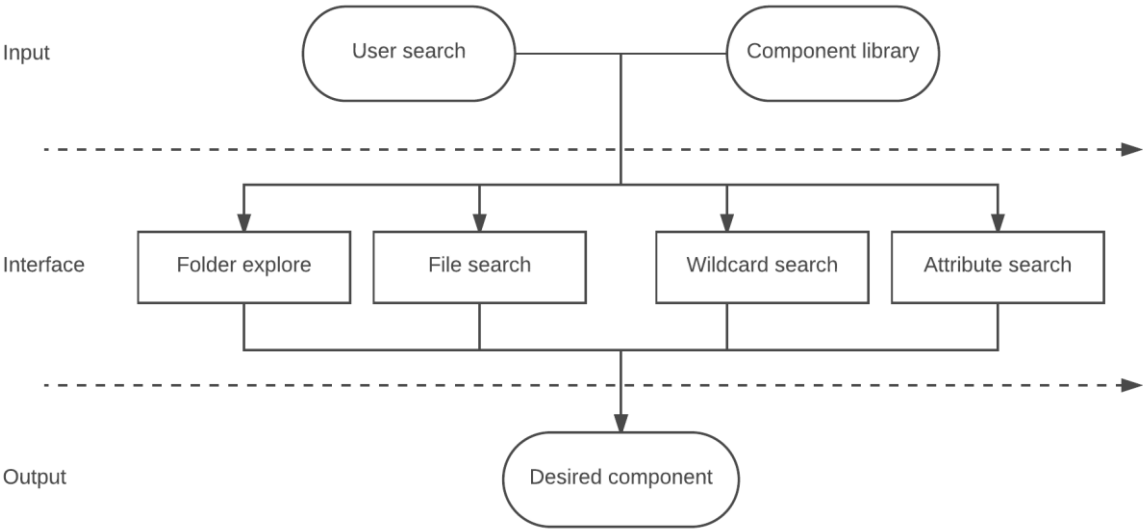

Figure 3-6 – Library search interface

The interface (figure 3-6) starts with two inputs, the user desired component, e.g. a crane and the component library storing the 3D models. The interface tells us how to get the search system works in the knowledge domain. Author suggest four methods handle this:

Suggestion	Description
PLM tool search function	Search via reuse library search tool for different parts of component name, e.g. search for SFI code 601 to get engines.
Folder library	Author suggest using a folder based system to store the 3D files in. In this, the breakdown of the given taxonomy will form the folder structure. PLM tool allow folder exploration under the selected library folder.

Wildcard searches	Wildcard searches (selected PLM tool uses (*) for this), allows user to find all components in several "sub taxonomies", e.g. SFI search 6* gets all folder below 60, 61, 601 etc.
Attribute searches	PLM tools can search for certain attributes of components. This can be volume, weight (if correct material is selected) etc. User can define own attribute and "track" so it updates whenever changes are made. Author suggest weight to be a useful attribute in concept design.

3.6.2 Retrieve part from library

When loading parts from library, some part can be used as they are, e.g. a lifeboat, a crane etc. Others may be project specific, like tunnel thrusters and shaftlines.
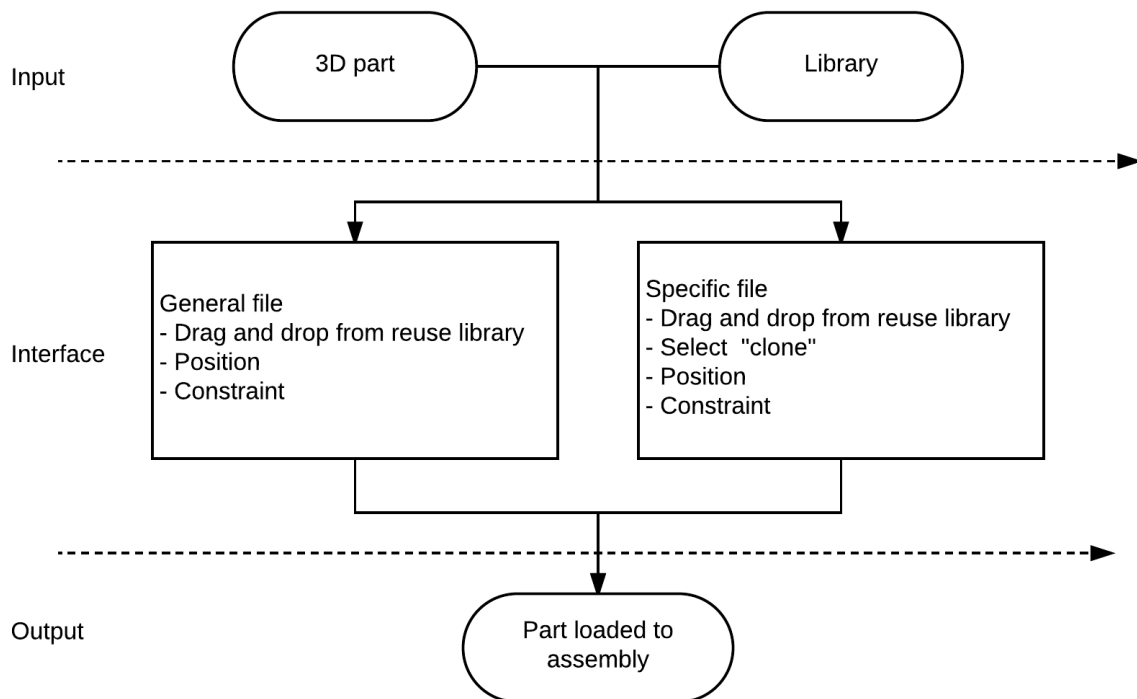
Figure 3-7 – Retrieving part from library

The interface for retrieving parts from equipment library is shown in figure 3-7. For general parts (file) user can just drag and drop it from library onto desired plane using and use standard load settings. Next, position and constrain it to the location wanted. If the file is specific for the model, designer must select "clone" when loading it. That way, changes can be made without affecting the library part.

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3.6.3 Maintaining library

When a new layout or part is completed, designer should evaluate whether to store it in library or not. If he/she decide to store part or assembly into library, company should have a standard method to do this for easier functionality and support. Author propose approach as shown in figure 3-8.
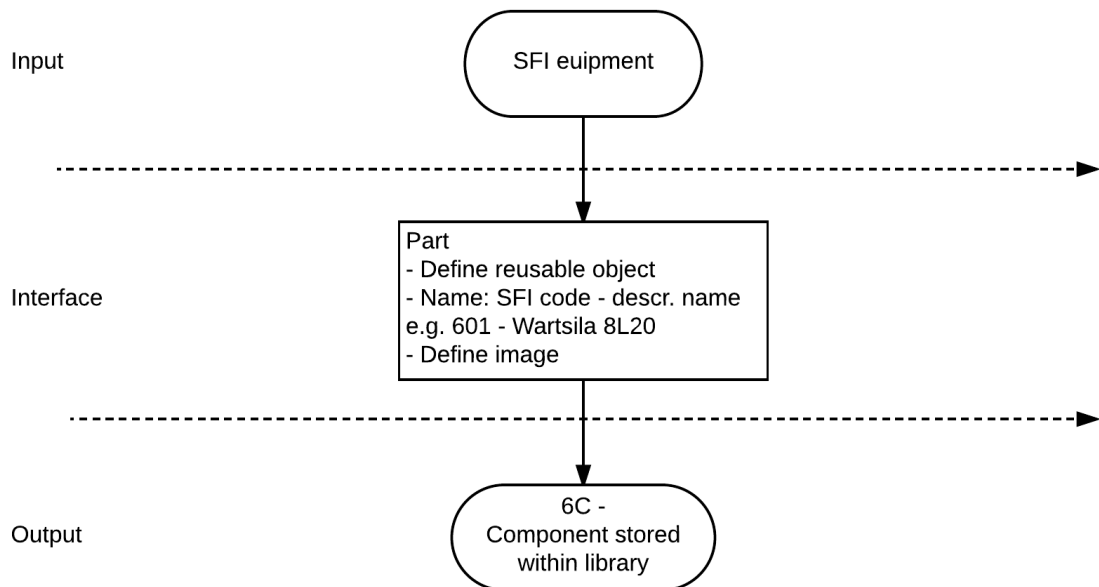

Figure 3-8 – Procedure of storing parts and assemblies within library

The input are several parts that are several parts stored in an assembly. To store the completed assembly, researcher suggest simply using 'save as', use a company standard name and select right library (taxonomy). For example, a provision crane can be named 563 – 3t provision crane.

3.7 Engine room case study

The case involves designing an engine room in the concept stage, to evaluate the suggested method. Case does not replicate any real-time vessel and the designer freedom will therefore be high. The engine room will first be modelled with no-reuse approach, then be stored in the library. Next author will test the partial reuse approach, by retrieving the layout (engine room) and applying a change case.

3.7.1 No-reuse evaluation

The layout of the engine room is shown in figure 3-9 and the case will consist of the following steps:

1. Establish common reference system
2. Create boundaries, in this case, deck and outer walls
3. Import and position three generator sets
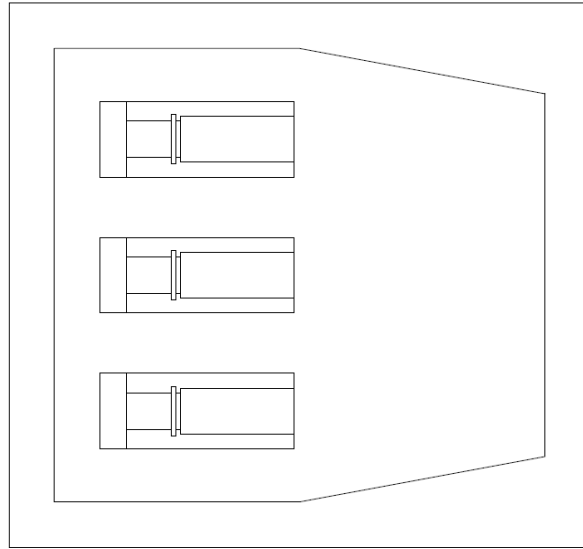4. Extract 2D drawing
5. Store in reuse library

Figure 3-9 – Engine room layout

3A: Start project with given requirement; another engineer has calculated power requirement of ship to be 3000 kW. Designer chooses 3 x 1000 kW gensets for electrical supply.

3B: In this case the reference system is not that important since it will not be included in a larger assembly. However, the author want to test it out how it easiest can be created. In this case author uses circles since they allow easy "snap" to geometry. A larger circle is shown for each five frames and these are also numbered as shown in figure 3-10.
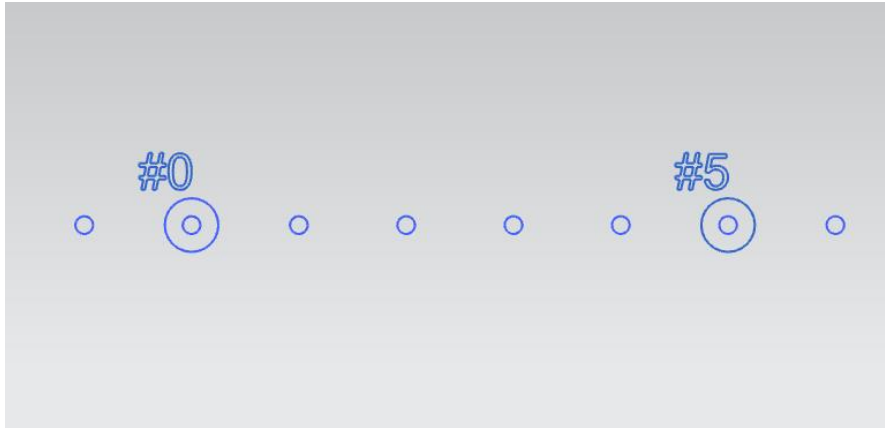
Figure 3-10 – Reference system consisting of circle for easier "snap"

3C: Next the boundaries were created using sheet metal.

3D: For this the built-in reuse library is used. Searching is handled in three ways as described in interface (section 3.6.1)

Figure 3-11 show a folder search for generator set

Figure 3-12 display when search for the component

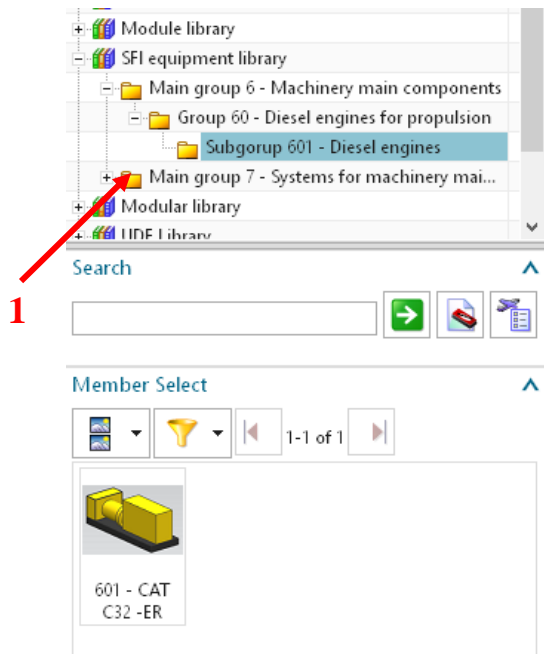Figure 3-13 present a wild card search

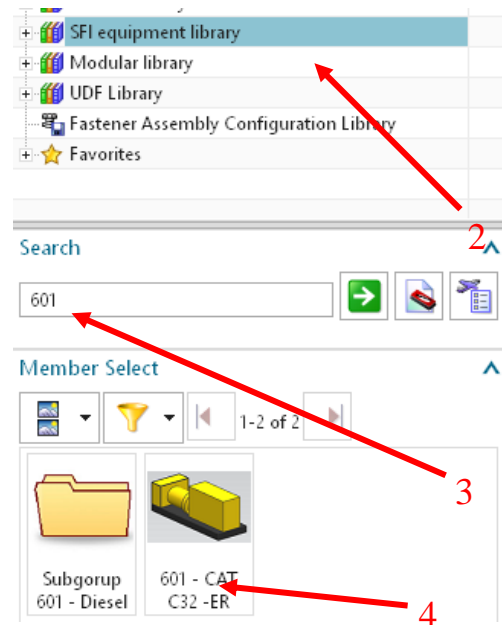Figure 3-11 – Library search by using folders

Figure 3-12 – Library search by SFI group code, note that correct library must be selected
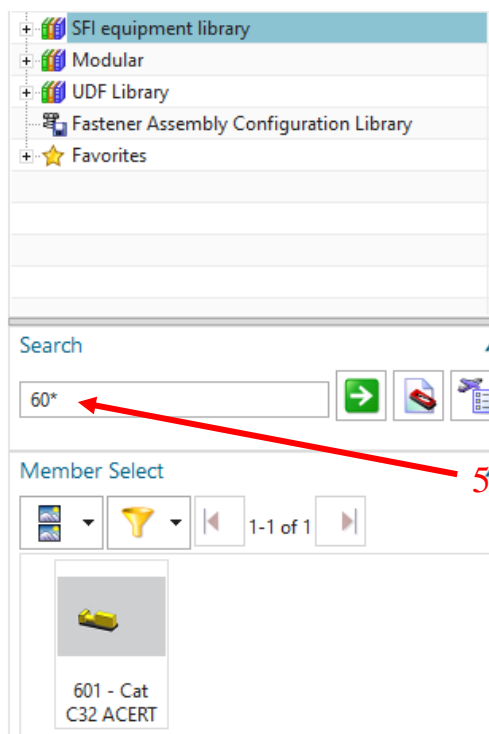

Figure 3-13 – Search with wildcard

1	Notice folder structure
2	SFI library selected
3	SFI number for selected component
4	SFI number in component name
5	Notice asterix when seaching

..

3E: For this case, author have just made one component under diesel engine category. In real life, there could have been several engines to choose from and user must decide which suits his needs.

3F: Now the generator set was imported into assembly by using add component. Author tried to drag and drop from library, but that linked the datum system restricting any movement. Constrains (see table 3-1 and figure 3-14) were then added.

Table 3-1 – Constrain used in engine room case.

Component	Constrain
Engine room boundaries	Fixed
Generator set	Touch, with ER deck
	Distance, with ER transverse bulkhead
	Distance, with ER longitudinal bulkhead

Transverse bulkhead   Longitudinal bulkhead   Deck
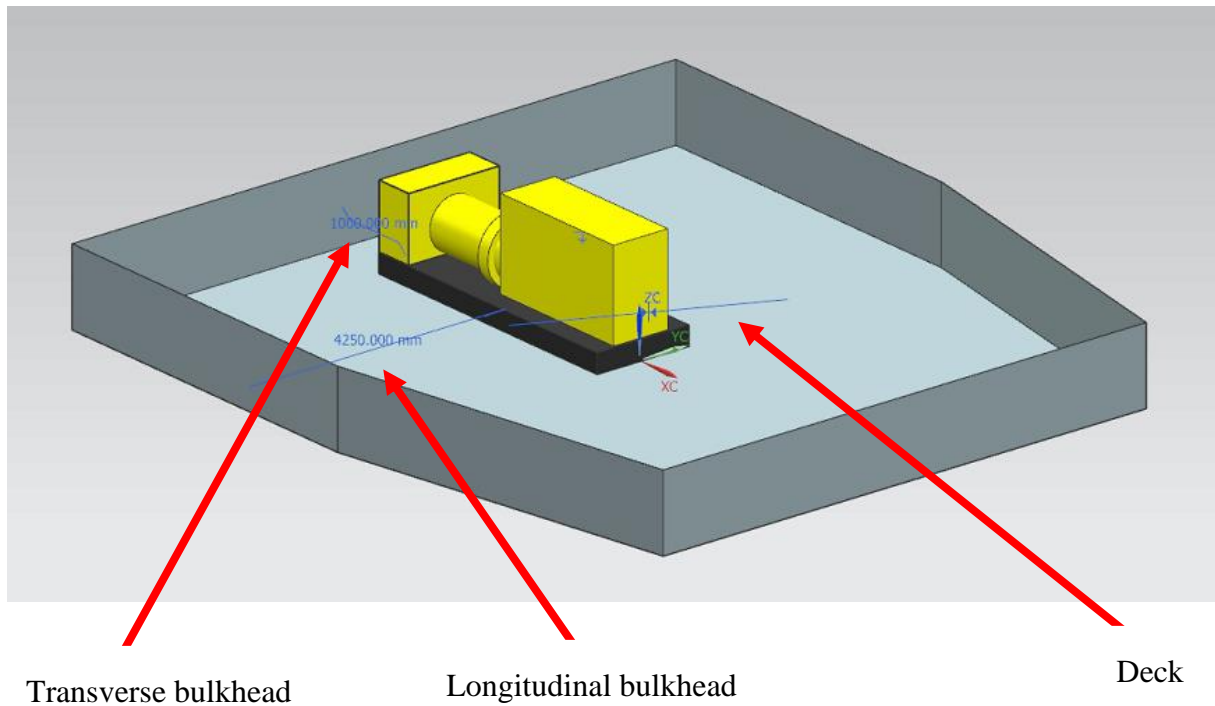
Figure 3-14 – Genset constrains

After component was added, "pattern component" function was used to get the other gensets, as seen in figure 3-15.
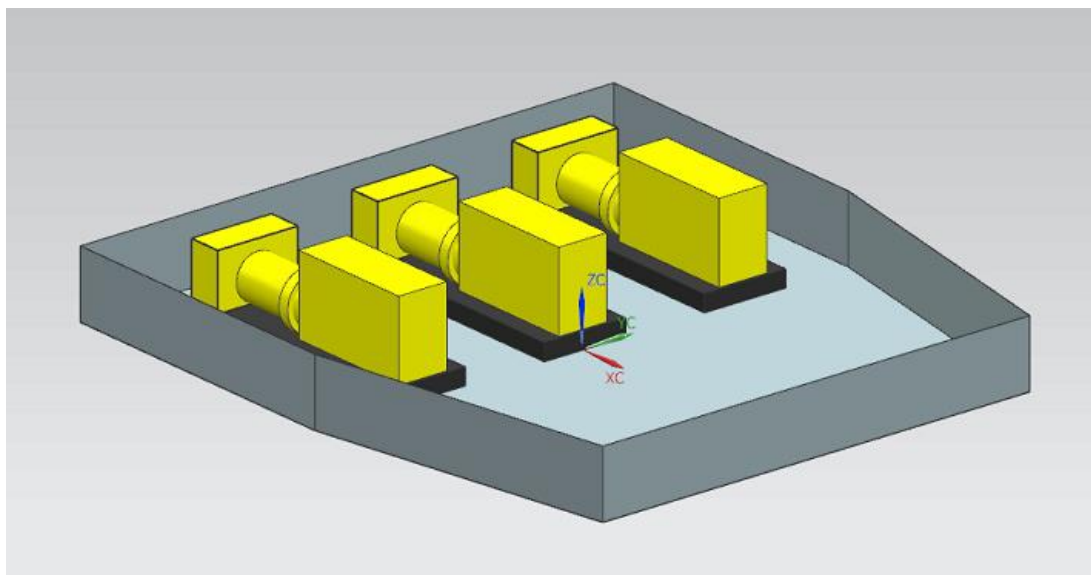

Figure 3-15 – All gensets in place, ER layout is complete.

3G: 3D layout is complete

3Ha: Designer decides that model fulfils the given requirement.

3Hb: Component is stored in library, as seen in figure 3-16.
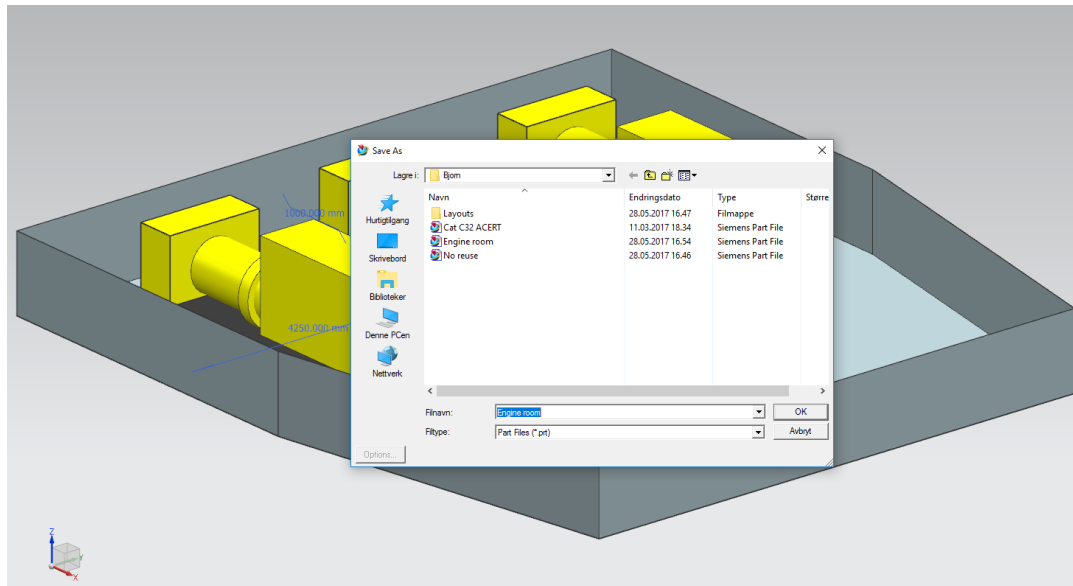
Figure 3-16 – Storing engine room

3I: Now that layout is complete the 2D drawing (figure 3-17) needs to be extracted from the assembly. Author uses PLM tool draft function to create the drawings. Typically plan and profile view are used in concept ship design, additionally, section view can be used in some cases. Therefore, the idea was to try to replicate these views with the drafting function. To do this functions described in table 3-2 was used, Figure 3-18 show the results.

Table 3-2 – Functions used to get desired views.

View	Function
Plan view	Base view, top
Profile view	Section view of CL, as shown in figure 1-7 (section BB)
Section view	Section view, as shown in figure 1-7 (Section AA)
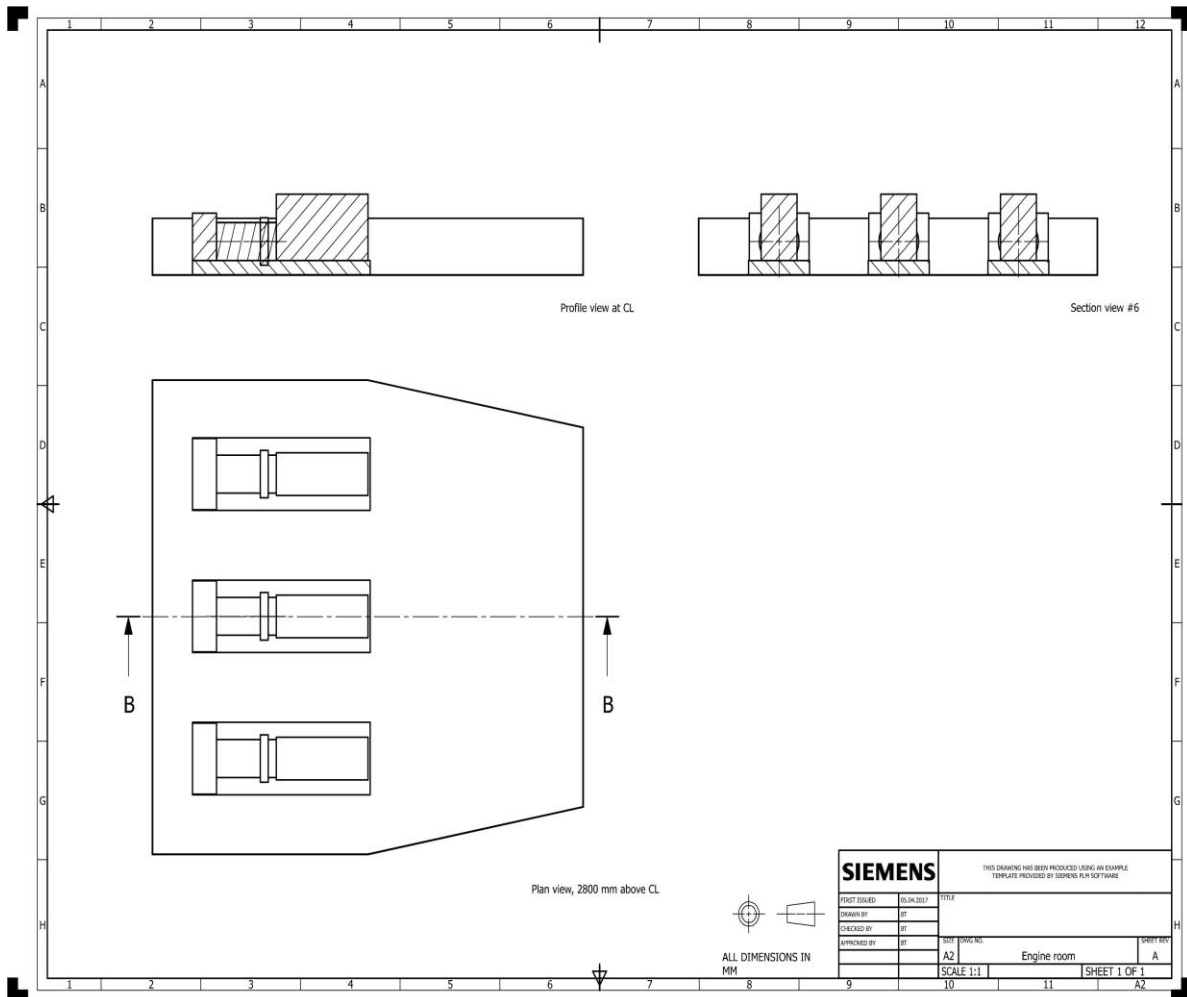
Figure 3-17 – 2D drawing extracted from 3D assembly, with profile view top left, plan view bottom left and section view top right

3.7.2 Partial reuse case

In this case, author will test and evaluate the partial reuse approach proposed. The case will have the following steps:

1. Retrieve assembly created in previous case
2. Increase size of engine room (change boundaries)
3. Change number of gensets from three to four (change population)
4. Extract 2D drawing of new 3D layout

The layout of the new engine room is as shown in figure 3-18.
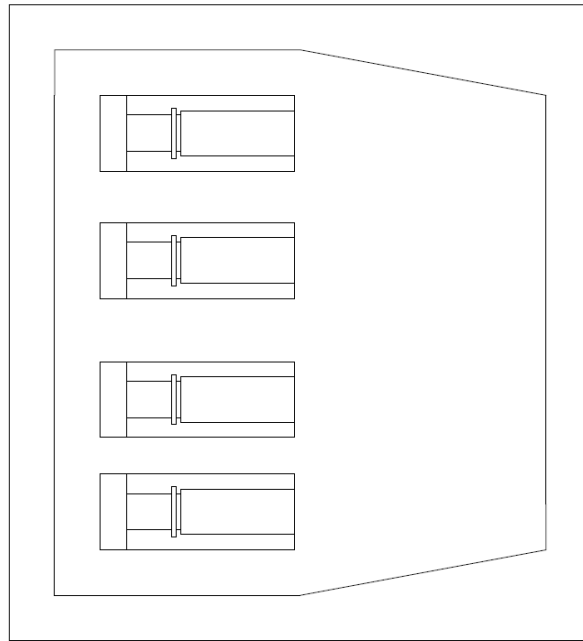
Figure 3-18 – New engine room layout

4A: Stability department calculates that ship need to be wider to meet stability requirements. Hydrodynamic shows that with the extra width propulsion power increases 1000 kW. Therefore, designer chooses to widen engine room and increase gensets from 3 to 4.

4B: Searching the library is similar to 3D in no reuse process.

4C: When retrieving the layout, it was noted that populating part files had to be stored in the same folder as assembly to load (error message shown in figure 3-19). File was transferred to the right folder and retrieval then worked without any errors.
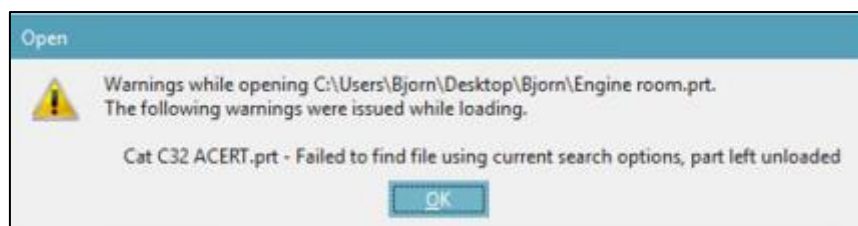
Figure 3-19 – Error message when component was stored in another folder than assembly.

4D: The reference system already established in previous assembly is not showing. Author did not create new one as it was not necessary for the task.

4E: As described in 4A there are new requirement is given, therefore partial reuse is chosen.

4Fa: In this step the engine room must be widened to fit the fourth gensets. This was done by entering the boundary part in assembly navigator. When size was increased (as shown in figure 3-21), user noted an error in the constrains (see figure 3-20). The constraint in question was linked to the side bulkhead, which had been moved.
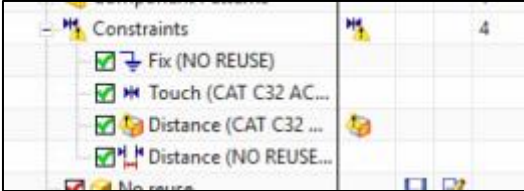
Figure 3-20 – Constrain error message.
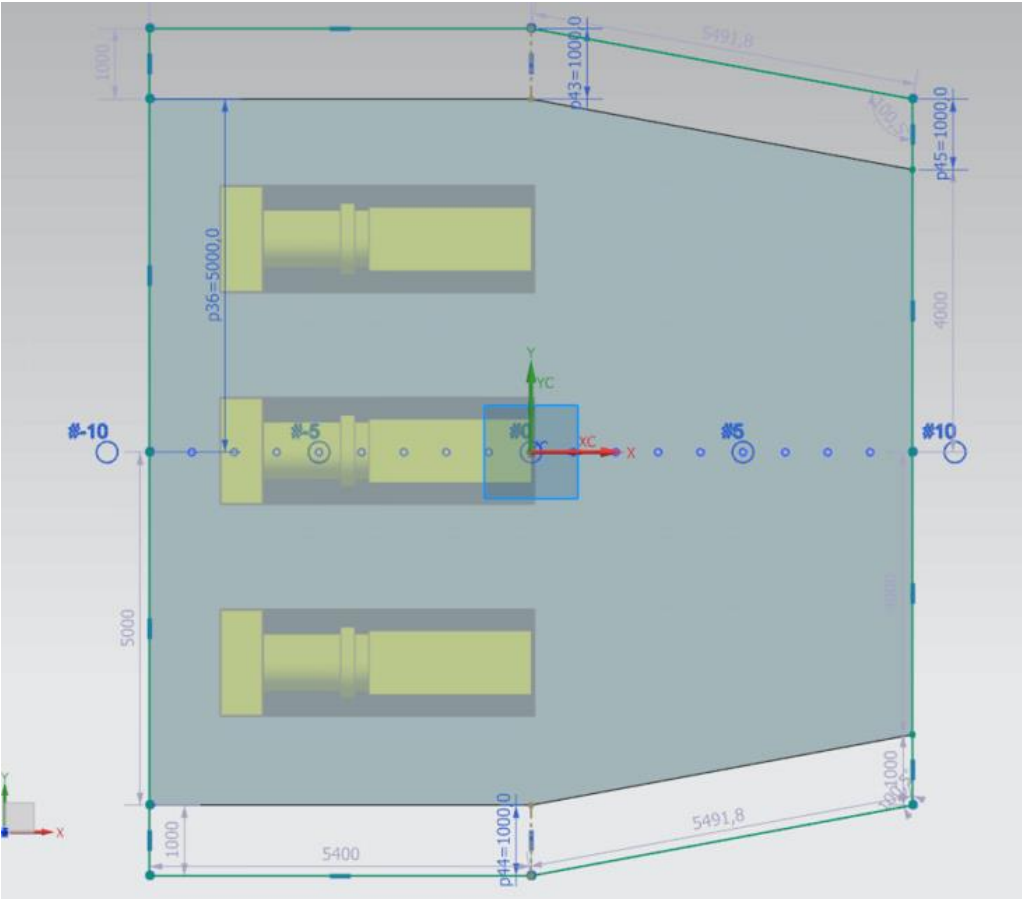
Figure 3-21 – Changing boundaries of engine room, note that when "boundary part file" was work file reference system can be seen again.

4Fb: Constrain governing the transverse (Y) position was changed to move engine from centered to left side. The old pattern components updated and moved to relative position to

parent component. When genset was correctly positioned, author deleted the patterned children engines since a symmetric pattern was not suitable for a four-engine setup. When deleting, user got warning showed in 3-22.
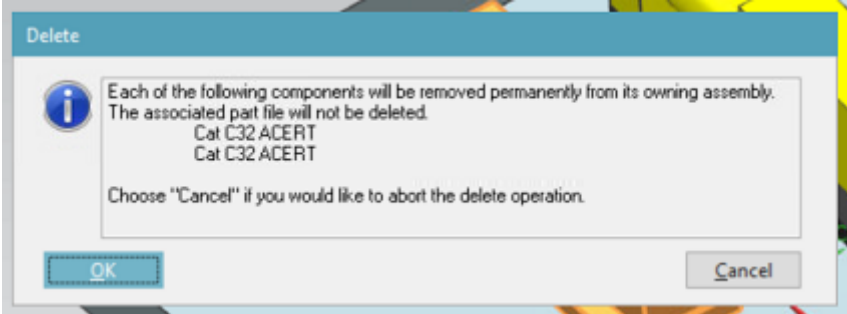
Figure 3-22 – Warning message when trying to delete pattern children components

However, when pressing OK the component was deleted anyway. Genset was then patterned and mirrored as shown in figure 3-23.

4G – 3D layout is as completed according to requirements
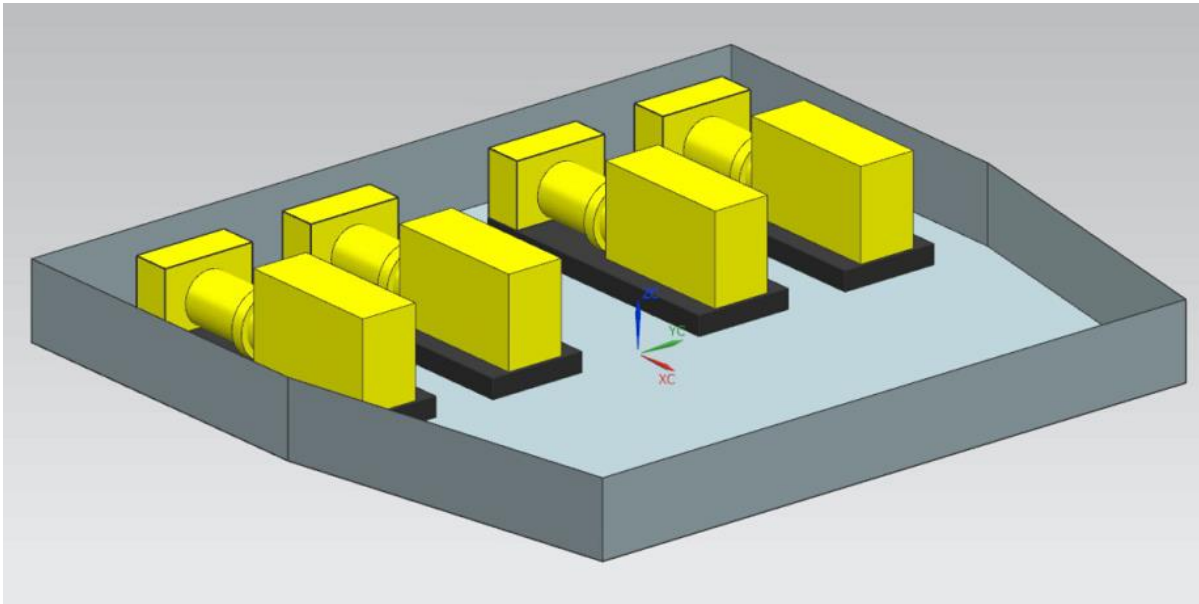
Figure 3-23 – 3D layout completed, with larger ER and four gensets

4H: Step is similar to 3Hb

4I: Finally, the 2D drawing (see figure 3-24) was extracted from the 3D layout. This was done in the same manner as "No reuse" case and worked without any issues
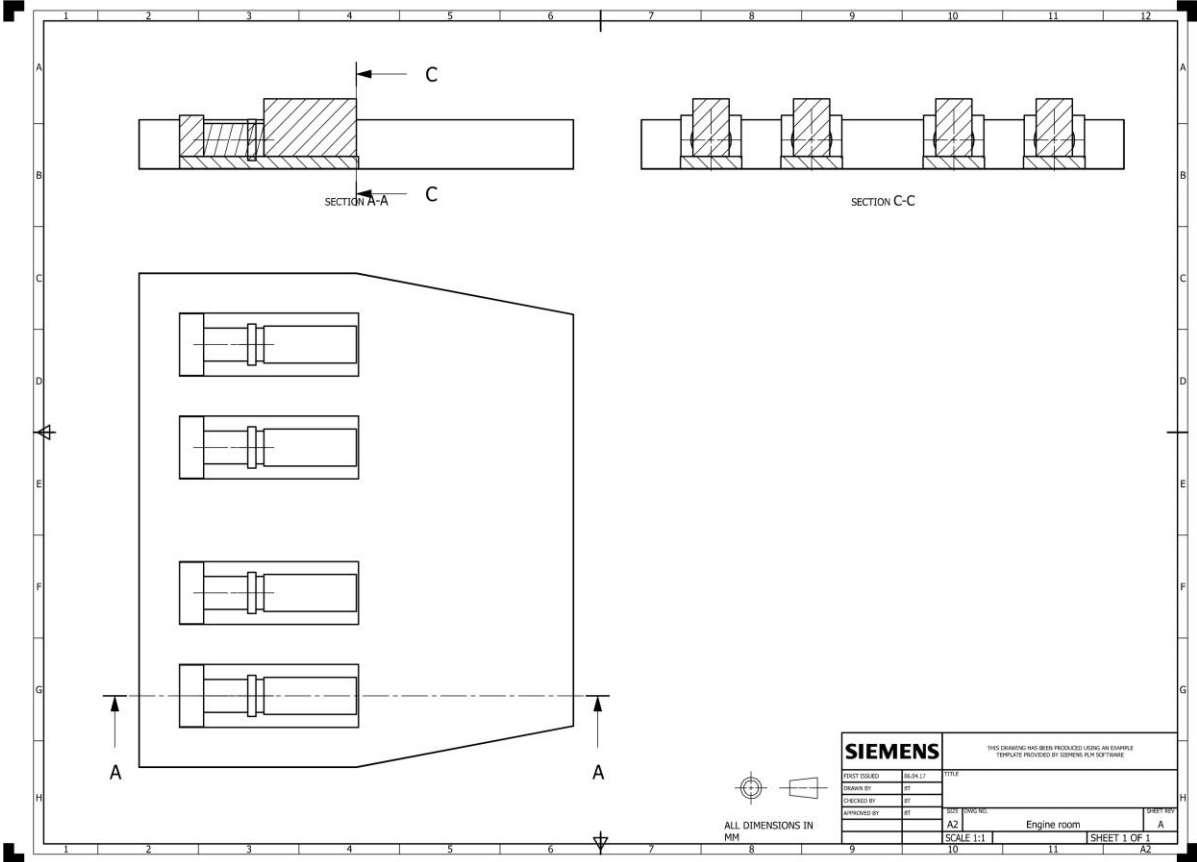
Figure 3-24 – 2D drawing extracted from 3D assembly

No reuse approach	Partial reuse	Suggested improvement
Different subversion of NX (both were version 11) gave slightly different functionality		Designer should note that this problem exists.
When saving assembly, engine and boundary parts were saved in different folders, when reopening, assembly could not load files that were not in assembly folder	Same message when loading layout assembly from library	Create search folders in NX, under "file -> option -> assembly option". Select folder where .prt files are stored.
Reference system disappears when part is loaded into assembly	Reference system disappears when part is loaded into assembly	Create reference system only in main assembly
	Engine constraint gave warning when bulkhead was changed	If such an error suspected, use part navigator to find it and re-constrain
	Warning when deleting pattern child	Deleting pattern child caused no problem. However, if pattern parent model is deleted this causes an error, hence children should be deleted first.
	No check if design is acceptable	Use decision point similar to "no reuse" between 4H - 4I

4 Main case study

This chapter will be dedicated to the main case, to test the method towards a larger, more realistic vessel model. To facilitate the case Siemen NX 11 will be used.

4.1 Case presentation

This case will be based on two PSV's, namely Viking Dynamic (Vessel A) and Bourbon Mistral (Vessel B). Vessel A will be designed using "no-reuse" method, where all features and equipment are designed to fit the vessel. When completed the modules and equipment will be stored in a library and Vessel B will be created reusing these either directly or adapted. At least one example of each processes in flow chart will be shown to test functionality.

The equipment used in this thesis is mostly the same as used by (Levišauskaitė 2016) in her ship case and is presented in figure 4-1. However, this case will not focus upon machinery links, tank sounding etc. but rather the big equipment that will be placed in concept phase to assess space for each room and compartment. Additionally, cargo capacities will not be of focus, but rather the different cargo types.

Taxonomy used will be a modular as proposed by (Gaspar et al. 2012; Levišauskaitė 2016), and divided in to modules (subsystems). Each module will inherit suitable subcomponents, e.g. propeller will be placed in stern module. How Table 4-1 lists subsystems and components.

Table 4-1 – To the left show vessel subsystems and right system encapsulations

Stern	This subsystem will contain the propeller or azimuth
Aft midship	This module will contain cargo tanks; dry bulk and special product.
Fore midship	Fore midship will contain the engine room; with gensets and/or engines and switchboard room
Bow	Contains bow thrusters and mooring winches
Superstructure	Contain the hotel accommodation; with cabins and the bridge with conning position and consoles
Cargorail	Cranes
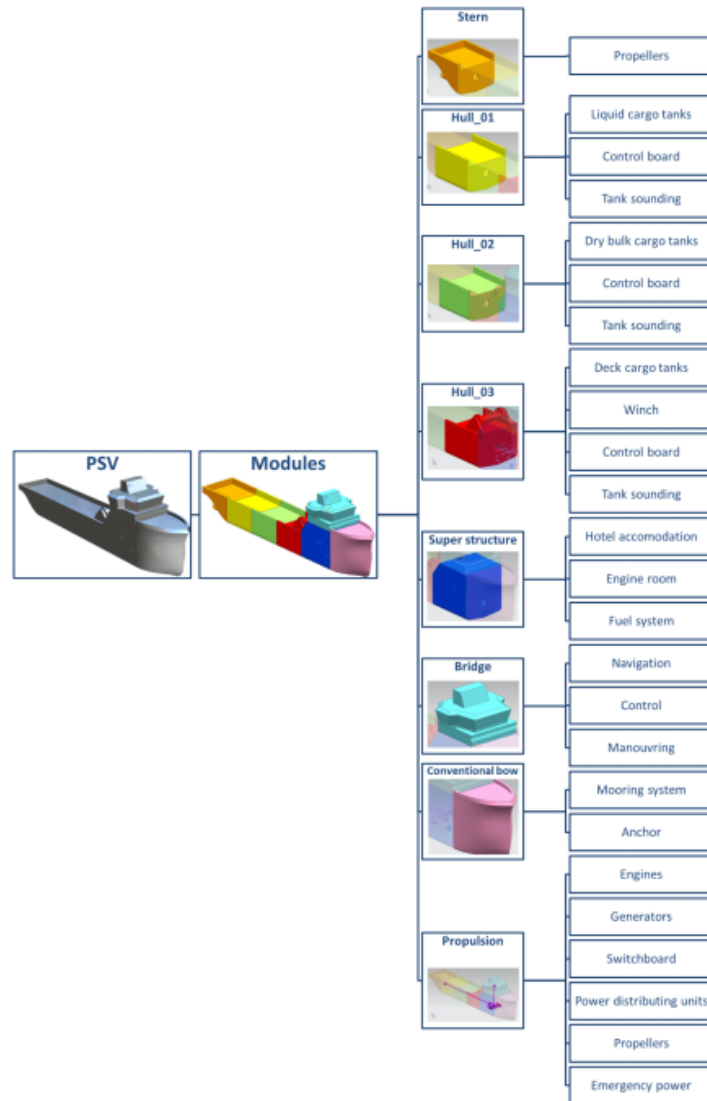
Figure 4-1 – Levišauskaitė's (2016) modular PSV taxonomy has been used as inspiration for case taxonomy.

4.2 Evaluate current process

This is the process (figure 4-2) as author derived it from observations and document studies:
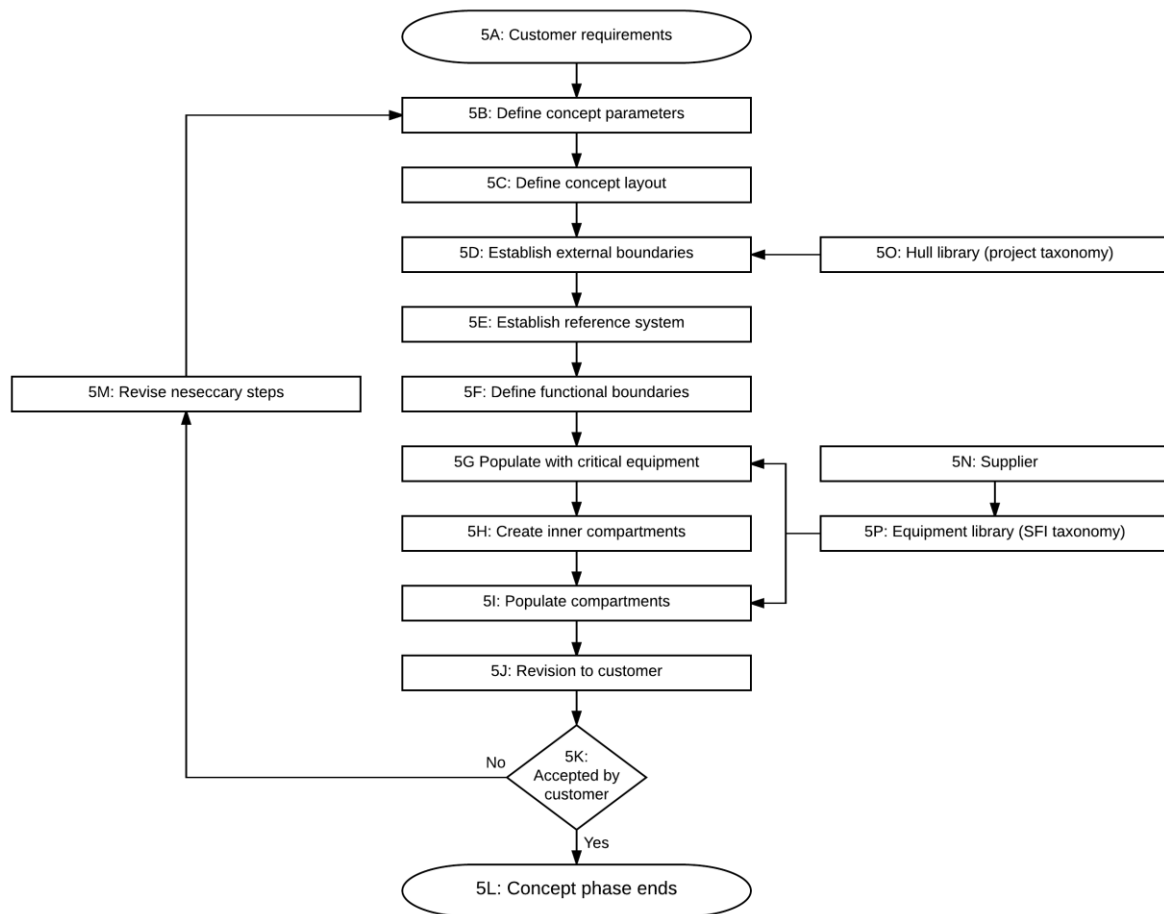
Figure 4-2 – 2D approach for concept design

5A: The main input for the design process is the customer requirements

5B: Design team interpret customer requirement and define the concept parameters, e.g. main dimensions, cargo capacity etc.

5C: Design team defines key features of the vessel, should it have a x-bow hull design, should azimuths or conventional propeller be used etc.

5D: hull designer search for a hull in the library, optimizes it towards concept parameters and exports 2D lines into the GA.

5E: designer establishes framelines in drawing.

5F: decks are created, then critical bulkheads, e.g. double hull, collision bulkhead etc.

5G: this is equipment that has large impact on the design, e.g. an offshore windmill gangway which should be located on or as close as possible to center of gravity. These are retrieved from SFI library or supplier.

5H: designer now can create the compartment (room, tanks etc.) of the vessel. This step is done simultaneously with 5I.

5I: the compartment is now populated with necessary content. E.g. a cabin is populated with bed and WC etc. In the concept phase it is often about the large components.

5J: first revision is sent to customer for approval.

5K: customer decides if project is acceptable toward requirements.

Yes: go to 5L

No: go to 5M

5L: first revision of vessel general arrangement is finished.

5M: designer must redo all impacted steps

5N: If designer cannot find equipment within library, the supplier is contacted for drawings

5O: hull library, sorted by project taxonomy

5P: equipment library, sorted by SFI taxonomy

4.3 Evaluate bottlenecks of process

These advantages and drawbacks are including to the ones found in section 3.5.2.

Advantages of the full 2D process:

- Hull is created in software purpose built for it
- Obtaining drawing from suppliers is easy due to well established export formats
- GA is made by one person allowing overall control
- 2D drawing are small in size permitting fast loading and response

Disadvantages:

- Only recycles equipment structurally (SFI)
- Larger assemblies with several equipment, boundaries etc. or not stored

Processes where 3D component library can assist (also presented in figure 4-3):

Library can store modules, containing typical content of that part of vessel, e.g. a midship module of a ferry containing the machinery room and fuel tanks. These can either be adapted or exchanged when working with another project. Using systematic taxonomy, helping to find right part.

Compartment (footprint) with simple geometry, e.g. a square cabin, can be stored as assemblies in the modules. When using them for a new project, designer can redefine the constraints to relocate the compartment or the content of it.

Were 3D component library fits in:
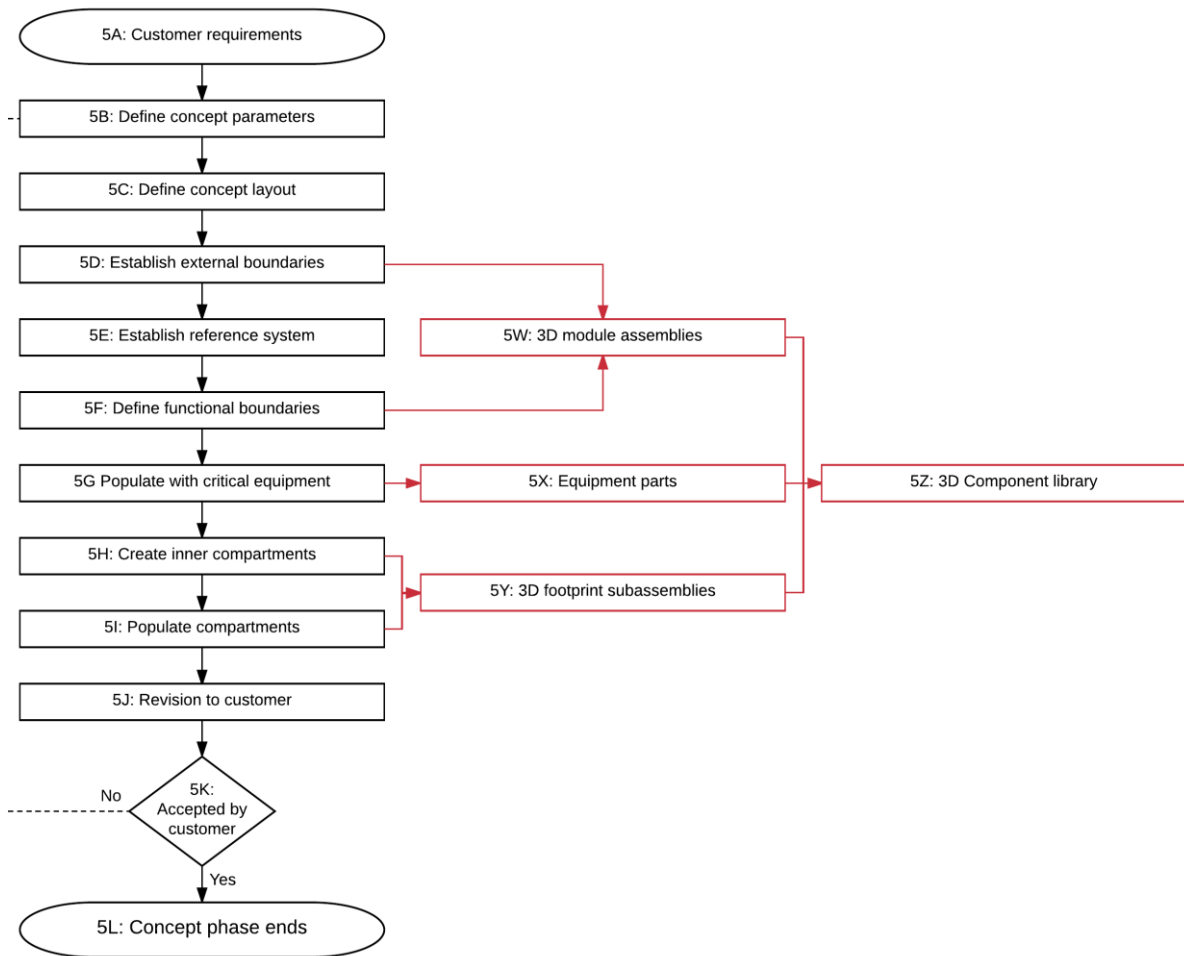
Figure 4-3 – Where 3D component library fits.

5W: Author suggest that the highest level assemblies be stored within 3D component library as 3D modules. According to taxonomy these can be a hull, a hull module, a propulsion system etc. These can also contain equipment parts (6N) and footprints (6O).

5X: Rooms or compartment created in the module and be moved around using move and constraints function.

5Y: Equipment parts, similar to SFI library in engine room case and contain 3D part models.

5Z: Is an assembly containing compartment boundaries (deck and/or walls) and the typical content of the room (6N)

4.4 Propose new process

4.4.1 No reuse approach

This approach is used when a ship is designed in 3D without using the component library (see figure 4-4), the process uses (El Hani et al. 2012) unplanned reuse as a framework to build upon. If a similar vessel is not in the library, designer can use this process to build vessel and store it for further use.
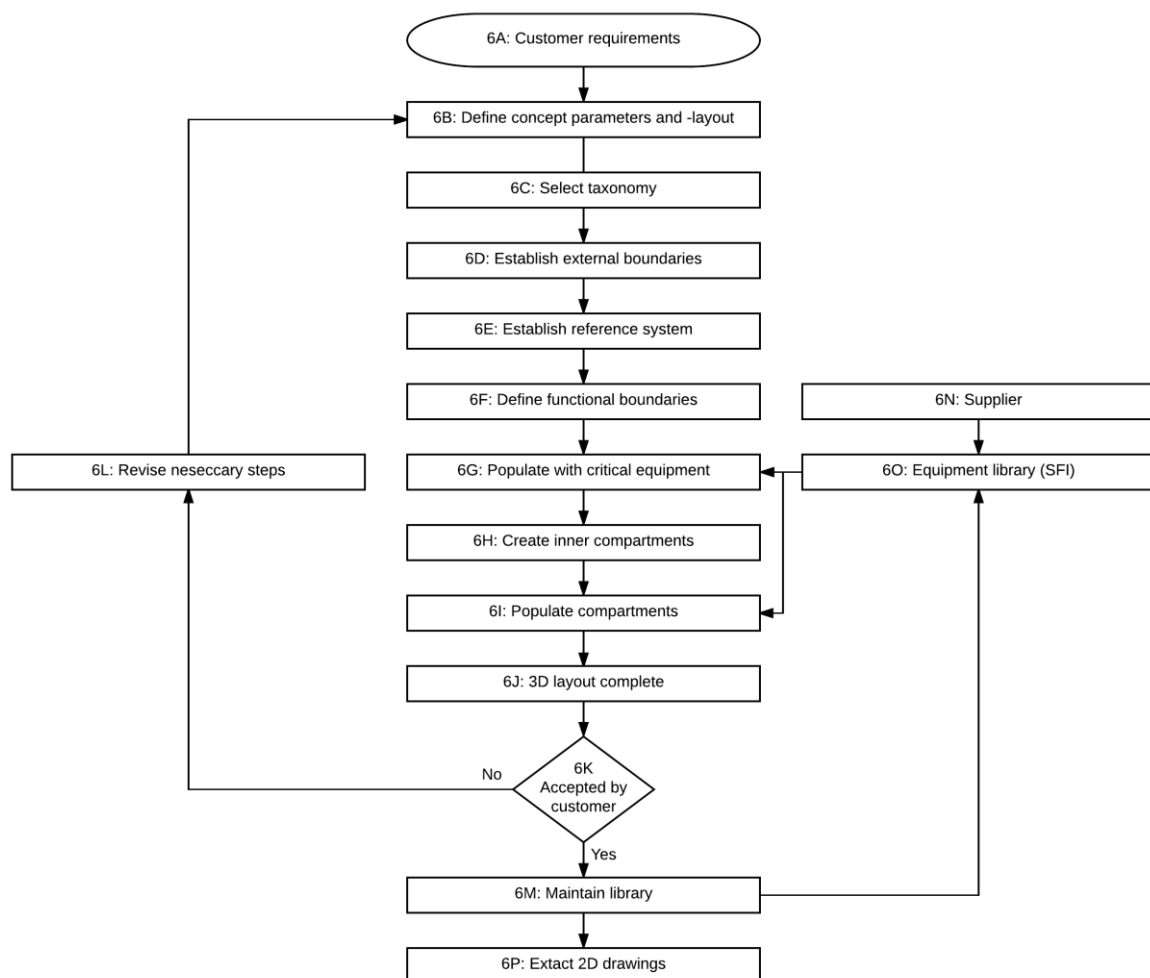
Figure 4-4 – 3D "no-reuse" with component library process

6A: Same as 5A

6B: Same as 5B and 5C

6C: Designer must now select the taxonomy of the vessel, e.g. modular, physical etc. According to (Levišauskaitė 2016), this choice has to be taken at the start when using traditional approach.

6D: Hull designer can now make the hull model, this can be done either in same software or another hull application is used and model is imported into NX.

6E: Same as 5E

6F: same as 5F

6G: Inner part of vessel must is separated by bulkheads into compartments.

6H: Compartment is filled with necessary content, e.g. a dayroom needs sofas, tables, TV etc.

6I: 3D layout is now complete

6J: Same as 5J

Yes: Go to 6M

No: Go to 6L

6L: Revise those steps that are necessary to fulfil customers need

6K: Extract 2D drawing, meaning profile, plan for each deck and necessary section views

6M: Designer should now consider which components to store in reuse library

6N: Same as 5N

6O: Equipment models stored using SFI taxonomy

6P: Extract the necessary 2D drawings from 3D model

4.4.2 Partial reuse approach

Figure 4-5 present the suggested approach for vessel being designed from components in the library. The process builds on (El Hani et al. 2012) planned reuse approach.

Figure 4-5 – Process when vessel is designed from 3D component in library

7A: same as 5A

7B: same as 5B

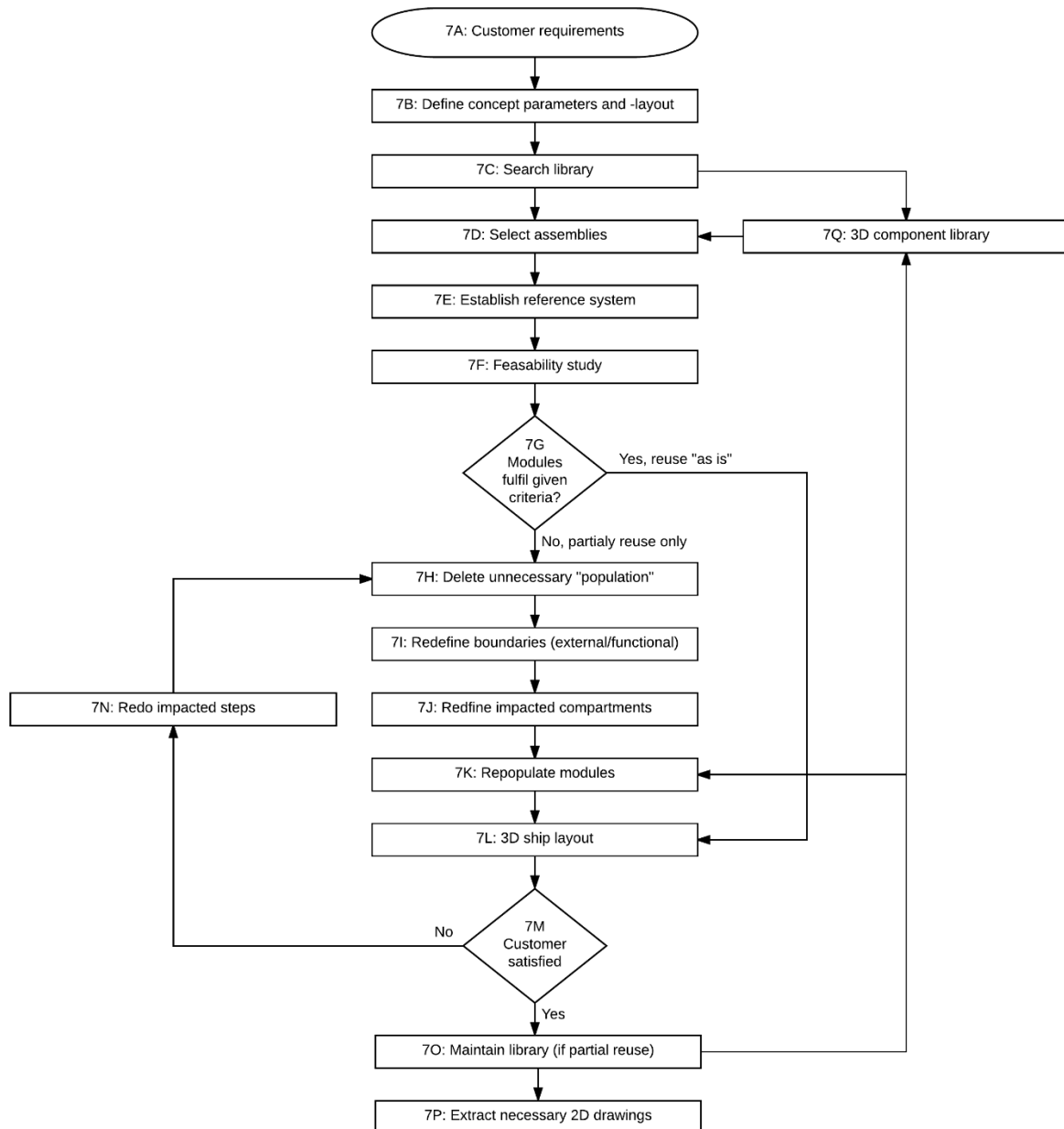7C: search library for assemblies via desired taxonomy, this can e.g. be a structural division to search for suitable modules used to create the vessel

7D: designer chooses desired modules and load these into vessel's master model and constraints them.

7E: establish reference system.

7F: in the feasibility study designer evaluate what must be changed (if anything) to meet requirements of the new vessel, e.g. deleting parts, adapting components etc.

7G: with the feasibility study as basis, designer can now make the decision whether module(s) can be reused "as is" or that they need changes. This assessment has to be done for each module.

Yes: module can be reused "as is", go to step 7L

No: module need changes (partial reuse), go to step 7H

7H: module did not fulfil given criteria, and designer must delete unnecessary population; this can be different equipment etc. This is done to avoid errors when conducting subsequent steps.

7I: This would for example happen if main dimensions of the vessel are changed. Outer dimension is changed first and functional boundaries secondly. If this is the case, user must make impacted modules unique.

7J: Designer must redefine bulkheads of compartments to fit the new concept layout.

7K: Repopulate the modules, starting with most critical equipment first, towards less important.

7L: Same as 6J

7M: Is customer satisfied with the total design?

Yes: Go to 7O

No: Go to 7N

7N: same as 5M

7O: same as 6M

7P: same as 6P

4.5 Interface

4.5.1 Importing files from suppliers

If the company gets a part file from one of its supplier that was created in another CAD software than the company's, the file must be imported. A standard approach (figure 4-6) to do this should be established to avoid any errors when dealing with the part. To develop the method, two foreign file format and how to introduce them in NX was investigated, namely; IGES and Step.
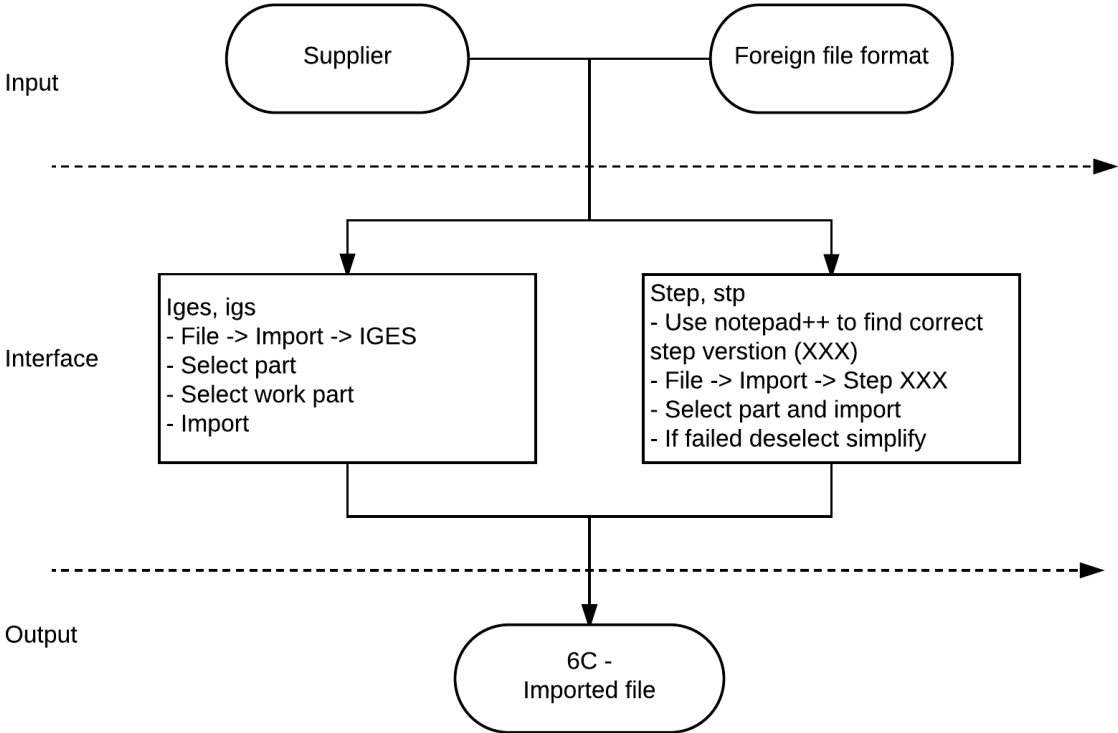
Figure 4-6 – Interface for handling foreign fil formats

To import an IGES 3D model, go to: `File -> import -> IGES`. First select the iges part in the file explorer, if it does not show up check file formats, .iges and .igs. Next when correct file is found, choose work part and import the file.

Step, use notepad++ to find which step format part is in (step203, step214 or step242. Go to `file -> import -> step XXX`, select file (choose .step or .stp correctly) and import. If part does not show deselect simplify option and try again.

Note that scales might not fit new part, and if part does not display, hit "view fit" to change scales.

4.5.2 Maintaining library

When maintaining a library using several levels of assemblies, a more extensive method to maintain the library is needed.
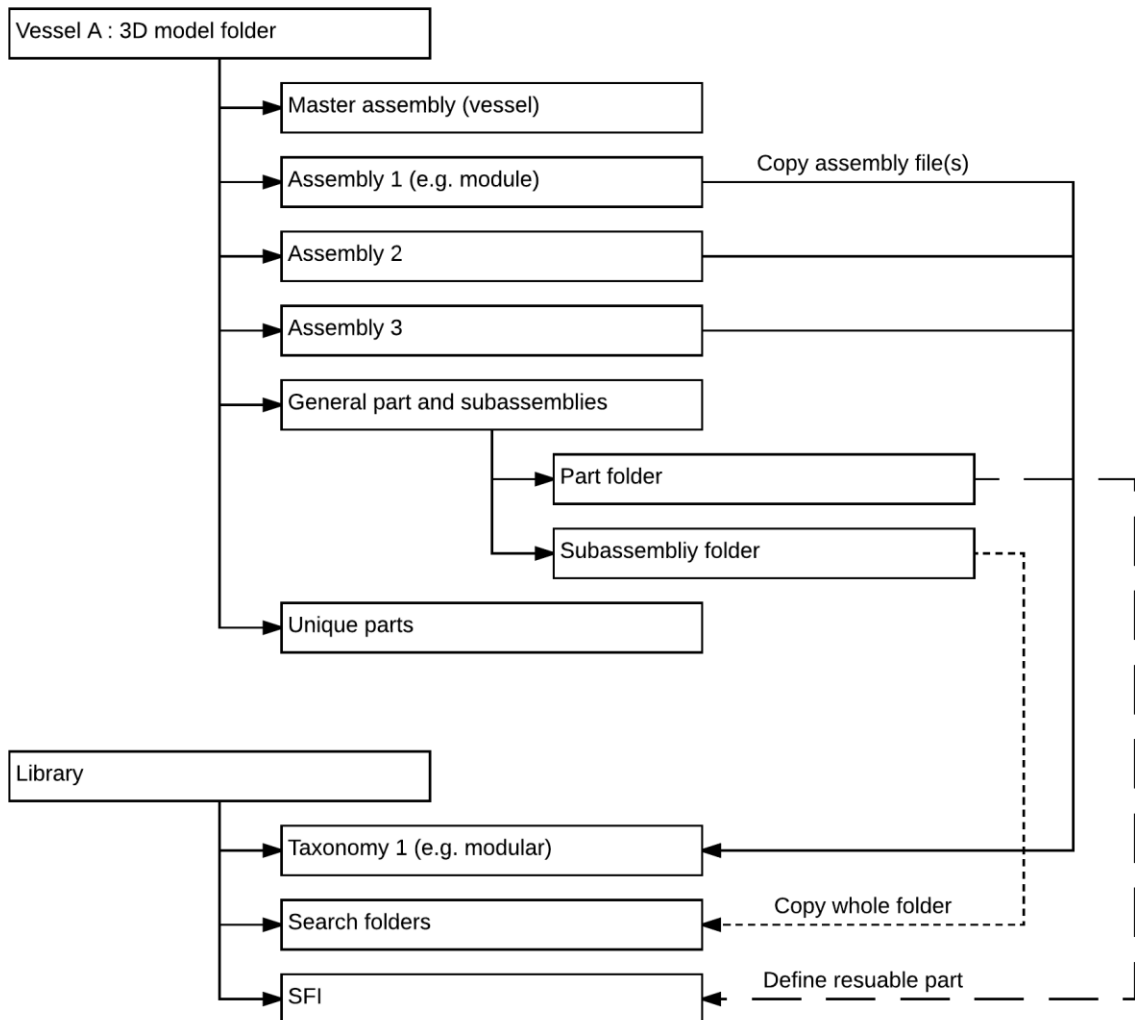
Figure 4-7 – Interface for maintaining library when developing full vessel model

First you have a master model structure assemblies and part to the vessel and a folder with unique part or assemblies. These are specific for this vessel and should not be copied to library. Further, author suggest to divide into assembly that build up the ship structure, e.g. a module. These should be copied to a taxonomy structured library. Next, all the subassemblies that build up the module assemblies should be stored in a content folder (search folder in figure 4-7). These are connected to the module via name including project number (e.g. Vessel A). The parts should be stored via "define reusable part" in NX reuse library.

4.5.3 Loading assemblies to vessel model

This is the procedure for loading assemblies that make up the ship, but the procedure (figure 4-8) is the same for other assemblies stored in library.
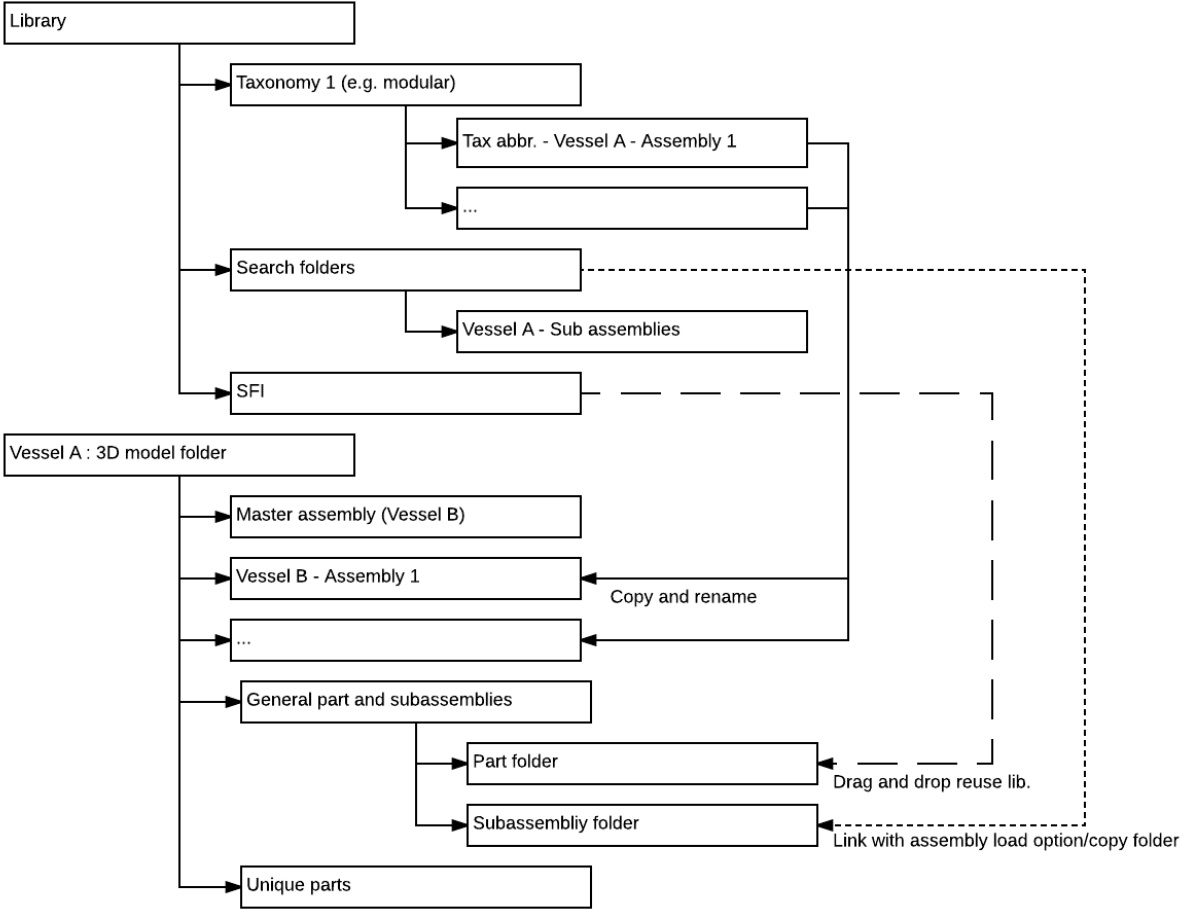
Figure 4-8 – Approach for loading assemblies from library

First the assemblies should be copied and renamed after project number or other unique name. Then assembly load options should be setup with the folders from the previous folder to fetch the sub-assemblies. NX remembers the name so only folder is required, if there are subfolders using "\..." (slash, triple dots) NX will include those as well. When link (search folder) has been established, user can use "saved as" option next time software is opened.

If parts have been correctly stored in NX reuse library, these should load automatically. If there are parts or assemblies not showing when process is complete, user may need to activate these in the assembly tree.

4.6 Applying "no reuse" approach on vessel A

To give case more realism the 3D model is loosely based on an existing vessel, Viking Dynamic. This is a PSV owned by Eidesvik, and was chosen because of information availability, mainly the vessel general arrangement (figure 4-9).

Figure 4-9 – Viking Dynamic GA (Eidesvik 2000)

6A: Customer requirement is a vessel similar to the Viking Dynamic.

6B: Normally, the concept layout and -parameters are of great importance. However, designing a vessel according to this would take too long time. Therefore, the layout is based on GA, however, no focus will lie on the aesthetics part, e.g. the bow, deckhouse and bridge. Concept parameters is taken from same vessel and consist of the main particulars; length, breadth, depth and frame spacing.
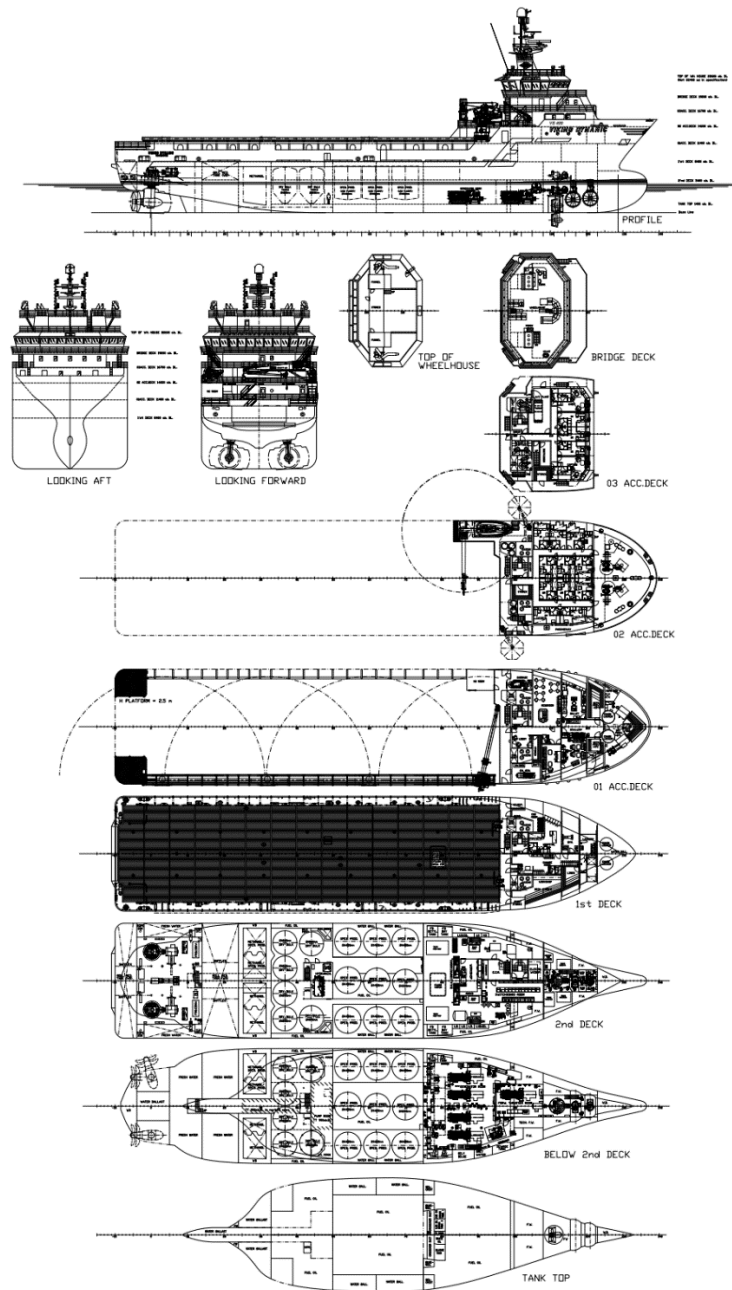
Table 4-2 – Principal particulars for Vessel A (Adapted from Viking Dynamic)

Length	90,20 m
Breadth	19,00 m
Depth	8,40 m
Frame spacing	0,60 m

6C: The taxonomy for this model is already selected to be modular.

6D: In this step, the outer modules were defined, in this case; hull, deckhouse (incl. bridge) and cargo rail. Hull were created in four parts; stern, aft midship, fore midship and bow. When selecting where to separate the hull into different modules, author choose to divide them at the watertight subsections. That way, no equipment will be standing in middle of two modules. When creating these sections, author noted the complexity forming the bow and stern geometry, and these modules had to be greatly simplified. Storing and reusing these can save significant time.

Modules were created as parts and loaded into a master assembly using "add component". When constraining the modules, the stern section was fixed and constrained to it.

6E: Reference system was created in similar fashion as in simple case.

6F: This step is exemplified by creating the vessel decks. To do this each module open in assembly and a sketch line was made from front to end of module at selected heights. This was then extruded to "until selected".

6G: An example of a critical equipment, is the azimuths, the placement is already set by hull shape. The azimuth modules are created as its own parts and added into the stern module. Then it was constrained into position and patterned (pattern component) (figure 4-10).
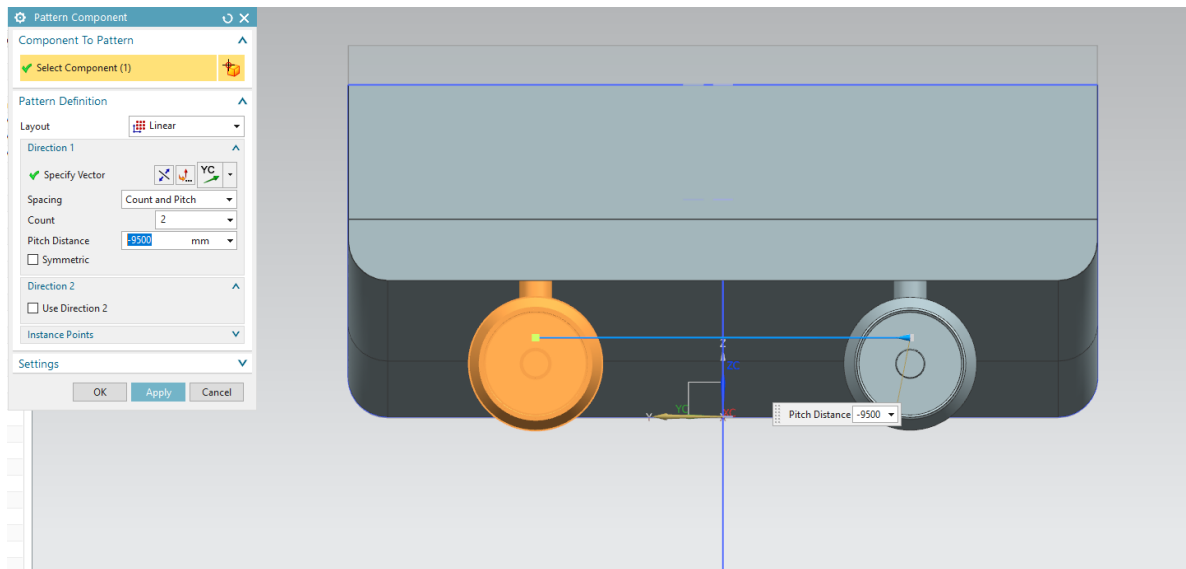
Figure 4-10 - Azimuth at #0, patterning to get the other

Additionally, dry bulk- and special product tank, gensets, mooring- and anchoring arrangement and provision crane were added and positioned on the vessel. A problem was to decide which equipment should be considered "critical" or not; and company should develop a standard for this. Author suggest that critical equipment include both equipment with large impact on the design and component with very restricted placement.

Mooring/anchoring arrangement was imported (IGES file) and same for provision cranes (Step file) to test the use of foreign file formats. Both imports went okay, but especially mooring arrangement was very detailed, and working with it slowed responsiveness of computer. Simplification of high detailed import files should be considered.

The tunnel thruster is a specific part that fit only the bow it was designed for (the tunnel). Therefore, to make usable for other designs, the tunnel was made wider than the typical PSV bow. Then when loaded into assembly it was made unique (figure 4-11) and shaped after the hull.

Figure 4-11 – Making tunnel thruster unique before shaping them.
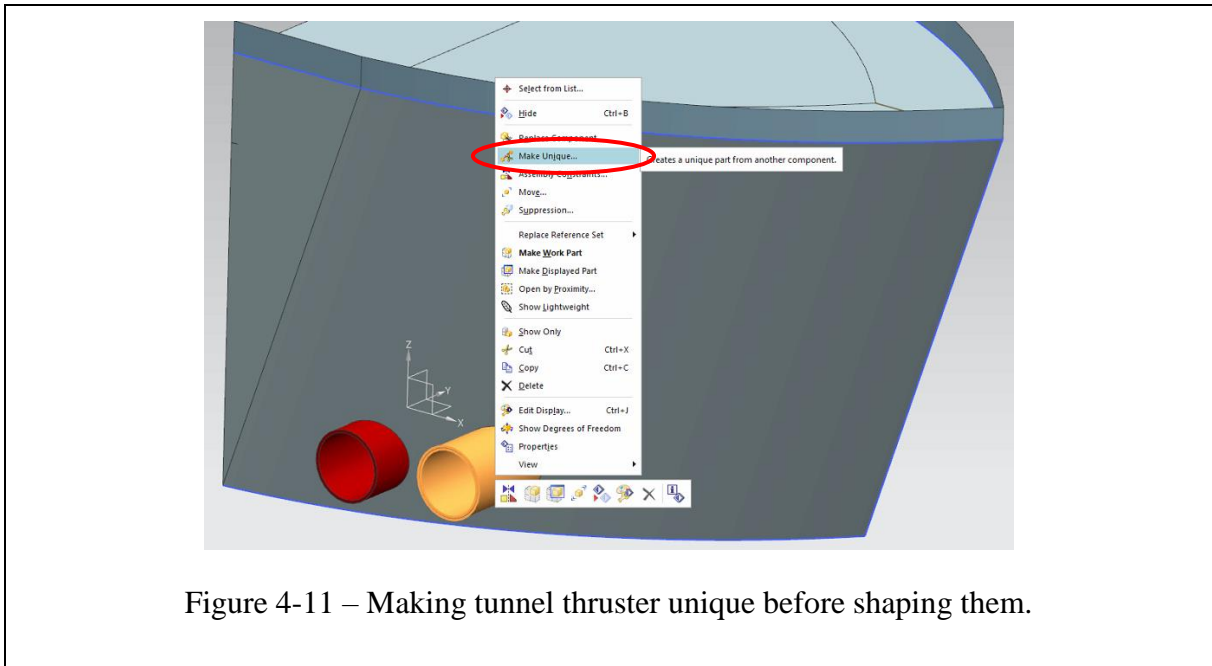
6H: To exemplify this step author has created two footprints; cabin and a switchboard room. The cabin is created as a part while the switchboard room an assembly. The cabin was constraint to a corner, mirrored and patterned to fill accommodation deck (figure 4-12)
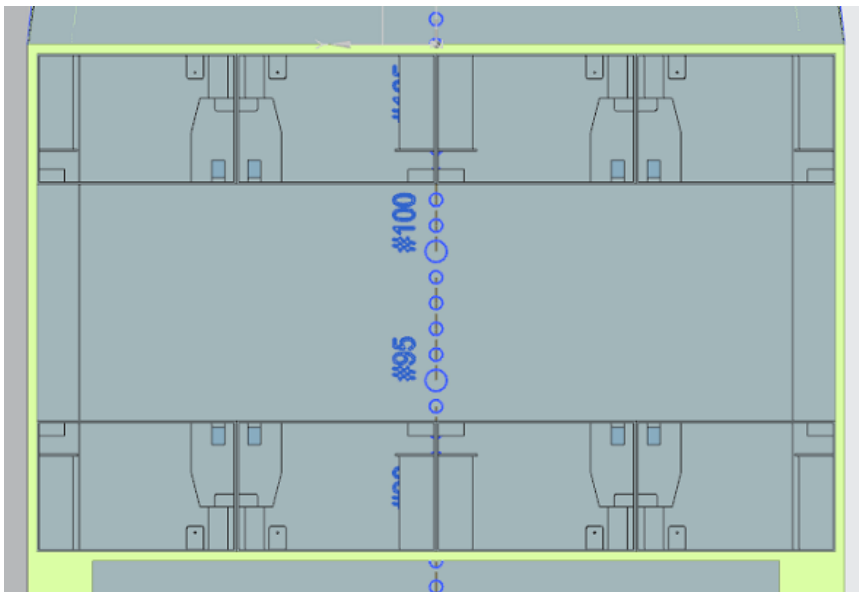
Figure 4-12 – Cabin footprint has been patterned and mirrored into 8 cabins.

6I: Machinery engineer decides that two new 1000 V switchboards is needed to handle the increased electrical requirement of new vessel. These are created directly in the boundary part (see figure 4-13) in the assembly. Additionally, the room area has to be larger to accommodate these.
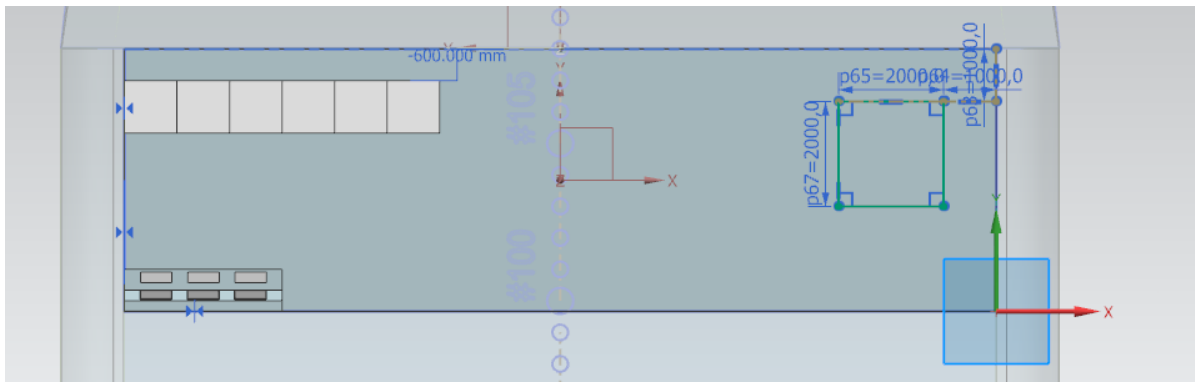
Figure 4-13 – Room lengthened and new 1000V switchboard being added.

6J: First revision of the 3D layout is complete (figure 4-14) and is sent to customer for approval.
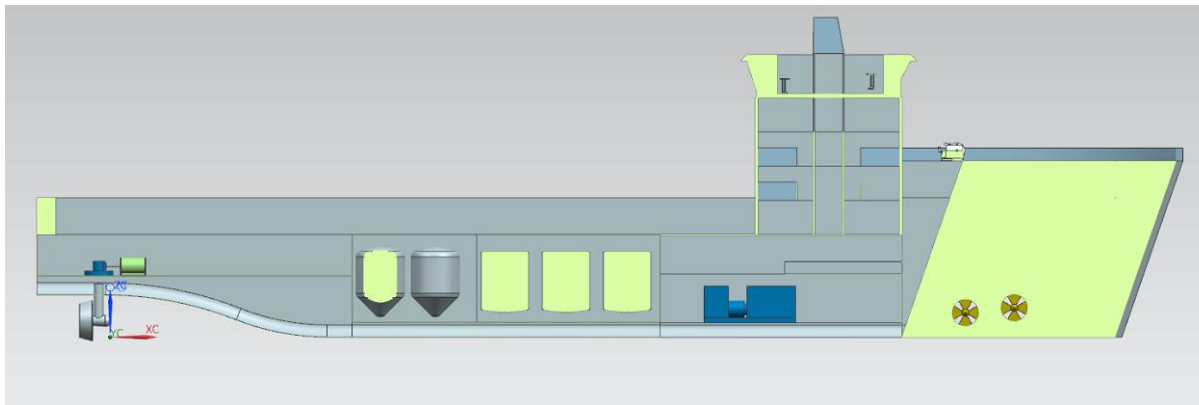
Figure 4-14 – Cross section of vessel 3D model

6K: The design is sent to the customer for approval.

6L: When storing the assemblies, a folder system is created with a modular taxonomy. Folder are created in a similar fashion as given in interfaces in section 3.4.1, the SFI library. Since SFI uses numbers to divide groups, author suggest the other library to use a combination of letters as taxonomy.

6M: Files where stored as suggested in interface (section 4.5.2)(figure 4-15).

Figure 4-15 – Vessel A project folder structure.

Modules where then copied in library folder assemblies. A short code for searching is then added to the name. Project name (in this case Vessel A) must be left on to see which search folder belongs to the module (figure 4-16).

Figure 4-16 – Module assembly file copied, PCR (PSV cargo rail)is used as taxonomy code

Further the sub assembly is copied to the search folder, here it keeps it name since taxonomy is taken care of by the assemblies. Parts can either be copied or stored in reuse library, by using define reusable object.

6P: The 2D drawings are made in drafting application inside NX. First, most GA plans (figure 4-17) are drawn in portrait view. To achieve this author used custom size and typed in dimensions for the sheet selected. Next, getting the profile view was done by "base view" and using front, if datum system is correctly this should be the same in draft mode. Next break views were made of each deck to get plan views. To free up space on the drawing boundary function were used up B- and C-deck, this can also be used if designer only want to show certain areas.
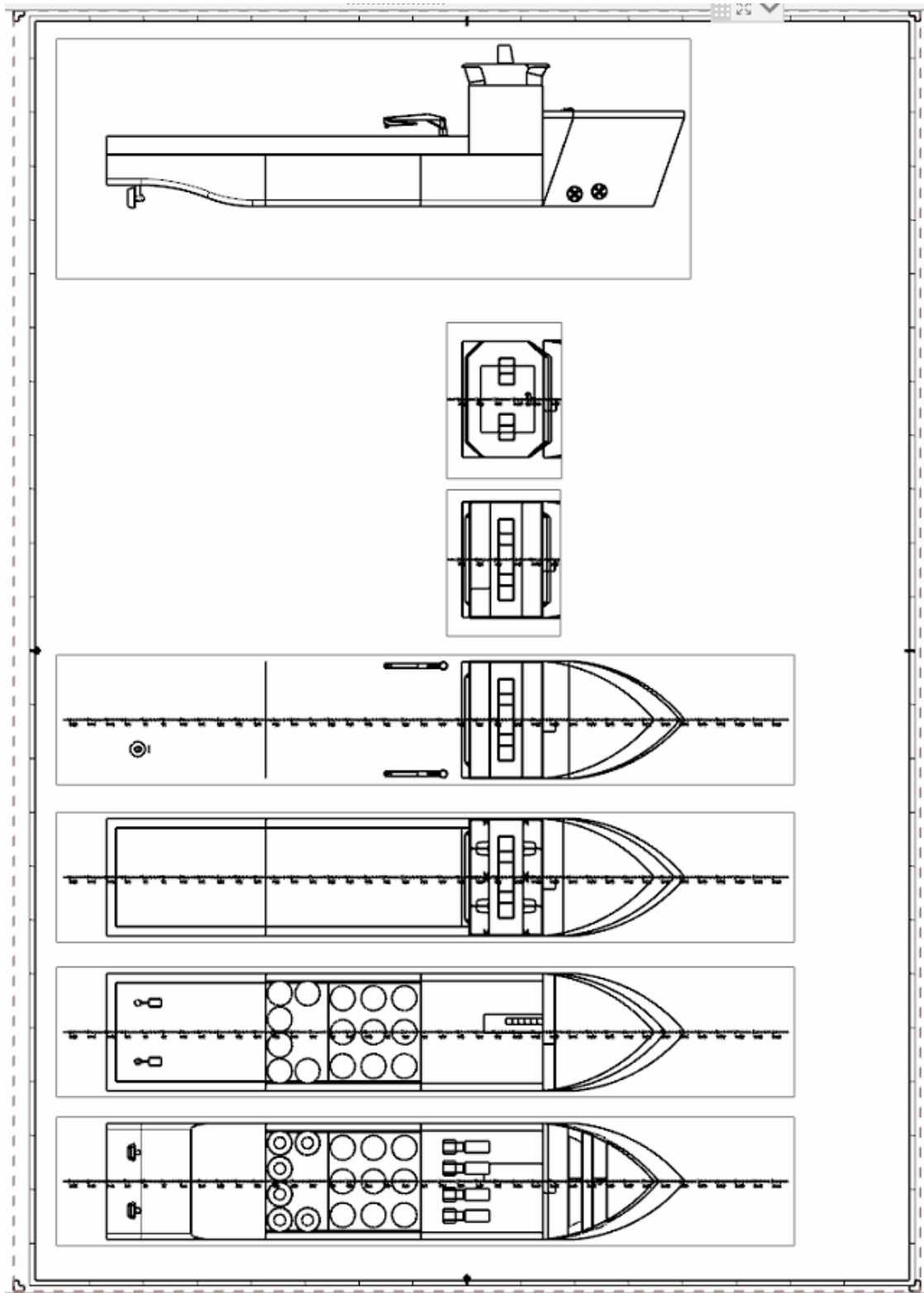
Figure 4-17 – Extracted 2D drawing, using NX draft application.

Creating the 2D drawing was quick, however, some of the content is missing. A benefit is that once the "views" are placed, they may updated with the press of button, to display new changes.

4.7 Application of partial reuse process on vessel B

Vessel B is based on the Bourbon Mistral. Drawings were found at Bourbon webpages (see figure 4-18) containing most of the plan views for the deck. On Vessel A, the focus lie on creating a vessel and some significant large component that would be a part of the concept design. On Vessel B the parts and modules will be reused to test the 3D tool- and the partial reuse process.
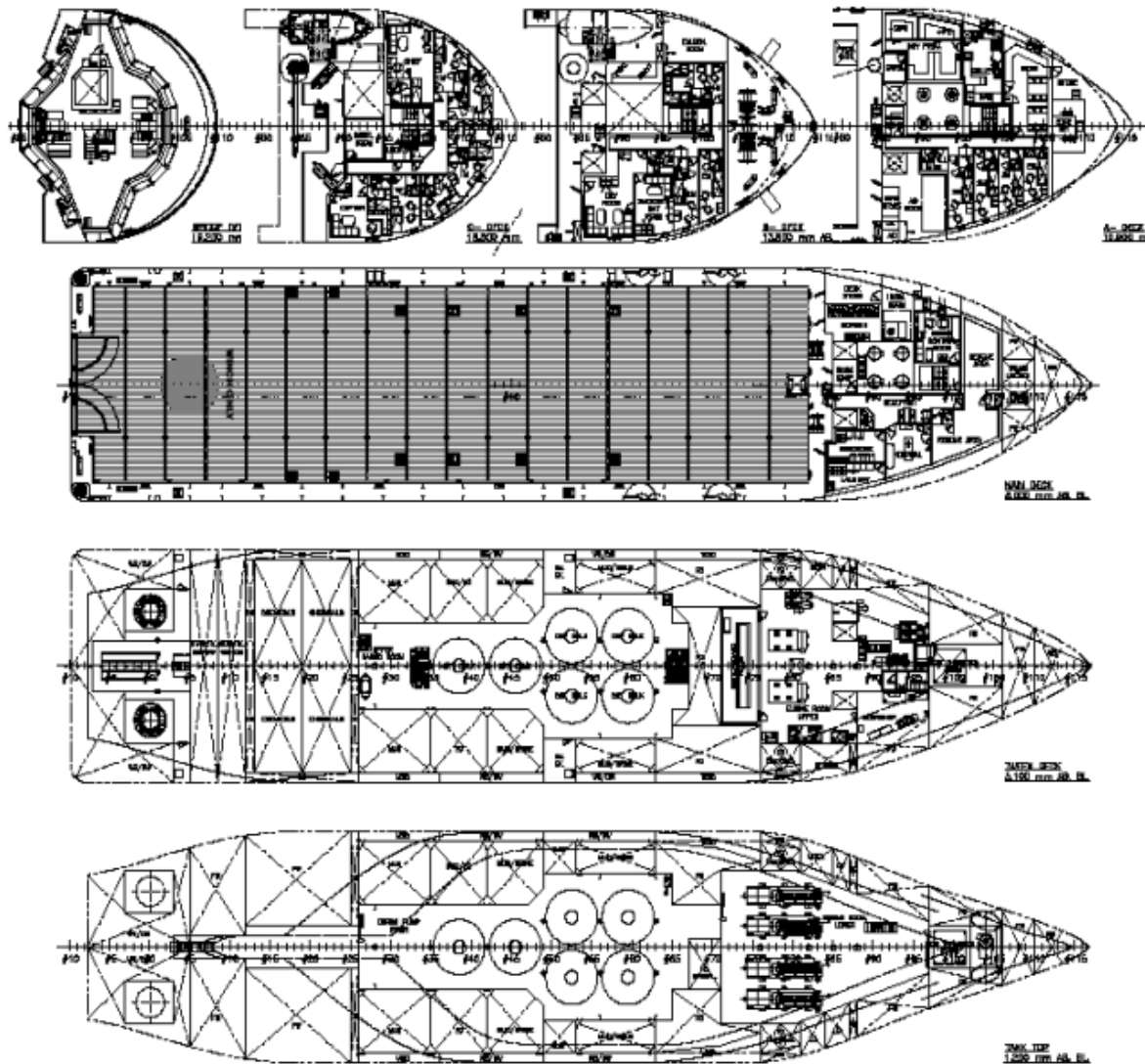
Figure 4-18 – General arrangement of Bourbon Mistral (Bourbon Offshore 2014)
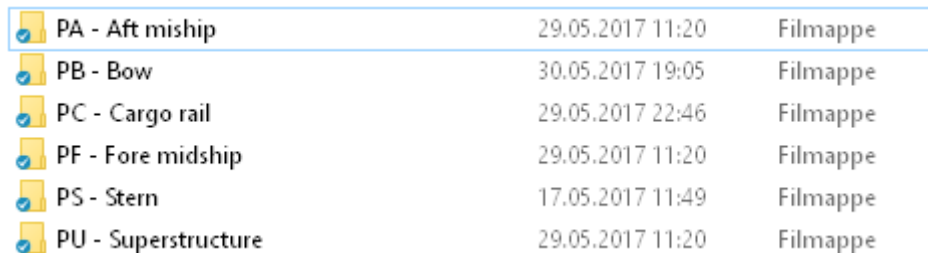
7A: Customer want a vessel similar to the Bourbon Mistral

7B: Vessel new main dimensions will be used, the layout will be similar to vessel GA (figure 4-18)

Table 4-3 – Principal particulars of Vessel B (Adapted from Bourbon Mistral)

Main dimensions	
Length	88,80 m
Breadth	19,00 m
Depth	8,00 m
Frame spacing	0,60 m

7C: First modules are found taxonomy (figure 4-19), in this case modular. Necessary module assemblies chosen are copied to new project folder.

PA - Aft miship	29.05.2017 11:20	Filmappe
PB - Bow	30.05.2017 19:05	Filmappe
PC - Cargo rail	29.05.2017 22:46	Filmappe
PF - Fore midship	29.05.2017 11:20	Filmappe
PS - Stern	17.05.2017 11:49	Filmappe
PU - Superstructure	29.05.2017 11:20	Filmappe

Figure 4-19 – Searching for correct module

Since large changes are planned to the vessel, the sub-assemblies and parts are copied to new project folder. Additionally, a folder is also created for the unique features (parts or assemblies) of the vessel. Search folder are also assigned as shown in figure 4-20.
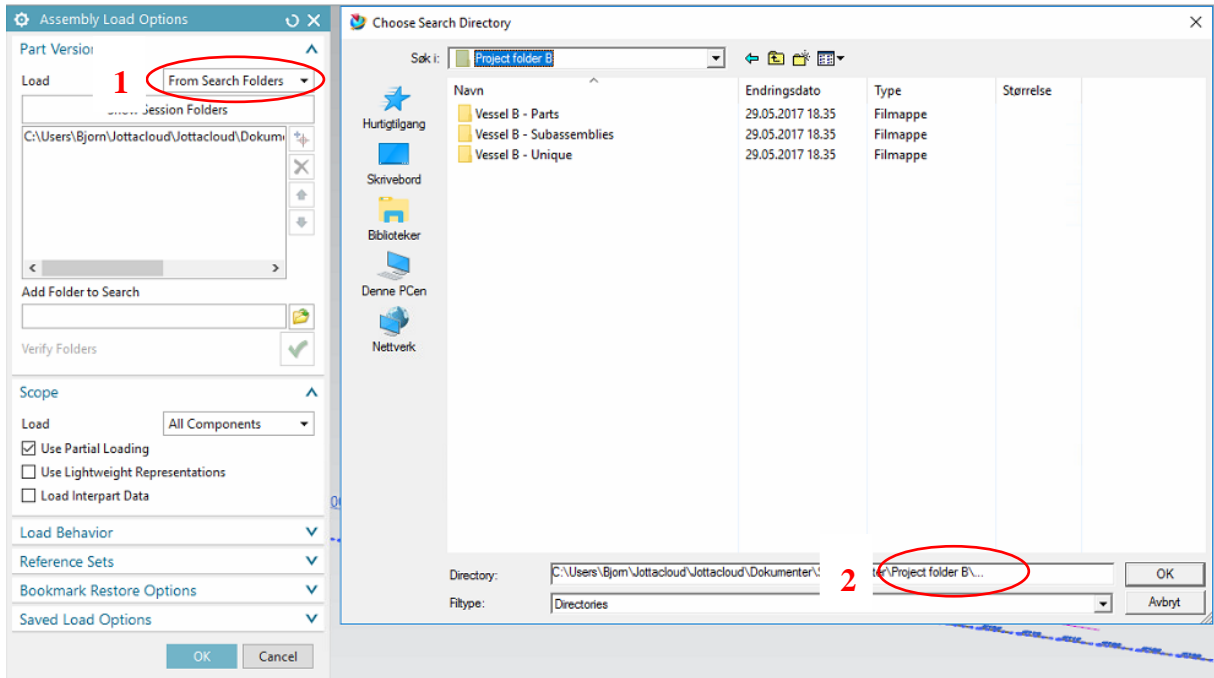
Figure 4-20 – Selecting search folder, 1: load to from search folder 2: \... to include subfolders

7D: To select and load the modules into assembly "add component" was used. The stern was fixed by constrains, and placing the module that the aft perpendicular goes through global datum system. However, when adding the "fore midship" module all the geometry was not fully loaded (figure 4-21). Module part file was opened, and it had the same error. Consequently, the missing geometry had to be redrawn. Loading the rest of the modules components presented no problems.
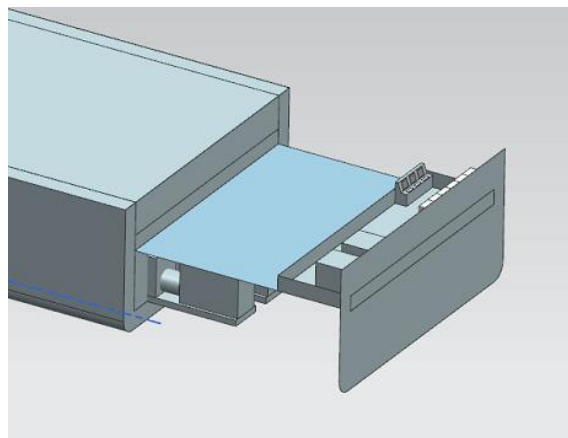
Figure 4-21 – One of the modules not correctly stored; hull and deck is missing.

Vessel A has a conventional bow while Vessel B features a x-bow. Using NX "replace component" to change bow module as shown in figure 4-22, these were exchanged and both position and constraints were kept.
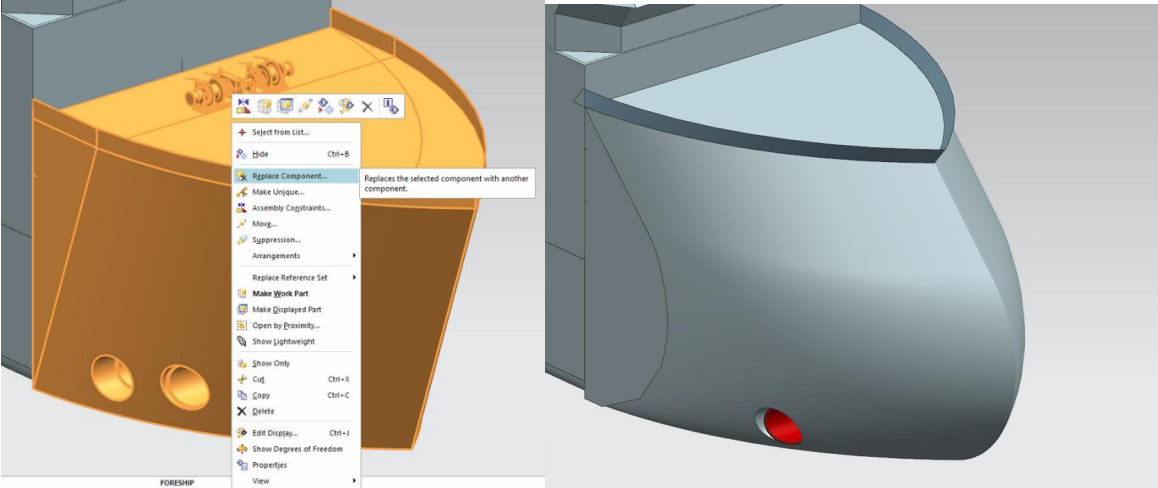
Figure 4-22 – Using "replace component" to change bow module.

7E: The reference system (RS) was added to the reuse library from Vessel A, to place it (a 2D sketch) a plane was necessary. The global datum plane was used and patterned to each deck.

7F: In this step, it is not of interest to find all differences, but rather at least one to present each process:

Cargo tanks: Vessel B has a different tank arrangement than Vessel A (see figure 4-23), this must be changed.
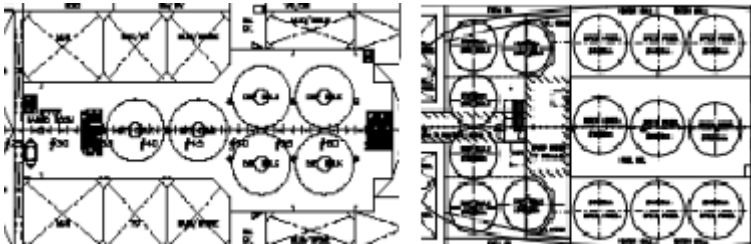
Figure 4-23 – Arrangement of loose tanks (circular), left Vessel B and right Vessel A

Change concept parameters: Vessel B is shallower than Vessel A, these changes must be made modifying boundaries of the modules. The vessel is also shorter, but reducing depth has bigger impact on master model so this was chosen to exemplify.

Switchboard room: this room must be relocated and adapted to new configuration.

Dry bulk tanks: These can now be repopulated (loaded into assembly) and placed according to new arrangement

Crane arrangement: cranes are arranged differently, see GA

7G: Since feasibility study discovered changes, "partial reuse" path must be followed. Since there were several changes, the content folders were copied from the library (see figure 4-24), rather using link and "make unique".
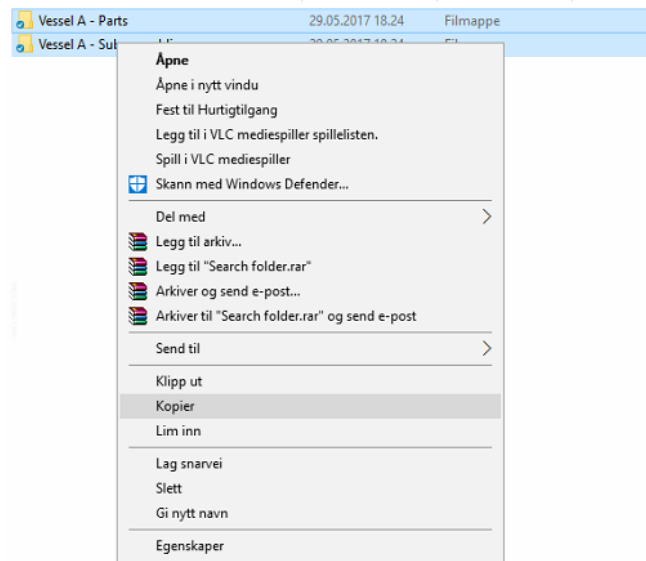
Figure 4-24 – Copying part and subassemblies belonging to module assemblies.

When it is pasted into project folder, user must remember to rename these. Copying the folders allow changes to be made to content without changes being made to library model.

7H: When deleting the tank configuration, NX did not allow to delete the parent pattern. When in an assembly, the component patterns is displayed in the assembly navigator (see figure 4-25) instead of part navigator. This pattern had to be deleted before the tanks.
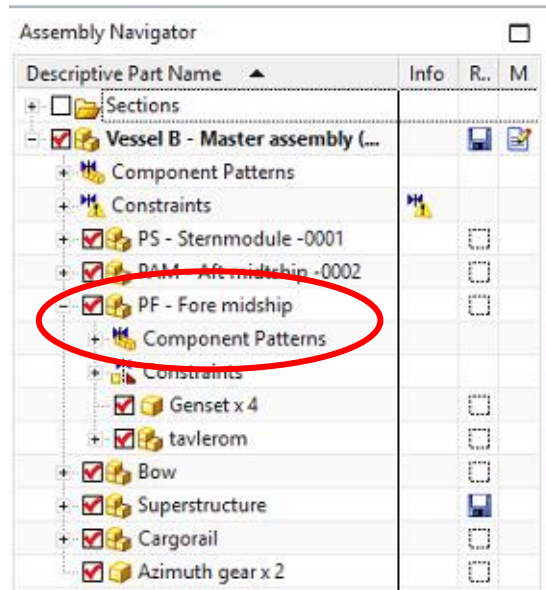
Figure 4-25 – When using NX assembly, changes in pattern features must be done in assembly navigator

Additionally, one of the cranes was deleted as Vessel B has one crane.

7I: When reducing the depth of the vessel, the height of the modules must be decreased. To do this all hull sections must be made unique to avoid changes to the library assembly file. When the height where reduced to 8.00 m, however, this gave several constraint dependency warnings (figure 4-26). The constraints causing problem were deleted and changes made. Redoing the constraints created a lot of extra work, and this step (7I) seemed not to be placed at optimal position in process.
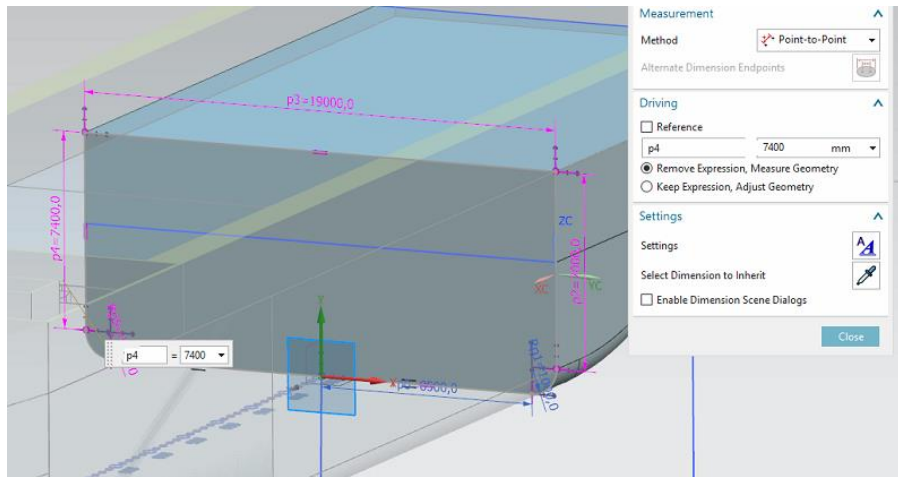
Figure 4-26 – Reducing depth, sketch changes dependent (purple) on constraint.

7J: Vessel B switchboard room is further back and is smaller. First existing constraints were deleted, then room bulkheads redefined and content of the room moved by altering the constraints. However, this process was slower than actually building the room in the first place and should be reconsidered.

7K: The dry bulk tanks were loaded from the reuse library, since these are exactly the same, "use referenced part" was chosen. The part was then constrained and patterned into new configuration.

To change the location of the crane arrangement, the crane was moved into new position, constraints was removed, the crane relocated and constrained into new location.

7L: 3D layout is complete

7M: Customer is satisfied with work

7N: This is the same as 6M

7P: Extract 2D drawing, this was done in similar manner as 6P, however, a section view was also extracted. This allowed easier placement of the deck break views and may done for all vessels. If the view is not necessary, it can be deleted after deck views has been positioned.
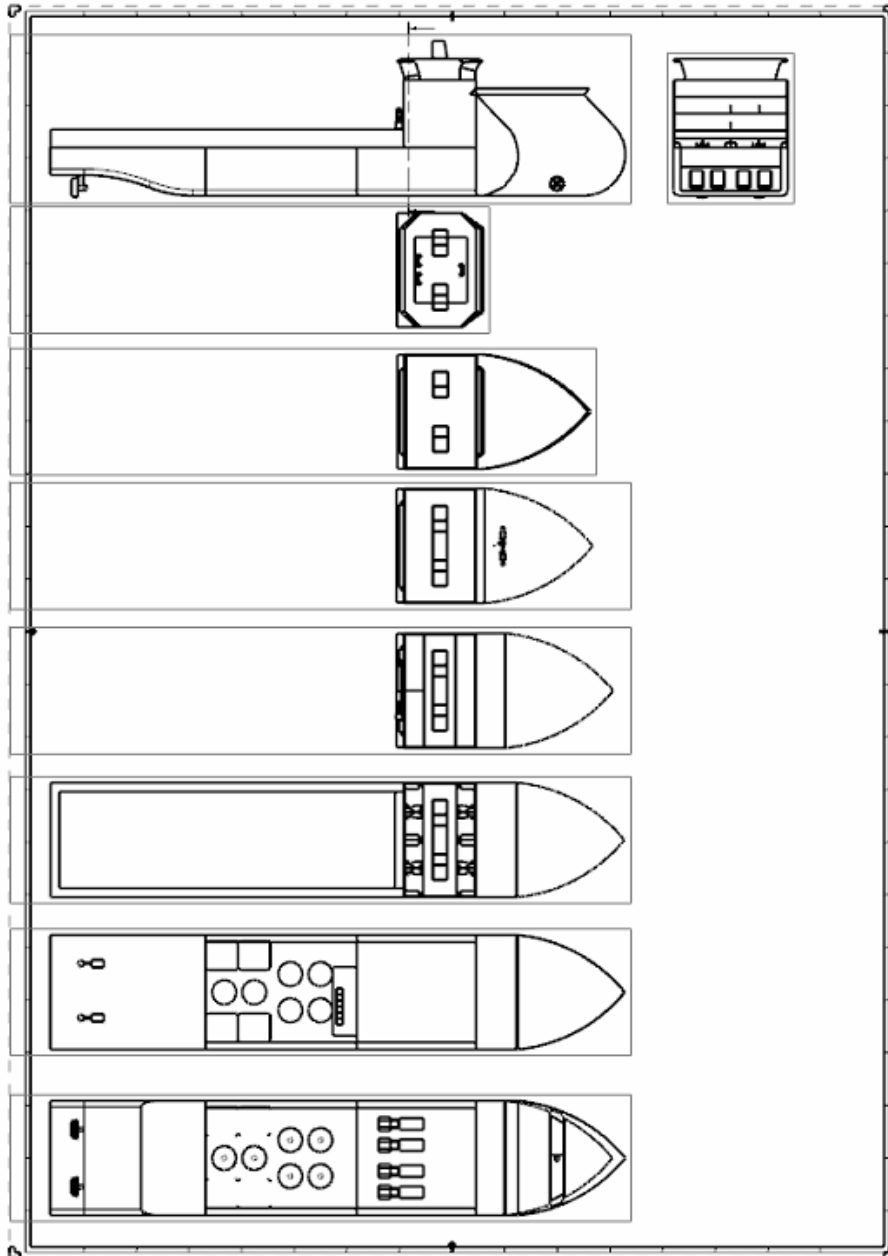
Figure 4-27 – General arrangement of Vessel B

5 Discussion

How to incorporate component into library using taxonomy?

Taxonomy consist of two parts, the attribute and the unique ID. The unique ID was not focused upon, as investigations in NX showed that this had to be written manually for each part.

The attributes are used to identify which type of component it is. This was used to develop a folder system, were components could easily be retrieved from the library. For SFI the number was put in front of the part, to be able to search directly on the component. For assemblies, letters were used to identify the attributes to avoid confusion with the letter from SFI. When storing the assemblies, only top level component was named with attribute letters or numbers. This worked well when having only one vessel to retrieve components from. However, combining modules from several vessels could cause an issue, if sub-assemblies or parts have the same name, as NX rely on names for the links and has to be tested. Therefore the unique ID should solved before introducing the method to a vast database of vessels.

How to deal with interfaces when using the library?

With the built-in reuse library, parts can be stored into different taxonomies by using a folder system. A folder system was set up for the SFI to test this solution, with good results, allowing user several ways to search and easy retrieval of the parts. Additionally, the PLM tool handled the link to the library making this interface handy to deal with single-part components.

When using assemblies the built-in library was less useful, the components sometimes only loaded partially and another approach had to be found. The solution was to manually create a folder system to store the assemblies and use "add component" to retrieve the model. The links with the sub-components had to be done manually in NX by using search folders. The first time all links has to be created, while the second time one can just change a setting. One issue the case-study shown was that if a sub-assembly or part of the components was renamed, NX will not recognize it. Therefore, company should have a strict naming regime. Additionally, the system has not been tested with a library with more than one vessel. Regardless, the method allowed quick retrieval of components and when using it in the case-study proved a useful tool if components retrieved from library consist of several sub-assemblies.

How to deal efficiently with changes in 3D component(s) when re-using it for different systems/ stages?

When testing reuse process capability to adapt to the new layout (general arrangement), this was tested with five examples:

- Changing bow module
- Changing the depth of vessel
- Modifying and relocating switchboard room
- Changing the arrangement of dry bulk tanks
- Altering the crane arrangement

Changing bow module: The bow module was changed using "replace component", which changed it instantly and kept both position and constraints. In this situation, vessel modules had same cross section, which probably simplified the process. Using this function, one can choose pick and choose models into getting a good starting point. This can save a lot of difficult changes and time.

Changing depth: When changing the hull modules depth, several dependency warnings were given. This was between various sketches and constraints, and therefore, sorting these out made this kind of change a time-consuming process. To simplify it, a solution could be to move the step, so that these changes are made when the fewest number of constraints are defined. This means moving step 7I: Change external boundaries aft of step 7D: Select modules. The reason this step was placed late in the process is that at that time designer will have more information. However, this is not the same for the external boundaries, since these are given in the 7B: concept parameters.

Modifying and relocating switchboard room: To modify the switchboard room to requirements the constraints had to be deleted, the room moved and new constraints had to be placed to fix the room position. The same process had to be done to the content. In the end, it seems easier to create the room from scratch, as the switchboard could be retrieved reuse library. Therefore, designer should consider which approach to be used, adapting the existing room creating a new one. Author suggest that if the compartment that needs need re-location, it should just be deleted and recreated. If only repositioning of the content is needed it is better to adapt the room.

Adapting tank and crane arrangement: Both these changes can be done in similar ways, but to test both tank arrangement where deleted and repopulated from reuse library. The crane arrangement was repositioned by changing the constraints. For reuse purposes relocating the part as was done with the crane proved to be the fastest way. However, this has effects on the assemblies the crane and tanks are a part of. If the higher level component needs changes, the

approach of the tank arrangement may prove useful, as it reduces number of constraints which could make this change more difficult.

How can we combine 2D- and 3D drawings using PLM tools?

Using the draft application within the PLM tool, setting up a GA drawing of the vessel was done in matter of minutes. When changes were made to the model, designer can use "update views" and the changes of the drawing were updated immediately. However, a GA drawing should have much more details and the method should be tested on a vessel which is in the end of the concept phase. If the approach works for a fully detailed model, it can be a useful tool to generate necessary drawings.

6 Concluding remarks

3D CAD tools have become more and more popular nowadays, allowing amongst other better visualization of product, computer analysis of design etc. Even so, in ship design, it is still combined with 2D drawings in the conceptual stage. At this point, developing the design in full 3D is not justifiable, since shipbuilding companies almost consistently use a no-cure no-pay principle at this stage. Vessel models and 3D software is just too complex and time-consuming. This causes the situation were a lot of rework has to be done, since these drawings are turned into 3D models if contract is won. A method is needed to support the process and reduce the time it takes. PLM is a holistic business approach which promotes amongst others reuse of information. Can PLM simplify the 3D design process for the use in conceptual ship design?

The main goal of this research is to create a framework where a virtual prototype can be built from existing components. The way the author wants to achieve this is by creating a library using PLM tools, where the component can be stored and reused in other projects easily. Several aspects will be studied towards giving the library better application for a maritime use.

The dissertation is based on the action-based research design. This method was chosen, since the thesis presents an intervention in ship design processes. Data was collected via field trips to Ulstein, and from this a flow chart of the existing method to develop a general arrangement was found. Then bottlenecks of the process and how a 3D library can assist this process where identified. Using this information a two new approaches were developed; one where the ship is built in 3D and components stored in component library and one where these components are reused. From the flow chart mapping of the processes, interfaces with library was identified and procedures how to deal with them established. Finally, the methods developed was tested out

by two case studies, engine room and platform supply vessel cases, to test the approaches and identify benefits and challenges.

Sorting the library by using taxonomies allowed easy retrieval of the desired components and linking with library vessel kept all sub-assemblies and parts which were stored in the module. This allowed fetching of parts and assemblies of existing designs, which designer can use to get a good starting point. The first time was meticulous job as the links need to be set manually, but further on it was done in the matter of seconds by changing a setting. If the vessel still needed changes to meet requirements, the case showed that small changes like parts or low level assemblies could be done quickly by either replacing- or adapting them. Changes high-level components, such as the module, was difficult to implement due to existing constraint and sketch dependencies. Finally, when model was complete, 2D draft application allowed easy extraction of deck-, section- and other drawings.

Therefore, it can be concluded that while there are still elements to handle, PLM shows promise in providing a tool to reuse vessel components in the conceptual design stage. This thesis only looked into a few of the aspects in 3D reuse in ship design in one step of the lifecycle. PLM is about integrating data from all the stages and processes together, and the 3D components should be combined with data from these connecting the models with e.g. specifications, manuals, BOMs etc. Additionally, it needs to be tested with a real database which contains models from several vessel and will be expanding with time.

6.1 Future work

The reuse potential is clearly there, however, there are still some issues that needs work.

Teamcenter is a software that can be integrated with NX and provide amongst other product data management. Looking into how this software can provide to process when using the reuse library, e.g. BOM- and taxonomy management, if it can simplify the links etc. Using the connection between these tools can probably unlock several benefits.

Testing out the reuse process when using the library in 4GD. Much of the problems when changing the parts lay in the existing constraint management. Several constraints had to be delete to allow the change of high-level parts. Firstly, this created a lot of re-work which takes time, secondly all constraint may not be replaced which, and can cause errors in future work on the model. 4GD uses geometrical constraints rather than the traditional between parts and assemblies, which should simplify the changes.

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Appendices

Appendix A: Unplanned reuse process (El Hani et al., 2012)
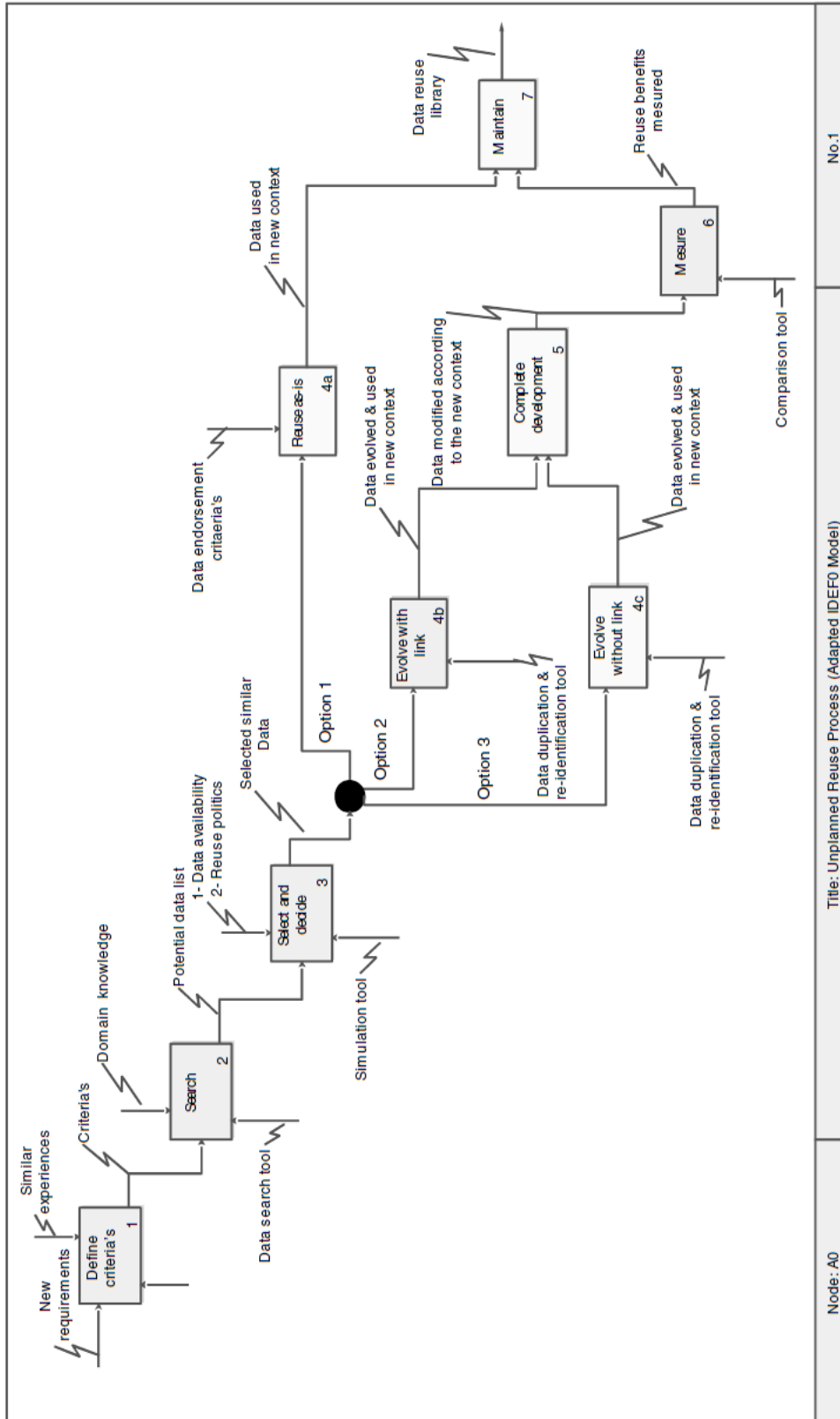
Title: Unplanned Reuse Process (Adapted IDEF0 Model)

Node: A0   No.1

Planned reuse process (El Hani et al., 2012)

Appendix B: Simplification of 3D CAD data (Kwon et al. 2015)

Simplification of
3D CAD assembly data

Import assembly data
(Geometric information)

Non-geometric
information
(Port etc.)

Calculate feature volume

Detect outer boundary features

Detect internal features
(part & feature level)

Detect adjacent features

Prioritize and rearrange features

Evaluation metrics
considering requirements
from the shipbuilding industry

$$F_i = N_i \cdot (P_i + C_i)^{N_i}, \quad (1)$$

where

$$P_i = P_a^i + P_b^i + P_c^i, \quad (2)$$

$$C_i = w_a \cdot C_a^i + w_b \cdot C_b^i + w_c \cdot C_c^i + w_d \cdot C_d^i, \quad (3)$$

$$w_a + w_b + w_c + w_d = 1, \quad (4)$$

Simplify assembly data

Set Level Of Detail

Merge and export assembly data

Appendix C: Conference paper

3D Reuse in PLM for Conceptual Ship Design

Bjørn Tornes[1]

Abstract

This paper will discuss PLM possibilities to introduce 3D design into conceptual ship design by shortening time used to develop the 3D model by reusing existing design components. The paper present theory about PLM related to the research, the domain of 3D design and ship taxonomy. The method chosen was a combination of action-based research design and case study, using a quantitative approach. In the case, two existing PSVs were replicated in a simplified way by using the suggested approach. The first vessel was designed using "no-reuse" method, where all features and equipment are designed to fit the vessel. The second vessel reused the components of the first and adapted them to fit the new requirements. The conclusion was that while there are still elements to handle, PLM shows promise in providing a tool to reuse vessel components in the conceptual design stage.

Keywords:

PLM, product lifecycle management, 3D reuse, conceptual ship design, virtual prototyping

1 Introduction

Ship building is an industry with heavy competition. As the traditional maritime shipbuilding industry has migrated from Nordics and Europe due to high salaries, strategies must be developed to keep what is left, design and building of advanced ships (see figure 1-1). To do this, shipbuilding and offshore engineering companies make great investments, both in computer aided tools and IT solutions for faster and better manufacturing. A typical company have several databases to store all information generated through the process. Still, shipyards are struggling to meet deadlines and liquidated damages are a common word within the industry. Now on top of this the oil prices have bottomed and well-paying customers, has

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become just the opposite. Therefore, to stay competitive and not lose the rest of the remaining market, an evolution in the companies is needed [1].

PLM is a holistic business approach, which promotes reuse of information, standardization, and strategic use of IT tools to increase innovation. It enables all parties involved to work jointly, with the latest information, no matter where they are. This is done by creating an product information backbone, which integrates people, data, processes and business systems through the product whole lifespan, from conceptual stage to disposal [2], [3] [2], [3].

3D CAD tools have become more and more popular nowadays, but in ship design it is still combined with 2D drawings in the conceptual design stage. The complexity of 3D ship models and -software makes it a very time consuming process. At this point, developing the concept design in full 3D usually is not justifiable since shipbuilding companies almost consistently use a no-cure no-pay principle in conceptual ship design. This causes the situation were a lot of rework has to be done. Concept department create 2D drawings of the vessel, and if contract is won, these drawings are turned into 3D models [4]. PLM tools gives a way to simplify this process through data re-usage. When designing the concept, old models can easily be re-used since all data is stored within the common and easily searchable database. The integration between PDM and CAD application creates a handy tool to handle indexing of the data generated in the process [5]. However, since neither of these are typically created for shipbuilding purposes, which is design and manufacturing of large-scale products, certain challenges arise [6].

The main goal of this research is to simplify the 3D design process for the use in conceptual ship design with PLM tools. The way the author wants to achieve this is by creating an example library using PLM tools, where the component can be stored and reused in other projects easily. Several aspects will be studied towards giving the library better application for a ship design.

2 PLM

2.1 PLM definition

According to Stark (2015), the typical scenario of today is that each department has their own database(s), which lead to different versions of the same data and information silos. This ends up in work being done twice, redundant functionality developed, automation that only works for some processes. Companies also got ineffective fixes and excessive product recalls. In the end this lead to lower revenues and higher product costs, this is what PLM seeks to solve. This

is done by creating a product information backbone, which integrates people, data, processes and business systems through the product whole lifespan, from conceptual stage to disposal (see figure 1) (PLM Techology Guide 2008).
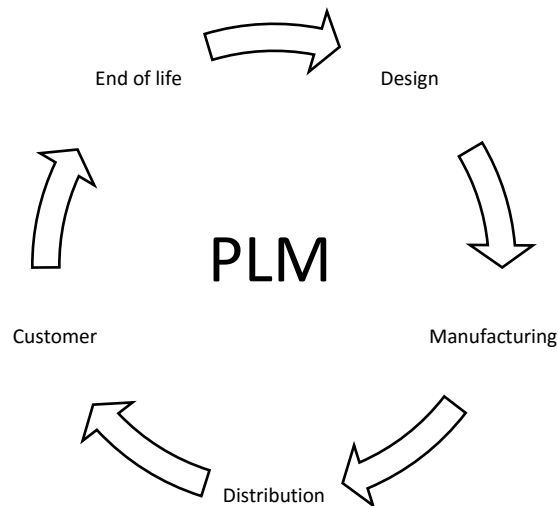

Figure 1: PLM general lifecycle of products [7].

2.2   PLM reuse

[8] has investigated product data reuse in project development from a user perspective. They have developed a framework with several steps to improve data reuse, tested its performances in several user cases and discussed the challenges. From the research, two reuse processes are proposed;

I.   Unplanned (ad hoc) reuse (user driven) meaning the developer do it on his/her own decision and is typically small in scale.

II.   Planned reuse (business driven) is usually reuse of large scale, e.g. the maritime company developing a vessel family. This type of reuse is typically engaged from management, and is generally about trying to reduce cost.

2.3   PLM in ship design

Figure 2 present a simplified vessel value chain, from first idea to decommission. Through PLM methods, a way of dealing with this huge amount of data generated in the vessel products life cycle can be provided. There are several ways of achieving this; information indexing, database management, product decomposition and –analysis and project management [9].
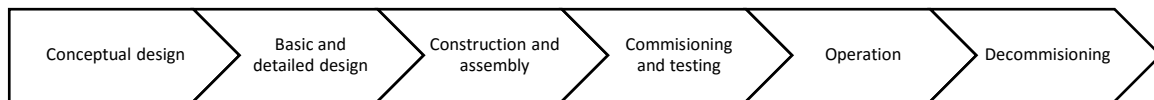
Figure 2: Simplified value chain of a vessel [9].

3   3D design

CAD is any design activity, were computers are used to develop, analyze or modify an engineering design. Implementing CAD has several benefits; it increases the productivity of designers due to the software helping visualize the products. Additionally, it allows computer aided engineering analysis of the design and makes it easier to include design errors control measures. Finally, it provides better drawings and designs and allows for easier standardization and can create databases useful for the manufacturing like BOMs, dimensions etc. [10], [11]

3D solid modelling which is the method most used today. This has two under-categories; parametric- and direct (explicit) modelling. Parametric approach of 3D modelling (see figure 3) has become the industry standard for mechanical CAD tools [12].

Parametric modelling consists of two approaches, an algebraic and an AI method. Using this method enables a designer to *"easily design a part by providing a small number of values of specified parameters instead of the full, enumerated description"* [13].
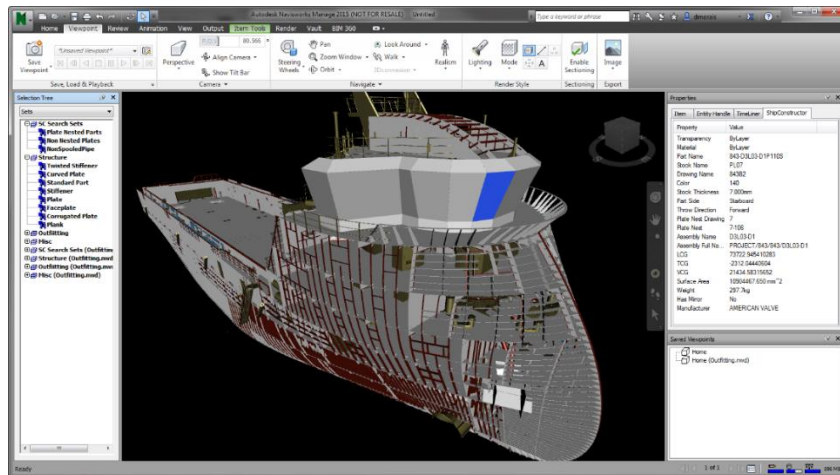
Figure 3 – Vessel designed in 3D CAD environment [14]

4   Ship taxonomy

4.1   Ship design

The ship design process start with the sales department capture a customer request for the build of a new ship or a tender, a company that offers a contract for a ship designed purposely to the mission [4]. The preparation stages of the design is often called initial design and consist of three stages; concept, preliminary and contract design. The process is iterative and the designer will balance depending attributes and features of the design [15].

4.2   Taxonomies

SFI grouping systems has become the industry standard taxonomy when creating a division for systems and components on ships. This taxonomy is based on the functional aspect where, the ship is grouped into main group, group, sub group (see figure 2-6) [16]. After the group numbers, each component is given a unique ID. A general arrangement for project 3517, would look like this: 3517-101-001.

[6] discusses the three taxonomies supported natively in Siemens NX 4GD module; functional, modular and spatial. In short, functional taxonomy divides components after their function (HVAC, piping, propulsion systems etc.). Modular division of a ship is broken down into modules (hull, superstructure etc.), sub-systems (bow, stern etc.), systems (thrusters, ballast) and components (propeller, motor etc.). Spatial uses divisions into zones e.g. decks, rooms etc. She suggests that traditional 3D CAD modelling (3rd generation) is very dependent on the taxonomy and should be decided before vessel model is created.

5 Case study

5.1 Case introduction

This case will be based on two PSV's, namely Viking Dynamic (Vessel A) and Bourbon Mistral (Vessel B). Vessel A will be designed using "no-reuse" method, where all features and equipment are designed to fit the vessel. When completed the modules and equipment will be stored in a library and Vessel B will be created reusing these either directly or adapted. At least one example of each processes in flow chart will be shown to test functionality.

5.2 No reuse approach

This approach is used when a ship is designed in 3D without using the component library the process uses [8] unplanned reuse as a framework to build upon. It is developed to fit the library interface, if the ship components is to be stored in the library. The approach is present in figure 4.

1A: The main input for the design process is the customer requirements

1B: Design team interpret customer requirement and define the concept parameters, e.g. main dimensions, cargo capacity etc. Design team defines key features of the vessel, should it have a x-bow hull design, should azimuths or conventional propeller be used etc.

1C: Designer must now select the taxonomy of the vessel, e.g. modular, physical etc. According to [6], this choice has to be taken at the start when using traditional approach.

1D: Hull designer can now make the hull model, this can be done either in same software or another hull application is used and model is imported into NX.

1E: designer establishes framelines in drawing.

1F: decks are created, then critical bulkheads, e.g. double hull, collision bulkhead etc.

1G: Inner part of vessel must is separated by bulkheads into compartments.

1H: Compartment is filled with necessary content, e.g. a dayroom needs sofas, tables, TV etc.

1I: 3D layout is now complete

1J: first revision is sent to customer for approval.

Yes: Go to 1M

No: Go to 1L

1M: Designer should now consider which components to store in reuse library

1L: Revise those steps that are necessary to fulfil customers need

1K: Extract 2D drawing, meaning profile, plan for each deck and necessary section views

1N: If designer cannot find equipment within library, the supplier is contacted for drawings

1O: Equipment models stored using SFI taxonomy

1P: Extract the necessary 2D drawings from 3D model

5.3   Partial reuse approach

This approach is suggested when company want to build a vessel from the component library. The process builds on [8] planned reuse approach and the following steps are suggested, see also figure 5):

2A: same as 1A

2B: same as 1B

2C: search library for assemblies via desired taxonomy, this can e.g. be a structural division to search for suitable modules used to create the vessel

2D: designer chooses desired modules and load these into vessel's master model and constraints them.

2E: establish reference system.

2F: in the feasibility study designer evaluate what must be changed (if anything) to meet requirements of the new vessel, e.g. deleting parts, adapting components etc.

2G: with the feasibility study as basis, designer can now make the decision whether module(s) can be reused "as is" or that they need changes. This assessment has to be done for each module.

Yes: module can be reused "as is", go to step 2L

No: module need changes (partial reuse), go to step 2H

2H: module did not fulfil given criteria, and designer must delete unnecessary population; this can be different equipment etc. This is done to avoid errors when conducting subsequent steps.

2I: This would for example happen if main dimensions of the vessel are changed. Outer dimension is changed first and functional boundaries secondly. If this is the case, user must make impacted modules unique.

2J: Designer must redefine bulkheads of compartments to fit the new concept layout.

2K: Repopulate the modules, starting with most critical equipment first, towards less important.

2L: Same as 1J

2M: Is customer satisfied with the total design?

Yes: Go to 2O

No: Go to 2N

2N: designer must redo all impacted steps
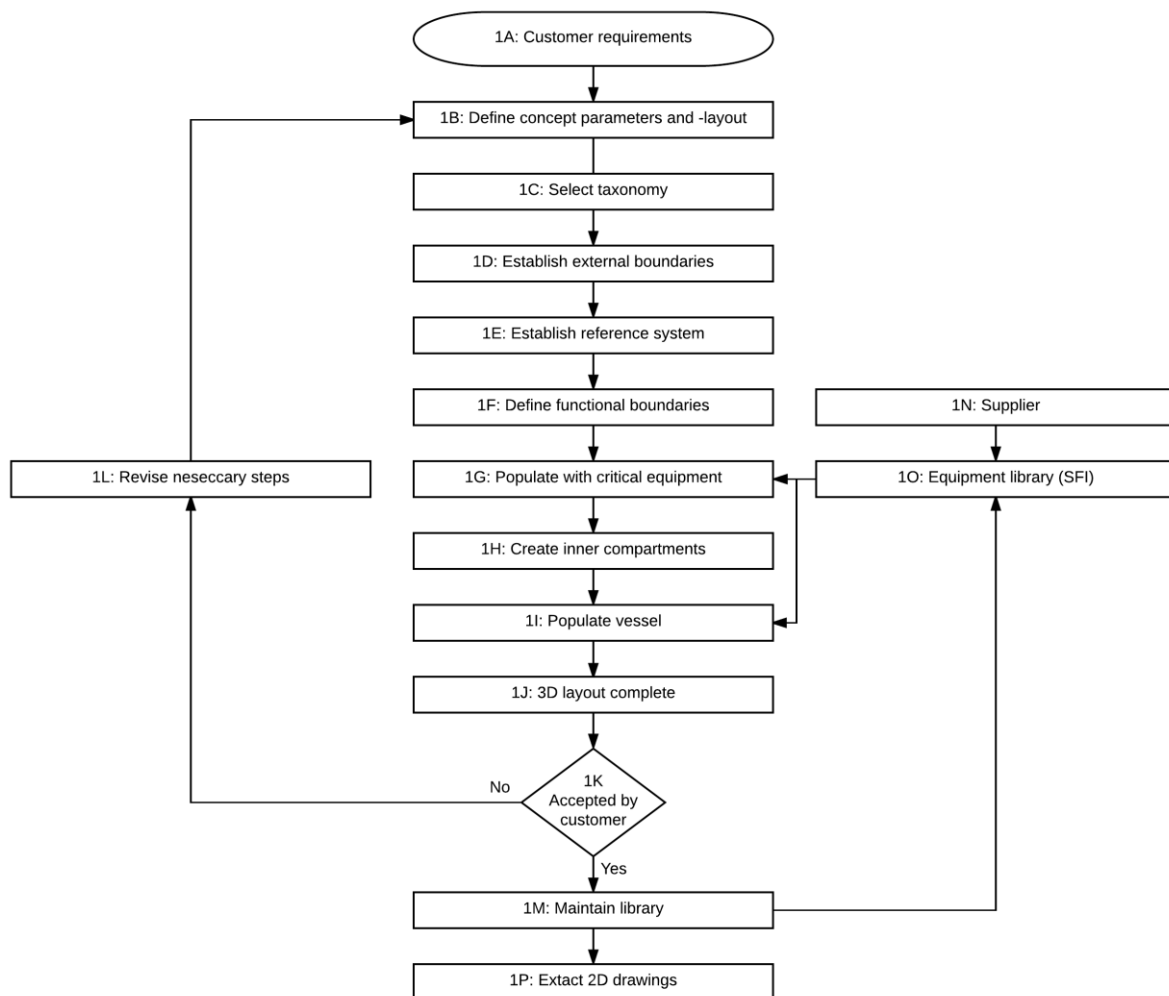
2O: same as 1M
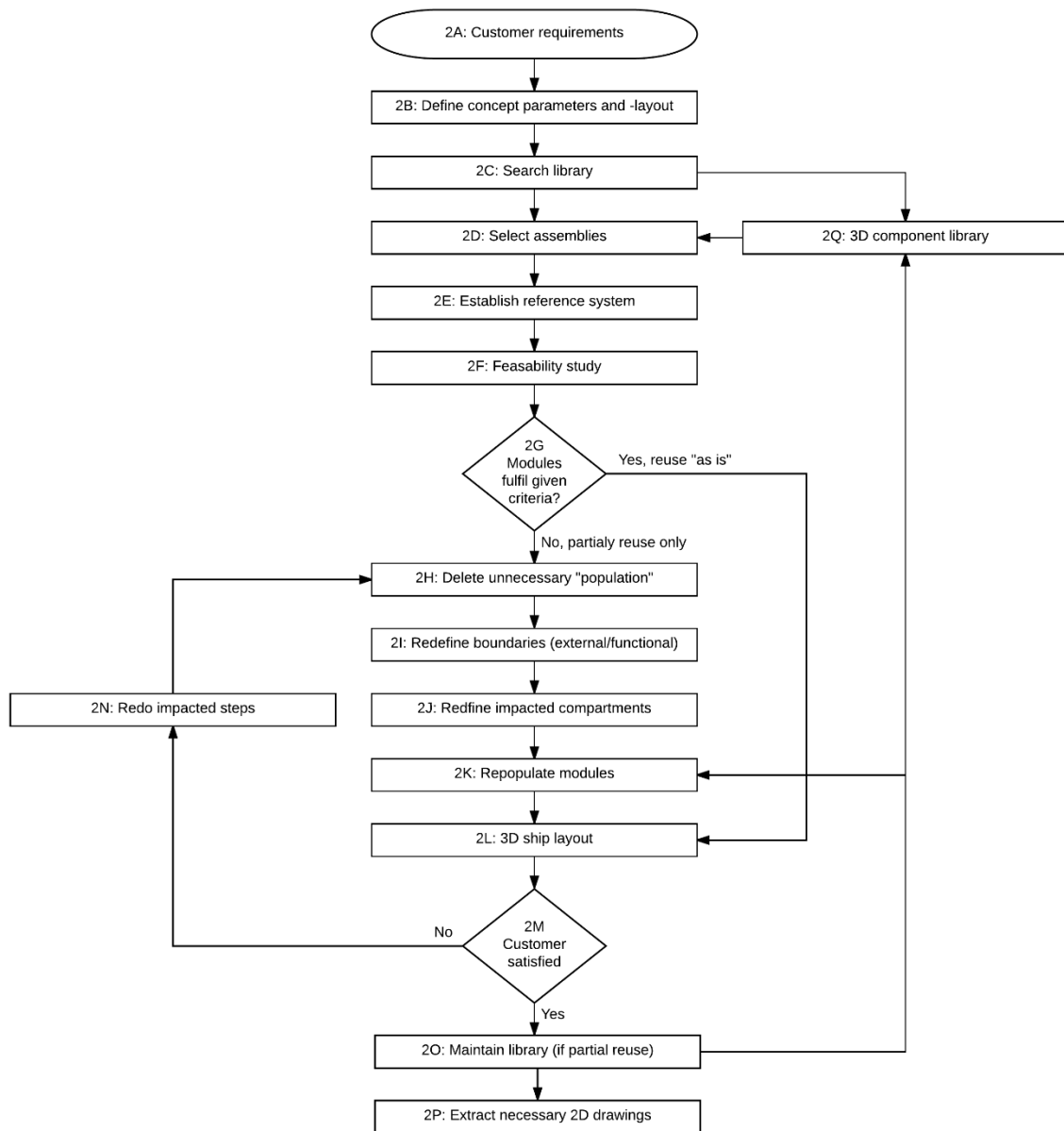
2P: same as 1P

Figure 4 – No reuse approach

Figure 5 – Partial- or full reuse approach

5.4 Interface - Input to library

When maintaining a library using several levels of assemblies, a more extensive method to maintain the library is needed.
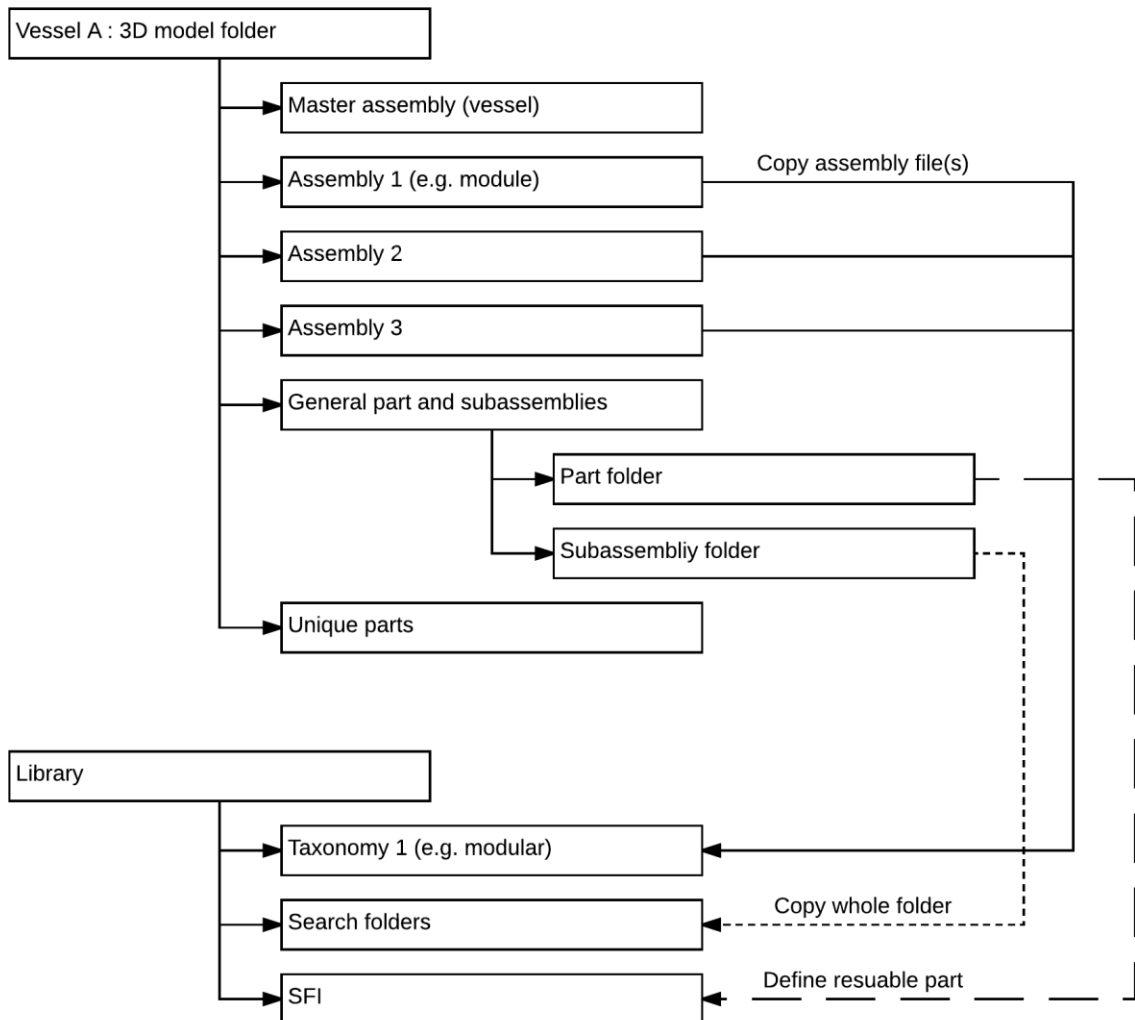
Figure 6 – Interface for maintaining library when developing full vessel model

First you have a master model structure assemblies and part to the vessel and a folder with unique part or assemblies (see figure 6). These are specific for this vessel and should not be copied to library. Further, author suggest to divide into assembly that build up the ship structure, e.g. a module. These should be copied to a taxonomy structured library. Next, all the subassemblies that build up the module assemblies should be stored in a content folder. These are connected to the module via name including project number (e.g. Vessel A). The parts should be stored via "define reusable part" in NX reuse library.

5.5 Interface - Library output

This is the procedure for loading assemblies that make up the ship, but the procedure (figure 7) is the same for other assemblies stored in library.
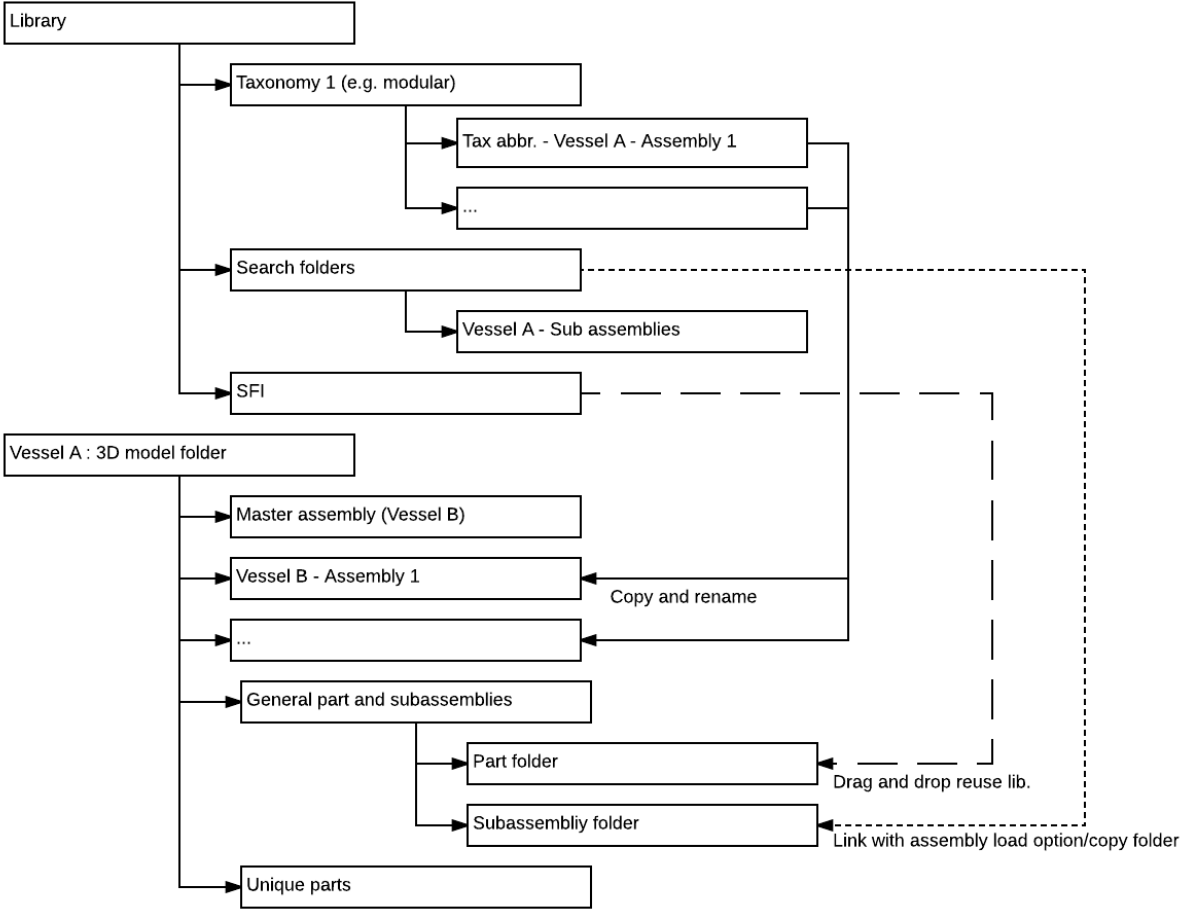
Figure 7 – Approach for loading assemblies from library

First the assemblies should be copied and renamed after project number or other unique name. Then assembly load options should be setup with the folders from the previous folder to fetch the sub-assemblies. NX remembers the name so only folder is required, if there are subfolders using "\..." (Slash, triple dots) NX will include those as well. When link (search folder) has been established, user can use "saved as" option next time software is opened.

If parts have been correctly stored in NX reuse library, these should load automatically. If there are parts or assemblies not showing when process is complete, user may need to activate these in the assembly tree.

6 Discussion

How to incorporate component into library using taxonomy?

Taxonomy consist of two parts, the attribute and the unique ID. The unique ID was not focused upon, as investigations in NX showed that this had to be written manually for each part.

The attributes are used to identify which type of component it is. This was used to develop a folder system, were components could easily be retrieved from the library. For SFI the number was put in front of the part, to be able to search directly on the component. For assemblies, letters were used to identify the attributes to avoid confusion with the letter from SFI. When storing the assemblies, only top level component was named with attribute letters or numbers. This worked well when having only one vessel to retrieve components from. However, combining modules from several vessels could cause an issue, if sub-assemblies or parts have the same name, as NX rely on names for the links and has to be tested. Therefore the unique ID should solved before introducing the method to a vast database of vessels.

How to deal with interfaces when using the library?

With the built-in reuse library, parts can be stored into different taxonomies by using a folder system. A folder system was set up for the SFI to test this solution, with good results, allowing user several ways to search and easy retrieval of the parts. Additionally, the PLM tool handled the link to the library making this interface handy to deal with single-part components.

When using assemblies the built-in library was less useful, the components sometimes only loaded partially and another approach had to be found. The solution was to manually create a folder system to store the assemblies and use "add component" to retrieve the model. The links with the sub-components had to be done manually in NX by using search folders. The first time all links has to be created, while the second time one can just change a setting. One issue the case-study shown was that if a sub-assembly or part of the components was renamed, NX will not recognize it. Therefore, company should have a strict naming regime. Additionally, the system has not been tested with a library with more than one vessel. Regardless, the method allowed quick retrieval of components and when using it in the case-study proved a useful tool if components retrieved from library consist of several sub-assemblies.

How to deal efficiently with changes in 3D component(s) when re-using it for different systems/ stages?

When testing reuse process capability to adapt to the new layout (general arrangement), this was tested with five examples:

- Changing bow module
- Changing the depth of vessel
- Modifying and relocating switchboard room
- Changing the arrangement of dry bulk tanks
- Altering the crane arrangement

Changing bow module: The bow module was changed using "replace component", which changed it instantly and kept both position and constraints. In this situation, vessel modules had same cross section, which probably simplified the process. Using this function, one can choose pick and choose models into getting a good starting point. This can save a lot of difficult changes and time.

Changing depth: When changing the hull modules depth, several dependency warnings were given. This was between various sketches and constraints, and therefore, sorting these out made this kind of change a time-consuming process. To simplify it, a solution could be to move the step, so that these changes are made when the fewest number of constraints are defined. This means moving step 7I: Change external boundaries aft of step 7D: Select modules. The reason this step was placed late in the process is that at that time designer will have more information. However, this is not the same for the external boundaries, since these are given in the 7B: concept parameters.

Modifying and relocating switchboard room: To modify the switchboard room to requirements the constraints had to be deleted, the room moved and new constraints had to be placed to fix the room position. The same process had to be done to the content. In the end, it seems easier to create the room from scratch, as the switchboard could be retrieved reuse library. Therefore, designer should consider which approach to be used, adapting the existing room creating a new one. Author suggest that if the compartment that needs need re-location, it should just be deleted and recreated. If only repositioning of the content is needed it is better to adapt the room.

Adapting tank and crane arrangement: Both these changes can be done in similar ways, but to test both tank arrangement where deleted and repopulated from reuse library. The crane arrangement was repositioned by changing the constraints. For reuse purposes relocating the part as was done with the crane proved to be the fastest way. However, this has effects on the assemblies the crane and tanks are a part of. If the higher level component needs changes, the

approach of the tank arrangement may prove useful, as it reduces number of constraints which could make this change more difficult.

How can we combine 2D- and 3D drawings using PLM tools?

Using the draft application within the PLM tool, setting up a GA drawing of the vessel was done in matter of minutes. When changes were made to the model, designer can use "update views" and the changes of the drawing were updated immediately. However, a GA drawing should have much more details and the method should be tested on a vessel which is in the end of the concept phase. If the approach works for a fully detailed model, it can be a useful tool to generate necessary drawings.

7 Conclusion

It can be concluded that while there are still elements to handle, PLM shows promise in providing a tool to reuse vessel components in the conceptual design stage. This thesis only looked into a few of the aspects in 3D reuse in ship design in one step of the lifecycle. PLM is about integrating data from all the stages and processes together, and the 3D components should be combined with data from these connecting the models with e.g. specifications, manuals, BOMs etc. Additionally, it needs to be tested with a real database which contains models from several vessel and will be expanding with time.

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