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Implementation of 4GD framework in Ship Design for improving exchange and 3D reuse

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MASTER THESIS 2016
FOR
STUD.TECHN. Greta Levišauskaitė

Implementation of 4GD Framework in Ship Design for improving exchange and 3D reuse

The shipbuilding industry is increasing rapidly with fleet needing to be modernised and improved constantly to meet the customer's needs. Shipbuilders are facing many challenges while modelling a ship with thousands of units and parts. Maritime companies have to be in control of their operations by tying together all the operations like: purchasing, accounting, maintenance, technical records, etc.

Currently, the shipbuilders are facing challenges to combine rich PLM data management with efficient 3D designing tools for large data volumes. In order to manage both adequately more advanced PLM system approach called 4^{th} Generation Design might be applied. It is an approach for managing and controlling the design tasks by using flexible component-based environment which improves the exchange and handles PLM data and 3D models as a system.

As the 4GD is a new concept in ship building industry, there comes the problem of this thesis as how to apply 4GD concept to a ship 3D model by combining the PLM data management with efficient 3D design? The problem also includes the conditions as the improvement of exchange within the ship structure assembly and facilitating the 3D re-use across the vessels.

The main objective of the thesis is to create functional ship product 3D model using 4GD concept which is to be narrowed to certain system or part of a ship due to complexity. The thesis will be performed in cooperation with Ulstein from where certain structure of investigation and 3D standards will be received.

Master Thesis' project plan:

- Pre-study:
  - Task 1: PDM and PLM systems' study
  - Task 2: Knowledge development of 4GD concept and its integration
- Problem specification:
  - Task 3: Analysis of the ship as a 3D product and current standards at Ulstein

- Task 4: Defining specific problem of ship 3D modelling

- Concept application:
  - Task 5: Analysis and acknowledgement of the Teamcenter 4GD integration workspace and interface
  - Task 6: Application of the 4GD concept to the certain ship structure
- Results:
  - Task 7: Evaluation of the 4GD concept, whether it improves the exchange and facilitates the 3D reuse or not
  - Task 8: Possible solution to the previous task and discussion of further work
- Conclusions:
  - Task 9: Overall work evaluation
  - Task 10: Realisation of the report

The report is to be handed in on 3rd of June and the detailed plan with approximate dates is displayed in Figure 1.

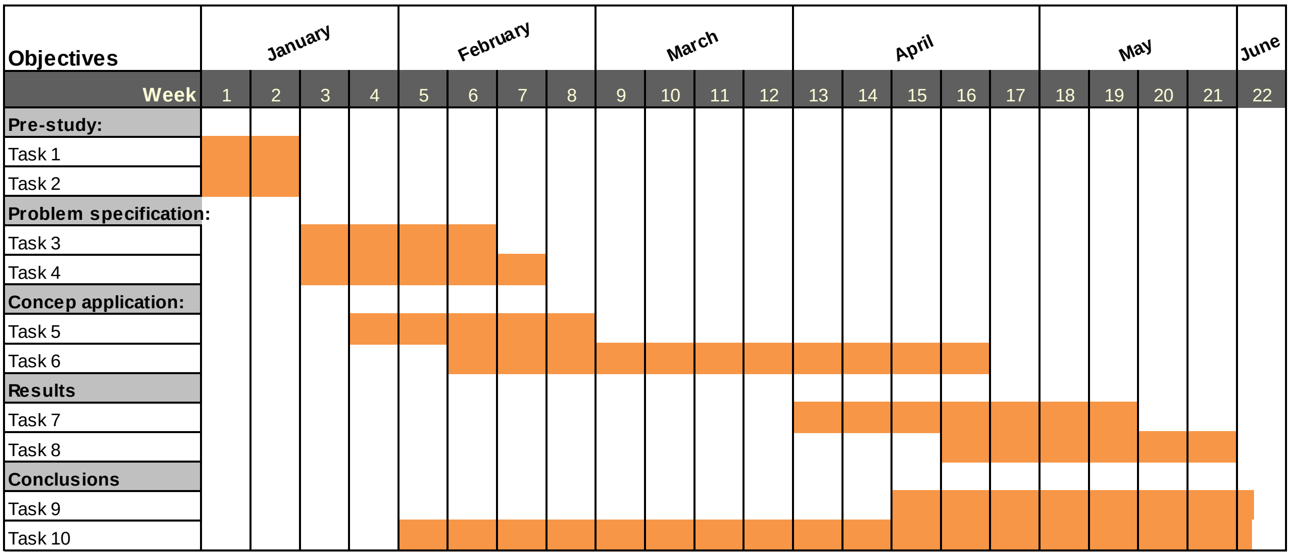

Figure 1. Gantt chart

In addition to the thesis a research paper for publication is prepared.

Supervision at NTNU i Ålesund: Henrique Gaspar

Finish: 3rd June 2016 Signature candidate:

Abstract

Together with the development of technologies in maritime industry the needs and requirements of the customers are increasing. The necessity of fleet modernization and business process optimization is specifically high in the current market. Shipbuilding companies are seeking innovation and production cost reduction by exploring the opportunities and capabilities of data management and modelling software. However, due to loads of data in a vessel the ship building companies are struggling with the combination of efficient 3D modelling tools and keeping high control on the product's lifecycle. Therefore, it is a significant matter for the maritime companies to have a well-develop tools and approaches to efficiently manage vessel's lifecycle and boost the innovation. There are several software and approaches how to manage vast amount of data of which the most current one is 4th Generation Design (4GD) that manages the design and product data in one environment.

The aim of this thesis is to apply and investigate the non-conventional approach (4GD) in ship design and evaluate if this is a beneficial approach in comparison with the conventional assembly method. Due to wide range of the topic the scope of the thesis was limited to the investigation of a simplified Platform Supply Vessel (PSV) in context of exchange improvement and 3D reuse facilitation from the 3D designer point of view. To achieve the main goal, a research method emphasizing particular issues in the design of a ship was established. The method was uniformly applied to the 4GD and traditional assembly approach to perform a comparative analysis. The main case study of the research comprises from the modelling and change processes of a PSV based on the challenges commonly met in the industry.

The results of the case study are summarizing the user's experience working with 4GD and traditional assembly approach. A comparative analysis is performed on the two methods to emphasize the advantages and disadvantages one against each other. This kind of approach aids to see and discuss how the exchange and 3D reuse is improved and facilitated by the 4GD paradigm. Finally, the concluding remarks are completing the thesis by defining that 4GD has a great potential for innovation in ship design and is potentially beneficial for the shipbuilding companies.

Preface

This thesis is a part of the Master of Science degree in Product and System Design at the Norwegian University of Science and Technology (NTNU) in Ålesund. The thesis focuses on the 4th Generation Design approach applied to ship design to improve exchange and facilitate 3D reuse in comparison with the traditional structuring method. The topic was chosen due to the personal interest in the modelling software and its constant improvements as well as increasing demand for more innovative and efficient approaches to designing and 3D modelling of ships. Therefore, the 4GD concept is applied specifically to the ship design and its current problems. This Master thesis is performed in cooperation with Ulstein where several weeks were spent to gain knowledge and insight of the ship modelling. This research used relevant information from NX and Teamcenter software which is owned by Siemens AG (Germany) and distributed in Norway by Digitread AS.

Ålesund, December 16, 2016

Greta Levišauskaitė

Acknowledgements

I would like to show my gratitude to several people who guided me while working on my Master thesis. First of all, I would like to thank my supervisor Henrique Murilo Gaspar for valuable knowledge transfer and guidance during the semester, for motivating me and enforcing to work hard from the very beginning. Moreover, for providing cooperation possibility with Ulstein Design & Solutions As, where I received valuable ship design related information. Additionally, to my co-supervisors Torill Muren and Bernt-Aage Ulstein who helped me to develop case study idea and methods for approaching it. Plus, thanks to Per Olaf Brett for wise comments and valuable feedback.

Due to the complexity of the 4GD integration and few people able to give some insights about it, the installation and configuration processes were very complicated. Therefore, I would like to thank Paul Steffen Kleppe from NTNU in Ålesund, Marius Slagsvold, Henning Kværnø and Torben Henning Stachowski from Digitread for all the help to make the software up and running. This research used relevant information from NX and Teamcenter software which is owned by Siemens AG (Germany) and distributed in Norway by Digitread AS.

Finally, I would like to thank my boyfriend and family, for believing in me and supporting me through the whole process.

Contents

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Abbreviations

2D	Two dimensional
3D	Three dimensional
4GD	4^{th} Generation Design
BOM	Bill of materials
BVR	BOM view revision
ERP	Enterprise Resource Planning
NX	Siemens NX software
PDM	Product Data Management
PLM	Product Lifecycle Management
PSV	Platform Supply Vessel
SME	Small and medium enterprise
TC	Teamcenter software

1 Introduction

1.1 Project background

The first chapter provides an introduction to the Master's thesis topic and explains the background of the case study.

The shipbuilding industry is increasing rapidly with fleet needing to be modernised and improved constantly to meet the customer's needs. As the vessels are composed of millions of parts, the modelling of such a large amount of data product becomes a complex and demanding process. In a meantime, maritime companies have to be in control of other business processes by managing the information in design, engineering, and production. The ship production processes (Figure 1.1) are highly collaborative and so the project planning has to coordinate ship engineering, construction and maintenance from project development to outfitting (V.T.Cang, et al., 2013). Therefore, it is necessary to have well-developed tools and approaches to efficiently manage vessel's lifecycle.

Figure 1.1. Project coordination in ship production process (V.T.Cang, et al., 2013)

'PLM is an integrated, information-driven approach comprised of people, processes, practices, and technologies to all aspects of a product's life cycle, from its design through manufacture, development, and maintenance culminating in the product's removal from service and final disposal' (M.P.Giddaluru, et al., 2013). In other words, PLM deals with mainly all processes in the whole products lifecycle. Whereas Product Data Management, an integral part of PLM, is mainly managing the product associated data and process-related information as one system by use of software (H.Kramer & P.Filius, 2014) thus providing easy accessibility by multiple teams across the company to the CAD models, parts information, manufacturing instructions, requirements and other documents of a product. This approach enables the possibility to each team working with particular vessel access the data related to their needs within their field of expertise. PDM allows the maritime companies to optimize operational resources, find necessary data quickly, reduce development cycle time, errors and costs. However, even if usage of the PDM in shipbuilding industry exposes many advantages, the implementation causes several difficulties due to different requirements for production documentation imposed by shipyards, misleading expectations and poor project management (Siddiqui, et al., 2004).

Another substantial tool in ship design is the virtual design environment. The CAD tools in certain maritime companies should be chosen according to the companies design requirements and business needs. It enables to have a first look at the conceptual ship design during the conceptual design phase which gives an opportunity for the customer to view visualized product and improves sales argumentation (Andrade, et al., 2015). Likewise, accurate visualization of the final product is committed during detail design phase which allows verifying interfaces between components, mechanical assemblies, and outfitting. There are different advantages when choosing the 2D or 3D CAD modelling tools. 2D modelling requires less time when preparing a pre-contract project and is easier to use in the early stages of design but it doesn't reflect and deliver all necessary information about the product (Roh & Lee, 2007). On the other hand, 3D modelling grants better presentation possibilities, superior solution, and functionality comprehension but require knowledgeable people to comprehend the complex interface (Sollid, 2016). Plus, using 3D CAD system allows to check, modify, give and receive feedback on design results in a real time (Kwona, et al., 2015). Therefore, most of the maritime companies are using the 2D drawings in the early stages of ship design which are later on remodelled into 3D objects for further processes. However, to ascertain future development the 3D CAD systems should be used in early stages of the ship design to maintain information quality and avoid inefficiencies in the design process (Hwang, et al., 2004).

As the ship design requires constant modifications and variations of existent vessels or parts of it, using 3D CAD system might be the best solution to ease the reuse of previous vessels. Depending on the customer requirements, maritime companies sense the need to re-use standardized parts from engineered vessels and customize it to the current project.

Especially, in ship families where the same purpose vessels are designed for different environments with different configurations and capabilities (Figure 1.2) but retain several standard parts and units used across all the vessels within that family (Sollid, 2016). However, maritime companies find it difficult to reuse designs across the ships due to a large amount of data, complex relations between the systems and also customization restrictions due to a possible change of software. This induces companies to remodel necessary units which is time and resource consuming. Therefore, to maintain productivity and profit, a solution to facilitate the exchange processes and reuse is substantial.

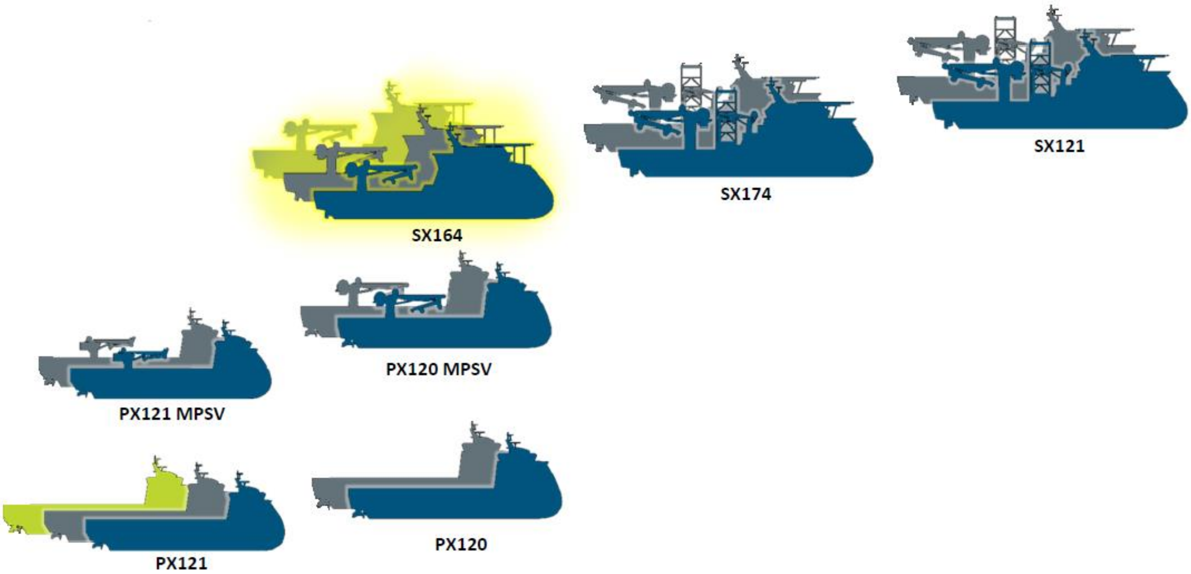


Figure 1.2. Ulstein's subsea family (Ulstein Design & Solutions AS, 2016)

Currently, the most widely used method in 3D designing is the conventional assembly approach or the traditional structuring approach. It deals with 'connection features between pre-defined geometric entities' which define the 'geometric positions, orientations, mating conditions, and parent-child relations' (Ma, et al., 2006). Regardless which CAD software is employed in ship design processes, the connection features remain an essential characteristics in the traditional assembly approach. The main feature in this approach is the hierarchical assembly structure that consists of assemblies, components and features which owns the set of entity attributes (XF, et al., 2001). The traditional structuring approach is very restrictive and becomes complex and highly interrelated as the amount of data increases.

There is a new non-conventional concept in the market - the 4th Generation Design, which asserts to overcome the shipbuilders struggle to combine effective virtual design environment with rich PLM data management (Siemens PLM software, 2013). It is a component-based approach which provides effective and independent data management, and controls the design, particularly of large amount data systems. As the ship design deals with this kind of data, it might be beneficial to employ 4GD to ease the re-use in ship families. Therefore, this approach will be used in a simple ship design case in virtual design environment to evaluate the functionality of non-conventional method against the conventional assembly approach.

1.2 Scope and objectives

As the 4th Generation design is a new technology which hasn't been employed to similar case study, there main aim of the thesis arises weather the 4GD approach is advantageous over the traditional assembly approach in ship design to improve the exchange and facilitate the 3D reuse across the vessels.

The overall goal of the research is to implement and study the 4GD framework in ship design in comparison to the traditional structuring approach. To achieve it, following objectives are to be completed during this Master's thesis:

- To present and discuss current ship design approaches and data management capabilities as well as the challenges faced in these subjects.
- To propose a framework to the case study that emphasizes the differences between the conventional assembly approach and non-conventional concept.
- To perform the empirical research on the simplified ship design case in both the traditional assembly and 4GD environments.
- Discuss and conclude on the results of the 4GD application and whether it can facilitate the exchange and 3D re-use processes.

Consequently, the scope of the thesis was established and is represented by Figure 1.3. Due to the goal and objectives described above, the scope was narrowed to the detailed ship design phase of a simplified platform supply vessel where the capabilities of 4GD and conventional assembly approach are compared from the 3D designer point of view.

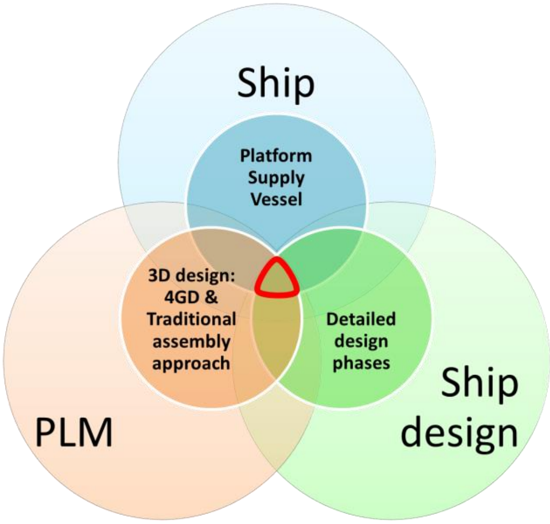


Figure 1.3. Scope of the thesis

1.3 Limitations

The main limitation of this Master's thesis is the lack of information where 4GD has been applied and how it worked out for particular industries. As there are only several people in the world who worked with 4GD, the installation and configuration problems were huge obstacles prior the application of the approach. Also, there is no relevant data published related to the real-time application of the 4GD in any kind of industry which restricts the evaluation of the results. Therefore, an independent case study is introduced which results are based on self-experience with the 4GD approach.

Another significant factor is the amount of information from the product, specifically from a vessel. Ship design contains a very wide range and high complexity of products that are usually customized to meet the certain company's needs. Plus, a ship has millions of products and systems in its assembly which is impossible to cover in one master thesis. Moreover, it requires high competence in ship design and 3D designing software to create realistic 3D model and perform accurate investigation on the systems, its relations and interactions. Therefore, this research uses a simplified vessel consisting of only several components as compared to a fully equipped vessel. Due to these limitations, the assembly components in the 3D model are created as boxes or cylinders to simulate the relation, dependencies and influences among the parts.

1.4 Structure of the report

Further chapters of this thesis are organized as following:

- Theoretical foundation.

Chapter 2 reviews the theory behind the 3 main subjects of investigation: PLM, ship design and 4GD. First it introduces and defines the PLM system and its concept prior describing the challenges of PLM system in ship design. The second part describes the ship design where a short introduction is made following with the description of modelling options: 2D and 3D. Then the development challenges of large scale products are presented and relevant challenges to the problem in current designing approach are introduced. Finally, the 4GD is presented and defined in detail with concept explanation, features and advantages.

- Methodology

Chapter 3 presents the research approach of this thesis. Moreover, it describes the importance of the taxonomy establishment for this case study and introduces a method to investigate the two structuring approaches in context of exchange and 3D remodelling. The simple case application is performed and described in this chapter in order to evaluate the validity of the framework.

- Case study

Chapter 4 presents the main case study of simplified ship design case where the product overview is given and the product taxonomy is defined. In addition to the methodology, the several assumptions for particular case are given. Further, modelling and change cases of an assembly in traditional assembly approach and 4GD are performed and detailed description is done.

- Results and discussion

Chapter 5 discusses the results obtained from the case study using two approaches. First of all, the challenges met and solutions made in the modelling and change cases are analysed separately for the traditional and 4GD approaches. Subsequently, the comparison of the two approaches in respect to the exchange and 3D reuse solutions is conducted. Chapter 6 concludes and gives the recommendations on further work to be done with a certain topic.

2 Theoretical foundation

2.1 Product Lifecycle Management

In order to effectively manage all the data of the product, PLM might be employed into companies business. Despite powerful capacity and a wide range of use, PLM remains a complex system which brings difficulties to the users. Therefore, this chapter introduces PLM and explains the challenges of using it.

2.1.1 Definition

According to Stark (2015) Product Lifecycle Management is defined as “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”. It is a complex and powerful system which is able to manage company’s products, all of its parts and even product portfolio in an integrated way which gives a wide range of employment. 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 (Saaksvuori & Immonen, 2008).

The reasons to utilize PLM in a company are mainly related to incremental savings and revenue growth (Saaksvuori & Immonen, 2008), costs reduction, and maximising the value of products. PLM does not only manage the products data but it enforces making necessary changes in company’s processes and retains control of products lifecycle processes. This way, PLM is fostering the product development and innovation which increases competitiveness in the global market (Sudarsan, et al., 2005).

By managing the overall lifecycle of products PLM connects various stakeholders by means of computer aided design (CAD) and product data management (PDM) systems into one centralized system (Ameri & Dutta, 2005). PDM is aimed for managing product data that includes retrieving and storing design data, maintaining the latest configurations, controlling releases, and recording BOM’s of engineered products. Data and product development is assured due to PDM’s ability to supervise large scale of design and manufacturing data, and maintain it through the whole lifecycle. PDM functionality is maintained through an application which ensures that particular stakeholders get exact information at the right time (Siddiqui, et al., 2004).

2.1.2 PLM and PDM software

PLM system keeps control of product's digital data structuring, using dedicated software which is a web-based solution for improving the management and collaboration of the team through product development process. There is a choice of functionalities within the software in order to meet certain company's needs (Pol, et al., 2008). PLM intents to a broader management concept that includes several software components, not only individual computer software. It comprises from integration between the ERP, PDM, CAD or other process related system for a particular company (Schuh, et al., 2008). As the PDM system constitutes a great part of the PLM system and both are closely interconnected, so later on the term PLM system will be used having in mind the integral part of PDM.

In recent years, the importance of a PLM system implementation in companies grew up significantly due to strategic reasons as the need for modern data management, product engineering, and production. However, the investments into software and services increased respectively making big industries like automotive, aerospace and defence, and electronics the leading investors (Mesihovic, et al., 2004). In order for SME's to implement PLM system in their business activities, it is necessary to effectively integrate CAD with PLM system. There are two ways how the PLM system can be integrated into company.

First of all, single vendor systems compose from design, engineering, production and PDM as one software. It means that PLM and CAD are combined and integrated to fulfil specific customers' needs. Single software used for all processes facilitates the collaboration between different work teams as they are using the same data format, interface, and common environment. However, the options decrease due to the limited variety of single PLM and CAD software.

Secondly, multi-vendor systems provide options of software for design, engineering, production, and PDM. It means that in order to manage different processes separate software might be used. This solution provides flexibility to the shipbuilding specialists to choose the best software that fits their requirements and company's business vision. The challenge here is to ensure good integration for each software implementation and precisely define owners of engineering data (H.Kramer & P.Filius, 2014).

The current market focuses on a particular interest of the potential software users and is developing tools to use the merits of both CAD and PLM systems simultaneously. There is a number of PLM software with different capabilities for particular industries. For example, Arena PLM by Arena Solutions or Autodesk PLM 360 by Autodesk is web-based software when CATIA by Dassault Systems or Teamcenter by Siemens PLM Software are installed PLM software (CIMdata, 2016).

Teamcenter provided by Siemens PLM Software was the world's 3rd most used PLM system in 2014 (Appendix A (CIMdata, 2014)) which will be used as the software for application in this thesis[1]. In order to simplify the PLM system and connect everyday use tools and processes into a single product design data environment, the Teamcenter is integrated with Siemens NX software. Teamcenter is a flexible platform with several deployment options like on premise, cloud, and Teamcenter Rapid Start. The Teamcenter functions are versatile depending from the customer needs and might include all or some processes from Figure 2.1.

Figure 2.1. Teamcenter functional structure (CIMdata, Inc., 2010)

Employing Teamcenter in company's business processes following improvements are provoked. Time and effort reduction is achieved by using single source for generating and managing requirement documents. Quality improvements attained by linking requirements to functional, logical and physical implementation of the product. Finally, the customer's

[1] The relevant information from NX and Teamcenter software is owned by Siemens AG (Germany) and distributed in Norway by Digitread AS.

requirements are assured due to the ability to define, manage and follow it through the entire lifecycle of the product (Siemens PLM Software, 2013).

2.1.3 Drawbacks of the PLM software

PLM software is a complex system managing large scale of data and incorporating few to many people in a single working environment. Therefore, as Siddiqui, *et al.* (2004) concluded, it evokes several issues related to the implementation and management which will be discussed further in this section.

First of all, the challenges arise when the time and resources required for the PLM software implementation are misjudged. Prior the implementation, a company has to set certain goals and expectations from the PLM system which lets to identify particular applications to be installed within the software. It is significant to understand how complicated and time consuming the project might become depending on the requirements. For this reason, the project has to be planned in advanced and all the areas where PLM system could assist should be considered. For this reason, companies consider PLM system as too much time and resource consuming before bringing benefits and they avoid to implement it.

Another drawback is the failures of previous implementation attempts. The reason to fail the implementation process might be unidentified goal of the PLM implementation and lack of point of focus during this process. Another reason might be not well defines needs and requirements of the company plus the expected benefits from the PLM system. Any company willing to implement PLM software into its business processes needs to identify the software requirements and adopt a software suitable and comprehensive with particular business processes (Schuh, et al., 2008) (Sollid, 2016).

Therefore, even if the PLM systems reveals potential benefit almost to any type of business but due to high requirements and expectations to the PLM implementation in a company the struggle derives weather it is worth to engage PLM into company's business processes. Plus, the previous practices of the PLM implementation exposed difficulty to manage large scale data. Those are the main reasons pulling back the potential customers from the PLM system implementation and application.

2.2 *Ship design*

2.2.1 Introduction

Ship design is a long and complex process that consists of several steps which will be introduced in this section. The modelling of vessels, current designing approach, management of large scale products, and traditional assembly approach with 3D re-use across the vessels will be described as well.

Ship design covers all the activities starting from analysis results until delivery of a new product where all drawings, 3D models, specifications and other product information is developed. The entire ship design process consists of two main stages: Conceptual and/or preliminary design, and Detailed or contract design (Molland, 2008). The conceptual design elaborates the basic ship characteristics affecting costs and performance that includes a decent selection of the ship's dimensions, hull form, power, machinery arrangement, and primary structure to meet the vessel's mission requirements. While detailed design phase processes the deliverables developed in the previous phase into the product information dedicated to the shipbuilder and suitable for the production.

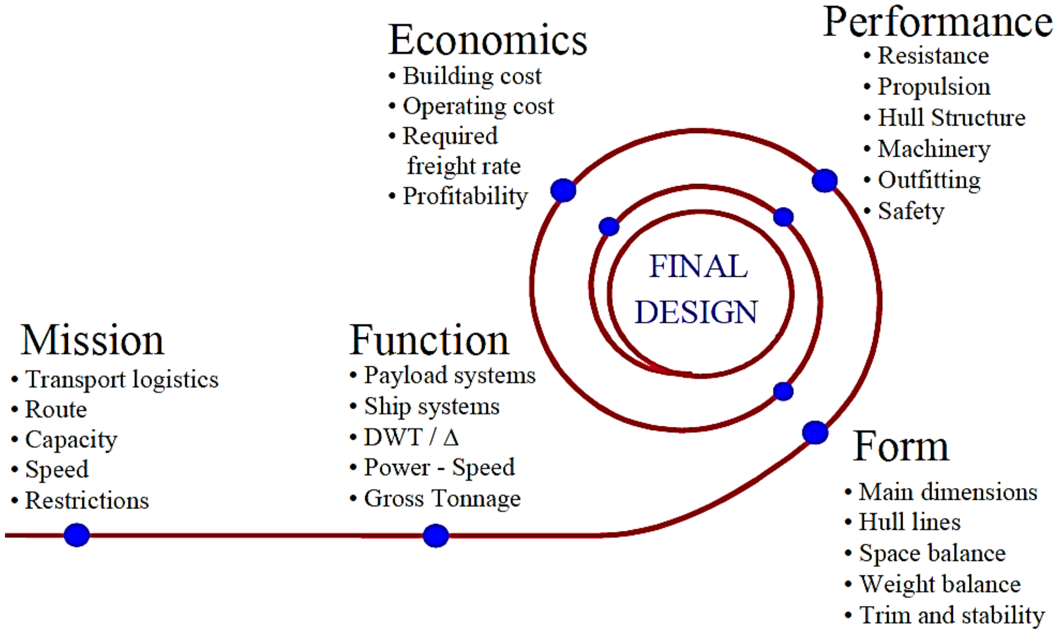


Figure 2.2. The ship design process (Levander, 2012)

The two stages of the ship design are well defined by Levander, 2012 as shown in Figure 2.2. The conceptual design covers the mission, function and form processes, where the detail design encompasses the performance, economics to the final design of a ship.

Further in this chapter, the ship design processes in context of the two stages will be described in detail.

Conceptual design phase covers the collaboration of the ship owner and designers in order to state and agree upon the requirements in terms of mission and main performances. The mission is specified and system requirements for specific tasks are brought into consideration. Further, the areas and volumes for required systems are calculated and defined which results in a full system description of a new vessel. Based on the mission and systems definition, the technical feasibility and economic analysis is performed in order find the solution for ship design corresponding with the ship owner's budget.

According to Levander (2012), the function step in Figure 2.2 can be divided in two sections: payload function and ship function. Depending on the mission, the payload functions consist of equipment and spaces for treating the mission oriented systems on-board whereas the ship functions are dedicated to safe carriage of payload from port to port.

The third step in ship design process is the form which deals with overall ship size and configuration establishment, selection of the top level components and assessment of their performance. Usually, only single-line diagrams are created for the systems but further refinement might be made. The outcome of this phase should be sufficient to estimate the costs of construction, operation, and support. Finally, an analysis is carried out in order to reduce major technical and cost risks.

During Contract Design phase (Performance and Economics (Figure 2.2)) the accurate technical specifications with appropriate drawings are issued in order to describe the ship in detail and make sure that the ship meets the preferences of ship owner and shipbuilder. The specifications include the main characteristics of a ship, description of the systems on-board, its sizes and performance capabilities. The most relevant document established in this stage is General arrangement of a ship which references the location of different systems. Review and finite establishment of the build strategy is carried out. Finally, the ship production plan with ship assembly schedule is conducted. Finally, in this phase the detailed calculations are performed and configuration of various systems completed. Preliminary system routing, piping, electrical wiring and vent ducting sizes are defined. Required material quantity and system weights are listed and first revision of the budget control is conducted. The final stage of this phase is the agreement upon documentation between ship owner and shipbuilder.

During the detailed design phase, the deliverables from previous stages are processed and investigated in detail whereas in the conceptual design phase, only the estimations and layout of a vessel is created. For this reason, the detailed design phase is a concern of this thesis due to modelling and change performance at this point of ship design. Therefore, the subjects in discussion in further sections are referred to the detailed design phase.

2.2.2 Ship 3D product model

In one or another way the ship design uses CAD modelling to define system arrangements and visualize the products configuration and relations. Different dimensions of modelling space are employed in certain companies depending on software in use and needs of the designers in a specific company. However, whether it is 2D or 3D tools used for modelling a vessel, both reveals one or another capabilities and limitations.

Maritime companies are still widely using the 2D modelling for different stages of the ship design. The general arrangement of a vessel is compiled rapidly in the pre-contract stage (Bucci, et al., 2013). Using 2D drawings requires less time to prepare a project for the customer due to easy simplifications of the product. This saves time and costs in the preliminary stages and gives more flexibility in detailed stages. (Sollid, 2016). However, at some point in detailing design stages the 2D models are elaborated to 3D models for better visualisation, simulation and analysis capabilities.

Nowadays, the CAD systems are more and more moving forward to the 3D models in conceptual and detailed design phases in order to assure direct perception of a vessel to the designers in charge and also to the customer. Vessel's 3D modelling features and capabilities are described further.

Ship 3D product model is the integration of geometric and non-geometric information which provides better cost estimations. Weight, material, analysis data, relations between systems, production, and lifecycle information are perceived as non-geometric data which is stored and maintained in a relational database system. Whereas the geometric information refers to the object presented as 3D solids and surfaces which constitute ship 3D model representation. Both connected as one system they present a ship product 3D model as shown in Figure 2.3 (S.J.Baum & R.Ramakrishnan, 1997).

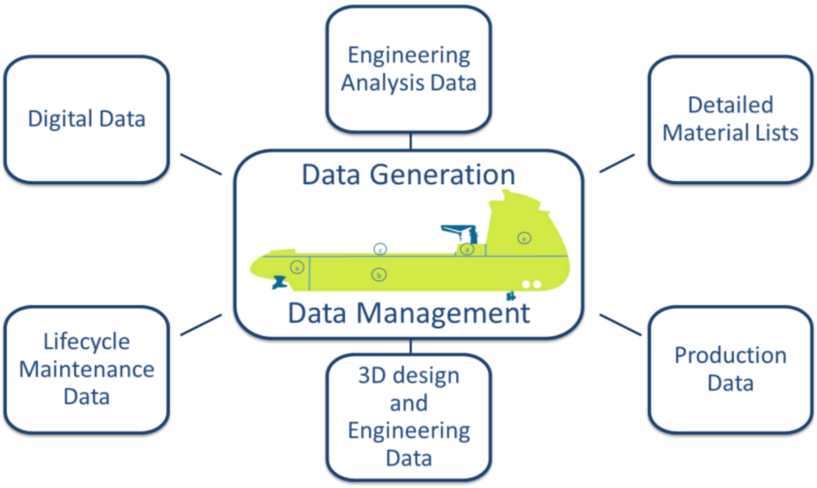


Figure 2.3. Representation of a ship 3D product model (S.J.Baum & R.Ramakrishnan, 1997) (O.S.Chaves & F.M.Rossi, 2014)

Modern 3D modelling software is provided with the multi-user environment where several designers can perform different tasks within the same design. Using the 3D models it becomes easier to analyse the design data and verify the interconnections between structures and outfitting. It reduces collision errors and maintains control of the compartments (Bucci, et al., 2013).

Usage of 3D models makes it easier to reuse and analyse the existing design data for a new project due to standardized data formats which can be exchanged between projects. It facilitates movement of the 3D models from conceptual design to the engineering phase and back which allows modification and adjustment of the models. That improves the quality of design and reduces the product development time (V.T.Cang, et al., 2013).

However, there are several reasons that are pushing the maritime companies away from using the 3D modelling in the basic ship design phase. As the vessels are large scale products and 3D modelling software is a complex system, it requires knowledgeable and comprehensively trained people to implement and work with the software in order to benefit from it. Therefore, in the beginning, it might increase time-to-market of the product in the design phase and require more resources for training and consultancy. In addition, the capacity of the maritime company might reduce due to changes in the designing processes as it requires time for implementation and adjustments to fit company's needs. The adaptation is also necessary to figure out how the simplifications might be performed in the pre-contract stage to present the preliminary ship model (Sollid, 2016).

2.2.3 Large scale products

According to the definition proposed by B.A.Behrens, *et al.*(2014) 'large scale product is 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'. A vessel is considered as such product due to loads of data, complex information within the ship product model, and high requirements for construction and manufacturing of a ship. Significant changes in structure proportions and quantity of industrially manufactured products are observed due to the rapid development of the industrial production in general. However, challenges in development of ship 3D product model arise by following aspects:

- Scalable design

With the technological improvement and demands from costumers, vessels are required to include more and more equipment which increases the scale of a ship as well as difficulty of the 3D model. It brings space issues, rearrangement difficulties as well as requires higher resources. Introduction of novel units or systems requires dedicated designers to be included in the designing process. The re-modelling issues arise as well because certain systems might need to be modified or changed that would influence the surrounding systems.

- Collaborative design

A sequential design generation is the traditionally used design system where the tasks are subdivided and distributed to certain designer in order to be serially performed in a predefined order. This approach is well working with small to medium products it's not that beneficial for large scale products design. In this case, the system become inflexible and requires several design iterations. The time-to-delivery is significantly longer and the process gets complex if changes are requested which makes the design more expensive to the customer. Therefore, collaborative design is an option to manage 3D design for a group of designer working on their specific tasks dealing with large amount of data. To maintain collaborative design, companies need dedicated software to support collaborative work and enhance the capabilities of individual specialists and interaction between the collaborators. However, it concerns high complexity of the design environment, requires various configuration and support characteristics, and contains diversity of engineering tools. Therefore, to employ the collaborative design in basic ship design phase it requires advanced technologies to sustain complexity and large amount of data (L.Wang, et al., 2002).

- Concurrent design

As ship is a large scale data product, the traditional product development approach is not enough to perform efficient designing process. Therefore, a concurrent design concept is introduced in ship designing as an improvement to the traditional serial development process. Concurrent engineering in ship design refers to simultaneous product and process design based on the agreement on constrains and coordination of the whole designing group members. Using this integrated approach the design models of a ship are viewed as a whole thus developed quicker which improves the quality, simplifies manufacturing and lowers production costs. However, it requires high integration and cooperation of all the key elements in ship design process as ship consists of loads of units which include complex systems that are connected to each other. The process management have to be well developed and implemented across the departments. In order to develop 3D model of a ship certain concurrent design rules and dedicated software have to be established and well implemented in order to gain profit (Su & Liu, 2008).

- User productivity

Large scale product as a ship requires high amount of specialists working on the 3D model of the whole system. Developing a 3D model of a ship it's difficult to maintain constant productivity of the users in the design process as each of the users has certain tasks to do but which are related one to another. However, one of the main disturbances in the modelling process is the load of the whole system data which takes time, space and is inefficient. Moreover, it evokes multi-configuration of the elements that takes time to be fixed.

All of the above mentioned reasons are slowing down the development process of a 3D vessel model.

2.2.4 Conventional assembly approach for product structuring

In order to construct a 3D model of large scale product some rules and concepts have to be followed. The most commonly used approach is the conventional assembly method (traditional assembly approach). It is composed using hierarchical structure of an assembly which means that the top level components consists of a set of features and entity attributes (XF, et al., 2001). Each of the elements belongs and is constrained to a specific unit or system thus constructing a top-down structure. The traditional assembly approach serves very well to construct the BOM of a product for manufacturing, assembling, controlling and maintaining services (Ma, et al., 2006). However, even if it’s the most common designing approach it does bring several challenges while 3D modelling a large scale product, that are described further.

2.2.4.1 Taxonomy

Ship as a product contains millions of parts which need to be grouped into systems and subsystems to ease the 3D modelling process. This kind of division of a product into sections is called taxonomy. The breakdown can be done by following different rules and approaches adapted or most suitable for certain maritime company. The most commonly used taxonomy in the maritime and offshore industry is the SFI Group System classification (Xantic, 2001). It helps to connect together all the operations in the ship building process. The SFI standard covers the division of a vessel into 10 main Groups (8 are in use) from which each consists of 10 more groups which are divided into 10 sub-groups. Each group have certain amount of digit to recognize the drawing and systems they belong to. Mostly, the maritime companies establish the taxonomy based on their business processes, mission of a vessel or its working environment. There are many various ways to organise a vessel which can be the functional, spatial, physical or modular breakdowns of a product.

Functional organisational breakdown divides a vessel based on function of the systems, for example, HVAC, piping, mission oriented, propulsion systems, etc. Each of the system includes sub-systems which are composed of assemblies. The functional division is an efficient structure to define detailed drawings and models of the routing systems and are particularly useful for the routing specialists. However, the interaction between the systems becomes complex and makes the model rigid as the assemblies in the conventional assembly approach is only viewed in hierarchy.

The modular organisational breakdown in ship design was discussed by (Chaves, et al., 2015) where the preliminary modular ship division was proposed. The modular taxonomy is defined based on maritime company’s business processes and might be unique in each case. This division aids creating product variations, improving re-use, and managing the complexity of a vessel. The modules are created by decomposing a vessel into certain modules, sub-modules, etc. (Figure 2.4). The division of a product depends on the final use which is why certain boundary criteria have to be established by the maritime company. Modular taxonomy is widely used in ship design due to flexible breakdown of a vessel which is adjusted to individual needs.

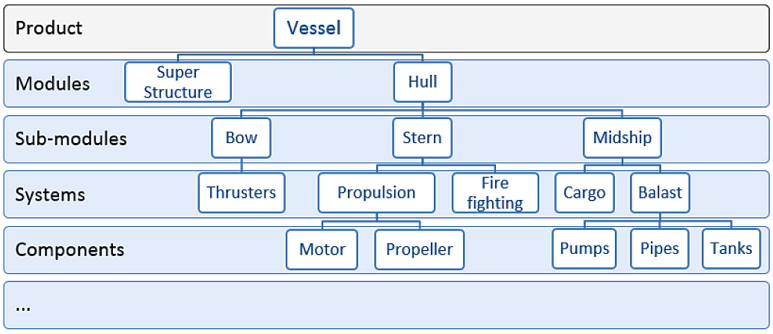


Figure 2.4. Modular taxonomy (Chaves, *et al*., 2015)

Spatial organisational breakdown of a vessel divides the product by zones and areas (rooms, decks, etc.). This taxonomy was published as ISA research in Daniels & Parsons (2008) and discussed in Andrews, *et al.* (2009). The spatial divisions concerns the arrangement of the vessel by pre-defined structural zones which are fixed and are further divided by major bulkheads and appropriate decks (Figure 2.5). The spatial taxonomy permits the view on the vessel based on specific area to which a component belogs to. It gives a neat representation of the vessel due to clear relations between the spaces but requires well established positioning of the extensive components.

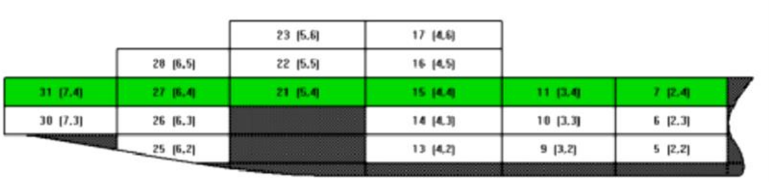


Figure 2.5. ISA Structural Zone Definition (DANIELS & PARSONS, 2008)

In the conventional assembly approach the taxonomy is significant because it is used through the entire lifecycle and it should meet the needs of each designer and stakeholder. The same division is followed up in the 3D modelling of a vessel which means that 3D parts and units can only be divided and viewed in relation to their parent systems as defined in the conceptual design phase. It restrains the view to the product from other perspectives and restricts the designers from different departments to one rigid breakdown.

2.2.4.2 PLM efficiency and large scale data management

As described previously, PLM is a complex system where product data is initially created and maintained in logical manner, requiring well defined expectations and implementation in business processes. If the PLM management is poorly working it means that the large scale data can't be appropriate handled and thus the implementation of PLM software is ineffective as it drives all other systems. In case of efficient PLM management in ship design the PLM software is still only able to manage small to medium amounts of data. Due to the hierarchical assembly structure, PLM software loads the whole assembly into the CAD working environment which complicates and overloads the day-to-day tasks. PLM software requires well defined connections and roles of the co-workers within the same department which brings difficulties as the ship consists of many interconnected systems.

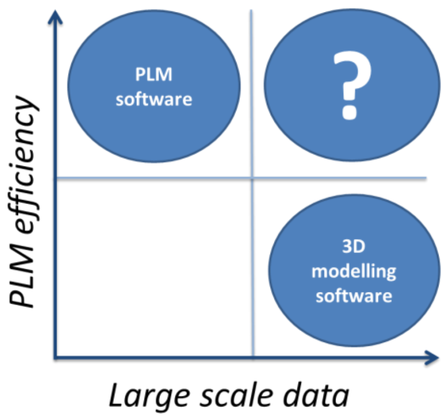


Figure 2.6. PLM efficiency over large scale data in ship design (Siemens PLM software, 2013)

In order to manage large scale data most of the marine PLM/CAD software are inefficient due to lack of following features:

- Ability to manage the evolution of the entire product's lifecycle which includes the early stages of project planning and conceptual design, change management, manufacturing planning, etc.
- Automated workflow which supports the verification, review and maintenance of the product through all business processes. It is important to control the changes throughout the evolution of the product and ensure the latest revisions.

- Re-use of the data from previous ship or ship class. Due to similar capabilities certain vessels or parts of it might be adopted in a new project without requiring duplication of common data.
- Support for data formats and exchange throughout the stakeholders.

Figure 2.6 illustrates the above mentioned problems in ship design to manage large scale data with efficiently operating PLM system and indicates the question how to efficiently employ the PLM system and manage large scale data (Siemens PLM software, 2013).

2.2.4.3 Object customization

In the traditional assembly approach the assembly structure is a significant matter describing the dependencies and relations between parts. It needs to be clearly defined before the modelling process starts. The hierarchical order specifies the location of parts within the 3D model which constrains each part to certain parent. This issues some challenges while customizing a product. If an object needs to be moved or replaced, the constraints are destroyed and errors come up due to dependencies to higher order parts.

Another struggle is the duplication of parts. If there are two or more identical objects within a model and they are copied, performing changes in one of them would issue changes in all of the copies. In this case the customization of an object becomes difficult (Ma, et al., 2006).

2.2.5 3D design re-use across the vessels

3D design re-use across the vessels refers to the products' or parts' models being re-used in future projects to avoid re-modelling of the same structure. Specifically in ship design, the re-usability is an important feature due to the following issues defined by Smith & Duffy (2001).

Ship Class Maintenance demands that all vessels in the same ship class have to consist of similar outfitting, system configuration or hull structure. It is required to ensure appropriate integration of the vessels in a ship class. Some types of ships take several years of designing and manufacturing. So to ensure faster development of a product, ship industry requires technologies to ease the re-usability and maintain innovation.

System Integration in ship design requires the objects to be designed to fit the purpose in several systems across the ship. This means that certain design elements need to be suitable to integrate in systems like propulsion, HVAC, navigation, etc.

Long in Service Life Span that expects the combination of robustness of components and minimisation of alteration required in individual ship systems. As the vessel is a large-scale product it requires time to design and therefore, it is expected to be reused for future projects.

However, ship design industry as any other industry requires innovation and so it’s important to balance the re-use with innovation in the product development. The market will point out to other companies if the re-use is constantly used and if not enough used, the excess of product variety will appear due to innovation out of the blue (Sivaloganathan & Shahin, 1999).

Typical designing approaches in ship design have been using limited re-use which typically turns out more like cloning of element. In other words, the 3D modelling software is only able to transfer and re-use previous designs as clones which include the whole ship’s design data. For an efficient 3D re-use, the CAD system needs to support a ship class in a single definition to avoid common data duplication.

Therefore, the ship building companies are aiming to the PLM systems which configuration management capabilities allows a design to be managed for the entire class of ships. It contains capabilities to qualify data according to the relevance and necessity to certain vessels only. If well implemented, PLM configuration management allows the user to customize the design data from previous ship and only use it where appropriately which give flexibility to the variations of a ship (Siemens PLM software, 2013).

2.3 4th generation design

2.3.1 Introduction

‘4th Generation Design (4GD) is a new design and data management paradigm that enables versatile and efficient methods for design in context and design collaboration’ (Sarfati, 2014). It combines the efficient PLM and CAD systems into one environment where complex, large scale products and its data are managed by rich, end-to-end PLM. It eliminates the limitations of traditional assembly approaches with a single, pre-determined, top-down assembly structure. 4GD functionality is implemented in Teamcenter integration for NX software (Siemens PLM software, 2013). Further this chapter includes detailed description of the concept, main features and principal theoretical advantages that are software sensitive information and is owned by Siemens AG (Germany) and distributed in Norway by Digitread AS.

2.3.2 Concept

4GD concept evolved as an improvement from the previous CAD design management systems. Therefore, to understand the importance of 4GD the previous generation are described further and are illustrated by Figure 2.7.

The first generation of CAD system was an inefficient approach with high complexity collections of files which were stored individually thus leading to multiple copies of parts and impeding the only basic management available.

The 2nd generation was already an improvement where assemblies were introduced which facilitated the management of large scale data. Due to single-part-per-file approach the components could be used in different positions at a time with no duplication required. It exceeded the limitations of the 1st generation design but still revealed drawbacks when the complexity of assemblies was increasing.

The PLM system was introduced in 3rd generation of CAD design enabling to access multiple revisions of assemblies, track product data through the lifecycle and manage sharing among the designers. However, this CAD generation requires well organized hierarchical structure of the product in order to avoid mess during the process because only one designer is able to work and modify an assembly at a time.

Consequently, 4GD introduced new possibilities for large scale data management which obviated the drawbacks of previous generations and extended the field of potentials. It uses a flexible working environment where assembly definition is made to fit certain working practices, allows to check-out only necessary data which keeps the designing process efficient, stores and manages data independently (Siemens PLM software, 2015).

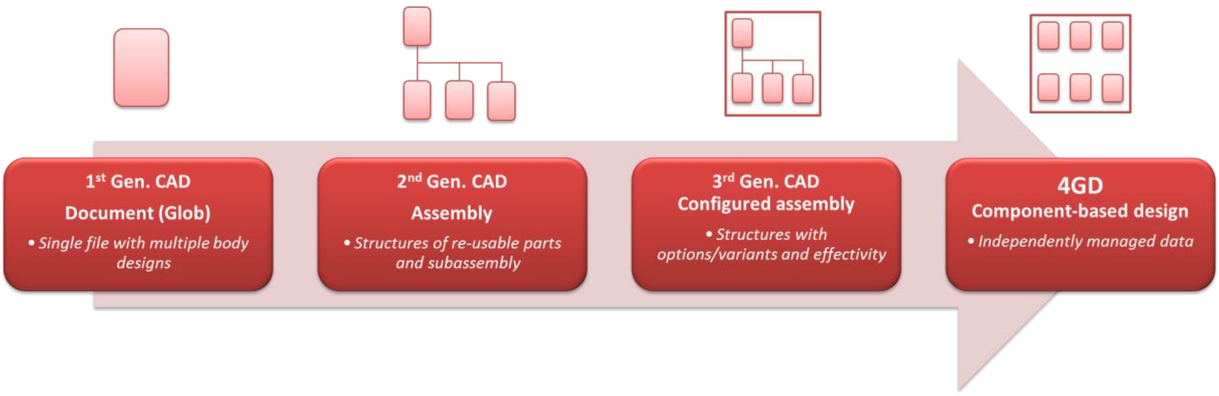


Figure 2.7. Evolution of large amount data management (adapted from (Siemens PLM software, 2013))

2.3.3 Features

4GD uses different modelling objects which need to be well perceived prior using this environment for the first time. 4GD working environment includes 5 main data management object which are described further and illustrated respectively by Figure 2.8.

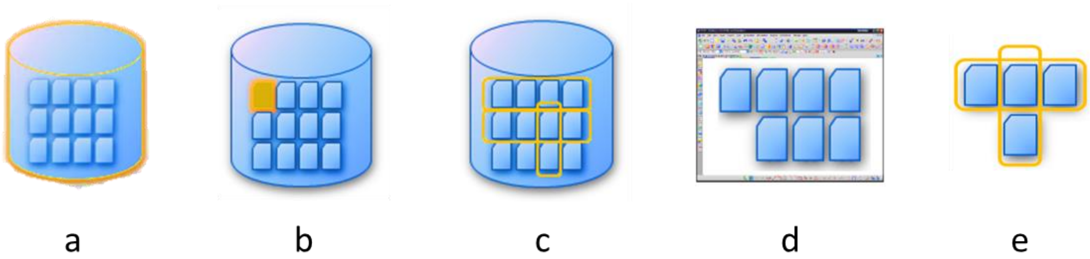


Figure 2.8. Data management objects: a) Collaborative design; b) Design element; c) Partition; d) Workset; e) Subset (adapted from (Siemens PLM software, 2015))

Collaborative Design is an object in Teamcenter which contains all the design data defining product(s).

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.

Partition object is an organizational container which helps to organize and find data in the assembly. Partitions do not control the position or any other property of a design element. They allow organizational flexibility which means that several organizational breakdowns are possible and design element are not restricted to only one of them but can be placed in multiple partitions. 4GD provides possibility of recipes which can dynamically add design element to partitions. Static partitions are also an option where designer have to add the design elements manually.

Workset object is the collection of design elements in personal design context in NX session. It can be created, modified, navigated and visualised in both, TC and NX. It consists of subsets and as many design elements as needed. Worksets are assigned by design team leader to certain designer with individual tasks which after completion is checked in.

Subset object selects a set of design elements to be included in the workset. It may include dynamic recipe to search for necessary design elements. Subset in certain designer’s environment is able to consist of design elements from different partitions or different subsets (Siemens PLM software, 2015).

Figure 2.9 illustrates the relationship between the main data management objects in 4GD environment. A collaborative design is an overall collection of design elements which are members of one or more partition schemes. Consequently, the DEs are managed and searched by a subset which is a part of the workset where further investigation of the 3D model is performed.

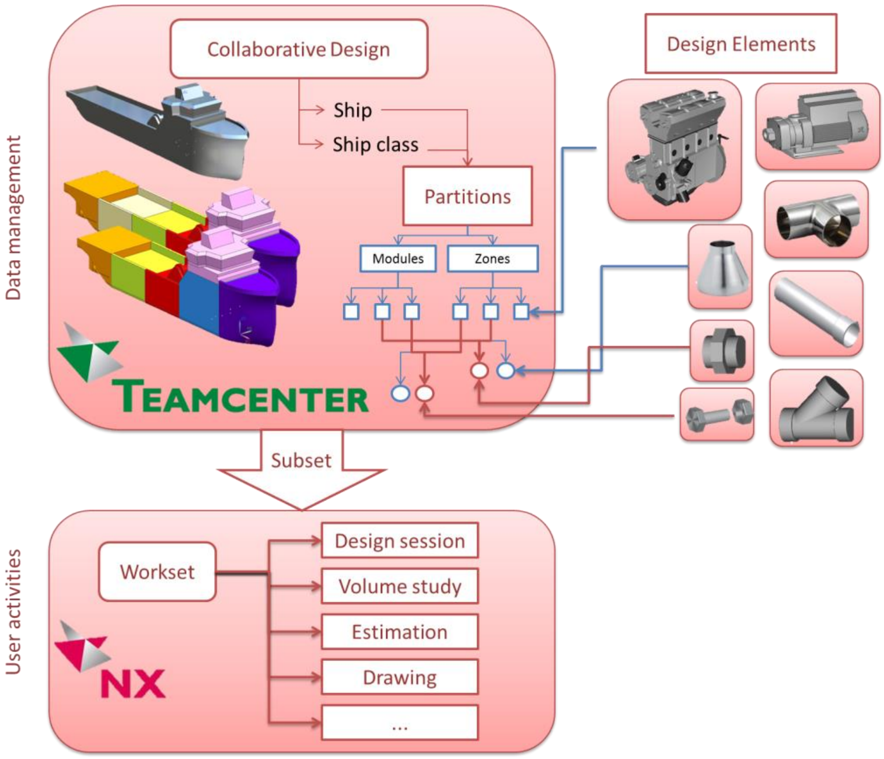


Figure 2.9. Relationship of 4GD data management objects (adapted from (Slagsvold, 2016) and Siemens AG)

2.3.4 Theoretical advantages

When used for design of large scale data products 4GD exposes advantages described further.

4GD allows retrieving only design-in-context data by means of partitions which means that only DEs relevant to a certain designer in certain area or system can be loaded in NX session without loading overhead data. It adds simplicity to the working environment due to ability easily reposition and modify only necessary design elements.

Concurrent access to the product in 4GD environment allows designers to work on different design elements within the same spatial or functional environment. Instead of a rigid subassembly structure where only one designer can work on a particular product, 4GD provides a dynamic manner of working environment that updates modifications performed by another designer. This feature of 4GD reduces the designing time and time-to- market of a product due to the ability for multiple teams to work on the same assembly at a time.

Each design element is an independently managed component of collaborative design environment with unique and declared: access privileges, maturity status, position in ship, set of attributes, revision history, unit effectivity, and locking status. In other words, the design elements do not need to be hierarchically ordered for controlling, accessing and managing the design data. Thus, it leaves the option for the shipbuilder to decide the level of detail in assembly by making separate parts or subassemblies as design elements in 4GD environment.

Data duplication is avoided due to the facility of multiple organizational breakdowns of a ship. This means that 4GD allows multiple views of an assembly (functional, physical, spatial (Figure 2.10)) which loads required unit once even if it belongs to multiple views, instead of pre-determined subassemblies of a product which add duplicates. This approach reduces complexity while loading and maintaining the design elements that makes day-to-day tasks easier.

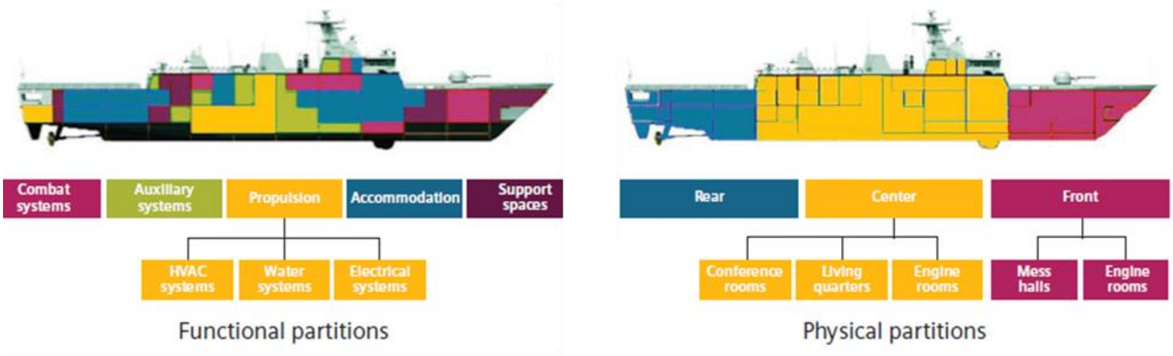


Figure 2.10. Organizational breakdowns (Siemens PLM software, 2013)

Assemblies designed in basic NX environment can be adjusted to 4GD concept and used as design elements due to Teamcenter capability to manage both approaches. It provides flexibility for the designers by using prior designed subassemblies which attain design element features when in 4GD environment. This means that assembly can be loaded separately without the whole structure. Using assemblies as parts in 4GD reduces re-modelling and speed up the designing process.

4GD incorporates the concept of effectivity which generates different configurations of a structure. The data can be configured based on date, specific intents, or unit number. In other word, the date effectivity specifies the content in certain time interval or until/from the certain date. Unit effectivity determines in which configuration a specific DE appears. Finally, the intent effectivity defines that the DEs appear in the structures which are specified to certain customer or which are composed from certain design. The effectivity specification should be done directly when the CD is created but it might also be added while designing in NX. The entire CD, separate DEs, worksets or subsets can be configured with effectivity.

PLM configuration management provides a capability to configure and re-use only relevant data among the ship family. In other words, only certain data can be selected from one ship, configured and re-used in another ship providing variations only when necessary and avoiding common data duplication. This ensures higher flexibility to the design process and facilitates the 3D re-modelling (Siemens PLM software, 2013).

3 Methodology

3.1 Research approach

Describing the method of investigation is an important matter in order to understand the direction of analysis and thesis construction. Therefore, this chapter will describe the type of research used for the case investigation and introduce the method which will be followed in the thesis.

Two types of research method can be distinguished which are quantitative and qualitative research. As Thomas (2003) defined, the simplest description of the research method says that quantitative research focuses on the measurement and amounts of characteristics that the test item exposes whereas, the qualitative research concentrates on the kind of characteristics that the test items reveal. According to the definition, the thesis will be constructed as a qualitative type of research due to the reasons described below.

Qualitative research involves broad focus and is mainly process oriented (Uwe Flick, 2009) which is the case in this thesis due to focus on the process of 4GD application and how it can reduce the 3D re-modelling. The 4GD application to the ship design haven't been analysed and described before, so the investigation is based on personal insight and observations which makes the conclusions more subjective. Plus, there will be no measured results only the theory whether the application of 4GD enhances the re-usability or not. That is one of the main features of qualitative research that the outcome is a theory or assumption (Uwe Flick, 2009).

Conducting any type of research it is important to define a method and follow certain framework to remain structured and goal oriented. As the research type was identified to be qualitative there are no measurable results to be expected and so the analysis will remain comparative. This means that the goal of the 4GD application to ship design in this thesis is to compare the 4GD against the current structuring method in context of exchange and re-modelling reduction. Therefore, the approach is mainly focused on the challenges met and observations made while performing the case study.

3.2 Taxonomy establishment

Prior to the methodology application, a preparatory step has to be taken that includes a decision on taxonomy.

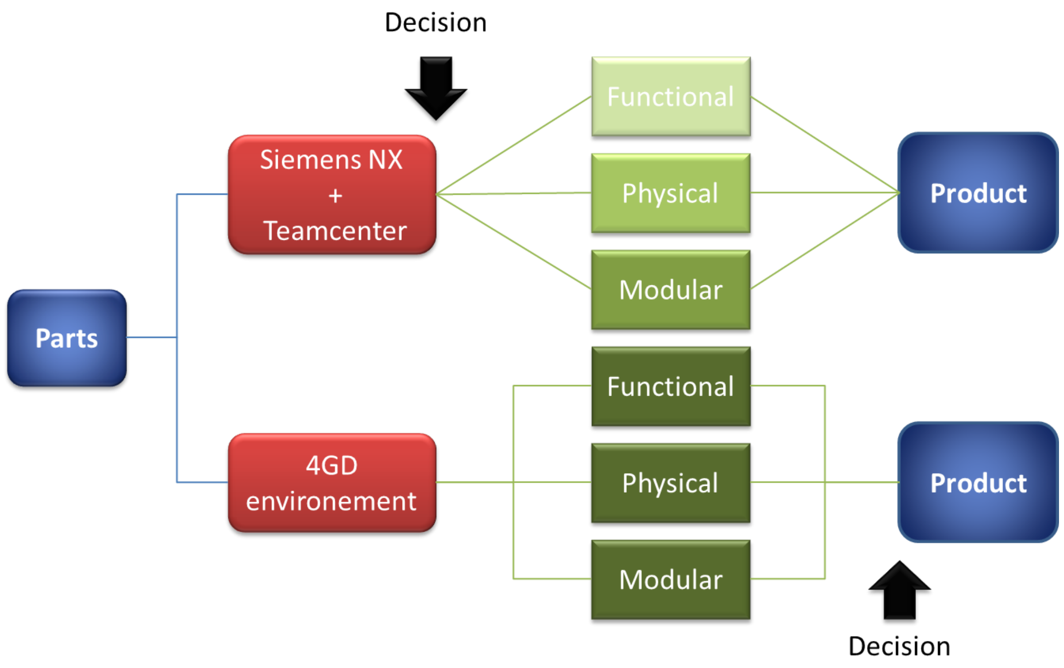


Figure 3.1. Taxonomy establishment in different modelling environments

As described in Chapter 2.2.4, using the traditional assembly approach it is important to establish the taxonomy to follow during the process prior the beginning of 3D modelling in ship design. It is necessary to have one common division of a vessel so that the stakeholders are able to perceive the same view of the ship. Moreover, most of the 3D modelling software require a well-established organizational breakdown of a vessel prior the basic design. The Siemens NX and Teamcenter software used for this case study are not an exception. Therefore, the taxonomy for a 3D object modelled in NX+TC environment is determined and described beforehand (Figure 3.1).

In case of 4GD approach, the decision doesn't have to be taken in advance. The 4GD approach deals with a different concept of vessel taxonomy where several organizational breakdowns are possible to use which makes it a significant part of the investigation.

The most ordinary taxonomy in ship design is functional, physical and modular structure which will be used in this case study. In case of NX+TC environment one of the organizational breakdowns will be selected primarily and 3D model composed according to that. In 4GD case, this decision is only taken when selecting the view of already finished 3D model. Figure 3.1 illustrates the taxonomy decision making in different modelling environments.

3.3 Method for 4GD application

As there are no current studies on 4GD, this study can't be based on previous experiences or research data. This is a limiting factor for comparison with previous research and knowledge development but provides freedom for assumptions. Therefore, the method to follow up in this research was devised concentrating on the comparison of the two approaches based on the individual experience.

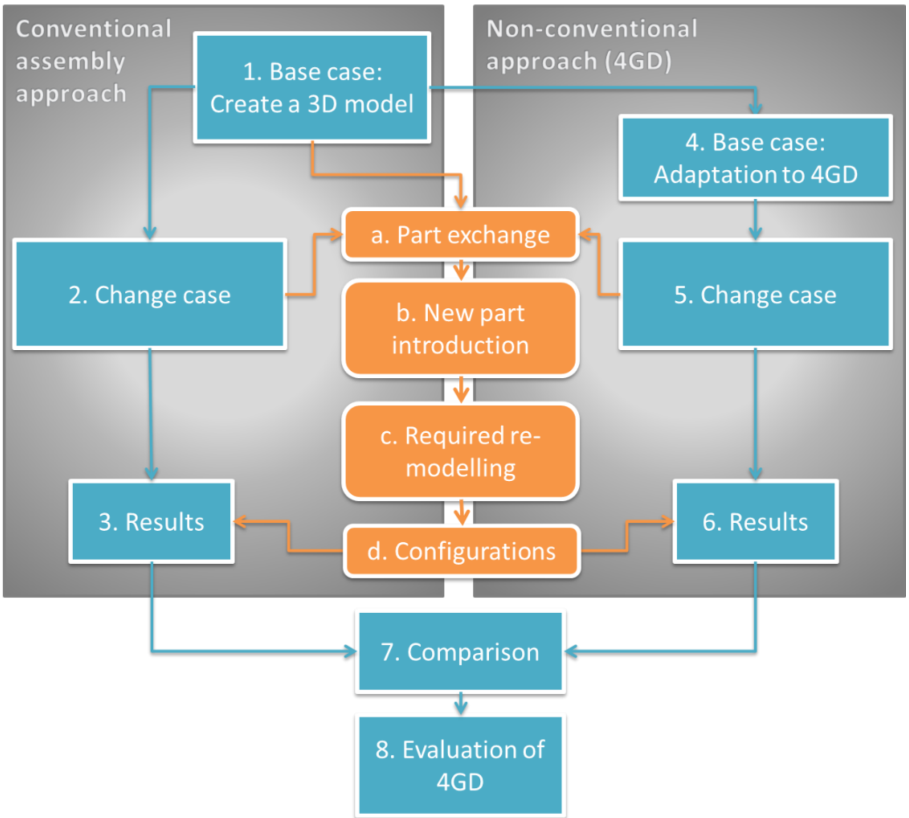


Figure 3.2. Methodology of 4GD application to ship design analysis

The method to investigate the 4GD capabilities is to perform the same modelling actions and modifications in two different environments (Figure 3.2).

The conventional assembly approach is the most commonly used structuring approach nowadays. The case study will be performed using Siemens NX modelling software with integration to Teamcenter (later on NX+TC). This means that the Teamcenter is used as a management and storage environment where NX will be used for 3D modelling the objects.

The non-conventional approach is the new 4GD concept for modelling large scale objects. 4GD environment is integrated within Teamcenter and NX but has its own features and functions. Here the 4G designer in Teamcenter is used for object creation and structuring, and NX is dedicated for creating DEs and modelling in 3D.

The method model is displayed in figure above where each step is numbered and the descriptions are defined further in this chapter.

1. Base case. In this step the 3D model of an object is established. The 3D model is created using NX and TC to store the documents and files of the model. The parts of the assembly are created randomly or imported from free online sources. The configurations of items in the assembly are well defined as well as the location of each object within the 3D model. In this step, the sequence of actions and the way of modelling is not of the highest importance as the focus of this case study is on the 3D re-modelling and exchange.
2. Change case. In this step the change in the model created in Step 1 is performed assuming that there is a new project which requires additional parts or exchange of some parts. This step is accomplished in the simple NX and Teamcenter integration using the current assembly structuring method. The sequence of operations in this step is documented and described as well as the actions itself.

   There are 4 sub-steps that include following actions:

   a. Assuming that there is a necessity to increase/decrease the dimension of a certain part, it is exchanged by the required one. Consequently, the location and constraint are changing due to the new requirements and dimension.
   b. Some new parts are created and introduced to the model which influence other object already located in the 3D model. This Sub-step includes setting new constraints of the objects while rearranging the 3D model in order to make space for new part(s). The constraints and configuration remain from the Step 1 but requires modification.
   c. In this sub-step, the required re-modelling means that due to exchange parts and some new parts in the 3D model, there is necessity to modify surrounding parts by re-dimensioning, exchanging or relocating them.
   d. Configurations here refer to the possibility to select a desired arrangement of a certain 3D model. This means that a 3D model will be created with two configurations from which a customer could choose.

The change is performed from the 3D designer point of view meaning that it only concerns the challenges met and steps taken using the modelling software (Siemens NX). This study doesn't investigate the change management, requests and variety of steps in the lifecycle management in order to perform a change. This case study is focusing on the ease of modelling using the 4GD and not the business processes in Teamcenter, so the change will be performed manually in NX.

The goal of this step is to perform different types of changes and evaluate the challenges met during the process as well as highlight the main features of the traditional assembly approach.

3. Results. The challenges met in the change process are described and summarized here. Ease of re-usability and the influence of any kind of change in the model to surrounding parts are evaluated in context of traditional assembly approach. The exchange of the parts in context of hierarchical assembly structure is of high importance as well as the impact of constraints while re-modelling. The results are expected to reveal the negative and positive aspects of current structuring approach.
4. As a part of the Base case, the 3D model created previously is adapted to the 4GD environment to avoid re-modelling of the same parts as the modelling is not the focus of this case study. Exactly the same 3D model assembly with its constraints might be imported using a special 4GD function 4gd_populate_cd which automatically imports the previous assembly structures and converts it into 4GD Collaborative design (Siemens PLM software, 2015). However, it requires additional knowledge in programming and might be time consuming. Therefore, a manual import of the assembly to the 4GD environment will be performed.
5. Change case. In this step the same changes performed in Step 2 are repeated on the 3D model in the 4GD environment. Here, the actions taken are defined and documented as the approach to introduce or exchange parts within the 3D model is based on a new concept. Due to the capabilities of 4GD it is expected that using this new concept the change case will be performed faster and easier than using the traditional assembly approach.

   In order to verify the suitability of 4GD for a certain problem, the features and advantageous points defined in Chapters 2.3.2 and 2.3.3 are used to perform the change.

6. Results. The evaluation of how easy/hard was the change process in 4GD environment is represented in this step. The main focus is on the parts exchange process, the actions made during that and how much the objects and their location were influenced. Another important point is how the 3D re-modelling works in 4GD environment and how the sub-steps were performed regarding that.
7. Comparison step refers to the comparison between the traditional assembly approach and the 4GD concept. Taking into account the results from steps 4 and 5, the advantages and disadvantages of both methods will be emphasised against each other. The comparison is performed according to four main features in concern: exchange, re-modelling, restrictions of constraints, structure importance. It is expected that this will define weather the 4GD improves the exchange and minimises 3D re-modelling in ship design.
8. Finally, the evaluation is assigned as the last point of the method where the validity of 4GD in specific case will be discussed. Here, the final implication is made to the 4GD application in ship design against the traditional assembly approach to reduce the exchange and facilitate the 3D reuse.

In order to verify the methodology, first of all it will be applied to a simple ship design case. The simple case application is necessary to test the 4GD environment to adapt its features and concepts as it is used for the first time. The simple case should already provide the first impression on 4GD and might expose some of the advantages against the conventional assembly approach. Following the Figure 3.2 step by step, the simple case application is performed and described in detail in the following chapter.

3.4 *Simple case application*

For the primary case analysis a simplified engine room will be modelled in order to evaluate the established method of investigation for this thesis. The ship design stages are avoided here as it only concerns the 3D modelling and change processes. It doesn't correspond to any real time vessel 'because available information is limited and the degree of design freedom is very high' (Lee & Lee, 1999). Therefore, the further designed engine room is entirely modelled for this case study.

3.4.1 Conventional assembly approach

Step 1: The Base case. A simplified engine room is established in this step as shown in Figure 3.3. It consists only from few parts that are: 1. The room outer walls; 2. Three engines; 3. Fuel day tank; 4. Fuel system pipes; 5. Exhaust gas system pipes; 6. Exhaust gas pipes support box. All of the parts were modelled separately and then imported into the assembly.

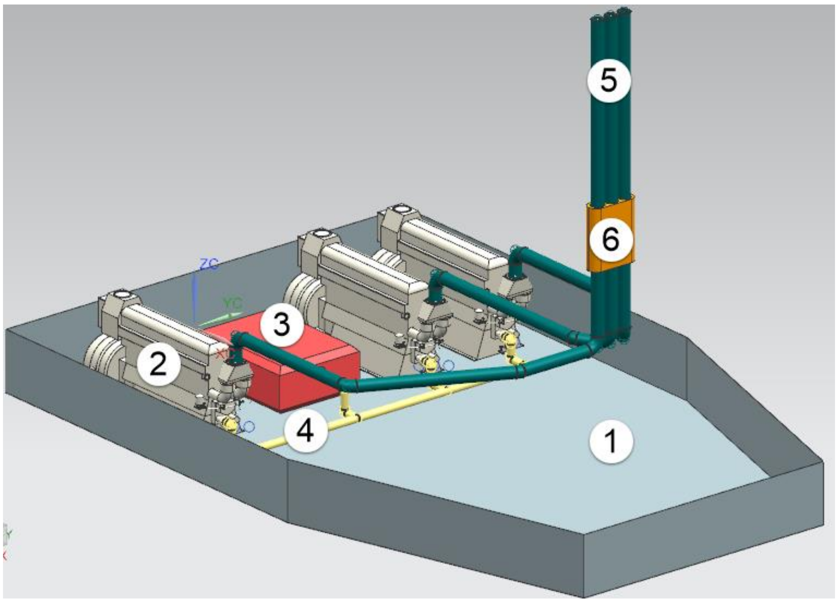


Figure 3.3. Simplified engine room (base case in NX+TC)

First of all, the room was constrained to be fixed (Figure 3.4: 1) as the base of the assembly to which the rest of the parts are constraint. Then, the first engine was added to the assembly and the two others were patterned. The engines were constrained to the room by aligning the bottom of the engine to the floor of the room and setting the distances in two axes to the two sides of the room (Figure 3.4: 2). Consequently, the day tank for the three engines was added to the assembly and was constrained in the same manner as the engines

(Figure 3.4: 3). Modelling of the exhaust gas pipes was performed as design-in- context in the Mechanical application in NX. The three pipes were constrained by adding ports to the engines. The support box was modelled according to the alignment of the pipes. Finally, the fuel pipes were also designed-in-context by adding the ports and setting the flow from the fuel tank to the three engines.

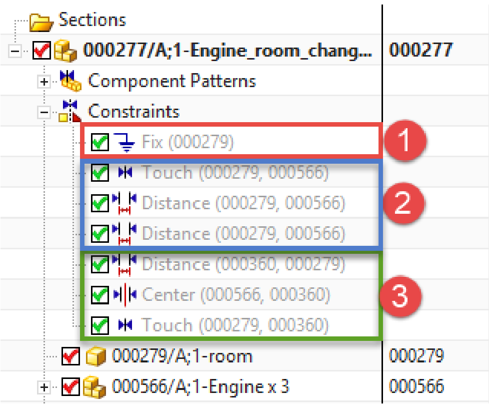


Figure 3.4. Assembly structure

Step 2: Change case covers the assumption that there is a request of change in the project which requires adding, increasing or reducing the number of certain parts in the engine room, altering the configuration and arrangement of units.

It is assumed that there is necessity of the 4^{th} engine in the engine room to increase the power of the vessel. Due to additional engine, the size of the day tank has to be increased. Also, the arrangement of the engine room has to be modified in order to make space for the 4^{th} engine. Following the methodology, the changes are performed by three steps:

a. Part exchange. The day tank requires higher capacity to supply engines with the required fuel. Therefore, in this step the day tank is exchanged by adding a new day tank. When a new part is introduced the constraints are lost and thus the pipes don't follow automatically the outlet port and have to be manually configured to correspond to the outlet port of the newly introduced day tank.

   As a next action in this modification, the relocation of the day tank (Figure 3.5: 3) follows in order to make some space for the additional engine. The day tank is moved by changing its orientation and the distances from room sides. As previously the pipes were configured manually, this time they followed the outlet port automatically.

b. The fourth engine is introduced in the 3D model as a new part. It is patterned from the other engines but the problems appear while relocate the engines. The routing parts are constraint to the engines and when the engines are intended to move, the error appears due to the intersection of the pipes. Therefore, the exhaust gas pipes have to be modified to comply with the outlet ports of the engines.

c. Required re-modelling means that due to exchange parts and some new parts in the 3D model, there is necessity to modify surrounding parts. As the new engine was located in the assembly, it requires addition of pipes in the exhaust gas and fuel systems. The rearrangement of the pipes is also performed in order to make enough space for additional pipes. Due to the extra pipe in the exhaust gas system, the pipe support box has to be exchanged by a bigger box (Figure 3.5: 6). This requires new constraints of the box to the pipes as it was designed-in-context.
d. The configurations application was not performed in the simple case analysis.

The engine room changed in this case is shown in Figure 3.5.

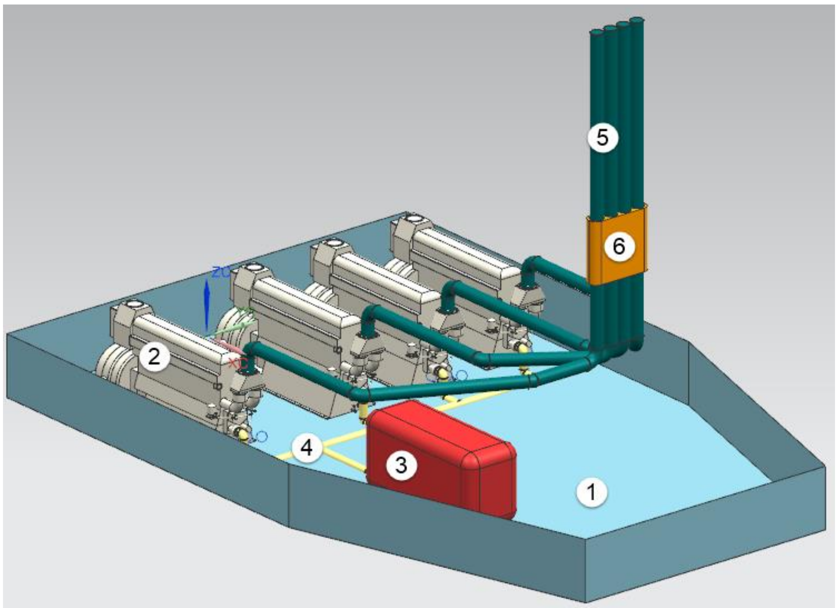


Figure 3.5. Simplified engine room (change case in NX+TC)

Step 3: Results will describe the main problems and difficulties during the change process:

- Following the changes of parts and its location in the model, the routing systems should update automatically. However, not in all cases it worked and thus the pipes had to be opened separately in order to issue the update. In case of a new part introduction, the port is lost which causes additional qualification of the parts into the routing system and manual connection with the piping system (Figure 3.6). In this case, it requires paying attention to every pipe and its constraints which consumes time.

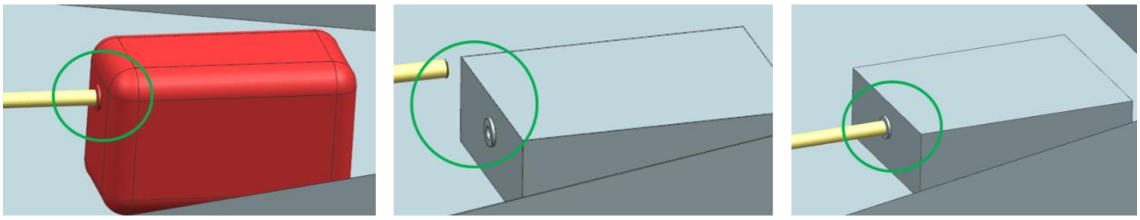


Figure 3.6. Manual configuration of the piping systems

- When the part is exchanged it requires deleting the constraint of the previous object and adding new constraints to the recent item. In case if there are children items constrained to the part which needs to be exchanged, all the constraints are lost.
- Trying to delete one of the engines in the assembly issues an error (Figure 3.7) which means that the parent item can't be deleted if it has the patterned children below. This restricts modelling possibilities and requires well organised structure beforehand. If there is an unpredicted change in the assembly the parts has to be made unique and additional constraints need to be established. Due to duplicates in the traditional assembly, the additional re-modelling of some items is required.

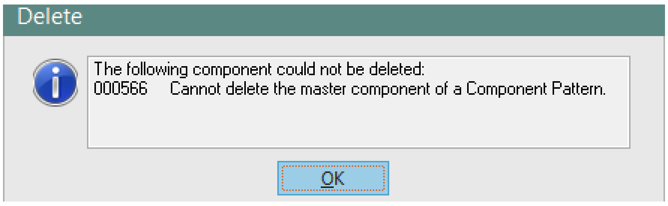


Figure 3.7. Deleting parent item error

3.4.2 Non-conventional approach (4GD)

Step 4: Base case – adaptation to 4GD covers the simplified engine room assembly introduced in to the 4GD environment as a collaborative design. As the methodology describes, the engine room is manually added to the 4GD environment.

The first two steps of the adaptation process are performed in the Teamcenter that includes creating the CD to which the partitions are added subsequently. Two partition schemes were created for this example in order to investigate different option of the organizational breakdown. Consequently, the partitions were added to the functional and physical partition schemes to create more complex model structure (Figure 3.8 and Figure 3.9).

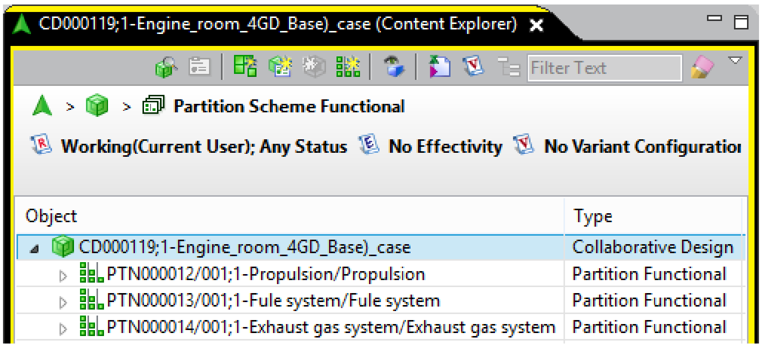


Figure 3.8. Functional partition scheme of the Engine room

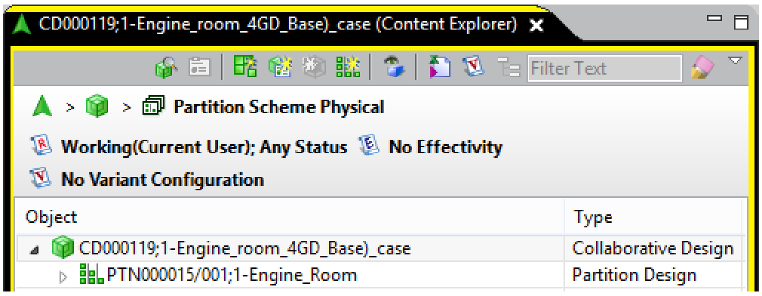


Figure 3.9. Physical partition scheme of the engine room

The following steps were performed in NX which is reached apart from the 4GD environment in Teamcenter. The CD was dragged-and-dropped into NX where the workset and subset were created (Appendix C, part 4). It was defined by the recipe that all partition of the Engine room CD are included in the workset (Figure 3.10). As soon as the subset was defined the Design element were created from previously designed parts (Appendix C, part 5). The parts were introduced as reusable DEs and the piping parts were created as route design shape elements.

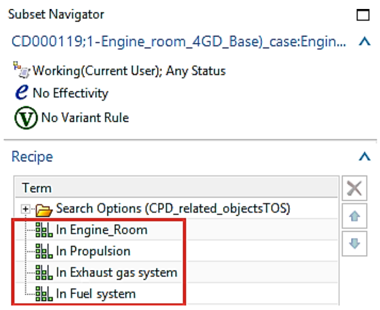


Figure 3.10. Subset recipe

The room outline is imported primarily in order to have a reference for locating the rest of the object in the engine room. The room 3D model is fixed to the Datum coordinate system of the engine room CD using the assembly constraints. Consequently, the rest of the parts were imported and located in relation to the same Datum coordinate system of the engine room CD. The DEs were located by moving the objects ‘By constraints’. The ‘Pattern component’ feature is not available in 4GD environment, so the engines were separately added to the CD. NX recognizes the engines as the same element but each of the parts within the engines have unique ID and are not duplicated. The routing systems were created from scratch due difficulties to import and relocate the pipes in the 4GD environment. Figure 3.11 shows the assembly structure of the engine room subset in alphanumeric order which is an option in 4GD.

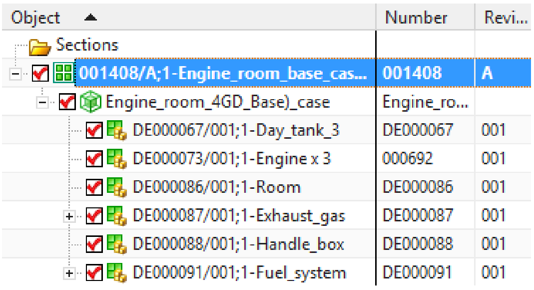


Figure 3.11. Alphanumeric assembly structure in NX

When all of the parts were located in the CD object, the DEs were assigned to certain partitions. As the assembly includes only few parts the partitions are aren’t necessary but they were created in order to test as much 4GD capabilities as possible. The final model of the base case is shown in Figure 3.12.

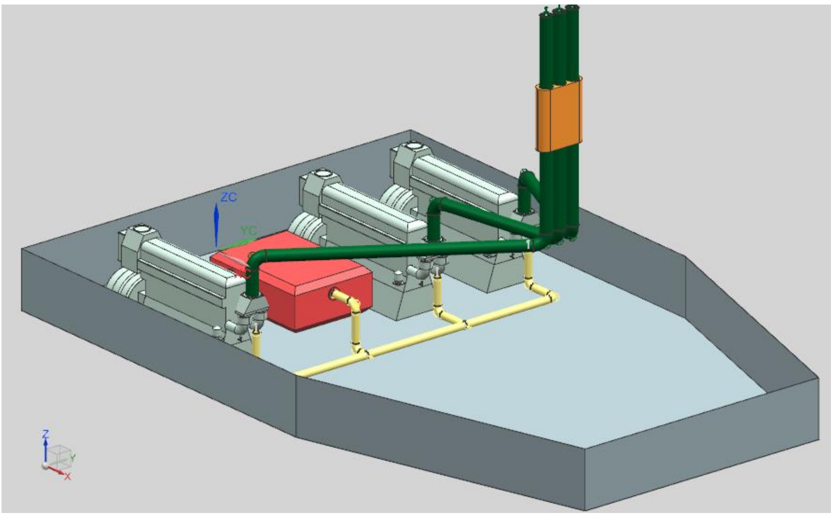


Figure 3.12. Simplified engine room (base case in 4GD environment)

Step 5: Change case is performed on the CD of the engine room by creating different subsets for each of the sub-steps in order to perform the changes in context of relevant objects.

a. In the sub-step of part exchange, first of all, the day tank is exchanged by another tank with higher capacity. The subset ‘Tank exchange’ is created which includes the DEs from Fuel system and Propulsion system partitions (Figure 3.13). Primarily, the day tank was created as reusable design element, so in order to exchange the tank DE a function ‘Replace Source Part’ is used that allows to exchange the DE and keep its location, and constraints according to the coordinate systems. The new tank was exchanged and as Figure 3.14 shows, the DE kept its location and orientation. In order that the fuel pipe remains attached to the new day tank, the fitting port of the tank was modified which lengthened the pipe due to different dimension of the day tank.

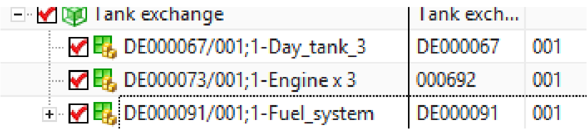


Figure 3.13. Tank exchange subset

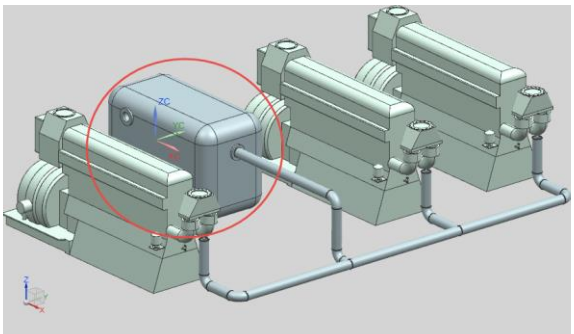


Figure 3.14. Exchanged day tank

The next action in this step is to relocate the day tank which is performed in the ‘Tank exchange’ subset as well. The tank was relocated by ‘Move’ function where the tank was rotated by 180 degrees and translated along X axis (Figure 3.15). The fuel pipe followed up the tank to the new location without any kind of errors.

b. New part introduction involves a fourth engine addition to the engine room. In 4GD it’s accomplished by creating a new DE and reusing the engine from previous case. The fourth engine is located according to the three other engines in order to combine a symmetric pattern of the engines’ location.

c. Required re-modelling refers to the modification of influenced parts after the new engine was introduced. First of all, an additional fuel pipe was modelled by modifying the existing Fuel system DE. Then, one of the exhaust gas pipes were moved in order to make space for additional pipe which was modelled consequently. Finally, as the new design include 4 pipes instead of three, the handle box has to be exchange by the previously modelled box for 4 pipes. This action was as well performed using the ‘Replace Source Part’ function which directly located the handle box in the required place.

d. The configurations application was not performed in the simple case analysis.

So, the final 3D model of the simplified engine room change case in 4GD is shown in Figure 3.15. It can be seen that the model is slightly different from the one made in the NX+TC environment which is because this study isn't concern of the detail of the model but the modelling approach itself.

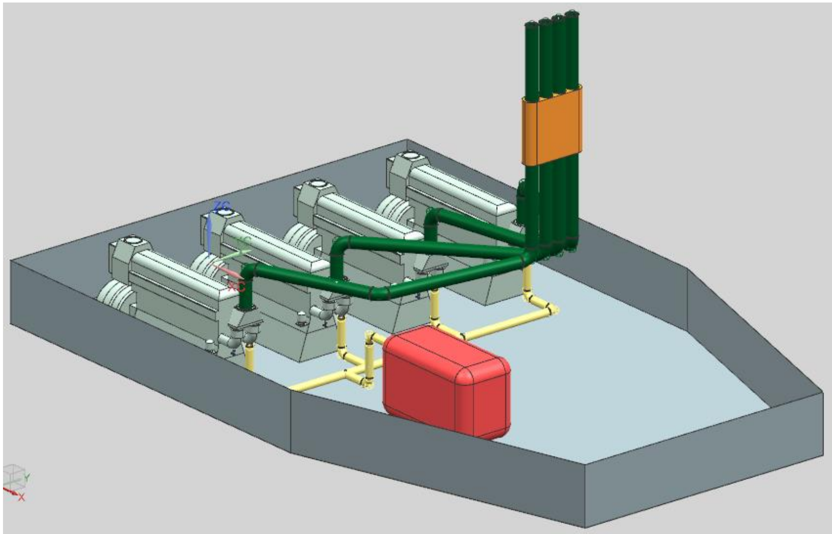


Figure 3.15. Simplified engine room (change case in 4GD)

Step 6: Results. Summary of the main challenges met during the modelling and change processes:

- Importing assembly from existing structure to 4GD caused issues due to unprecise assembly structure which required changing the revision rule of the assembly. However, even if the revision rules of the assembly were change, the problems appeared anyway. Therefore, instead of assembly structure of the engine it had to be simplified to a single part. This brings issues if one of the parts in the assembly need to be modified which becomes impossible due to single part.
- The datum coordinate system location in the design element is very important in order to have a precise allocation of each design element within a workset. For this case, as most of the parts were previously modelled some of the coordinate systems were not coinciding with the DEs, so several manual modifications were performed.
- The part exchange was performed smoothly and quickly. Only by using one function one source part was exchanged by another and located in the same position. This influenced only the fuel system for which to be connected to the tank, it had to be qualified as a routing part. This was done simply by modifying the fitting port.

- The re-modelling was performed similarly as in the NX+TC because the routing application doesn't differ from the one in 4GD. However, the handle box didn't require re-modelling to fit new model because it could be exchanged by already existing part.
- Since the 4GD doesn't involve the assembly constraints, there were no errors while relocating parts or introducing new parts within the 3D model. They were simply located by moving the parts by constraints and the location remained in a certain workset.

3.4.3 Comparison and evaluation

This chapter presents a comparison and evaluation derived from the results of performing the change case by two different approaches. Table 3.1 is composed according to the four main criteria to evaluate the modelling. As it can be seen, the traditional assembly approach in NX+TC is displayed against the 4GD approach.

Table 3.1. Comparison of the conventional assembly and non-conventional (4GD) approaches (simple case)

	Conventional assembly approach	Non-conventional approach (4GD)
Exchange	▪ One part is deleted, the other is introduced instead ▪ The location constraints are lost ▪ Routing requires manual editing ▪ Influences the children parts	▪ Performed using one function ▪ Correctly located ▪ Routing requires manual editing ▪ No influence on surrounding parts
Re-modelling	▪ Additional constraints required ▪ Design-in-context	▪ Parts exchange might be used to avoid re-modelling ▪ Design-in-context
Restrictions of constraints	▪ Location by constraints ▪ Change constraints to relocate ▪ Hierarchy order	▪ No constraints ▪ 'Move' the DEs to relocate
Structure importance	▪ Requires well organisation beforehand	▪ No structuring order is required

The comparison shows that part exchange is much more complicated using the traditional assembly approach than 4GD due to high importance of constraints and hierarchical order of the assembly. Where in 4GD the exchange was performed by one function and the DE was already located in designated space. The re-modelling step didn't expose such high difference between the two approaches as the design-in-context for this small 3D model was easily performed in both cases. However, the biggest difference is observed in sections restrictions of constraints and structure importance due to different designing method. In the traditional assembly approach the objects are highly restricted by constraints where in 4GD the DEs are not constrained but still contain appropriate location. This is an advantage in 4GD because it allows relocating the parts easily and provides freedom to the designer. The structuring importance exposes the same advantage of 4GD due to low importance of order within the assembly. Parts don't necessarily have to depend on parent parts and thus are easy to move or modify whereas in traditional structuring model the hierarchy is of high importance.

From this simple case application it can already be seen that 4GD exposes several of the theoretical advantageous when used in practice. However, no conclusions weather it improves the exchange and facilitates the reuse can be made. As for the methodology application, it can be concluded that the framework is suitable for comparative analysis in this research.

4 Main case study on the 4GD applied to PSV

4.1 Product overview

The Platform Supply Vessel (PSV) is selected as a vessel of investigation in this case study. This chapter gives a basic overview on the main design requirement for any kind of PSV, so that later on the vessel configuration 3D model could be created based on this chapter. The capacity of the vessel and its parts are not in concern, yet the cargo and propulsion configuration is of the highest importance. (Torgersen, 2009)

Platform supply vessel is designated to carry all sorts of materials and goods from the shore to the platform. The cargo depends on the type of the platform and area of operation (Díaz-de-Baldasano, et al., 2014): Fuel oil, Ballast water, Base oil, Potable water, Dry Bulk Brine, Drill water, Liquid, Mud, Methanol. According to the type of cargo and specific needs of logistics, the tanks and containers are accommodated and arranged differently in the vessel. Figure 4.1 illustrates one of possible ways to arrange the tanks on the decks of the PSV. For this case study, it is assumed that the PSV carries 3 different types of cargo which are located separately from each other.

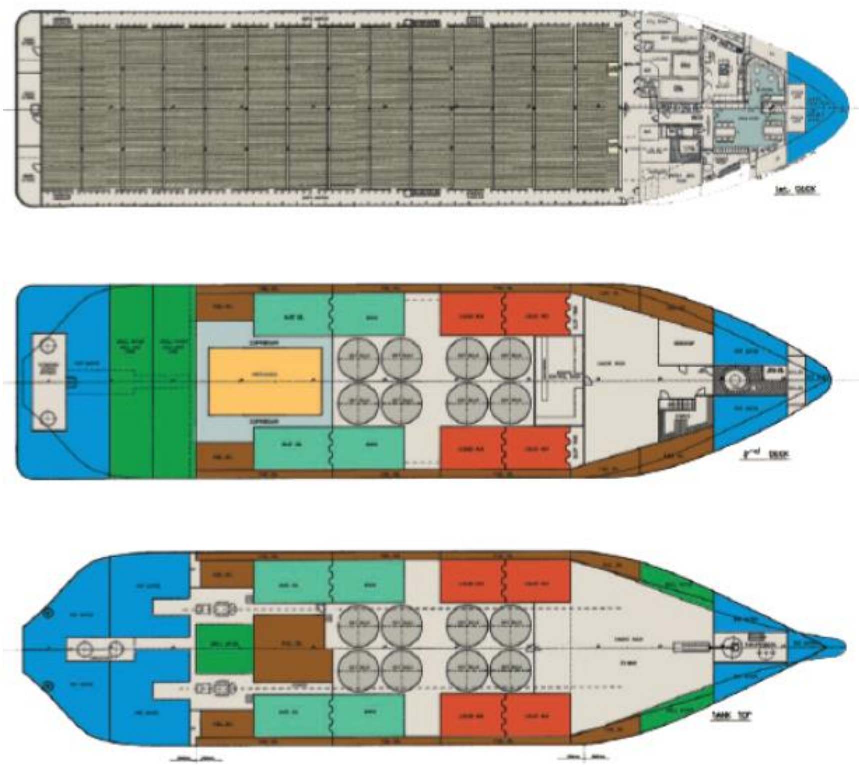


Figure 4.1. FAR supplier: cargo area GA drawings (Torgersen, 2009)

From the Figure above the three decks can be excluded which will be also modelled in this case study: Main deck; Tween deck; Tank top.

In this case study, propulsion is one of the most important systems in the vessel as it has interconnection with all modules of the vessel. Depending on the size and working environment of the PSV appropriate number of engines is used in the propulsion. Most commonly the diesel engines are used in the aft or forward part of the vessel. Here, three engines in the front of the vessel are selecting to power two generators running two propellers at the rear of this PSV.

PSV might have between 20 to 50 crew members that influence the number of the accommodation decks and rooms in the wheelhouse. However, for this case study the number of the persons in the vessel is not defined but the wheelhouse contains 3 decks with several rooms and common areas.

4.2 Product taxonomy

4.2.1 Introduction

As discussed previously in chapter 3.2 there are different taxonomies such as physical, functional, and modular. All of them compose different blocks of objects. It was established that for traditional assembly approach it is necessary to decide in advance by which division the ship 3D model will be arranged and what approach will be followed. For the case study of 4GD application to PSV this decision can be made just before displaying the product. That is a significant difference between the two approaches which will be described in this chapter.

4.2.2 Single organizational breakdown for conventional assembly approach

The 3D model of PSV used for this case study was created for design project '3D Printing – Ship Modularisation Pilot Project' as part of EMIS Project (Andrade, et al., 2015). The 3D model is already designed by the division of modules and includes only the hull structure. Detailed model created further as a part of the case study itself. As the PSV is already subdivides, the organizational breakdown employed in NX+TC environment is selected to be modular.

In order to perform a detailed investigation on how the organizational breakdown works and influences the designing process, several sub-modules were created for the already existing structure. The presentation of a PSV, the division into modules and sub-modules is purely made from assumptions and is dedicated only to this research. It's devoted to investigate the ship designing problems and does not represent an actual vessel. The 3D model is very simplified and therefore consists only from several parts.

The division of the PSV 3D model is illustrated in Figure 4.2. As it can be seen the vessel is divided into 8 main modules and several sub-modules which will be used for this case study:

- Stern module is the rear part of the 3D model which only consist of the propellers in this case study.
- Modules Cargo hull_01 for liquid cargo, Cargo hull_02 for dry bulk cargo and Cargo hull_03 for deck cargo are very similar to each other. All of them include tanks for specific cargo type, control boards and tank sounding system. However, the configuration of the tanks and it's dimensions are different which is why they are excluded as different modules.
- Super structure module locates the hotel accommodation which is divided into cabins, day room, galley and service room objects. Another sub-module here is the engine room which include piping, HVAC and control systems.
- Bridge module consists of navigation, control that is in connection with the cargo and engine, and manoeuvring sub-modules.
- Conventional bow module is sub-divided into manoeuvring and anchoring system that will not be investigated in this case study.
- Propulsion module includes 5 sub-modules to produce power and movement of a vessel. This module is related to all of the other modules as its extent passes through the whole vessel which is why the propulsion is excluded as a module of this PSV.

  Each module and sub-modules consists of assemblies and parts appropriate to location and function of the modules.

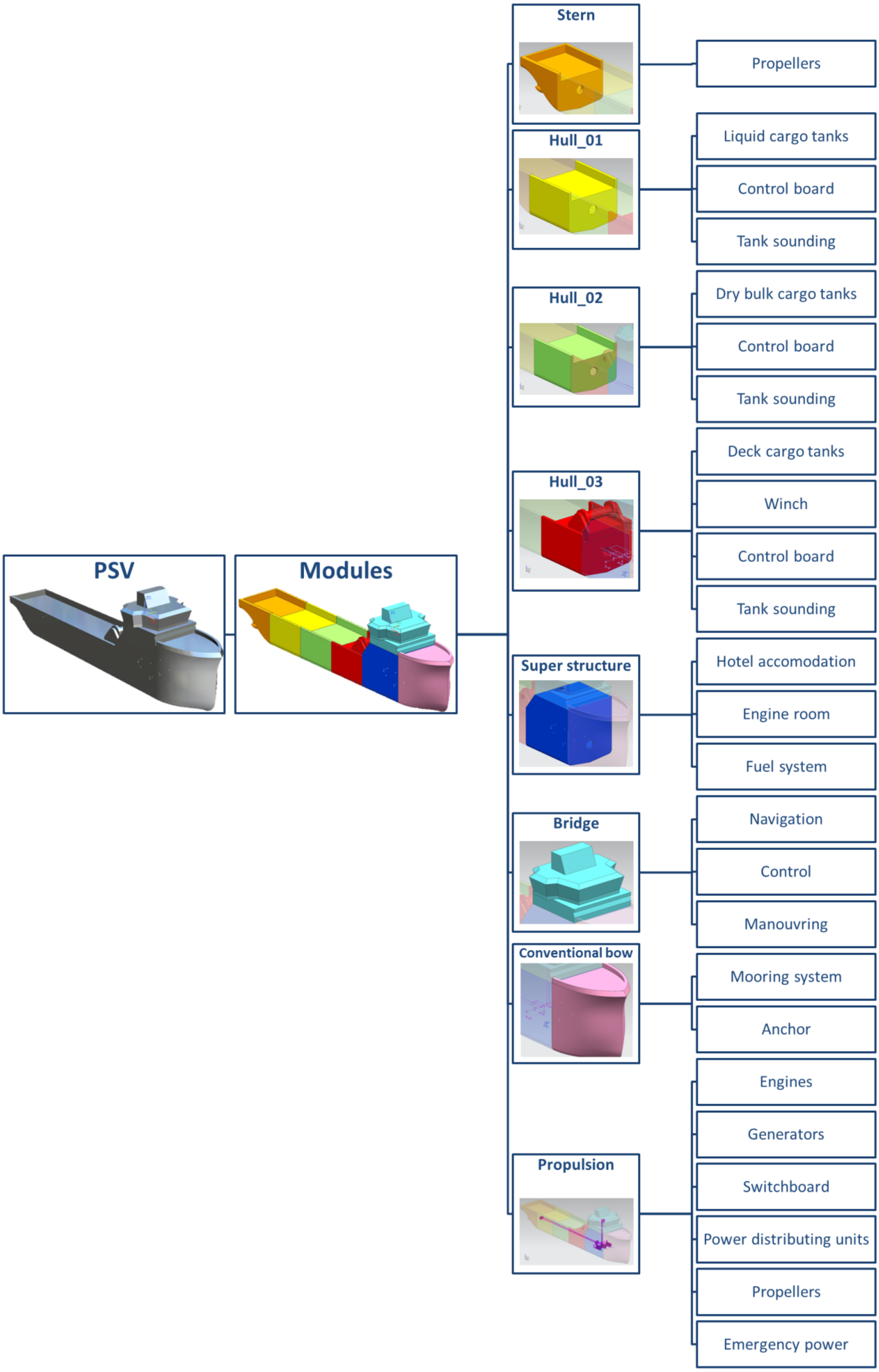


Figure 4.2. Modular PSV structure

4.2.3 Multiple organizational breakdowns in 4GD

The main feature of 4GD concept is the multiple organizational breakdowns which enables different views on a vessel. According to the Figure 3.1 the decision on the taxonomy in 4GD approach doesn't have to be taken prior the designing. In this case study, all three organizational breakdowns will be employed in the vessel structuring as partition schemes. The partitions will be created as sub-modules of the structure. In order to test out different ways of designing, the modular division of PSV will be created in the Teamcenter prior the designing when partitions of functional and physical partition schemes will be created during the modelling process. 4GD supports three types of partition schemes: functional, physical and spatial. In this case study, modular division corresponds to the spatial partition. Therefore, this chapter establishes how the PSV with the same parts is divided by different organizational breakdowns.

- Modular. Figure 4.2 illustrates the modular PSV taxonomy which will be used for the modular organizational breakdown in 4GD as well. This taxonomy is defined as a partition scheme which comprises of partitions. The modules are established as partitions and sub-modules as design elements in 4GD.
- Physical organizational breakdown of the PSV is composed based on Figure 2.10 where the physical structure of a vessel consists of Rear, Center and Front parts that further comprises of physical sub-systems. This division of a vessel is location based where the systems are certain vessel spaces which include all of the assemblies and sub-assemblies within its area. Some parts as power distributing unit (PDU) are extended throughout the vessel and are included in several sub-systems. In the 3D modelling software such parts are divided and added to the appropriate physical module. The physical organizational breakdown of the PSV in this case study is shown in Figure 4.3.

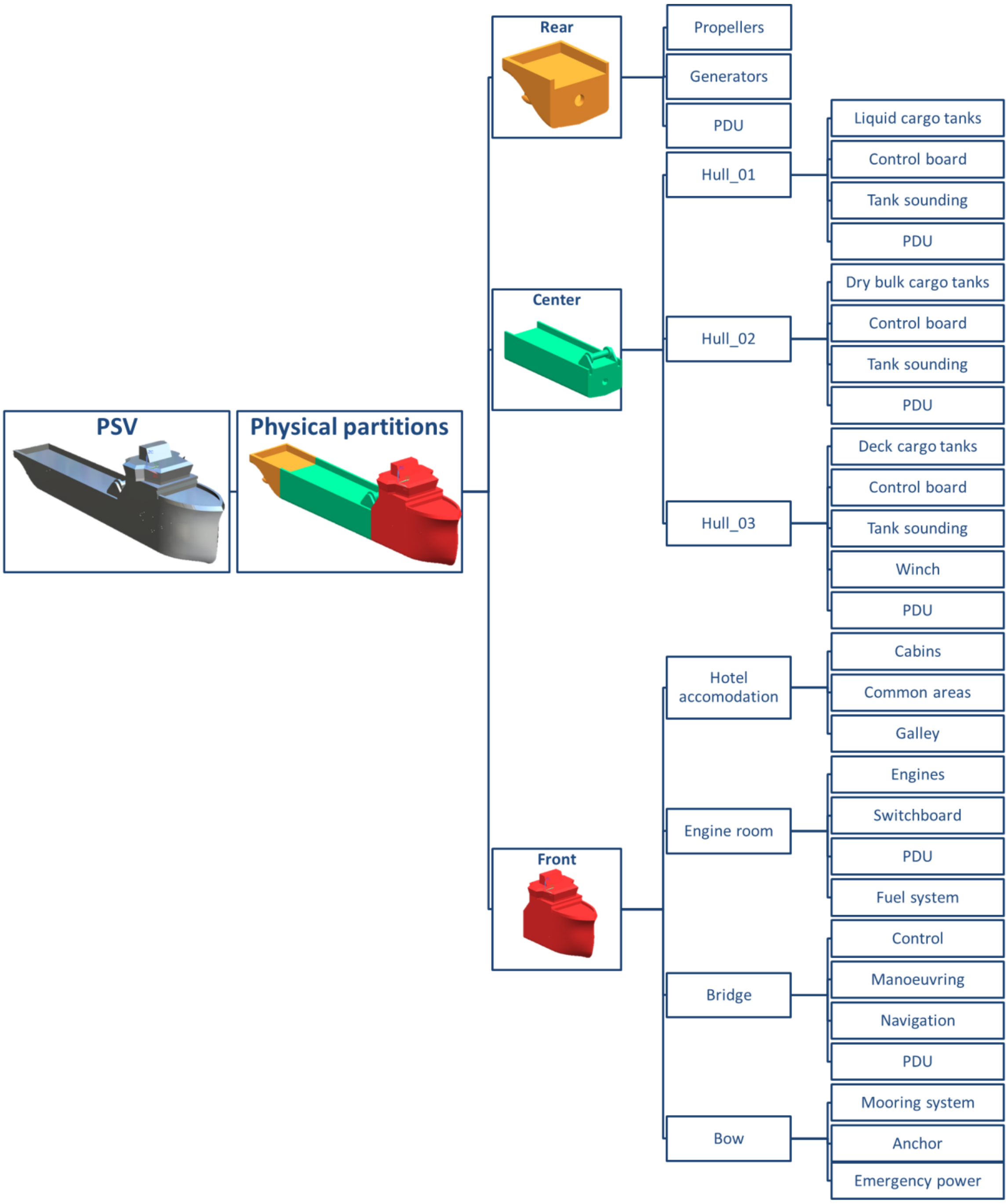


Figure 4.3. Physical PSV structure

- Functional organization breakdown is also based on the organizational breakdown suggested by Siemens (Siemens PLM software, 2013). This PSV structure is oriented to the functional groups of objects within the vessel. For this case study, functional partitions shown in Figure 4.4 are used. As the 3D model of the vessel will be simplified, not all systems and parts required for a vessel are designed which makes it difficult to divide the PSV by function. Nevertheless, some of the systems were assumed and the functional partitions includes auxiliary system, mission oriented system, accommodation, propulsion and hull.

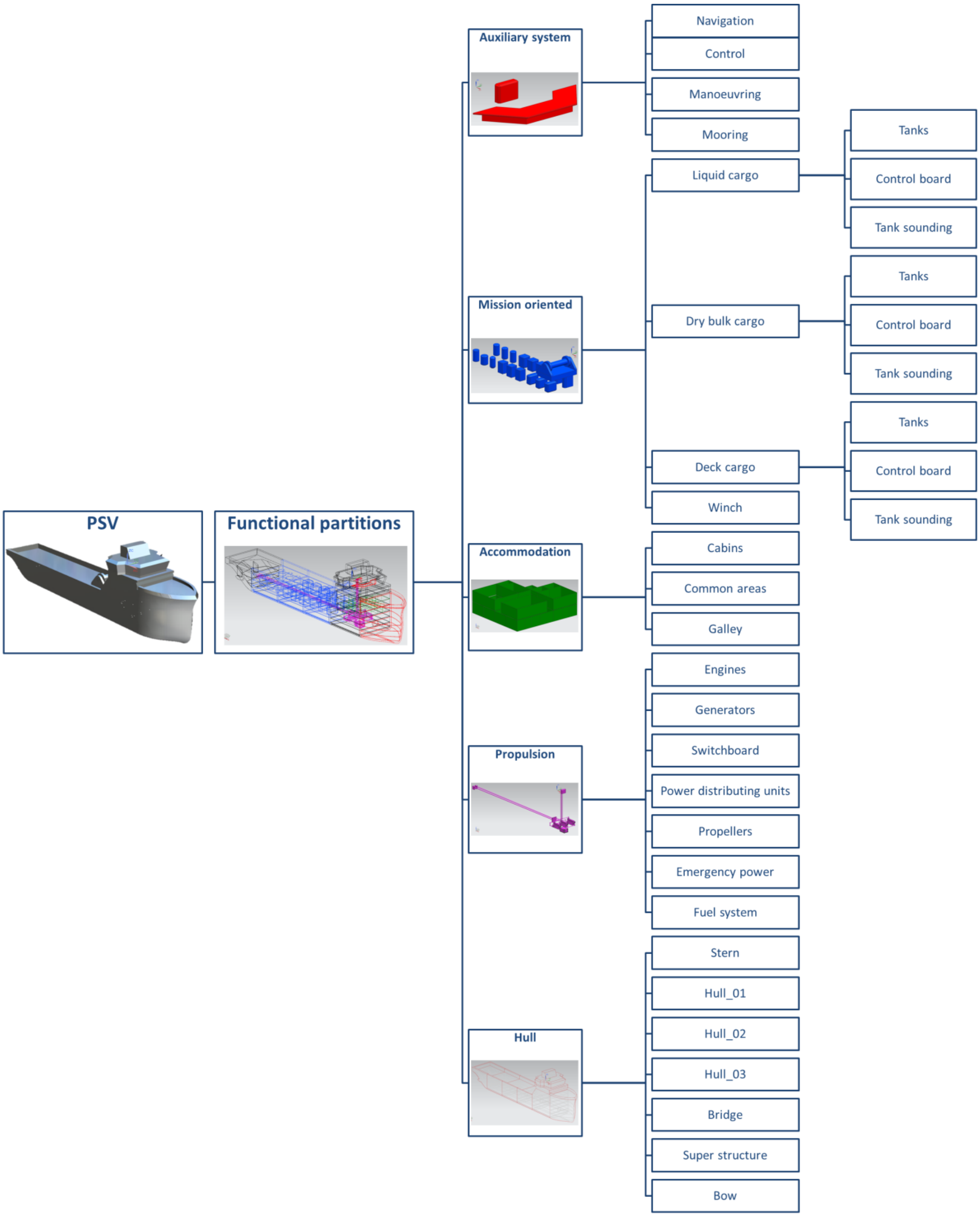


Figure 4.4. Functional PSV structure

4.3 Change case assumption

One of the steps in the methodology applied to this case study is a 'Change case' in two different environments. This step consists of three sub-steps which are part exchange, new part introduction and required re-modelling. Specifically for the case study of PSV several assumptions were done in order to perform different types of changes within the assembly. These changes were equally applied in both design environments in order to observe how the exchange and re-modelling are handled.

The assumption is that the working environment of a vessel and platform changed, so a different hull configuration and more powerful propulsion system are required. Therefore, different parts are modified in order to meet new requirements. Assumptions for each step are described below.

a. **Part exchange.** In this step the Stern module will be exchanged by another design stern with different propellers.
b. **New part introduction.** In this step there will be several parts which will be introduced in the 3D model of the PSV. In order to increase power, an additional engine and generator are required. Both are identical to the ones already in the assembly so there is no need for new modelling.
c. **Required re-modelling.** The parts through the entire vessel influenced by part exchange and new part introduction are re-modelled and described in this step. Several new pipes will be modelled due to the additional engine and generator. Plus, most of the parts in contact with the edited object have to be relocated at some point.
d. **Configurations.** It is requested that the vessel contains 2 different configurations: two cargo hulls and three cargo hulls PSV. The propulsion system is the same for both cases the only difference is the hull. However, for the three cargo hull model, two additional cargo tanks in Hull_02 will be designed in context in order to make the model more complex. Due to the two configurations of a PSV, some systems will be modified to fit certain configuration.

These assumptions involve quite various fields of 3D modelling which gives broader view on the problems in the two approaches. It includes exchange, design in context, re-modelling and generating various configurations.

4.4 3D modelling by conventional assembly approach

4.4.1 The base case of the PSV

As mentioned in previous chapter, the 3D model of the PSV hull divided by modules was used from the EMIS project (Andrade, et al., 2015) and adapted to this certain case. The ship is already designed by modules (Figure 4.5) so the ship design application in NX couldn't be used due to the assembly structure of the model which is not supported by this application. Moreover, this case study doesn't require an exact model of a vessel but focuses on the concept of modelling and re-modelling.

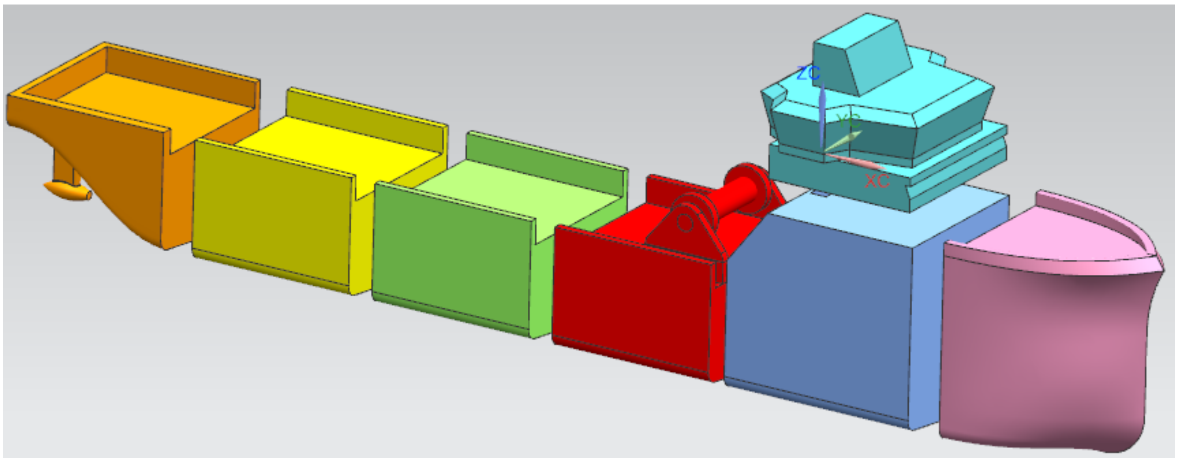


Figure 4.5. Exploded view of the PSV

The PSV doesn't correspond to any vessel and might be not realistic at some points. The systems here are only created to illustrate the interaction between the modules and different systems across the ship. The attention while modelling is mainly paid to the propulsion system and how the control comes from the bridge and power is transmitted from the engine room to the propellers.

As it can be seen from the modules presented in Figure 4.5, some sub-modules might be constituents of several modules due to complexity of a vessel and high interaction between the objects. However, modelling in NX requires assigning all of the parts to certain assemblies, so each object in the overall assembly was assigned only to one module.

First of all, the modules of the vessel were imported into Teamcenter and afterwards were constrained to each other in NX. The Conventional bow is fixed which means that the rest of the modules are constrained one to each other by 'align' and 'touch' constraints starting from the bow. Afterwards, the decks of the vessel were modelled separately to each module which are assemblies itself. As the modules are separate objects the distance between the decks had to be maintained constant for each part in order to comply and compose a single deck.

Secondly, the cargo tanks are modelled in the three cargo hulls. Due to the duplicated cargo hull modules any kind of modification in one influence changes on the other two. The same applies when adding parts to the modules which are duplicated as well (Figure 4.6). It was assumed that the cargo hulls include different cargo tanks and have different arrangement. Therefore they were made unique manually to enable distinguished configurations within the modules. This step required renaming the hulls to possess the unique ID and name. Subsequently, the cargo tanks were modelled constraining them to the hull or one to each other. Assembly construction can be viewed in Appendix B.

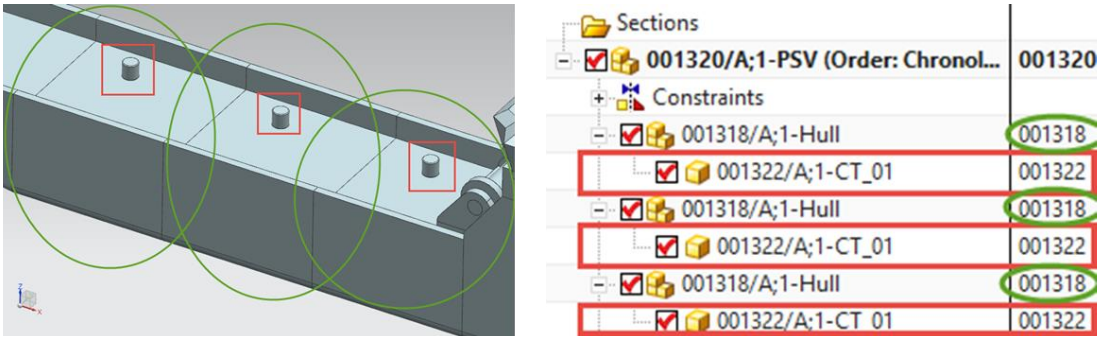


Figure 4.6. Duplicates in traditional assembly modelling

The rest of the sub-modules were only added or designed as boxes only in the main modules to simulate the complexity of the vessel and create a higher order hierarchical structure. Plus, as the modelling is not of the main focus in this case study, the design of these sub-modules will not be discussed in detail and can be viewed in Appendix B.

At last, the propulsion module was designed. It consists of the 3 engines, control, switchboard, power distributing unit and links between these units across the ship. Propulsion is interfacing with all the modules but the main fixed constraints are set to the engine room in super structure were the engine is fixed. As it can be seen from the Figure 4.7 the engine is fixed ‘distance’, ‘touch’ and ‘center’ constraints. The rest of the parts in propulsion are constrained in relation to this certain engine. The links of the control from the bridge to the engine room, from the engines to the switchboard and from the switchboard to the power distributing unit are modelled as pipes in order to illustrate the connection.

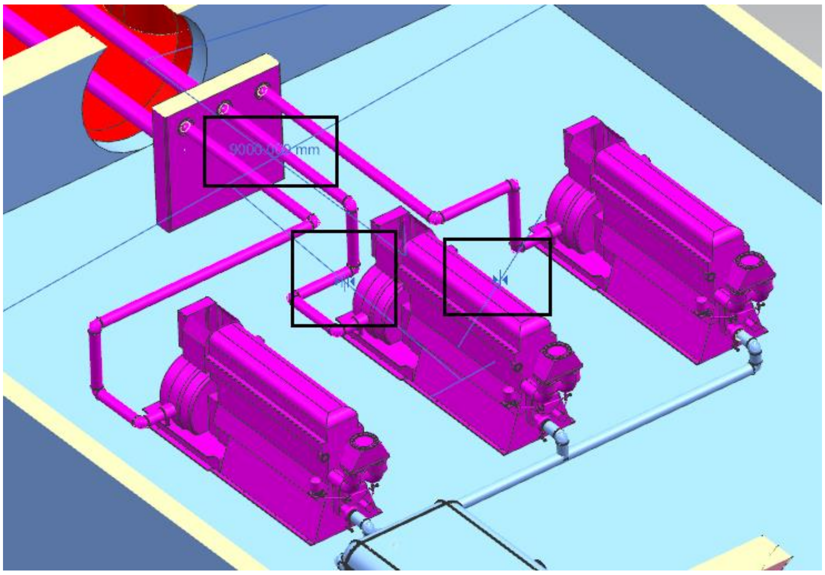


Figure 4.7. Main fixed propulsion constraints

4.4.2 The change case of the PSV

This chapter describes how the change case was performed in in the conventional assembly environment involving the assumptions described in the chapter 4.3. The change was performed from 3D modelling point of view, so the Change management function in TC is not applied here. The changes were done in four steps where different functions and techniques are investigated.

a. Part exchange. In this sub-step, the stern part is exchanged by a different design stern (Figure 4.8). The designs of the two sterns are slightly different by the propellers and main deck. However, the overall dimensions are the same and matching with the vessel.

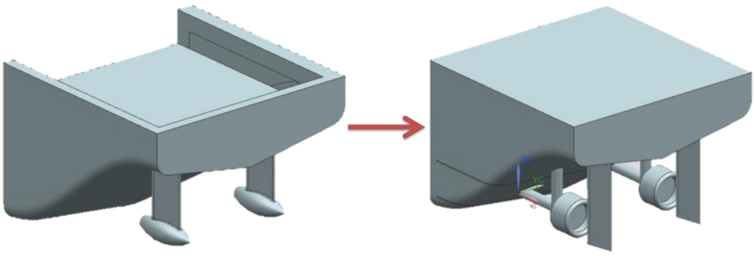


Figure 4.8. Stern exchange

The entire vessel was loaded into NX session and the exchange was done using the function 'Replace component' which replaces a part in the assembly by another object. The constraints, by which the part is located within the assembly, remain valid if the new part design corresponds to the constrained design of the replaced part. In this case, one of the constraints is not valid anymore due to change of design in the new part which allows vertical movement of the stern in context of the vessel (Figure 4.9). Therefore, additional modification or new constraint is required. This also issues positioning errors in the objects constrained and located within the Stern.

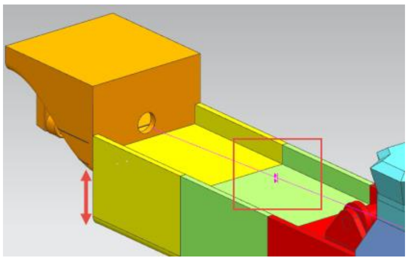


Figure 4.9. Constraint error enables vertical movement

b. New part introduction. First of all in this step the additional engine is introduced in the PSV assembly. The modification is done in context of the entire assembly but the propulsion system is made as work part in order to relate the engines with the surrounding parts in the engine room. The Pattern assembly feature, based on symmetry, was used previously to add the three engines in the assembly. Now the linear pattern was modified and made in two directions, so the four engines are positioned in equal distances one from each other. The positioning of parts in NX is performed by assembly constraints which causes errors in constraints of the propulsion system (Figure 4.10) as the previously centre positioned engine is relocated. Due to these issues some constraints were deleted and new ones introduced to properly locate the parts. Figure below also indicated how some parts did or did not follow the engines. The re-modelling of these parts is described in subsequent step.

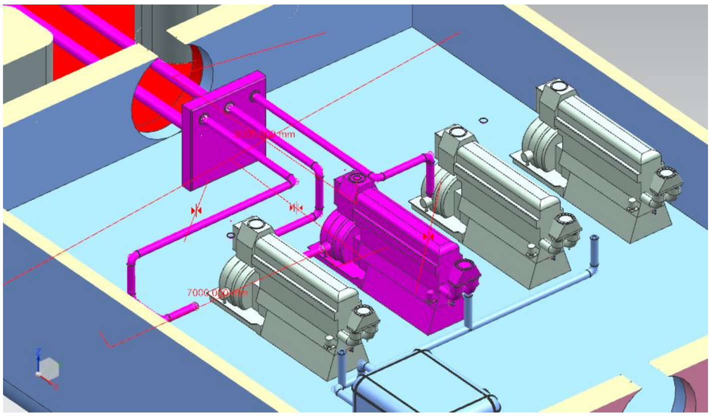


Figure 4.10. Constraint errors in the engine room

The additional generator was added to the assembly using the pattern feature as well (Figure 4.11). This requires relocation as the main generator was positioned in a distance and now it had to be in the centre. Plus, new link from the switchboard to the generator is needed.

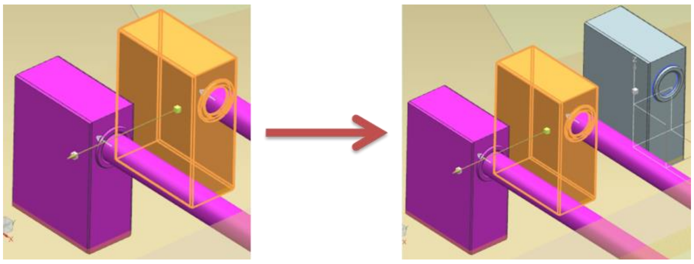


Figure 4.11. Pattern feature of the generator

In both cases when the part is patterned, NX creates a duplicate of the original part so the parts are entirely equal. Plus, the constraints that the source part contains are applied to the patterned parts as well. The propulsion system was created as a module and contains certain constraints within its assembly, so when the main engine was repositioned the dependent parts changed the location accordingly and doesn't fit with the other modules anymore.

c. Required re-modelling. Firstly, as the engines were relocated and pattern was edited, it lost the port of the routing system. Therefore, the fitting ports were modified to fit the desired engines, plus due to the fourth engine new pipes were created. Secondly, the current switchboard holds three ports for the pipes, so it was re-modelled to contain one more inlet. The same applies to the engine control unit in the bridge module. All the sketches of the inlets were edited and thus it lost the connections with the routing parts. It issues several constraints error and automatically relocated some pipes incorrectly. All of the parts in the assembly are positioned by the constraints and trying to move certain parts constantly causes errors so the constraints are modified several times to position the parts correctly.

   Finally, as the propulsion system is extended from the bridge to the stern, it's interconnected with most of the modules in the PSV. When the additional pipes were created and engine relocation was performed, it caused some discrepancies between the propulsion and interconnected modules. Therefore, the modifications of the passage were done in the super structure and bridge modules.

d. Configurations. The last thing in this change case according to the methodology is the two different product configurations. In order to create two product configurations of the conventional assembly there are no certain solution supported by the traditional assembly approach. Therefore, two options to complete this step are assumed: using revisions, arrangements or creating copy of the assembly and then modifying it.
In this case study, revision method was selected where a revision B is created (Figure 4.12) to the existing PSV model. The revision A will contain the data of the 3 cargo hulls PSV 3D model and revision B – 2 cargo hulls PSV 3D model.

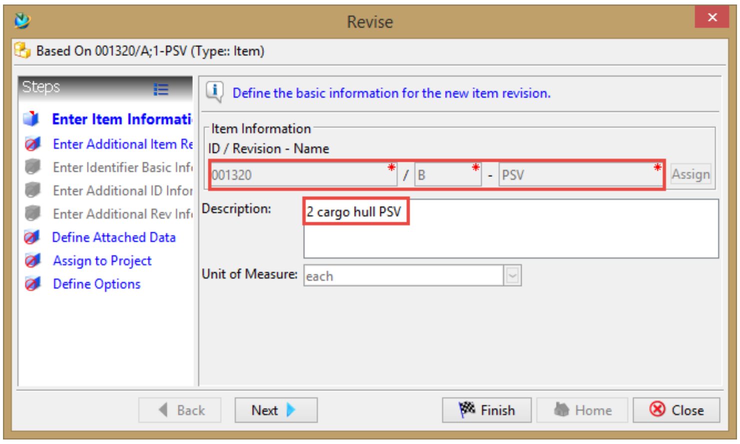


Figure 4.12. PSV revision B

Opening the revision B model in NX loaded the same PSV model which was later on reduced. The Hull_01 with its constraints was simply deleted and the Stern was constrained to the Hull_02 to form a complete vessel. This made the generators outside the structure and required relocation. However, the revision rule doesn't support unique repositioning of the parts in different revisions which is why the generators were exchanged by a new item in the revision B.

The revision B of the whole assembly doesn't make the assemblies within the model of the revision B. This means that the modules' assemblies are identical in both revision and if one is modified, the other one changes as well. Therefore, to modify some parts the revision B is required for parts separately. In this case, the revision B was created to the link between the switchboard and the generators, where the changes were performed. Finally, the additional tanks in the Hull_02 were added to the revision B model and the changes are observed in Figure 4.13.

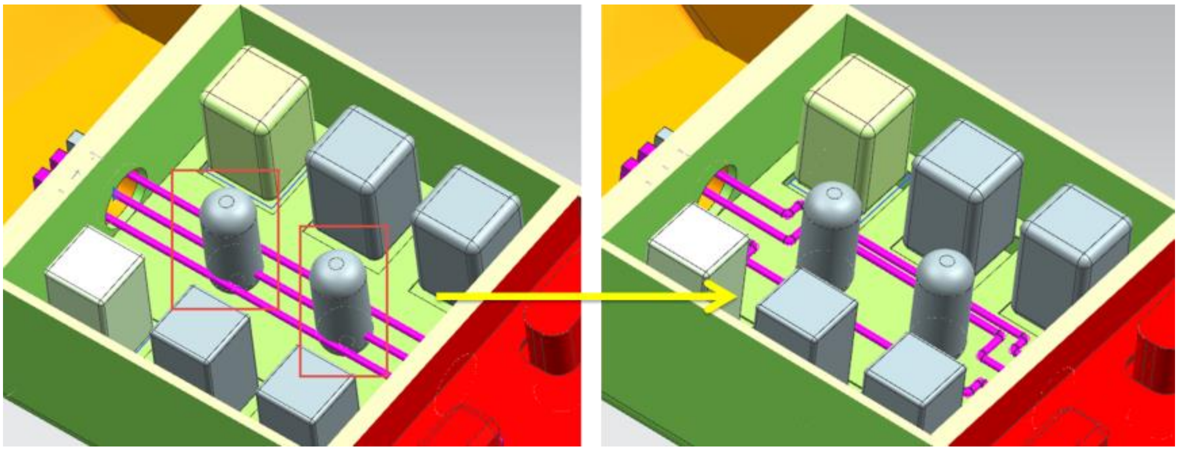


Figure 4.13. Modification of the links

The two other approaches to make two configurations weren't performed but are considered theoretically. Setting the arrangements of the assembly allows presenting the sub-assemblies with alternative position or content within the same assembly. However, the elimination of some sub-assemblies only in one arrangement is not possible because arrangements are constituents of one single assembly file where only the location can be modified. Plus, it's only possible if the sub-assemblies are not fully constrained and are movable which means that it's mainly for presentation purposes.

Using copy/paste method, the already existing model in NX can be duplicated and renamed, that makes any change in the copy of the assembly independent which is why all the required modification are performed without constraints. This approach might be a solution for simple and light assemblies but large scale data would take too much space and time to be copied.

4.5 3D modelling by non-conventional approach (4GD)

4.5.1 Base case of the PSV: adaptation to 4GD

This chapter includes the designing steps performed in 4GD environment. At this point of investigation, the 4GD features are familiar to the user and so a deeper analysis can be performed on the functionality of 4GD in ship design. Following the methodology, 1st step in 4GD environment part of the case study is to adapt the PSV 3D model to comply with the 4GD features. The implementation of the model to the 4GD is performed in a similar manner as in the simple case application and following the creation steps described in Appendix C.

The CD by the name Platform_supply_vessel_4GD is created in Teamcenter. The next step is to create partition schemes and partitions which are optional depending on type and scale of product. It's optional to create the partitions before the modelling or after, 4GD enables both possibilities. For this case study, all three organizational breakdowns described in chapter 4.2.2 are created as partition schemes: functional, physical and modular. Consequently, the partitions in the three partition schemes are created based on the divisions defined in Figure 4.2, Figure 4.3 and Figure 4.4, and are observed in Figure 4.14, Figure 4.15 and Figure 4.16 respectively.

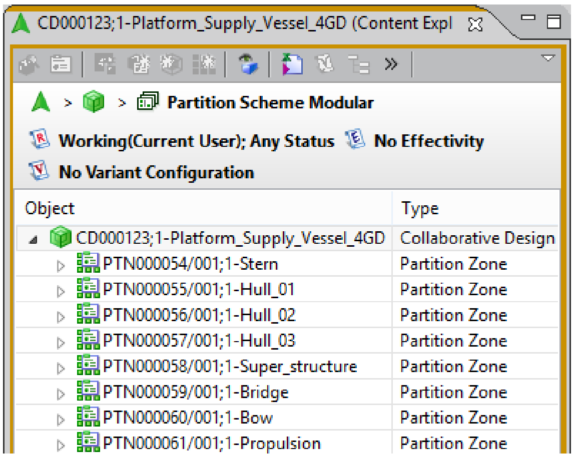


Figure 4.14. Modular partitions in Teamcenter

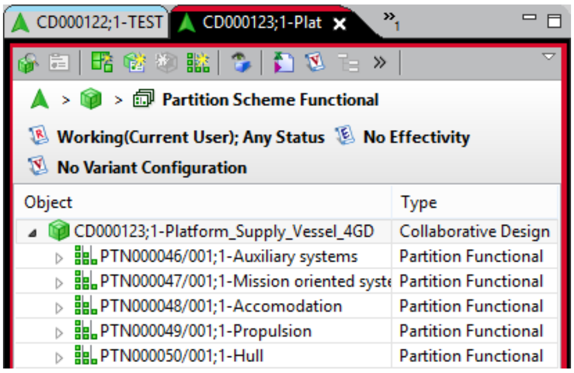


Figure 4.15. Functional partitions in Teamcenter

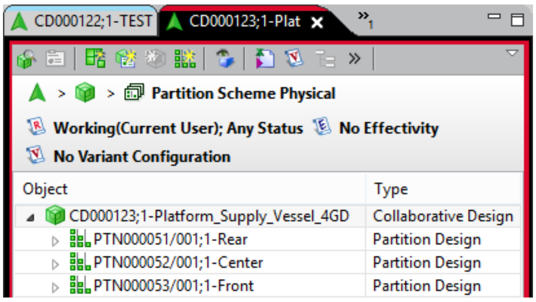


Figure 4.16. Physical partitions in Teamcenter

The DEs are created as Promissory Design elements in Teamcenter environment following the steps described in Appendix C part 5.b. The BVRs are copied from the modules of the PSV in the My Teamcenter environment and then pasted on the Promissory DEs in the 4GD environment. This action converts the Promissory DE to Reuse DE, assigns the structure to it and converts the children components in assembly into the subordinate DEs. It is important to note, that all of the assemblies are required to have precise structure in order to introduce the assemblies as 4GD objects (Appendix C, part 5.a). However, due to some internal error 4GD was unable to load some of the children components. Therefore, the BVRs of these parts were copied and pasted directly into the partitions where the DEs were created automatically. This makes the components in CD equal and there is no hierarchy in the structure. As it can be seen from Figure 4.17, the parts are not dependent one from another and each contains own ID and revision. The partitions are not defining hierarchy here, they are only the way to organize the design data so that the designers are able to find their particular data and load to the working session.

The next step is to create the overall workset and a subset definition for a PSV which is performed in TC. It is done following the TC approach described in Appendix C part 4. The subset definition recipe incorporates the Modular partition from the CD because this organizational breakdown includes all parts of the PSV. Generally a product developer creates the different worksets and assigns it to certain designers. In this case study, only one workset, including all the DEs in the CD of a PSV is created for a single user. The workset is issued while opening the subset definition in NX. A ‘Create Workset’ window pops-out and workset is created to which the DEs are loaded according to the recipe of a subset definition.

> CD000123;1-Platform_Supply_Vessel_4GD > Partition Scheme Modular

Working(Current User); Any Status No Effectivity No Variant Configuration

Object	Category	Type	Source Obje...
CD000123;1-Platform_Supply_Vessel_4GD		Collaborative Design	
PTN000057/001;1-Hull_03		Partition Zone	
DE000280/001;1-Hull_03	Reuse	Design Element	ItemRevision
DE000328/001;1-H03_CT1	Reuse	Design Element	ItemRevision
PTN000058/001;1-Super_structure		Partition Zone	
DE000281/001;1-Super_Structure	Reuse	Design Element	ItemRevision
DE000332/001;1-SS_CB_01	Reuse	Design Element	ItemRevision
DE000333/001;1-Cabins	Reuse	Design Element	ItemRevision
DE000335/001;1-Hotel_accomodations	Reuse	Design Element	ItemRevision
DE000346/001;1-SR_deck_01	Reuse	Design Element	ItemRevision
DE000351/001;1-Dinning_area	Reuse	Design Element	ItemRevision
DE000352/001;1-Day_rooms	Reuse	Design Element	ItemRevision
DE000345/001;1-SR_Deck_02	Reuse	Design Element	ItemRevision
DE000350/001;1-Salon	Reuse	Design Element	ItemRevision
DE000347/001;1-Service_rooms_deck_01	Reuse	Design Element	ItemRevision
DE000331/001;1-Galley	Reuse	Design Element	ItemRevision
PTN000059/001;1-Bridge		Partition Zone	
DE000282/001;1-Bridge	Reuse	Design Element	ItemRevision
DE000329/001;1-Control_system	Reuse	Design Element	ItemRevision
PTN000060/001;1-Bow		Partition Zone	
DE000283/001;1-Bow	Reuse	Design Element	ItemRevision
PTN000054/001;1-Stern		Partition Zone	
DE000277/001;1-Stern	Reuse	Design Element	ItemRevision
PTN000055/001;1-Hull_01		Partition Zone	
DE000278/001;1-Hull_01	Reuse	Design Element	ItemRevision
DE000326/001;1-H01_CT1	Reuse	Design Element	ItemRevision
PTN000056/001;1-Hull_02		Partition Zone	
DE000327/001;1-H02_CT1	Reuse	Design Element	ItemRevision
DE000279/001;1-Hull_02	Reuse	Design Element	ItemRevision
PTN000061/001;1-Propulsion		Partition Zone	
DE000359/001;1-Engine_simplified	Reuse	Design Element	ItemRevision
DE000330/001;1-Switchboard	Reuse	Design Element	ItemRevision
DE000317/001;1-Propulsion	Reuse	Design Element	ItemRevision
DE000356/001;1-SB_PDU	Reuse	Design Element	ItemRevision
DE000357/001;1-BR_EN	Reuse	Design Element	ItemRevision
DE000358/001;1-EN_Control	Reuse	Design Element	ItemRevision
DE000355/001;1-EN_SB	Reuse	Design Element	ItemRevision

Figure 4.17. Modular partition scheme with assigned DEs

Later on the DEs were assigned to additional partitions in Figure 4.18 and Figure 4.19 according to the division presented by Figure 4.3 and Figure 4.4 respectively. It was performed manually due to complexity to create dynamic partition recipes. However, as this case study doesn't investigate the whole vessel with millions of parts, the manual assignment is manageable. The 4GD allows viewing partition schemes in both NX and TC environments so the user is able to verify if the required DEs are assigned to appropriate partitions. It is not necessary to assign all the DEs to some partitions, unassigned elements are also supported in 4GD.

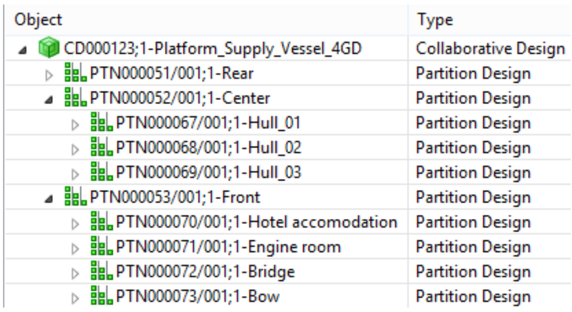


Figure 4.18. Physical partition scheme

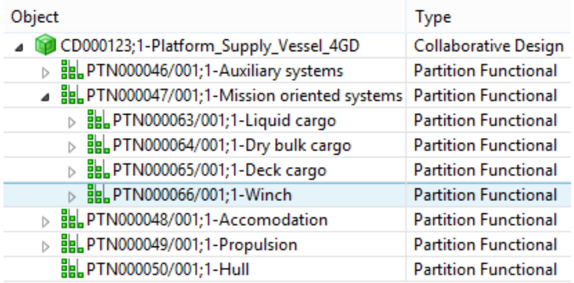


Figure 4.19. Functional partition scheme

As the DEs are assigned to certain partitions, it is possible to view the assembly structure in context of selected organizational breakdown. It doesn't add constraints or position restrictions but allows for the user to view the model in different context. Figure 4.20 shows the subset view in the assembly navigator in NX when the View Partition Scheme is on and off. Here, the subset structure is viewed as a flat assembly structure which is a choice of the user. 4GD provides possibility to view an assembly in traditional hierarchical structure as well.

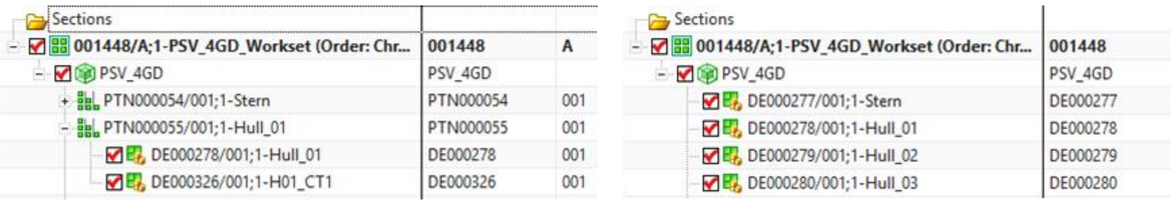


Figure 4.20. Partition view in NX: on and off

When the previous steps are established the subset definition is opened in NX which issues the workset creation. As the DEs were created in TC it doesn't contain positioning and so all the parts of PSV are located according to the absolute coordinate system. The Bow DE was located at the absolute coordinate system of the CD and the rest of the parts were located in a sequence one after another. It makes the objects dependent from the absolute coordinate axis but located according to an object in touch. Each DE was located separately. The PSV also includes some parts which have the same geometry. As the pattern feature is not supported by 4GD a new DE was created by selecting several elements to create based on the same source part. Each of the DEs received unique ID and was name under the same name which means that the DEs with the same geometry are not duplicates. Due to newly introduced parts, the routing object lost connections to the qualified parts, so the fitting ports were edited to coincide with the desired DEs.

So finally, a 3D model of PSV was created in 4GD environment. It was assigned to three partitions schemes and so the vessel can be viewed and managed in context of three organizational breakdowns. Figure 4.21, Figure 4.22 and Figure 4.23 illustrates the three divisions which partitions and its DEs are designated by different colours. To have a better view on a vessel, the wireframe view is displayed on the right side.

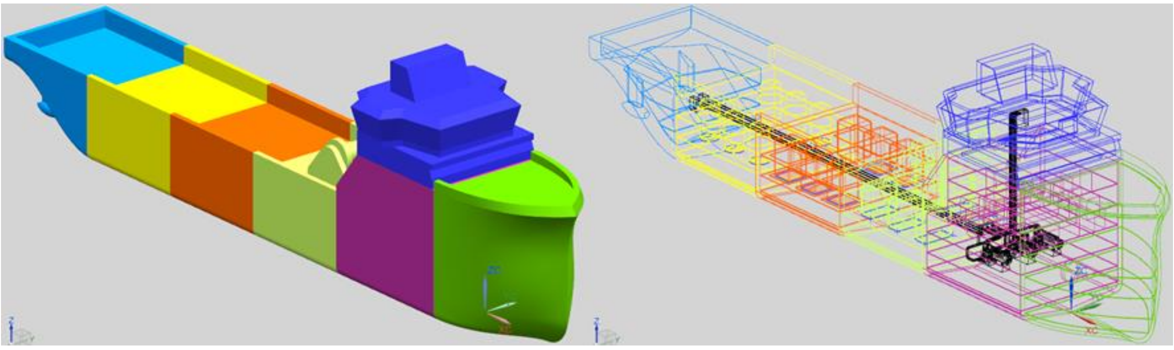


Figure 4.21. PSV (modular organizational breakdown)

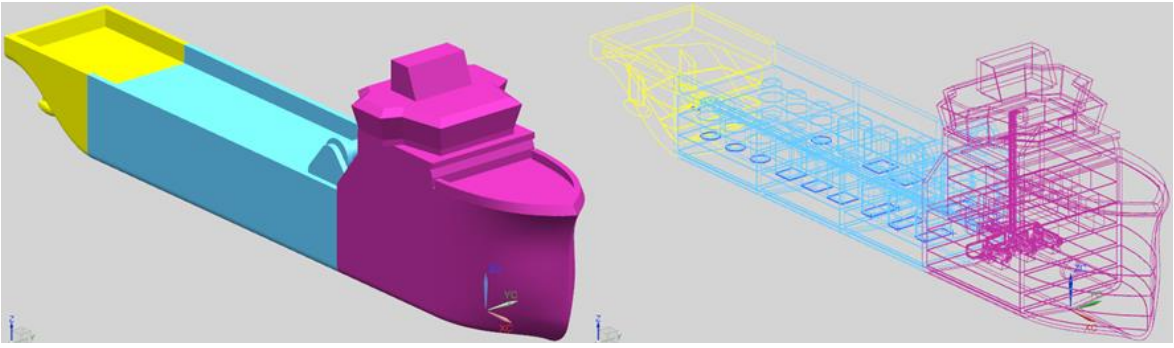


Figure 4.22. PSV (physical organizational breakdown)

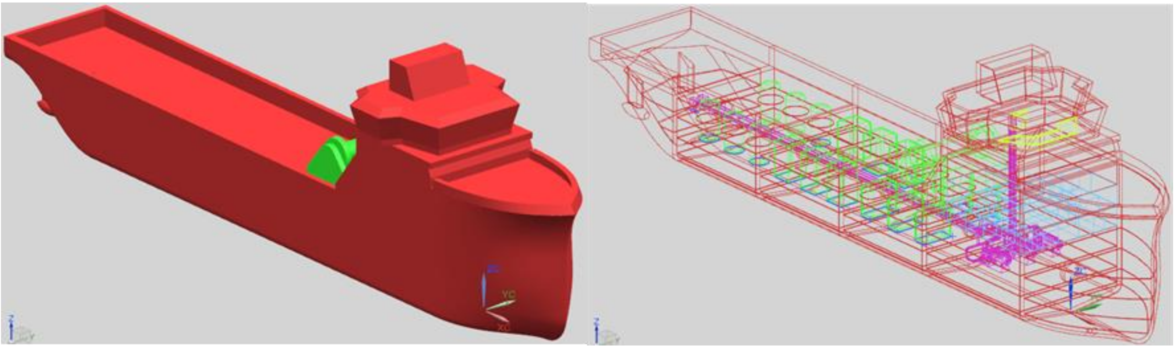


Figure 4.23. PSV (functional organizational breakdown)

4.5.2 Change case of the PSV

The change case is performed on the PSV divided by the three partition schemes which will be used to load and manipulate only necessary data related to certain changes within the vessel. Making this change case in 4GD several subsets were created which might be not necessary but are done in order to test out as many feature and 4GD capabilities as possible.

a. Part exchange. The subset for Stern exchange is created in the overall PSV workset. It includes only the stern and Hull_01 modules filtered by the hull functional breakdown (Figure 4.24: a). This means that only the hull parts from the stern and Cargo_Hull_01 modules will be loaded into the NX session (Figure 4.24: b) because only the two are necessary in order to exchange the stern and locate it in accordance to the Cargo_hull_01.

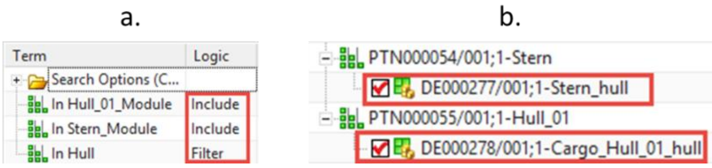


Figure 4.24. Stern exchange Subset: a. Subset recipe definition; b. DEs within subset in NX

The stern is exchanged using the Replace Source Part function. This locates the new stern at the absolute coordinate system so it is moved by constraints to touch align to the Hull_01. The changes performed in this subset are also updated in the overall subset of the vessel.

b. New part introduction. Here, an additional engine and generator will be introduced in the 3D model of PSV. Both are the constituents of propulsion system so it's firstly included in the subset of New part introduction (Figure 4.25:1). Subsequently, the physical front partition is included and filtered by hull functional partition. This adds only the hull of the super structure in current subset (Figure 4.25: 2). Finally, the engine room from physical partition is included which adds the fuel system and results in the subset in NX as shown in Figure 4.25.

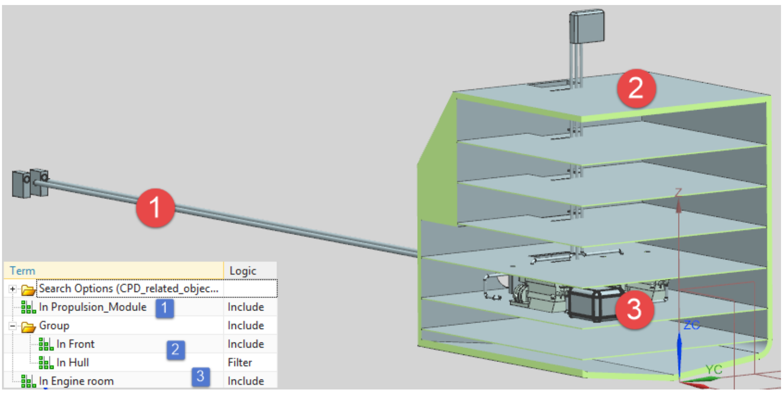


Figure 4.25. New part introduction subset

Using the subset, space for the fourth engine was made first by moving other engines by constraints and according to the dimensions established in previous change case. Then the engine is introduced by creating a new reusable DE and selecting the engine part as a source part. The DE is then assigned to the appropriate partitions in order to be recognized in the subsets. The location is established by moving the engine in relation to the engine room and other engines. The generator was introduced using exactly the same approach.

The routing links did not follow the relocation of the DEs so they are modified and described in the next step.

c. Required re-modelling. The same ‘New part introduction’ subset is used in this step to create additional routing links and reposition the existing ones. The routing links were created in context and by connecting it to desired DEs. As the position of DEs is not constrained the relocation of the pipes is easily performed without any errors. The routing elements‘ ports are modified to coincide with the current configuration and thus are following the appropriate parts.

   The switchboard is remodelled to fit the additional inlets by editing the sketches but it didn‘t influence the configuration of the routing. Therefore, the links‘ ports were relocated to fit the new configuration. Finally, the modules in connection with the propulsion system were corrected to properly fit the routing links.

   As the main PSV subset is loaded into NX session and updated, it automatically includes all the DE‘s added and modified in other subsets if they were properly assigned to certain partitions. Appendix D gives an explicit view on the modified DEs and configuration changes.

d. Configurations. 4GD incorporates a concept of effectivity, described in chapter 2.3.3, which is employed in order to create two configurations of PSV with different hulls. The effectivity is set by editing the subset of entire PSV and assigning effectivity to it (Appendix E). The effectivity 1 is assigned to the two cargo hulls PSV which means that the effectivity 2 is automatically referred to the primary vessel which is the three cargo hulls PSV. To manoeuvre from one effectivity structure to another, the subset has to be edited and unit effectivity needs to be set to necessary value. When the effectivity is assigned, the DEs added to the assembly afterwards contain the same effectivity. However, until any changes are done to the structure the PSV contains the same elements as the primary vessel.

The assumption states that the two cargo hull PSV should contain two additional tanks and modified link between switchboard and the generators. First of all, the tanks were added to the subset as new DEs following by the links. All were located by moving the objects by constraints. As the new DEs were added after the effectivity specification, these elements have automatically assigned unit effectivity (Figure 4.26).

DE000405/001;1-DE000405	DE000405	001	001326/A;1-H01_CT1	Design Element	e
DE000403/001;1-DE000403	DE000403	001	001326/A;1-H01_CT1	Design Element	e
DE000404/001;1-DE000404	DE000404	001	001356/B;1-SB_PDU	Design Element	e

Figure 4.26. Effectivity indications

As the PSV with effectivity unit 1 includes the same DEs as the primary vessel this means that the links and cargo_hull_01 are still present in the structure and will remain present if not modified (Figure 4.27). However, simply deleting the unnecessary DEs would delete it from the whole CD which is not the goal here. Therefore, effectivity unit 2 will be assigned to these elements separately, so they are only present in the three cargo hull vessel.

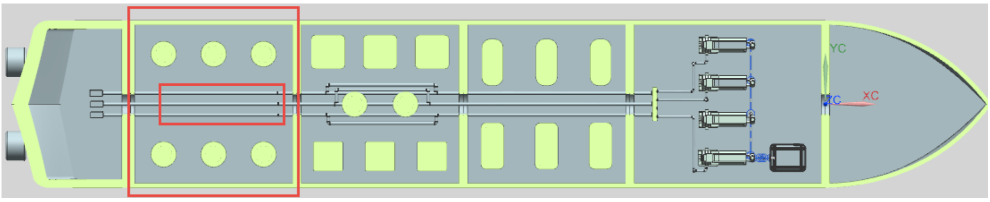


Figure 4.27. Unnecessary DEs for two Cargo hulls PSV

To assign separate DEs to structure with certain effectivity, the subset with this specific effectivity has to be opened. The Hull_01 and links effectivity was edited and set to 2 in the three cargo hulls PSV so they are the constituents only in this configuration. As the Hull_01 is not included in the two Cargo hulls PSV anymore, a gap between the modules is experienced and problem arises. If a DE is relocated in one effectivity configuration it is then automatically relocated in another one. This makes the two configurations rigidly connected to each other which is why the effectivity to stern and generators was assigned in one configuration and introduced as new DEs in the second configuration.

Using the effectivity concept, two different configurations of PSV were generated in one single CD and are subject of choice and necessity for certain customer. Figure 4.28 illustrates how the two configurations are distinguished by effectivity specification.

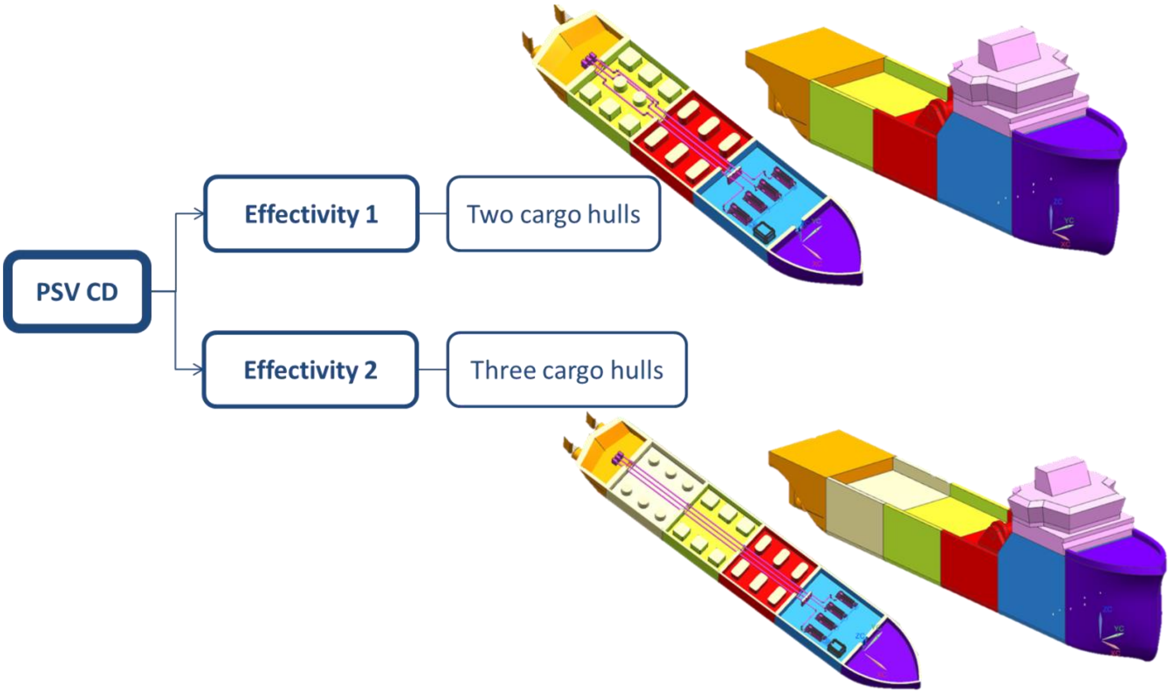


Figure 4.28. PSV configurations using effectivity

5 Results and discussion

5.1 Introduction

This chapter discusses the key points and main challenges of the modelling and change processes faced in the two approaches: traditional structuring and 4GD concept. The comparison is performed according to the four main features in concern described in methodology. Here the two approaches are put one against each other to emphasize the differences and highlight the exchange and re-modelling possibilities. The case study was performed mainly focusing on processes in NX which is why the results are mainly discussed from the 3D designer point of view.

5.2 Modelling and change processes (conventional assembly approach)

First of all, the modelling of the PSV was performed in NX+TC environment where the change case was carried out consequently. The processes had minor and major severities and solutions which are described below pointing out the most important observations.

Constraints. The positioning of the parts and sub-assemblies within the assembly in traditional structuring approach is done by fully constraining objects one to another. In this case study the hull modules where consequently constrained starting from fixed bow module. It keeps the order of constraints, rigidly locates the sub-assemblies where it belongs and maintains the position if changes are applied. The case study showed that constraints are the reliable aid to exact positioning however in some cases they were the restricting matters when object needed re-positioning, exchange or re-modelling. The constraints interferences throughout the whole modelling and change processes are observed in the subsequent points.

The BOM structure and single organizational breakdown of the PSV had to be defined before the modelling process which means that each assembly within the overall vessel needs to be established according to the hierarchy. This case study of a simplified PSV showed that the traditional structuring approach is based on the import order of the modules' assemblies into NX which needs to be well defined and followed to ensure correct positioning and constraints system as well as the hierarchical structure. Due to the user mistakes several times in the modelling process the order was violated which caused mix up of the constraints that influenced the errors in the change case study. However, in the context of a large-scale data, to establish the structure of the assembly is time-consuming and requires high preparation to define the organizational breakdown and the parts' relation of the whole product.

Duplicates. Parts that contain identical geometry are automatically duplicated in the traditional structuring approach when imported in the same assembly in NX. The cargo hulls' modules in this PSV case study are of the same structure and so are duplicated. This makes it difficult to modify the parts separately and requires making them unique in order to add different children parts. In this case study it was easily performed using one function but if the small parts like bolts are duplicated within a large scale product, to make each of them unique is not a solution due to high time and effort consumption.

Inter-assembly constraints. Using the traditional assembly approach the large amount data products are composed of sub-assemblies in the assemblies which have the assembly constraints already in the model but are also constrained by the main assembly model. The parts are mainly located within the sub-assemblies but in some situations, parts are required to be constrained to certain parts in another sub-assembly. In this case, the assembly constraints are not valid because if one assembly is a working part, the selection of the constraining object is made only from the objects in the same assembly. This means that in order to perform such constraints it is necessary to open the overall assembly and thus these constraints are then added to the main assembly. It wouldn't be a problem in small and uncomplicated assemblies like the engine room example to find the required constraints. However, the complexity is added to vessel model if local importance constraints are added to the main assembly constraints collection. Then the change or elimination of the constraints causes errors in the previous constraints if there are any discrepancies in the model. Figure 5.1shows how a constraint 1 added to the overall assembly influenced the rest of the constraints. In this situation, an error in the model or user mistake has to be found in order to continue modelling. As the number of parts in the 3D model increases, it gets difficult or might be impossible to find an error among thousands of constraints.

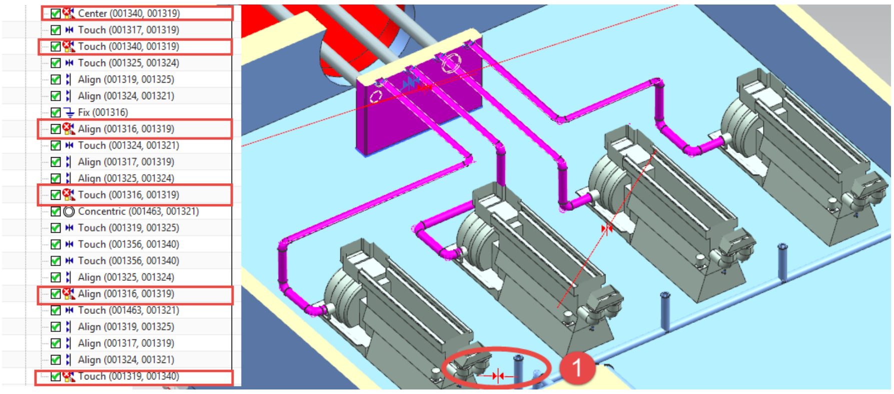


Figure 5.1. Errors due to constraints modifications

Exchange. In this case study, the replace component function was used to exchange the stern and it revealed that for a simple case exchange this function is easily applied and constraints remain where it belongs to if the overall design corresponds to the exchanged part. However, the positioning errors appeared already in this simple case and the constraints had to be modified due to the purpose of this function being to replace parts by its revisions.

For a broader analysis purpose, an additional hull module was replaced by a totally different design module which resulted in constraints and position disruption. Moreover, all the parts within the assembly disappeared because the hull assembly was designed on top of the hull model which is a result of a mistake made in the pre-design process when the assembly structure was defined. Therefore, this function can’t be used in the large-scale data products due to the complexity to modify separate constraints and add the missing parts to the sub-assemblies. The only solution here might be re-modelling the parts to achieve required design which requires additional revision. It leads to a conclusion that the exchange in the traditional assembly approach model is difficult to perform due to constraints and the interaction between the parts.

Remodelling. To create two configurations for a PSV the revision rule was applied where the revision is created with different content but as described further this approach is not a solution for a large scale product. Therefore, the Arrangements were considered as a tool to create different configurations but weren’t efficient enough. Using the arrangements allows moving parts but requires deleting some constraints in order to do this. Moreover, to delete unnecessary part is impossible and thus, this case study showed that in order to maintain two different configurations, a remodelling of a vessel is necessary. This is a very time-consuming process due to a large amount of data and complex constraints system. It is efficient for this simplified PSV because only a few parts have to be deleted, relocated and remodelled but for a full equipment vessel, it becomes a difficult task. All the data in TC is duplicated and should contain the same information of the vessel. Plus, as soon as there is a change applicable to both configurations, additional remodelling is then done twice because the vessels are no longer related.

Working environment. As described in the theory, the traditional assembly approach loads the whole assembly and can't filter only the necessary data. This feature was frequently encountered through this research as parts inside the vessel where modified. To view the insights of the PSV the hulls where either hidden or section view was applied to clearly see the parts in concern. Moreover, if only some parts of the sub-assembly are important, the rest have to be hidden separately. It makes the user interface complex as it is overloaded by the whole assembly as well as to prepare the correct working environment by hiding the objects is time and effort consuming.

Re-positioning. In order to introduce new parts in the assembly, the surrounding objects had to be repositioned. The main focus was on the additional engine in the propulsion system assembly. The whole assembly was centre located and constrained according to the middle engine in the context of the PSV. Therefore, when the fourth engine was introduced and constraints modified to fit the engines in the engine room space, the whole propulsion system moved together with the middle engine (Figure 5.2). The reason is that the parts within propulsion system are constrained to each other and not the entire assembly which keeps the parts dependent only on the propulsion. To fix this problem, the parts of the propulsion system were one-by-one re-positioned by editing constraints. This case study showed that in order to re-position some parts within an assembly the constraints have to be tracked back and modified or deleted to reach required result which in large scale product is not an efficient way and might cause even more constraint errors.

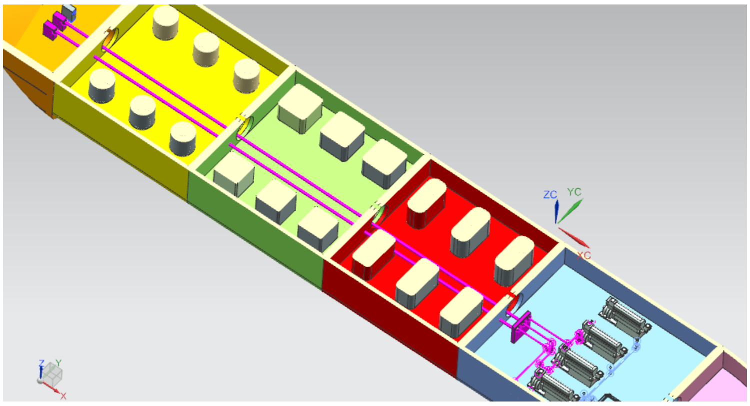


Figure 5.2. Propulsion system relocation

Revisions. The two configurations of a PSV were generated using the revisions. However, the purpose of the revisions in TC is to maintain and keep track of the significant changes of certain parts and isn't a solution for different configurations in the industry. For this certain case study it came as a possibility due to the small amount of data but in the real time ship design case, it couldn't be used. Revisions are generated in the TC and can be separately loaded in NX but as explained previously, the parts are shared between the two assembly revisions. This means that parts which need to be different between the revisions of PSV have to be manually and separately revised. In ship design it adds complexity to the designing process as each part has to be checked out, revised, modified and then checked in back to the assembly. The case study showed that if the difference is minor and only a few parts need modification, the process is easy and fast but taking into account a vessel of which several modules need to be changed the revisions are too confusing and adds up too many data to the model.

5.3 Modelling and change processes (non-conventional approach)

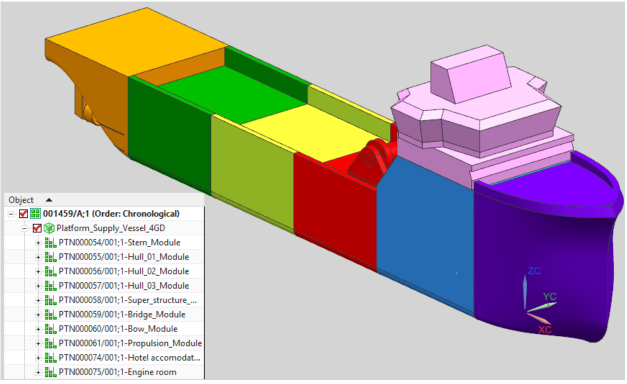
Following the methodology, the modelling and change cases were performed in the 4GD environment where the same design but different approaches were used as in the traditional assembly framework. The case study in 4GD was performed by a novice user which means that some statements or observations might be inaccurate. The main points how the 4GD does or does not overcome the challenges faced in the traditional assembly approach in the context of exchange and 3D remodelling, are discussed below.

Multiple organizational breakdowns. For this case study of PSV the three organizational breakdowns as a default in 4GD were used by creating the partition schemes manually. The modular, functional and physical divisions assist to sort the DEs in different ways but it doesn't define the position or constraints of DEs. This means that a vessel can be viewed by different breakdowns which make it easier to search and filter the design data. This case study showed that the multiple organizational breakdowns help to filter the PSV design data based on which, only the relevant data is loaded in NX session.

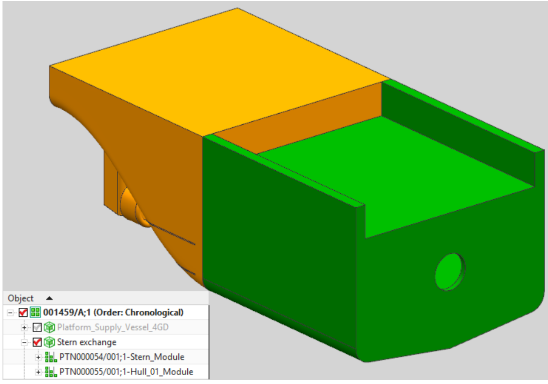
Using the partition schemes enabled multiple hierarchical views of the PSV for different design tasks which makes the working environment more flexible and adjustable to the user's needs. In a large scale product like a vessel the multiple organization of a product might be very powerful tool as the engineers need to create BOM structures to various systems like electrical, piping, HVAC, etc. which can be very time consuming. For example, in an engine room where the water piping and electrical routing experts need to create and maintain their dedicated BOM structure the 4GD might support easier creation and maintenance of these different structures due to different partitions which allow viewing the systems by the function.

Positioning. Each DE in 4GD is located by moving the object and positioning them according to particular surrounding object. This means that the DEs aren't locked to a certain position or to certain assembly and are movable across the assembly. Nevertheless, the assembly constraints might be used in the workset as the first DE is imported in the assembly because any additional DEs in the workset make it a single component. In this case study, the bow was fixed to the absolute coordinate axis and the rest of the parts were positioned by moving the DEs in the subset. 4GD doesn't support the assembly constraints in a subset which makes it easier for a designer to move the objects during the designing process as the DEs aren't constrained to anything. This case study showed that the assembly is well managed and positioned without the constraints in case of a change. Only the required DEs were moved to a new location while the rest of the elements remained in their primary position. Moving certain DEs didn't interrupt with other DEs and didn't cause any error which is a significant point in the design of a large-scale object.

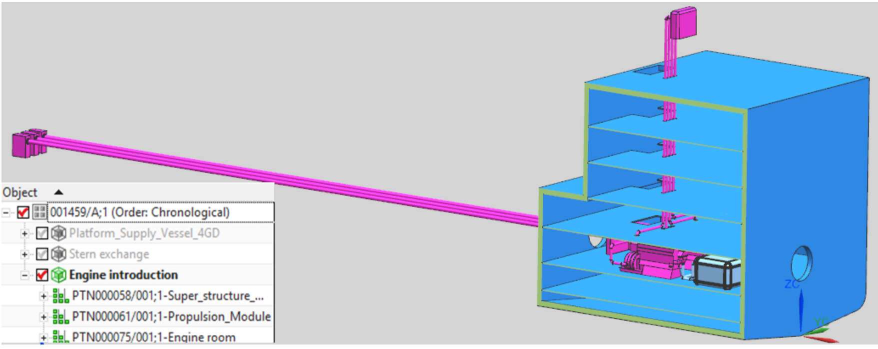
Relevant data. One of the 4GD features is loading only the relevant data in NX session which is possible by defining a subset where the certain partitions are selected, a particular volume of the assembly is set or a recipe to select design data is defined. It was a useful tool in this case study as there were several changes and exchanges performed which not always influenced the whole PSV.



a)



b)



c)

Figure 5.3. Relevant data loaded by the subset definition: a) Overall PSV; b) Stern exchange; c) Engine introduction;

First of all, for the modelling of a vessel a subset was created where all the partitions were added to the working environment (Figure 5.3: a). Later on, to perform the exchange of a stern, only the rear parts of the hull were necessary and a new subset was created were the stern and hull_01 modules were selected and filtered by functional partition of the hull. This means that only the parts from the stern and hull_01 which are also constituents of Hull partition in functional breakdown were added to the subset (Figure 5.3: b). The rest of irrelevant data was left outside this subset. Finally, the third subset for the additional engine was created and as it can be seen from Figure 5.3: c only the super structure of the hull was added together with the propulsions system.

This approach allows working only with necessary data for certain design task and doesn't overload the NX session. The case study revealed that it's easier to approach particular parts inside a vessel when just the relevant data is loaded into the working environment as less 'Hide' function and section views are needed. This also means that less data is checked out and needs to be released afterwards. In large scale products that might be a powerful tool as many designers are working concurrently on the same vessel but different systems. They only need to access a certain set of data to work with but not the whole hierarchical structure.

Design in context. Several parts in this case study were designed in context. The DEs were created and assigned to certain partitions. As there is no hierarchical structure, the design was performed directly in the subset of the overall PSV. This makes the design in context easier because it can be performed in the context of the whole vessel, unlike the traditional assembly approach where certain sub-assembly needs to be opened. In ship design, it does make a huge difference as to find a certain sub-assembly might be difficult due to a large amount of data. Moreover, 4GD eases the 3D remodelling as the design in the overall context of a vessel or substantial parts of it, is possible which means that to remodel necessary parts only the parts in contact or surrounding parts can be loaded into NX to perform this design task.

Exchange. In order to exchange one part by another in 4GD a function 'Replace Source Part' was used where the source part of a reusable DE is exchanged by another part. The function uses a positioning approach which locates a part to the origin axis of the replaced part without any restrictions or constraints. This means that if the parts are only slightly different and contain the axis of origin at the same point when exchanged, the new part will be positioned at the exact same location. In this case study the stern was exchanged by another stern which kept the position due to coordinate axes and the inside objects remained in the same position. The additional movement of the DE is avoided, it doesn't require constraints and doesn't affect surrounding parts or the subordinate DEs. Plus, any DE in 4GD can be converted into a reusable DE which means that any part in the assembly might be exchanged. This case study showed that the exchange in 4GD was accomplished without any difficulties and is user-friendly even for a novice user. Therefore, it can be assumed that for a large scale product this exchange approach would be useful to keep the parts at the same position, if several part of the same geometry needs to be exchanged, this can be done at once.

Effectivity solution. One of the points in the methodology was to create different configurations for the same PSV. In the 4GD case, this step was performed by using the effectivity method. First of all, the effectivity was assigned to the PSV in concern which means that further actions are applicable to the new version of a vessel and the 1st configuration of the vessel remains uninfluenced. This feature keeps two different configurations of a product in a single file, without duplicates and possibly with different constituents. For this certain PSV, one of the hull modules was deleted and some propulsion parts were introduced. When the effectivity is assigned to a CD, any new parts in the model are marked by effectivity sign which indicates that this part is only valid for one or another configuration. However, the repositioning of parts appeared to be an issue using this effectivity. As one hull was deleted the parts within the stern had to be moved to coincide with the new configuration. Performing this action moved the parts in both configurations (Figure 5.4) as these DEs are constituents of both effectivities. This means that the positions of the DEs in two configurations are highly related as they contain the same information.

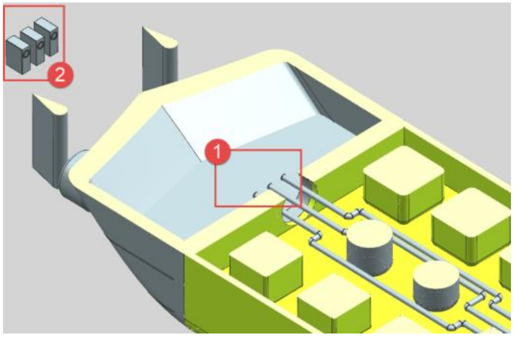


Figure 5.4. Positioning issue

Several attempts were taken to solve this issue. Firstly, different effectivities were set to these two parts expecting that the changes of DEs will apply only to the corresponding effectivities of PSV. However, the repositioning of theses DEs was observed in bot configurations. Secondly, the revisions were configured to the stern and power distributing unit in order to add one revision to 1st configuration and another revision to the 2nd configuration. Even so, adding revision B to the 1st configuration it was also added to the 2nd configuration. Finally, these parts in the two hull configuration were introduced as new DEs which make them unrelated from the same elements in the three hull vessel. This solution enabled the repositioning of the parts yet the DEs aren't related which means that if there is a remodelling in concern, the changes will be applied only to one configuration.

Even if for this case the solution was found but taking into account a complete model of a vessel, the same approach is not applicable due to a large amount of data. Therefore, this repositioning question using the effectivity in 4GD remains unsolved.

Re-use. As described in the theory chapter 2.2.5 the possibility to re-use models across the vessels is a significant concern for a ship building company. It avoids re-modelling of the same system and allows re-using the already designed models in current design. As this case study showed, the re-use can be accomplished by several means.

The easiest way to do it is using the effectivity where the new version of a vessel can be created based on the existing structure which is already in 4GD format. As the effectivity is assigned to a CD, any further actions are applied to the new version of a vessel. In this case, only the necessary DEs and configurations of DEs remain in the model and the rest is deleted, and remodelled or exchanged by parts from the library. This approach preserves the data which is relevant for the new vessel and allows adding or changing the models which make a difference between two vessels.

Another way to perform a re-use from older ship models to 4GD is to import an assembly from Teamcenter which is not considered as a 4GD object. Using 4GD_populate_cd function an assembly with its components is converted to a CD with DEs. This function requires programming and takes a time to process all the data but is the best solution for large scale products. The whole assembly is translated and named automatically to the 4GD correspondents which afterwards can be modified or reused for further projects. Likewise, the translation of data can be made manually, as it was done in this case study. Using this way only the necessary assemblies or parts are added to current vessel model but it is only efficient for small amounts of data.

Finally, 4GD concept contains the Reusable DEs which allows reusing components from the TC and introducing them into the CD. This solution is an effective tool if there are only a few parts that need to be re-used and they are distinct over the assembly. In this way, the DEs are created to which the components from previous assemblies are added.

Either way, the re-use in 4GD might be efficiently used according to certain business requirements if the configuration of the software is well defined which is described further.

Configuration and establishment. This case study showed that in order to effectively use TC and NX in 4GD environment it is absolutely necessary to establish the ship design companies goals and requirements to the software. 4GD is a complicated integration in TC and NX which requires a lot of configuration settings to be well established. In this research, the user utilized the 4GD for the first time and the configuration was set as a default which is why some of the functions in NX and applications in TC were not accessible or did not work as it should. For example, the import of assemblies in the CD issued a client error for which the workset was unable to open in NX. The before mentioned repositioning problem using effectivity was a consequence of missing TC and 4GD relation bundles which are not enabled by default. Due to this kind of misconnections or configuration flaws, the 4GD might not work as expected by the company.

5.4 Comparison of the current structuring method and 4GD

This chapter displays the comparison of the traditional structuring approach and 4GD based on the results presented above and taking into account the four criteria defined in the methodology.

Table 5.1. Comparison of the conventional assembly and non-conventional (4GD) approach (main case)

	Conventional assembly approach	Non-conventional approach (4GD)
Exchange	▪ Function 'Replace component' ▪ Positioning according to the existent constraints ▪ Constraints errors, readjustments ▪ Parent parts can't be exchanged ▪ Reuse of large scale data is complex	▪ Function 'Replace source part' ▪ Positioning according to the axis of origin ▪ Supported in large scale products ▪ Any DE is exchangeable and reusable
Remodelling	▪ Design-in-context of certain sub-assembly ▪ Loads parent parts of the components	▪ Design-in-context of overall product ▪ Loads only relevant data ▪ Effectivity solution
Restrictions of constraints	▪ Particularly high ▪ Rigid model ▪ Reused components are overloaded	▪ No constraints (certain constraints if needed) ▪ Flexible model ▪ Reused DE are positioned but not constrained
Structure importance	▪ Hierarchical assembly structure ▪ Predefined structure ▪ Single organizational breakdown	▪ Flat assembly ▪ Organisation defined by partitions ▪ Multiple organizational breakdowns

First of all, the exchange done using the two approaches is compared. In both cases, particular functions were used to exchange one part by another. The difference here is that the traditional assembly approach positions and constraints the new part to the particular location where the 4GD places a new part depending on the components coordinate axes. This means that 4GD allows free movement and allocation of the new part when traditional assembly approach restricts it due to certain constraints and requires readjustment if there is movement in need. However, the function ‘Replace component’ in the traditional assembly approach is mainly used to replace parts by revisions and is not always applicable for exchange. For example, the exchange of the parent part in an assembly can’t be accomplished as the children parts are lost in this case. So, it can be concluded that 4GD improves the exchange due to automatic positioning, no constraints or hierarchical assembly restrictions.

Secondly, remodelling was performed in both approaches, and the results show that design-in-context was straightforward in both cases. The only difference is that the traditional assembly approach requires working with the precise assembly where the design is performed, unlike the 4GD where the design-in-context is performed straight in the whole assembly or certain subset. Due to the partitions which sort the design data but do not constrain it, the components can be modelled first and just then assigned to the particular partition. Plus, to remodel relevant part in the sub-assembly the parent and children components are loaded into NX session where in 4GD only the necessary set of data might be used in the NX session. In large scale products, it exposes a big advantage over the traditional assembly approach because the working environment is not overloaded, contains only the significant components and requires only a few parts being checked out. Plus, an effectivity solution might be employed instead of remodelling in 4GD by creating an equivalent model in the same file which contains the same information and is different where needed.

Thirdly, the restriction of constraints turned out to be unusually high in the traditional assembly approach. The positioning of the components is always defined by the constraints so any movement, modification or exchanged part issues constraints errors and demands for alterations. On the one hand, the constraints make the assemblies well-structured, and parts are moving together as fixed structure but on the other hand, it makes the assembly very rigid and any change influences surrounding parts and constraints whereas 4GD makes the assembly a flexible structure which also retains the position of objects. Plus, 4GD allows the assembly constraints at some level if needed. Moreover, the constraints overload the assembly because the reused sub-assembly comes with the existent constraints and might mix up with the assembly constraints of the primary model. It can be seen, that, in this case, the 4GD exposes an advantage over the traditional assembly due to the absence of constraints system.

Finally, the importance of the structure in the two approaches is compared. This research verified that the hierarchical structure in the traditional assembly method is of high importance and influences entire design process. Assembly structure needs to be pre-defined to follow it while modelling a large-scale product. Due to the high amount of data, the structure of assemblies and sub-assemblies has to be clear and meet the requirements of different design teams whereas 4GD allows a flat assembly structure where the parts don't have to be the dependent one to each other but is an option. Using this approach allows deciding the structure at the beginning or during the design process due to multiple organisational breakdowns and search capabilities to load only relevant data for design teams.

5.5 Exchange improvement and 3D reuse facilitation

The main aim of the thesis was to investigate the new 4GD approach in terms of exchange and 3D reuse improvement. However, the thesis touched only certain points of this subject and was directed more towards the comparison of the two structuring approaches due to wide scope and complexity of the 4GD approach. Nevertheless, the exchange and reuse were performed with several components, so the result will be discussed further in this section.

Due to the multiple organisational breakdowns and flat assembly structure where each DE is independent, the 4GD provides a more flexible assembly structure of a product which means that there are no constraints and very few restrictions to position components in the assembly which make it easy to exchange. Even the top level element which couldn’t be exchanged in traditional assembly approach is exchangeable in 4GD and doesn’t influence the parts below. The components, which would be the children components in conventional assembly approach, remain their position in 4GD even if the surrounding parts are exchanged.

As described in theory, a class of vessel needs to contain the same configuration or have the same outfitting which integration must fit with all the vessels in the same class. The results showed that due to the effectivity solution it is possible to create a series of ships with the same hull or the same propulsion system within the same collaborative design file. In this way, the same configuration is reused across the vessel family. Plus, as the reusable DEs are widely used in the 4GD models, the previous designs can be directly reused in a new design ship. These features bring the highest influence to facilitate the 3D reuse across the vessels.

However, the exchange and reusability were investigated on basic level and for continuation of 4GD analysis this thesis might be a good starting point. The reuse and exchange process differences in 4GD from the conventional assembly approach were observed but they weren’t enough significant to conclude that this new approach improves the usability.

6 Concluding remarks

6.1 Discussion

Nowadays the market situation drives the shipbuilding industry to modernise and improve the fleet continuously due to demand of more sophisticated and customised vessels for different missions and working environments. Therefore, the shipbuilding companies are in search for innovative and efficient ways to maintain the modelling process and keep control of design, engineering and production data management specifically in large-scale products. The ship production processes are highly collaborative and so, to sustain the efficient management of the vessel's lifecycle, it is necessary to have well-developed and adapted tools and approaches. Therefore, this thesis aimed at investigating the 4GD approach against the traditional assembly approach to evaluate the benefits for maritime applications.

The main goal of the thesis was to implement and study the non-conventional 4GD framework in ship design in comparison to the conventional structuring approach. Therefore, several design and change cases, emphasising particular challenges in ship design like an exchange, re-modelling, alternatives and re-use across the vessels, were assumed and established as the framework for this analysis. The method proved to be a powerful tool for this research to verify whether the 4GD improves the exchange and facilitates the 3D re-use.

The case study showed that the 4GD approach requires different thinking on the assemblies and designing process as the components and features are distinct from the traditional assembly approach. Due to the absence of assembly constraints together with flat assembly structure in 4GD, the positioning of the parts becomes straightforward, and changes are accomplished smoothly. These features influence the exchange of the parts which is non-restrictive and fluent process in comparison to the traditional assembly approach. Plus, the effectivity in 4GD proved to be an efficient solution for alternative vessels or various ship configurations across the vessel family. It aids the designers to avoid remodelling and instead, re-use the 3D models of previous products. In ship design, it is a powerful tool which is innovative, cost effective, and time saving.

However, this master thesis scratched only the surface of the 4GD framework from novice user point of view. 4GD is a highly advanced approach to work and organise the design data which requires high competence in programming, configuring and working with Teamcenter and Siemens NX to gain significant benefit out of this approach. Plus, it requires well established needs and requirements to the software of the company to efficiently employ 4GD to the business processes. The installation and configuration must be well set and customized. To verify whether 4GD is a beneficial approach for continuous improvement in shipbuilding industry it has to be implemented and tested out in real maritime business and products. Therefore, it can be concluded that even applied to a simplified PSV, the 4GD exposes advantages over the conventional assembly approach but significant improvement of the exchange and 3D re-use across the vessel weren't observed. This is why the thesis requires further investigation of this case study applied to a more complex vessel.

6.2 Contributions

The main goal of the thesis was to implement and study the 4GD framework in ship design in comparison to the conventional assembly approach. The goal was achieved by completing the objectives defined in the introductory chapter.

- The current ship design approaches and data management capabilities were identified and analysed. Ship design is coping with significant problem how to employ an efficient PLM system together with large scale data management for maritime company's business processes. It was studied that due to continuous improvement and increasing requirements for the shipbuilding industry, companies are required to implement approaches that are able to manage both. The current method in ship design is the conventional assembly approach which uses hierarchical structure of a product and managed data in PLM system. Research was performed on challenges issued by this approach and how to overcome them. Further, the non-conventional approach was investigated in detail due to theoretical possibility to eliminate the challenges of the traditional assembly approach. By defining the features and theoretical advantages of this approach, an image was created.
- The methodology was derived to investigate the case study of PSV by emphasizing the differences between the conventional assembly approach and non-conventional concept. For the verification of the framework, the method was applied to a simple case which proved the method to be suitable for this case study.

- Empirical research was done on the simplified PSV where the 3D model was created, adapted to certain environment and modified to fulfil particular requirements. The previously established method gave results and views on conventional and non-conventional approaches from the same perspective which emphasized the differences.
- A discussion based on the results and concluding remarks finalised the research. The case study proved that the new 4GD approach shows a great potential for ship design as compared to the conventional assembly approach. Finally, it was concluded that due to limitations of complexity and human resources, the question if the 4GD can improve the exchange and facilitate the 3D reuse remains unsolved and requires deeper investigation.

6.3 Further work

The benefits of 4GD against the traditional assembly approach are already noticeable from this research, but there is always room for improvement.

This case study was carried out from the 3D designer point of view, but there are so many people working with different tasks not only in Siemens NX which is why the further step in the analysis should be the investigation of the 4GD capabilities in the Teamcenter. The data management, structuring, views on the BOMs, the search of data, etc. are maintained in 4GD Designer environment in Teamcenter which is unlike the traditional data management in Teamcenter.

Another important matter for future analysis is a large amount of data. This case study was performed on a simplified PSV with several sub-assemblies and components, but it’s nowhere near the level of data in a real vessel. Therefore, to verify if the flat assembly structure, effectivity, absence of assembly constraints and other differences in 4GD are beneficial for a maritime company, the approach has to be applied to a fully equipped vessel. Analysis of large-scale data should expose greater differences among the two structuring methods and aid analysing the PLM system at the same time.

Finally, to continue with this case study of change in the traditional assembly approach and 4GD a dedicated function in Teamcenter should be employed. For working with changes in the vessel which might influence several components, design tasks and designer, the Change Management feature in TC should be used. This function might simplify and optimise the change process which boosts the innovation. The change management wasn’t employed and investigated in the case study of PSV due to simple structure, therefore, it should be used for a further case study of 4GD. The change management tool used together with 4GD might expose even greater advantages and development possibilities in comparison to the traditional assembly approach.

To finalize this research, several ways for continuation of the thesis are identified:

- 4GD application in ship design for a vessel customization
- Exchange and reuse across the ship class employing 4GD
- Basic vessel design in 4GD employing ship design application in modelling software
- Research on PLM methods and techniques combined with 4GD large-scale data management
- Analysis of the PLM and 4GD application areas in ship design to meet particular customer’s needs

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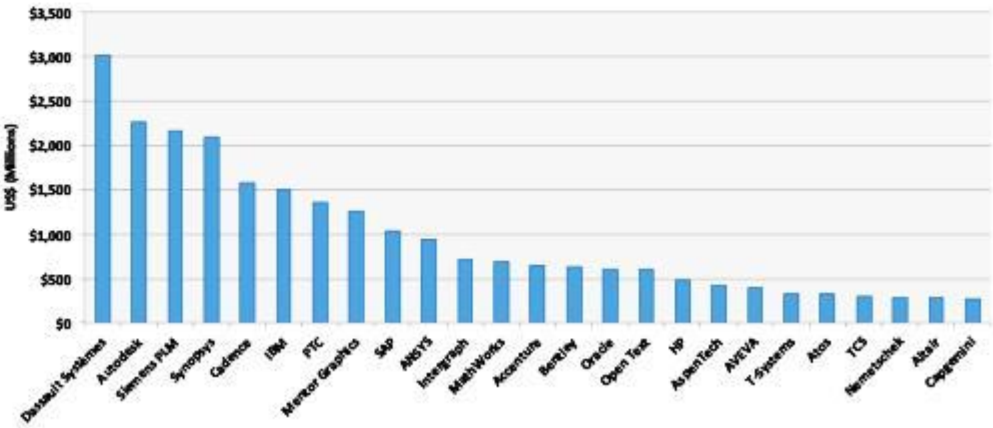
Appendices

Appendix A. The most used PLM systems in 2014 (CIMdata, 2014)

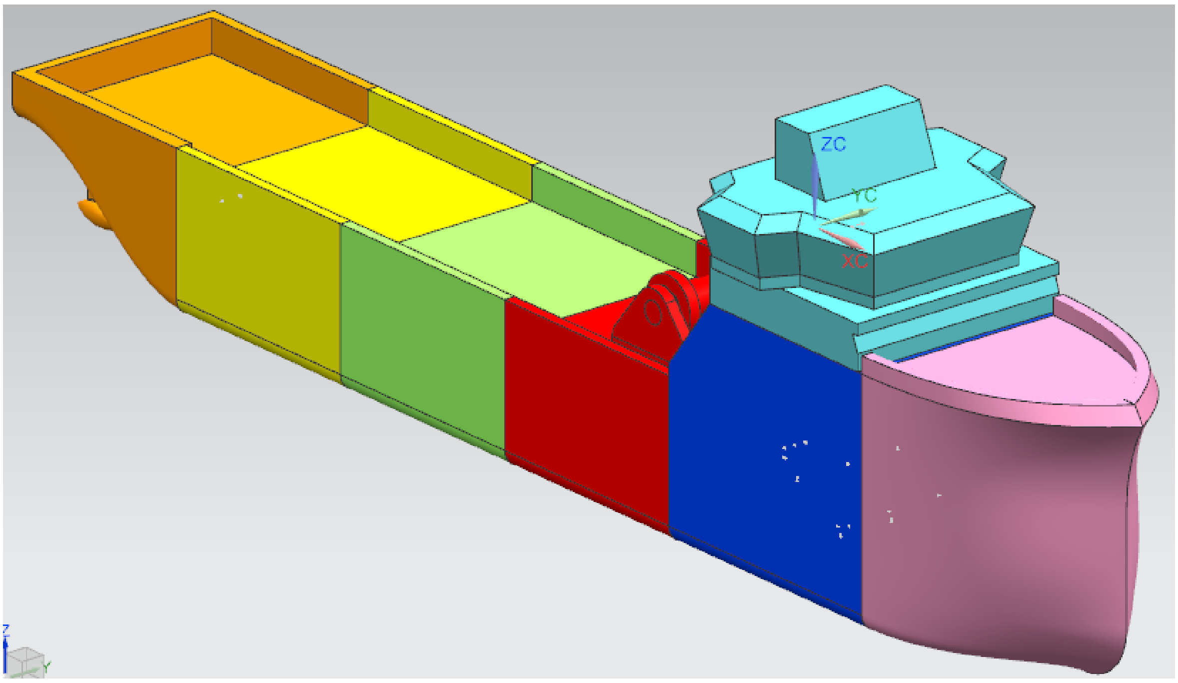
The most competitive PLM system evaluation is completed by CIMdata. CIMdata's annual PLM Market Analysis Report (MAR) Series provides detailed information and in-depth analysis of the worldwide Product Lifecycle Management (PLM) market. However, it is not accessible for every user and has to be purchased. Therefore, the most recent data accessible is from year 2014 and is shown in the graph below. Here, the revenues of most common PLM systems are compared. It can be observed that Siemens PLM remained in the 3rd place which by now probably outgrow.



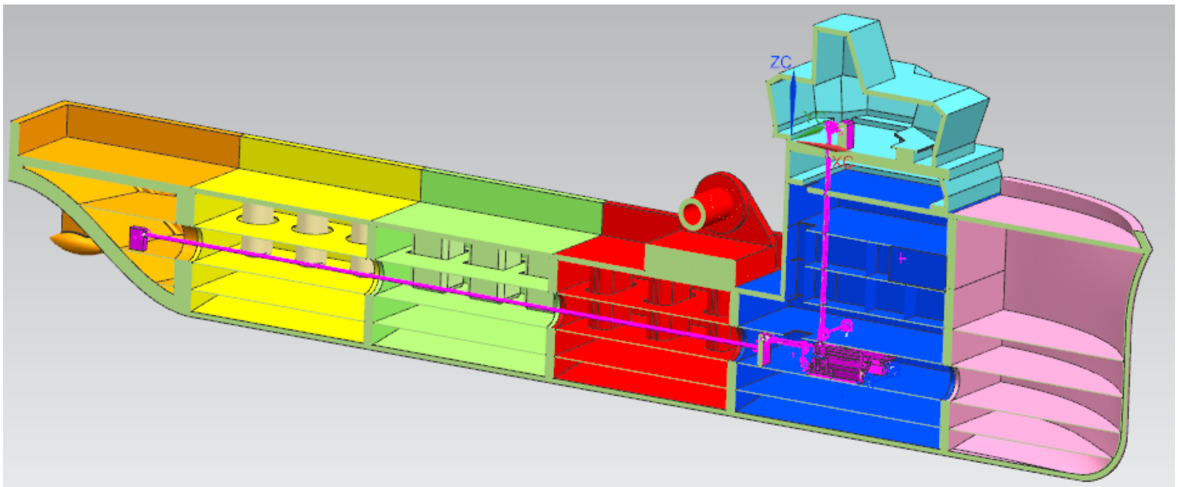
Appendix B. PSV 3D model: base case

This appendix gives an image and overview of the PSV 3D model which is analysed in this research. The 3D model is made up of several modules which consist of several assemblies and components. This appendix displays separate 3D models of each module with its cross section as well as the full 3D model of the vessel. The view on the 3D model of PSV is perceived and the complexity of the vessel is observed.

3D model of the PSV coloured according to the division by the modules (in Siemens NX):



Cross section of the PSV (in Siemens NX):



BOM structure of the PSV in Teamcenter:

Structure Manager

001320/A;1-PSV (View) - Latest Working - Date - "Now"

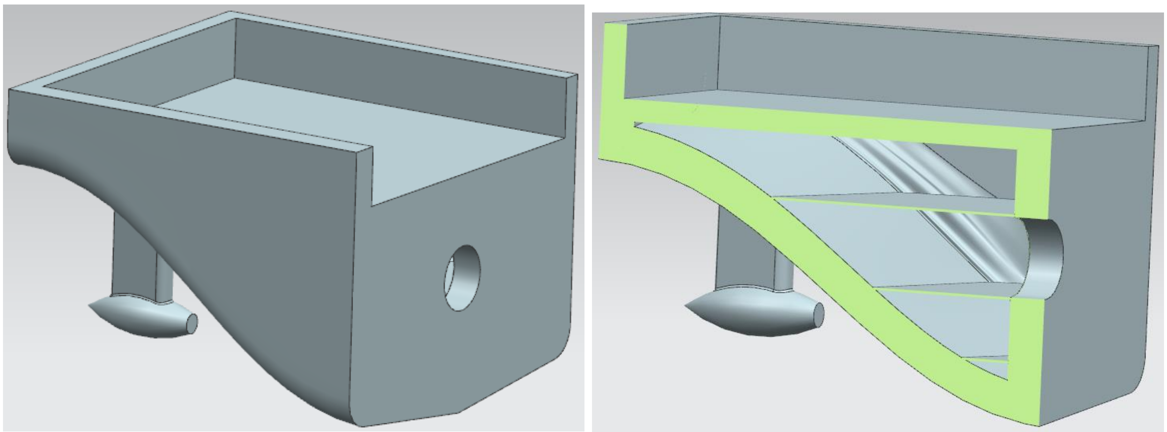
BOM Line	Item...	Rule config...	Item Re...	Find No.	All Notes	Mak...	Unit ...	Referenc...	VO...	HC...	Variant Conditio
001320/A;1-PSV (View)	Item								Y	False	
001315/A;1-Stern	Item	Working( )		20	UG REF SET,UG NAME,UG ...		each		Y	False	
001316/A;1-Conventional bow (View)	Item	Working( )		30	UG NAME,UG REF SET,UG ...		each		Y	False	
001321/A;1-Hull_01 (View)	Item	Working( )		40	UG NAME,UG REF SET,UG ...		each		Y	False	
001325/A;1-Hull_03 (View)	Item	Working( )		50	UG REF SET,UG NAME,UG ...		each		Y	False	
001324/A;1-Hull_02 (View)	Item	Working( )		60	UG NAME,UG REF SET,UG ...		each		Y	False	
001317/A;1-Bridge (View)	Item	Working( )		70	UG REF SET,UG NAME,UG ...		each		Y	False	
001319/A;1-Super structure (View)	Item	Working( )		80	UG REF SET,UG NAME,UG ...		each		Y	False	
001340/A;1-Propulsion (View)	Item	Working( )		90	UG NAME,UG ENTITY HA...		each		Y	False	

PSV assembly structure in Siemens NX:

Object	Number	Rev
Sections		
001320/A;1-PSV (Order: New Or...	**001320**	**A**
Constraints		
001315/A;1-Stern	001315	A
001321/A;1-Hull_01	001321	A
001324/A;1-Hull_02	001324	A
001325/A;1-Hull_03	001325	A
001319/A;1-Super structure	001319	A
001317/A;1-Bridge	001317	A
001316/A;1-Conventional bow	001316	A
001340/A;1-Propulsion	001340	A

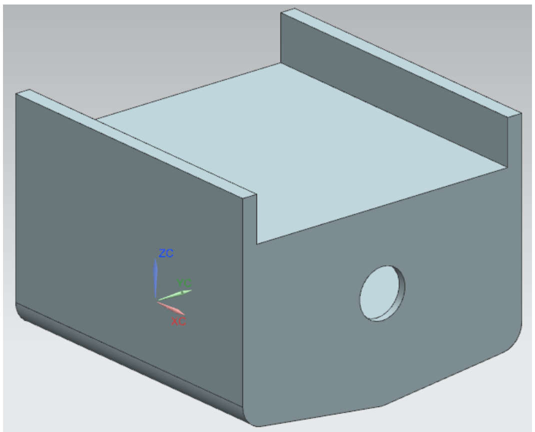
Further, the separate modules' 3D models will be displayed together with the assembly structure (in Siemens NX).

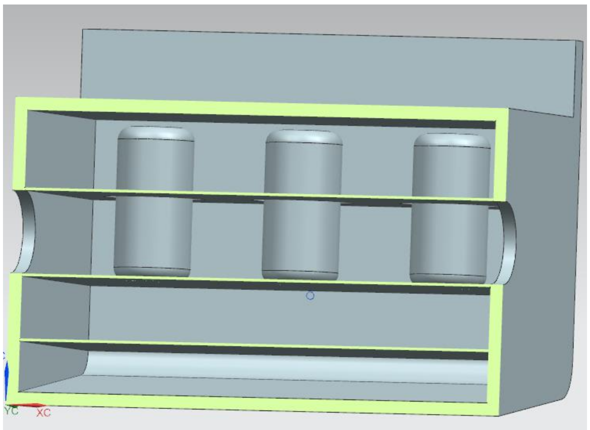
1. Stern



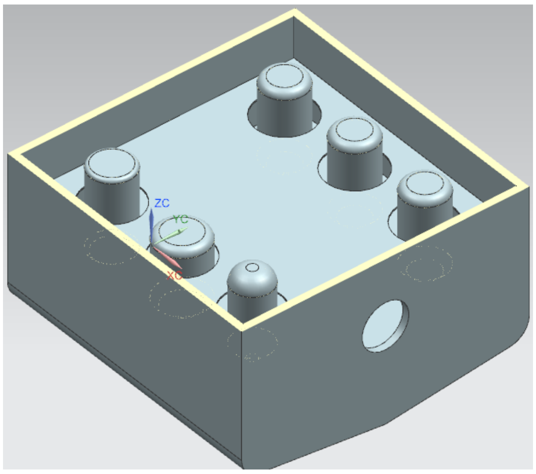
2. Hull_(01_02_03)

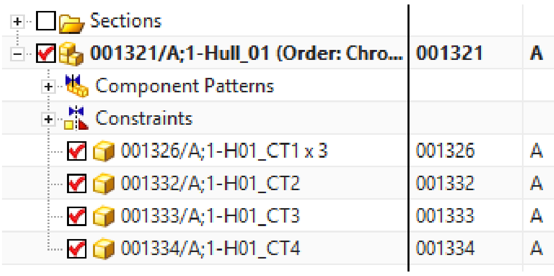
The three hulls are of the same outer shape and deck construction as shown below.



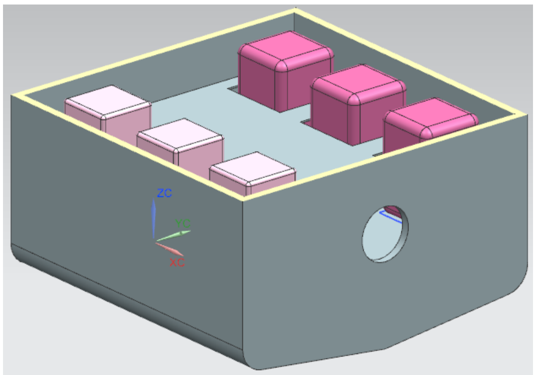


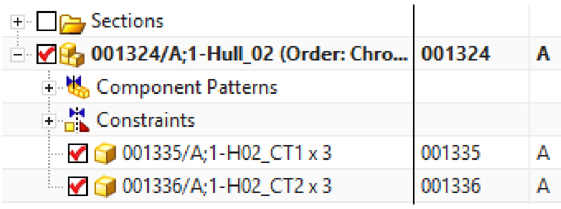
The sub-modules in the three hulls are different and the configurations of the Hull_01, Hull_02 and Hull_03 are accordingly displayed further.



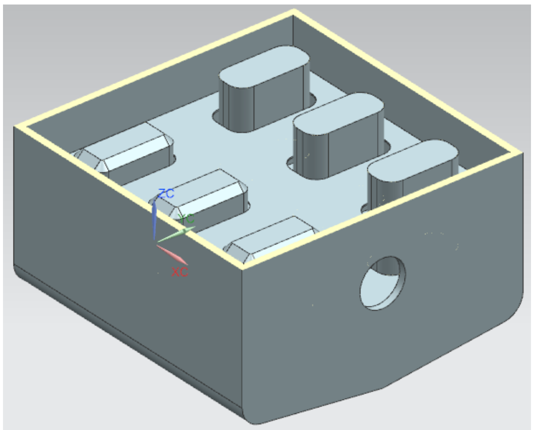


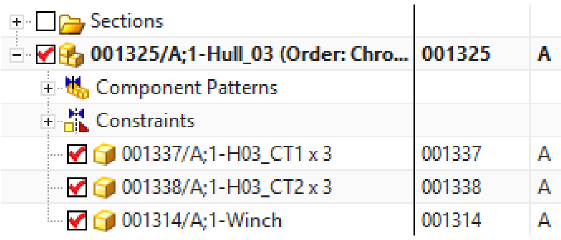
Sections		
001321/A;1-Hull_01 (Order: Chro...	001321	A
Component Patterns		
Constraints		
001326/A;1-H01_CT1 x 3	001326	A
001332/A;1-H01_CT2	001332	A
001333/A;1-H01_CT3	001333	A
001334/A;1-H01_CT4	001334	A





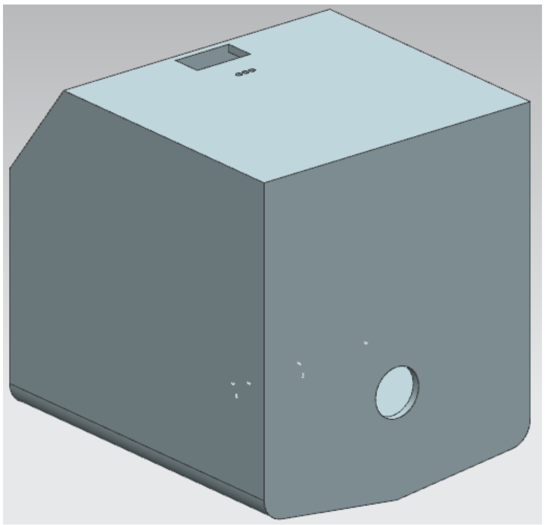
Sections		
001324/A;1-Hull_02 (Order: Chro...	001324	A
Component Patterns		
Constraints		
001335/A;1-H02_CT1 x 3	001335	A
001336/A;1-H02_CT2 x 3	001336	A

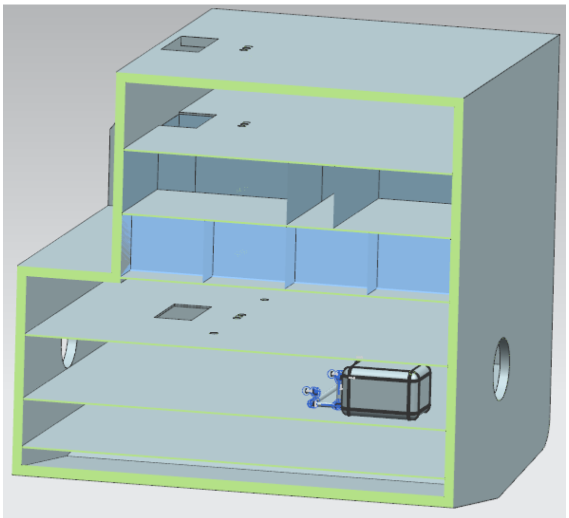


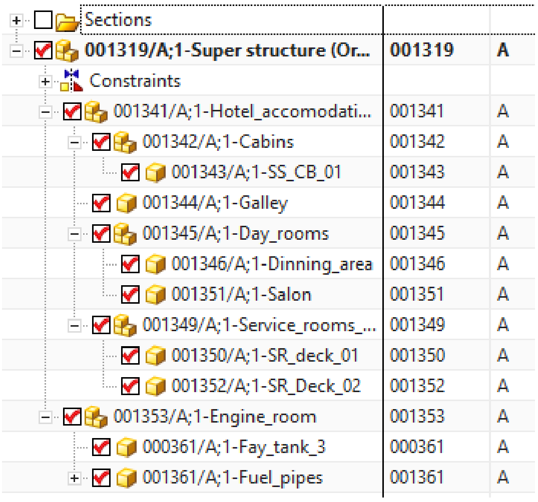


Sections		
001325/A;1-Hull_03 (Order: Chro...	**001325**	**A**
Component Patterns		
Constraints		
001337/A;1-H03_CT1 x 3	001337	A
001338/A;1-H03_CT2 x 3	001338	A
001314/A;1-Winch	001314	A

3. Super structure

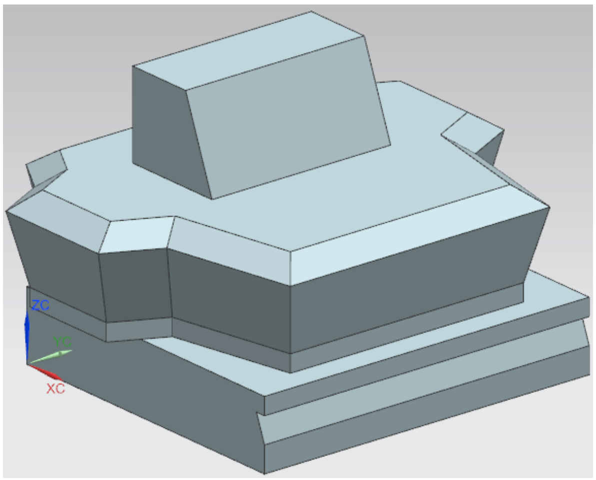


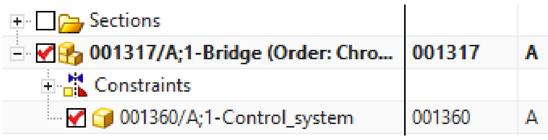




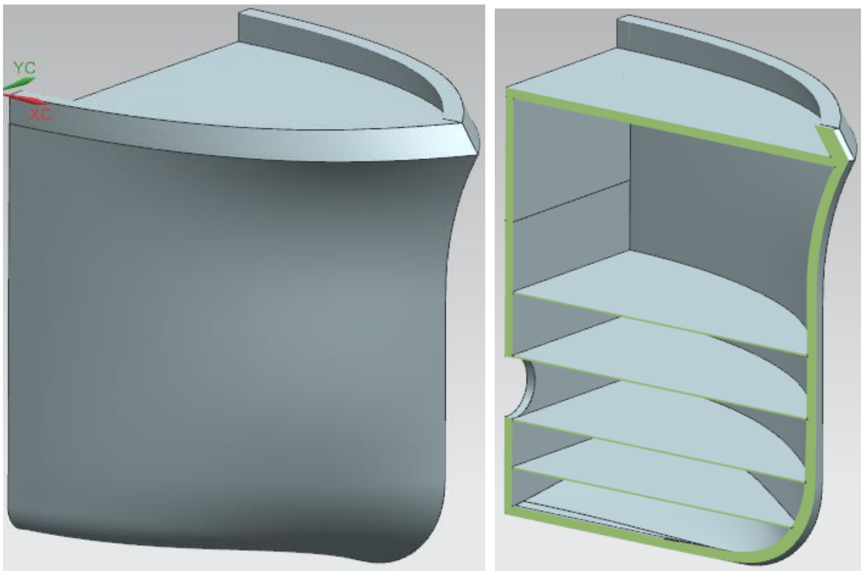
Sections		
001319/A;1-Super structure (Or...	**001319**	**A**
Constraints		
001341/A;1-Hotel_accomodati...	001341	A
001342/A;1-Cabins	001342	A
001343/A;1-SS_CB_01	001343	A
001344/A;1-Galley	001344	A
001345/A;1-Day_rooms	001345	A
001346/A;1-Dinning_area	001346	A
001351/A;1-Salon	001351	A
001349/A;1-Service_rooms_...	001349	A
001350/A;1-SR_deck_01	001350	A
001352/A;1-SR_Deck_02	001352	A
001353/A;1-Engine_room	001353	A
000361/A;1-Fay_tank_3	000361	A
001361/A;1-Fuel_pipes	001361	A

4. Bridge

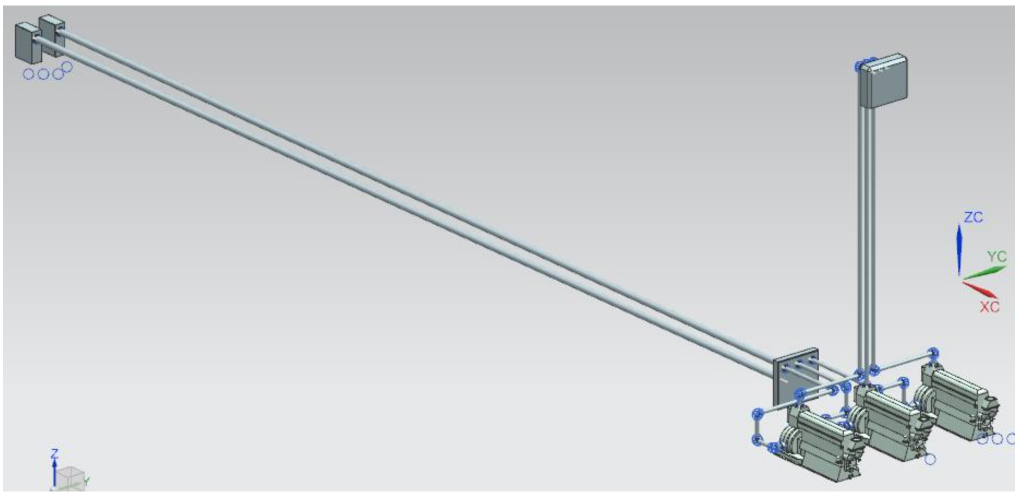


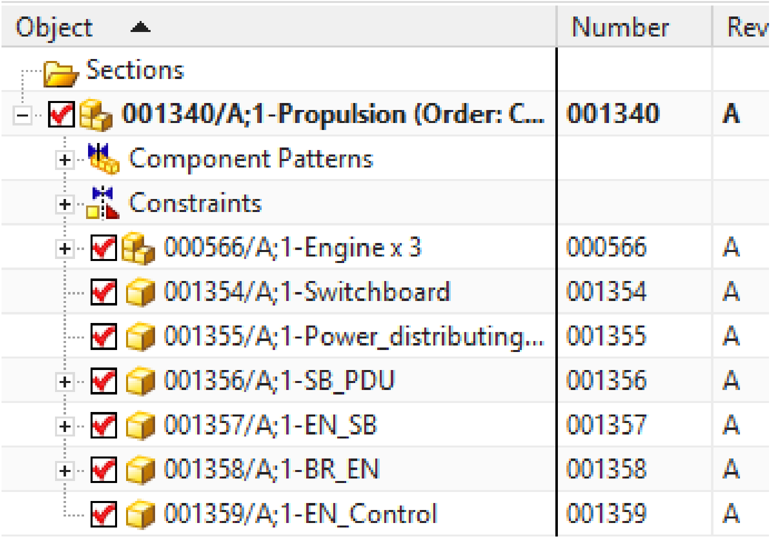


5. Conventional bow



6. Propulsion

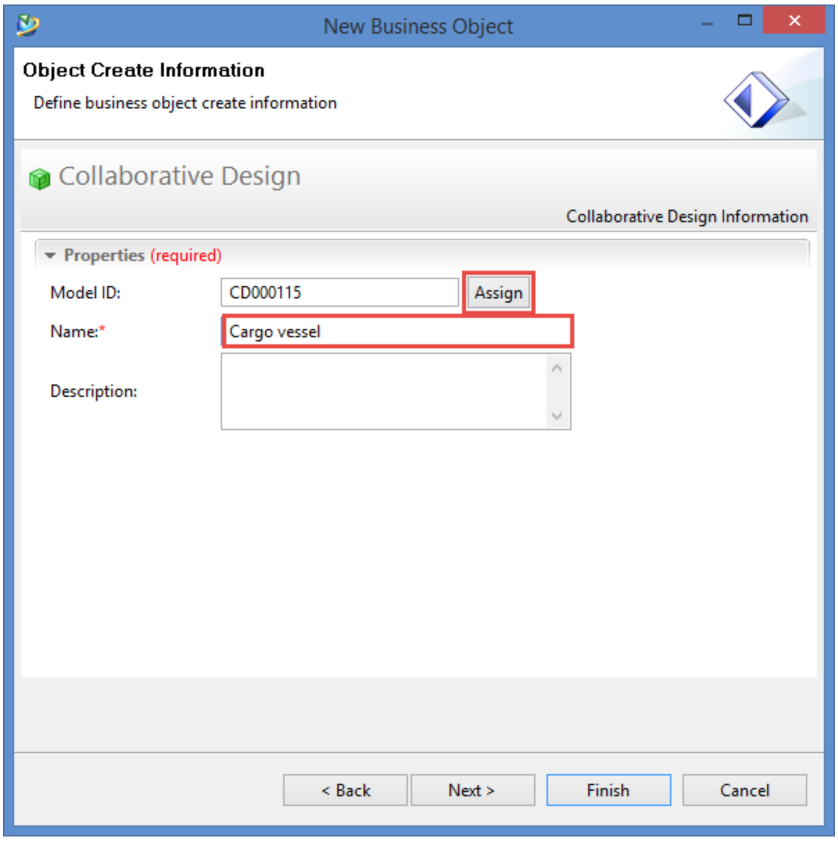



Object
Number
Rev
Sections
001340/A;1-Propulsion (Order: C...
001340
A
Component Patterns
Constraints
000566/A;1-Engine x 3
000566
A
001354/A;1-Switchboard
001354
A
001355/A;1-Power_distributing...
001355
A
001356/A;1-SB_PDU
001356
A
001357/A;1-EN_SB
001357
A
001358/A;1-BR_EN
001358
A
001359/A;1-EN_Control
001359
A

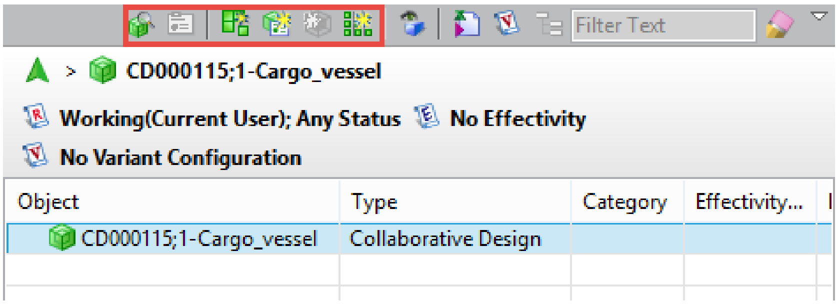
Appendix C. Creating objects in 4GD

This appendix is as a tutorial on how to create data management objects in 4GD environment. It was created due to lack of basic information on the initial object creation processes in 4GD. The appendix covers basic actions and steps taken in order to create Collaborative design, Desing elements, Partition schemes, Partitions, Workset and Subset. It shows these processes performed in Teamcenter and NX environments as 4GD allows creating data management object in different ways.

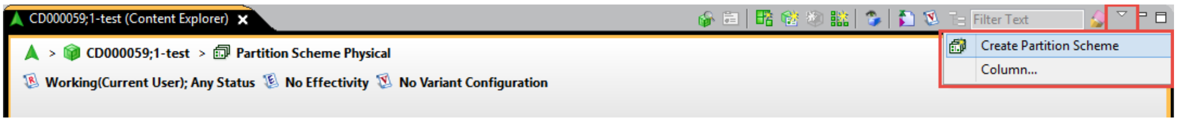
1. First of all, a Collaborative design is created which is a collection of all the objects in the assembly. The model ID is assigned automatically by pressing the button 'Assign' and the name of the CD has to be given by the user. The creation is completed by pressing 'Finnish'.



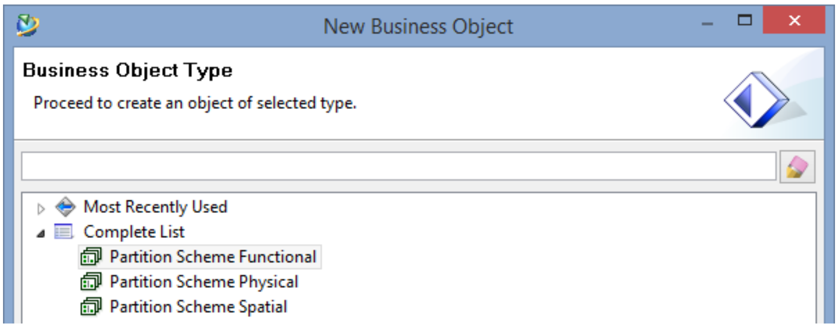
2. The Collaborative design opens on create in the Content explorer where the content of the collaborative design can be viewed. Here, the Design elements, Subset definitions and Partition can be created for the overall model.



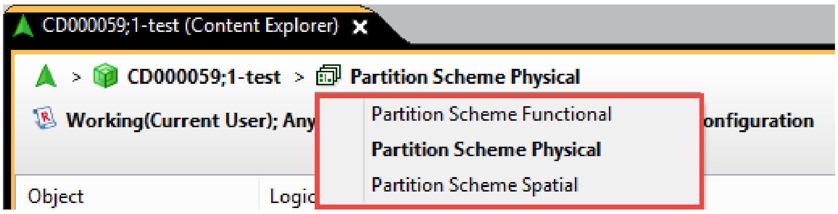
3. In order to create organizational breakdowns of the CD, partition schemes are used and can be found as shown in figure bellow.



There are three types of partition schemes available to which a specific name has to be given.

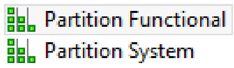


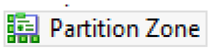
When the three types of partition schemes are created they can be viewed in Content explorer window. Note that only one partition scheme with its partition can be viewed at once.



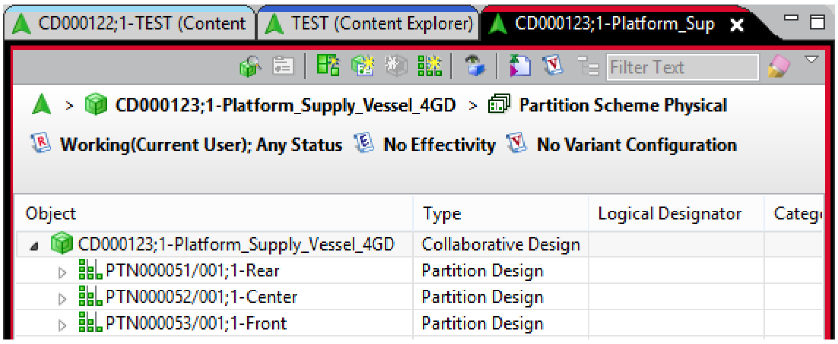
The Partitions in the Partition Schemes are created in the Teamcenter using command ‘Create Partition’. Depending on the partition scheme, the Partitions are of different types:

Physical partition scheme: 

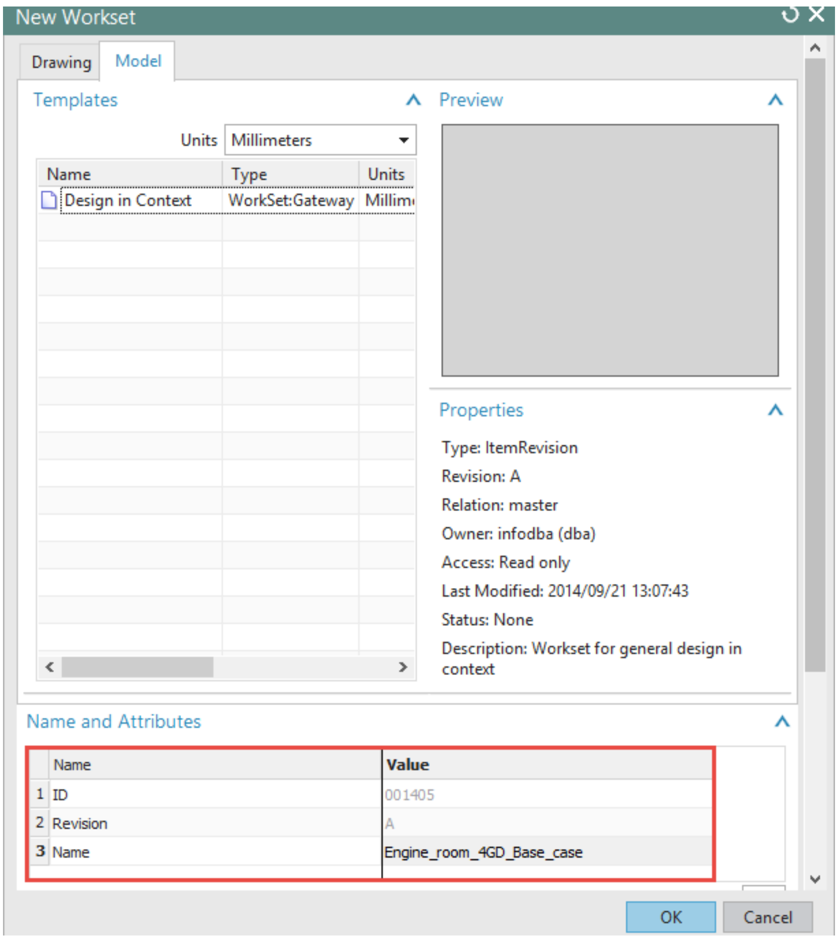
Functional partition scheme: 

Spatial partition scheme: 

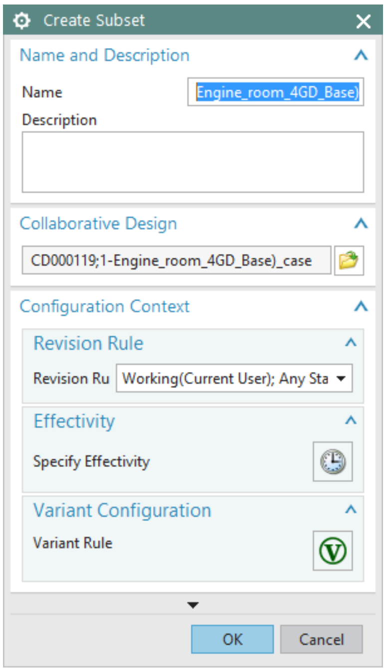
When the required partitions are created, they appear in the Content explorer under appropriate Partition scheme as it can be seen in the example bellow.



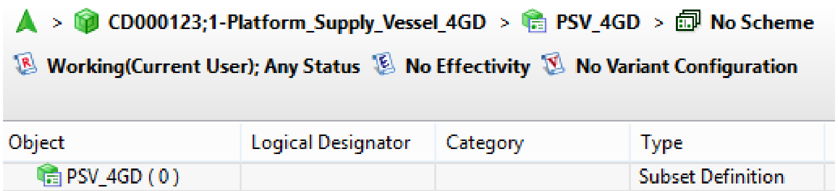
4. When the partitions are created, the next step is to create a workset. This is easily done by drag-and-drop of the CD into the NX session which issues the 'New Workset' window. Here the ID, Revision and Name of the workset are established.



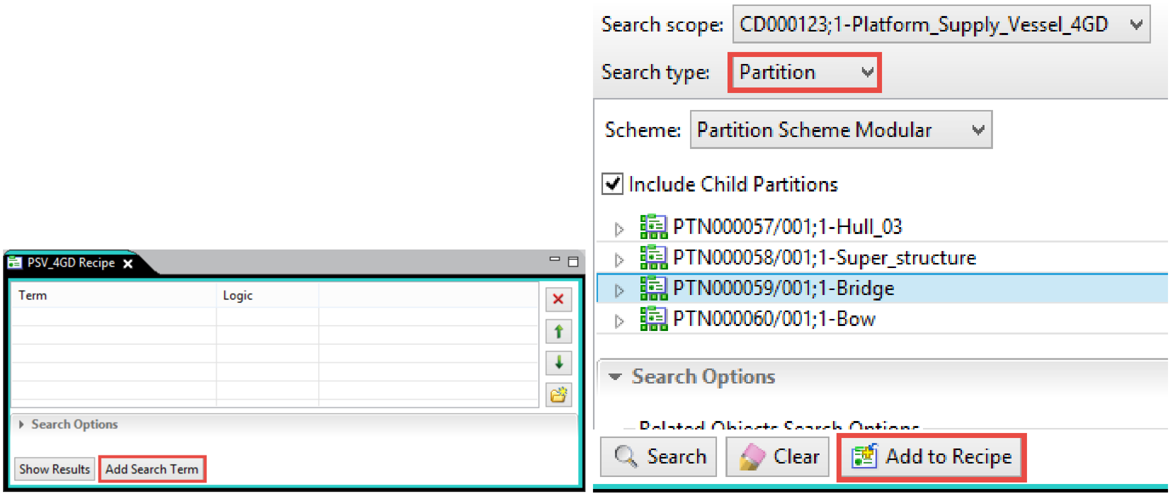
Consequently, a ‘Create subset’ window pops up in order to create a subset which by recipe includes only specific design elements that a certain designer is concerned of. The subset is every designer’s personal working environment.



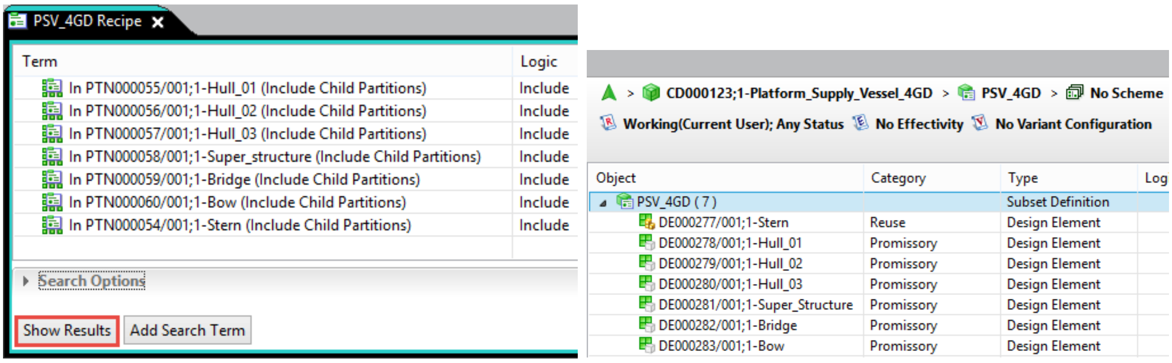
Another approach to create the workset and subset definition is using Teamcenter. First, the subset definition is created using the button ‘Create Subset Definition’ on the toolbar in 4GD environment. When created, the Content explorer window opens as shown in figure bellow. The zero close to the Subset definition object means that there are no DEs included in this recipe.



Therefore, View/edit content recipe is used to add object to the subset definition. Recipe window opens where ‘Add Search Term’ is used to select required DEs to include (Figure on the left). The search method is similar to the one used in NX, the parts can be searched by attributes, partitions, proximity, etc (Figure on the right). The desired object or criteria is selected and then enclosed to the subset definition by ‘Add to Recipe’.

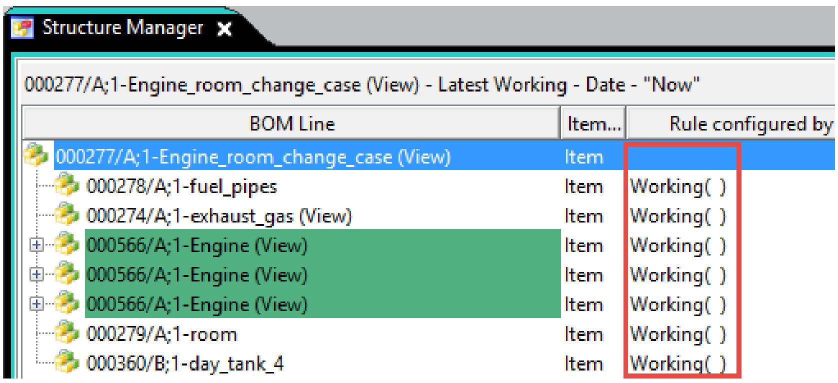


The objects within defined criteria appear in the Recipe window. Selectin ‘Show Results’ issued a content explorer window of the Subset definition where the DEs are seen.

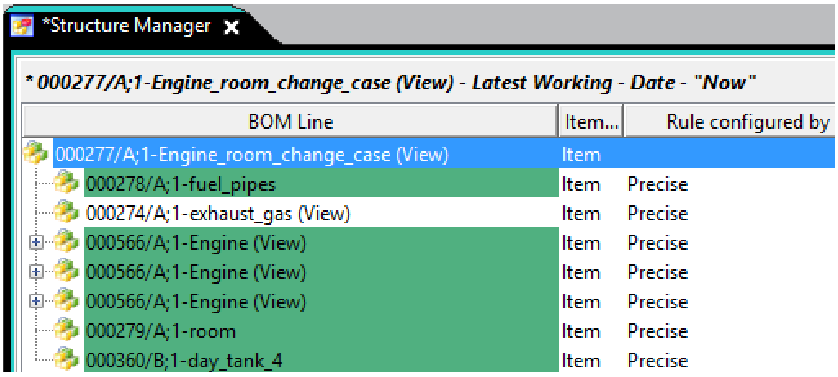


5. The DEs might be created using the Teamcenter or NX. Both ways are possible but they differ in approach which will be described in this section.

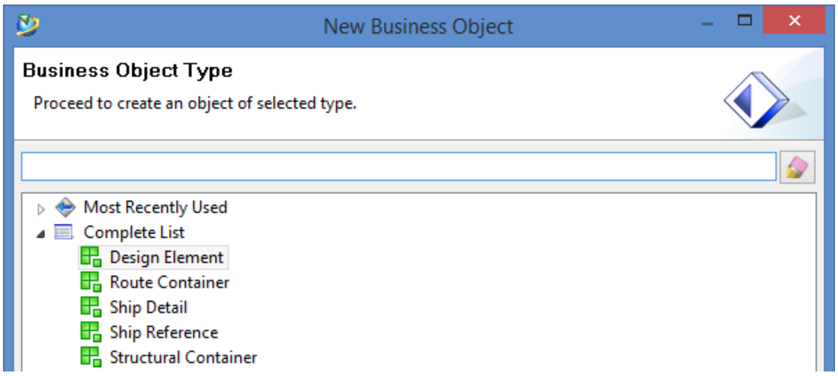
   a. **Precise assembly structure**. 4GD environment only recognizes precise assembly structure, therefore it is necessary to ensure that assemblies intended to use as 4GD object are precise. This can be performed in Structure manager where the rule configured by indicated the structure.



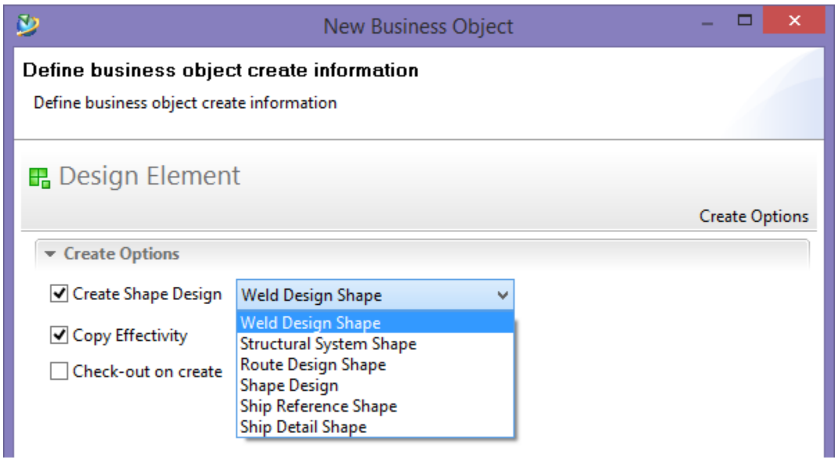
To make the assembly precise, the command Edit -> Toggle Precise/Imprecise is used. It makes the assembly and its children as precise structure which is shown in figure bellow.



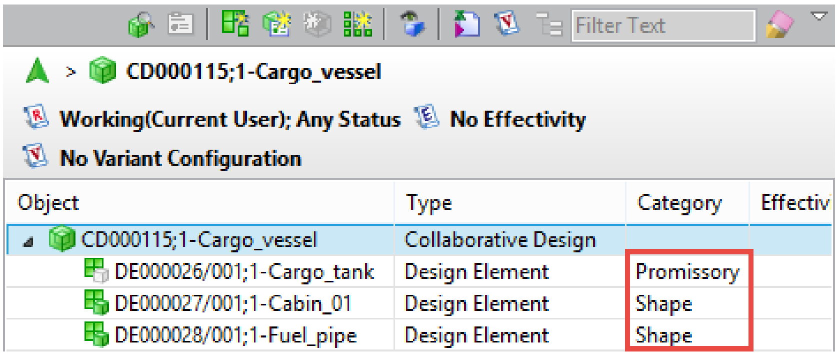
b. **Teamcenter.** In order to create a Design element, few options appear as shown in the Figure bellow. According to the needs and type of a 3D model, the type of an object can be chosen,



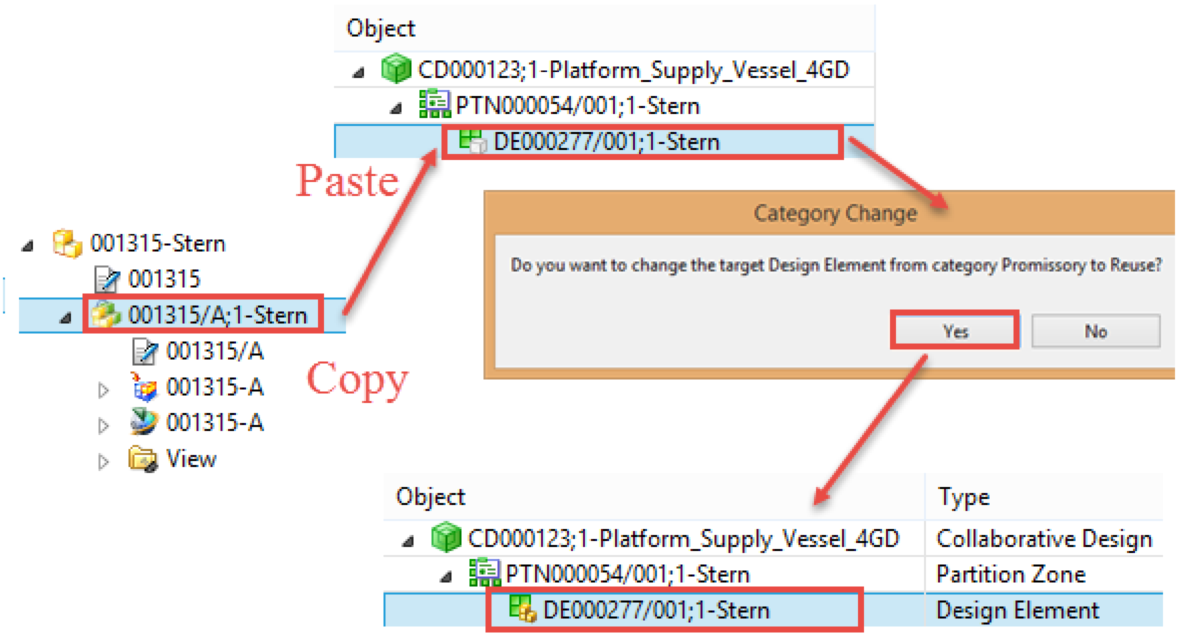
If the Design Element is chosen, in the next step several options appear as shown in figure below. If the ‘Create Shape Design’ is checked, there is a variety of shape design elements to be chosen which all create a Shape DE. If the check point is not marked, the Promissory DE is created.



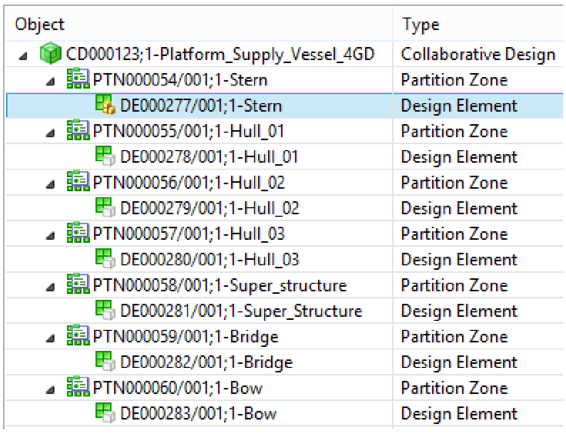
The software created different types of DEs which are displayed in the Category section in 4GD Content Explorer.



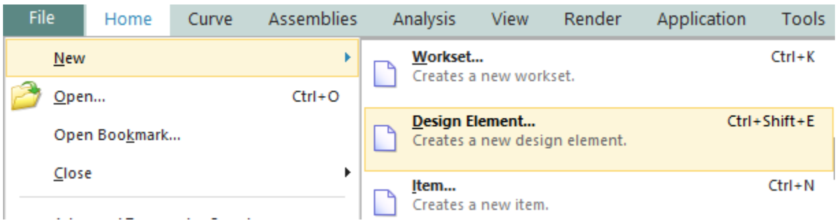
In order to assign an already existing assembly or part structure to a 4GD business object this can be easily done by copy-paste of part BVR from My Teamcenter to the promissory design element in 4GD environment. This action issues message of Category change and the Promissory DE become Reuse DE which includes the required assembly. The steps are visualised in figure below.



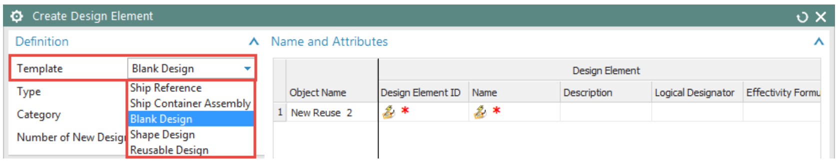
Using this approach, the DEs are directly assigned to certain partitions.



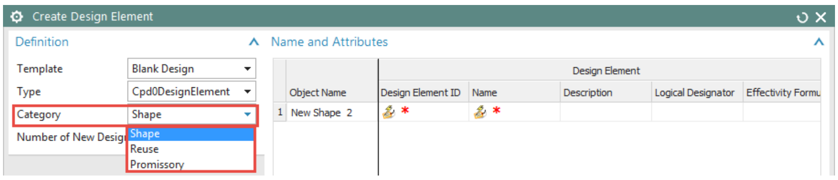
c. **Siemens NX.** The design element can be added to the subset by following File > New > Design Element.



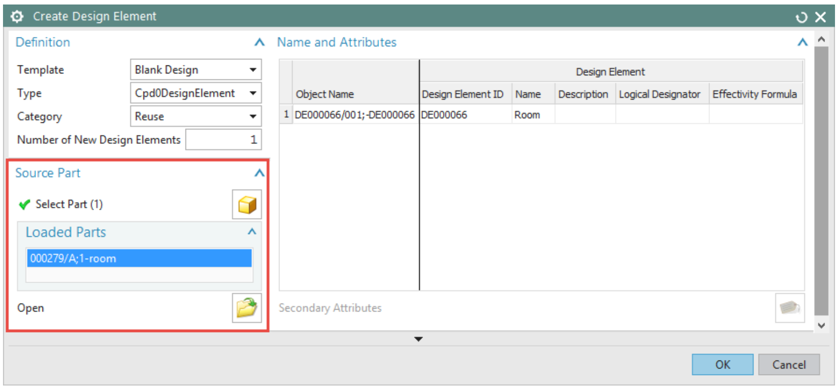
In the 'Create Design Element' window several option are available. First of all, the DE template has to be chosen among the types in the figure below.



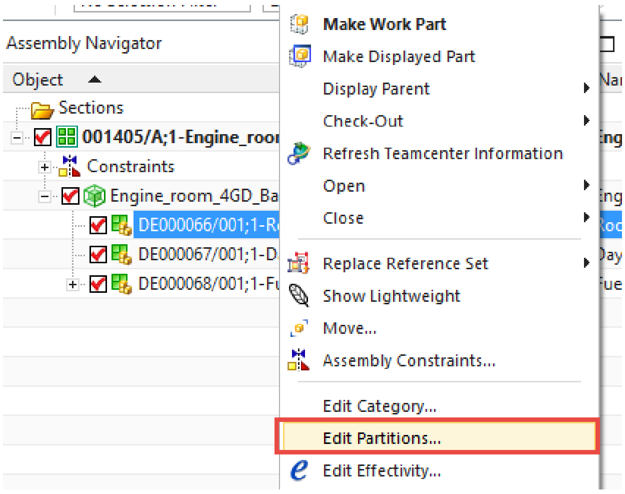
According to the template chosen, the Category options appear appropriately. The easiest approach is to select the Blank design template from which the three types of DE's described in the theory are available.



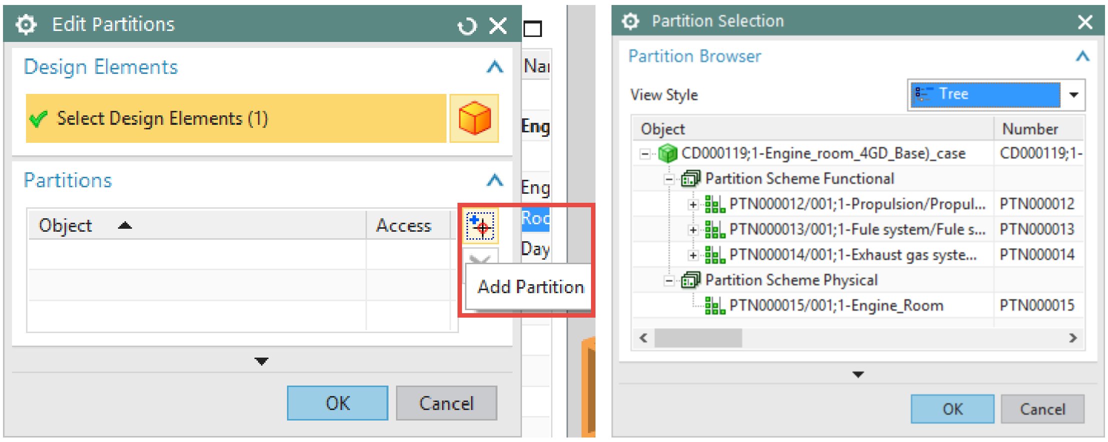
In case if the geometry is used from previously designed parts, the reuse DE should be selected where the Source part can be uploaded and introduced as a 4GD object.



6. In order to add the DEs to certain partitions it might be done automatically by creating recipes or manually editing the partitions. In this case study, the objects were assigned to one partition using Teamcenter. To add the object to several partitions, it's possible to do by right clicking on a DE where option window appears and 'Edit Partitions' are selected.



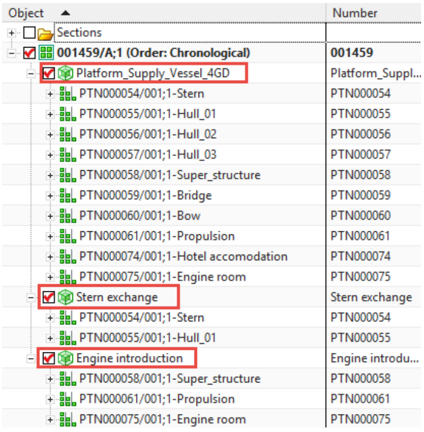
The DEs to be assigned to certain partition are selected and then the partition is chosen from the ones created previously.



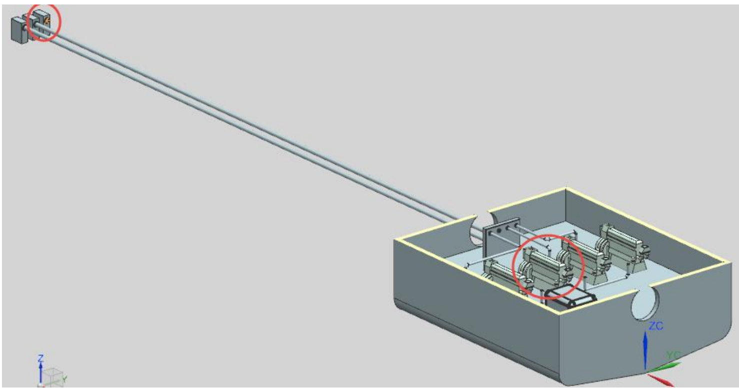
Appendix D. Change case of the PSV in 4GD

This chapter gives additional views on certain change case actions which were performed in 4GD environment and gives an image on different views and changes done in this case study.

View on the three subsets created in overall PSV workset. Due to specific recipes the subsets include only certain data relevant for specific design context.



Additional generator and engine included in the ‘New part introduction’ subset.



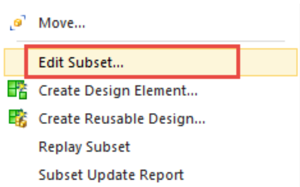
Changes performed in the PSV shown in the cross section. The parts were remodelled to fit with the surroundings. Main modifications: 1. Stern exchange; 2. Generator introduction; 3. Engine introduction.

Appendix E. Effectivity configuration

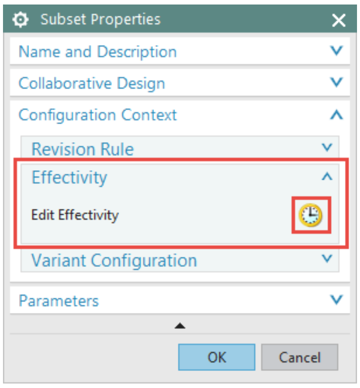
This appendix explains the steps taken to set the effectivity for the PSV. Effectivity is a solution in 4GD which allows created different configurations of a vessel in the same single file. This chapter is also as a tutorial on how to set the effectivity and how it appears in the structure of the model.

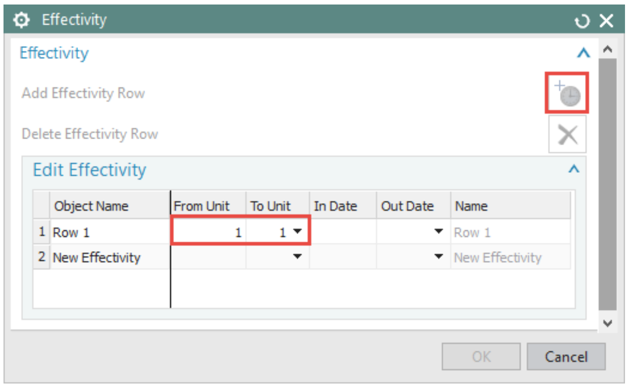
To set the effectivity following steps were done:

1. Right click on desired subset and choose Edit Subset. In the subset recipe window select the subset properties.



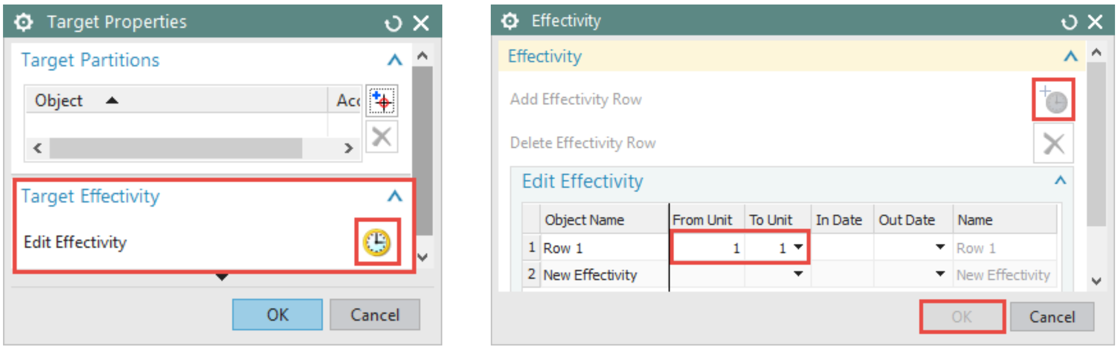
2. The Subset properties window opens where Effectivity can be edited. It opens the Effectivity window where it can be set by unit or date. Here, the from and to unit are set to 1 which means the subset contains the effectivity. To add and save this effectivity the button Add Effectivity Row and Ok are pressed.



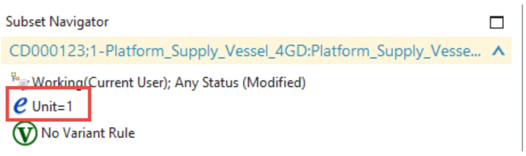


3. Subsequently, the target properties are opened in order to ensure that the DEs added to the structure after this effectivity is set, will contain the effectivity unit 1.

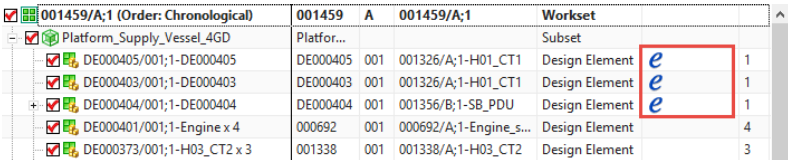
The same effectivity as in previous case is set to the target.



4. As the effectivity was set it can be viewed in the subset navigator.



Moreover, all the DEs added to the structure afterwards will contain the effectivity within they description.



Implementation of 4GD Framework in a virtual Ship Design environment for improving exchange and reuse

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KEYWORDS

4GD, PLM, PDM, traditional assembly approach, ship design, component-based design.

ABSTRACT

The objective of this paper is to apply 4GD to a virtual ship design environment in comparison with the traditional assembly approach in order to improve exchange and 3D reuse across the value chain. 4GD is a component-based concept incorporated in Siemens NX Teamcenter integration which provides comprehensive and efficient methods for design of systems comprising large amount of data. Additionally, the 4GD concept will be analysed in detail in order to understand the designing processes and tools used in specific environment. The case study on PSV was investigated using the conventional and non-conventional assembly approaches to perform the comparative analysis by exposing the theoretical advantages of this new approach.

This research uses relevant information from NX and Teamcenter software which is owned by Siemens AG (Germany) and distributed in Norway by Digitread AS.

INTRODUCTION

The shipbuilding industry is increasing rapidly with fleet needing to be modernised and improved constantly to meet the customer's needs. In a meantime, the maritime companies have to be in control of their business processes by managing the information in design, engineering and production. The ship production processes (Figure 1) are highly collaborative and so the project planning has to coordinate ship engineering, construction and maintenance from project development to outfitting (V.T.Cang, et al., 2013). As a consequence, the challenge to combine rich product lifecycle management (PLM) systems and well developed designing tools, to perform 3D modelling of a ship with thousands of units and parts, arises. Currently the shipbuilders are struggling with one of the two cases and in order to manage both adequately more advanced PLM system approach should be implemented.

As an integral part of PLM, Product Data Management (PDM) allows to manage product data and process-related information as one system by use of software (H.Kramer & P.Filius, 2014) thus providing easy access by multiple teams across the company to the CAD models, parts information, manufacturing instructions, requirements and other documents of a product. This approach allows each team working with particular ship access the data related to their needs within their field of expertise. PDM allows the shipbuilders optimize operational resources, find necessary data quickly, reduce development cycle time, errors and costs. However, even if usage of the PDM in shipbuilding industry exposes many advantages, the implementation of it brings problems due to different requirements for production documentation imposed by shipyards.

Figure 1. Project coordination in ship production process (V.T.Cang, et al., 2013)

Virtual design environment is becoming more and more essential in ship design. It enables to have a first look at the conceptual ship design during the conceptual design phase which gives opportunity for the customer to view visualized product and improves sales argumentation (Andrade, et al., 2015). Likewise, accurate visualization in the detailed design phase is extremely important to evaluate interfaces, perform volume, motion or any other analyses on a product. Therefore, it is significant to have well developed tools for making virtual design environment user friendly and beneficial for visualisation.

Currently, the most widely used method in 3D designing is the conventional assembly approach which deals with ‘connection features between pre-defined geometric entities’ defining the ‘geometric positions, orientations, mating conditions, and parent-child relations’ (Ma, et al., 2006). Regardless which CAD software is employed in ship design processes, the connection features remain an essential characteristics in the traditional structuring approach. The main feature in this method is the hierarchical assembly structure that consists of assemblies, components and features which owns the set of entity attributes (XF, et al., 2001). The traditional structuring approach is mainly used by companies which are using the CAD systems for their products but becomes a complex and highly interrelated as the amount of data increases.

There is a new non-conventional approach in the market, the so-called 4th Generation Design (4GD), which combines the effective virtual design environment with rich PLM data management (Siemens PLM software, 2013). It is a component-based approach which provides effective and independent data management, and controls the design, particularly of large amount data systems. As the ship design deals with this kind of data, it might be beneficial to employ 4GD to ease the re-use in ship families. Therefore, this approach will be used in a simple ship design case in virtual design environment to evaluate the functionality of 4GD against the traditional approach regarding the exchange and 3D remodelling facilitation.

The case study is performed in cooperation with Ulstein Design & Solutions AS and is investigating a Platform Supply Vessel (PSV). As the shipbuilding industry requires modifications and variations of existent vessels or parts of it, the solution to facilitate the exchange processes and facilitate reuse is necessary to maintain productivity. Therefore, the 4GD concept will be used in order to perform configuration and arrangement alterations of a simple ship design case in virtual design environment.

4TH GENERATION DESIGN

The information presented in the following section is a combination of information retrieved from Siemens Documentation (Siemens 2014), the Teamcenter resource library (Siemens), and workshop provided by Digitread, the Norwegian provider of Teamcenter (Marius Slagsvold , 18.02.2016).

Generations of CAD systems

4GD concept evolved as an improvement from the previous CAD design management systems. Therefore, to understand the importance of 4GD the previous generation are described further (Figure 2):

The first generation of CAD system was an inefficient approach with high complexity collections of files which were stored individually thus leading to multiple copies of parts and impeding the only basic management available.

The 2nd generation was already an improvement where assemblies were introduced which facilitated the management of large scale data. Due to single-part-per-file approach the components could be used in different positions at a time with no duplication required. It exceeded the limitations of the 1st generation design but still revealed drawbacks when the complexity of assemblies was increasing.

The PLM system was introduced in 3rd generation of CAD design enabling to access multiple revisions of assemblies, track product data through the lifecycle and manage sharing among the designers. However, this CAD generation requires well organized hierarchical structure of the product in order to avoid mess during

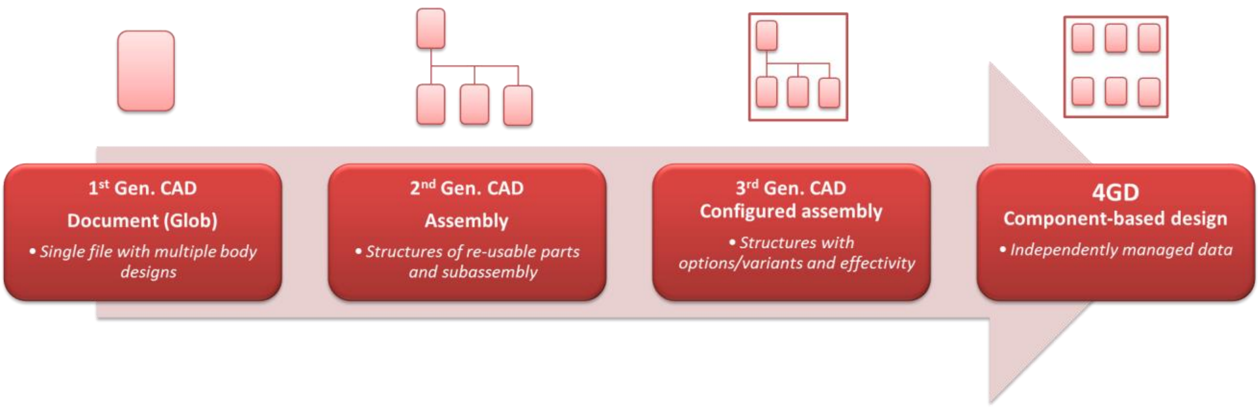

Figure 2. Evolution of large amount data management (adapted from (Siemens PLM software, 2013))

the process because only one designer is able to work and modify an assembly at a time.

Consequently, 4GD introduced new possibilities for large scale data management which obviated the drawbacks of previous generations and extended the field of potentials. It uses a flexible working environment where assembly definition is made to fit certain working practices, allows to check-out only necessary data which keeps the designing process efficient, stores and manages data independently (Siemens PLM software, 2015).

Features

The non-conventional approach encompasses several data management objects which are different from the ones used in conventional assembly and are significant to be understood for further discussion.

Collaborative Design is a data management object in Teamcenter where the entire design data defining product(s) is accumulated.

Design element is an independently managed object which contains its unique geometric and locating data. There are different types of design elements which are defined as shape, reuse and promissory and have certain capabilities and attributes.

Partition in the 4GD is an organizational container that helps organizing and finding data in the assembly but they do not control the position or any other property of a design element. Due to partitions the multiple organizational breakdowns are possible in 4GD which gives the structuring flexibility for the product. Plus, the design element are not restricted to only one of division but can be assigned to multiple partitions.

Workset is the collection of design elements in specific user's design context in NX session but can be created, modified, navigated and visualised in both, Teamcenter and NX. The design team leader usually assigns the workset to certain designer to perform individual design tasks. Therefore, it might consist of several subsets depending on the design task. As the workset is opened the elements are checked out.

Subset in 4GD is a collection of filtered design data in workset. There might be several subsets within the same workset (Siemens PLM software, 2015).

Theoretical capabilities

As described in Siemens White paper (Siemens PLM software, 2013) the 4GD exposes several advantages as compared to previous CAD systems.

The non-conventional approach retrieves only the relevant design-in-context data by means of multiple organizational breakdowns without loading the overhead data. It ensures simplicity to the working environment due to ability easily reposition and modify only necessary design elements in particular context.

Working on different design elements within the same spatial or functional environment is ensured by concurrent access to the product in 4GD environment. Instead of a rigid subassembly structure where only one designer can work on a particular product, 4GD provides a dynamic manner of working environment that updates modifications performed by another designer. This feature of 4GD reduces the designing time and time-to- market of a product due to the ability for multiple teams to work on the same assembly at a time.

Each design element is an independently managed component of collaborative design environment with unique and declared: access privileges, maturity status, position in ship, set of attributes, revision history, unit effectivity, and locking status. In other words, the design elements do not need to be hierarchically ordered for controlling, accessing and managing the design data. Thus, it leaves the option for the shipbuilder to decide the level of detail in assembly by making separate parts or subassemblies as design elements in 4GD environment.

Data duplication is avoided due to the facility of multiple organizational breakdowns of a ship. This means that 4GD allows multiple views of an assembly (functional, physical, spatial (Figure 3)) which loads required unit once even if it belongs to multiple views, instead of pre-determined subassemblies of a product which add duplicates. This approach reduces complexity while loading and maintaining the design elements that makes day-to-day tasks easier.

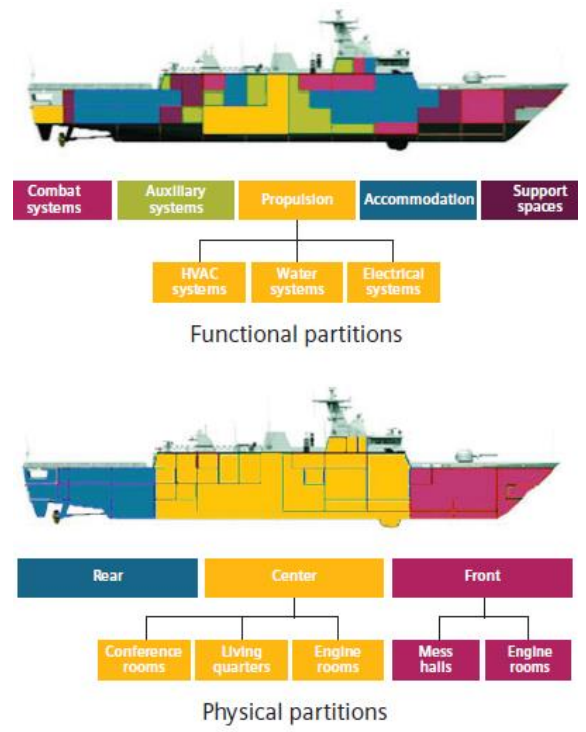

Figure 3. Organizational breakdowns (Siemens PLM software, 2013)

Assemblies designed in basic NX environment can be adjusted to 4GD concept and used as design elements due to Teamcenter capability to manage both approaches. It provides flexibility for the designers by using prior designed subassemblies which attain design element features when in 4GD environment. This means that assembly can be loaded separately without the whole structure. Using assemblies as parts in 4GD reduces re-modelling and speed up the designing process.

4GD incorporates the concept of effectivity which generates different configurations of a structure. The data can be configured based on date, specific intents, or unit number. In other word, the date effectivity specifies the content in certain time interval or until/from the certain date. Unit effectivity determines in which configuration a specific DE appears. Finally, the intent effectivity defines that the DEs appear in the structures which are specified to certain customer or which are composed from certain design. The effectivity specification should be done directly when the CD is created but it might also be added while designing in NX. The entire CD, separate DEs, worksets or subsets can be configured with effectivity.

PLM configuration management provides a capability to configure and re-use only relevant data among the ship family. In other words, only certain data can be selected from one ship, configured and re-used in another ship providing variations only when necessary and avoiding common data duplication. This ensures higher flexibility to the design process and facilitates the 3D re-modelling.

CURRENT TENDENCIES IN VIRTUAL SHIP DESIGN ENVIRONMENT

As the need for modern data management, product engineering and production is increasingly growing, shipbuilding organisations are aiming to effectively integrate CAD with PDM system to push their limits. However, prior investigation of the company's demand is required as the two choices of the software are available.

First of all, single vendor systems comprise design, engineering, production and PDM within one software which means that PDM and CAD are combined and integrated to fulfil specific needs of customers. Single software used for all processes facilitates the collaboration between different work teams as they are using the same data format and interface. However, the options decrease due to limited variety of single PDM and CAD software.

Secondly, multi-vendor systems provide options of software for design, engineering, production and PDM. It means that in order to manage different processes separate software might be used. This solution provides flexibility to the shipbuilding specialists to choose the best software that fits their requirements and company's business vision. The challenge here is to ensure well integration for each software implementation and precisely define owners of engineering data (P.Filius et al., 2014).

Current market focuses on a particular interest of the potential software users and is developing tools to use the merits of both CAD and PDM systems simultaneously.

CASE STUDY ON THE PSV

The method to follow up in this research was devised concentrating on the comparison of the two approaches based on the theory and individual experience as there are no current studies on 4GD.

The methodology (Figure 4) covers the investigation of the modelling and change processes accomplished in two designing environments: traditional assembly approach and 4GD.

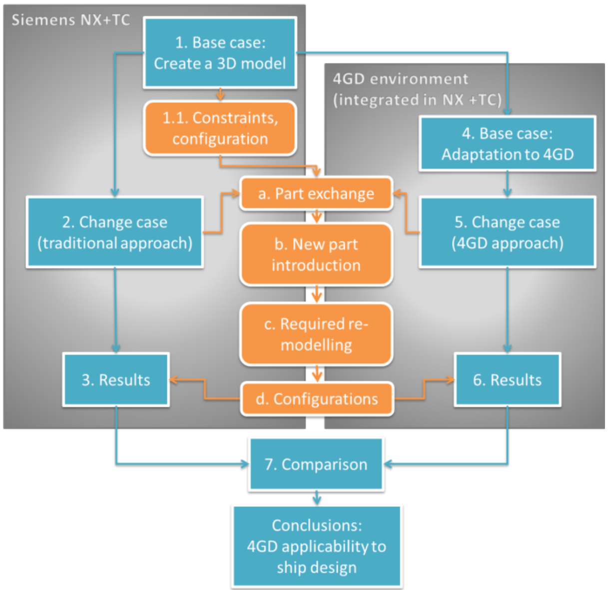

Figure 4. Methodology of 4GD application to ship design analysis

First of all, the 3D model of PSV is created in the traditional assembly approach and is later on adapted to the 4GD environment to fit certain design features. The change cases are performed identically in both environments to evaluate the difference. The change case assumptions derived for this research are:

a. The stern is exchanged by slightly different design stern to evaluate how does this influences the surrounding components and how smooth the exchange process is.

b. New engine is introduced in the assembly which requires repositioning and readjustment of the other engines,

c. Due to new part introduction required remodelling is performed. It includes designing of additional links to the new engine, exchange components in relation to comply with the 4 engine configuration.

d. Two configurations to the same vessel are created which are two cargo hull PSV and three cargo hull PSV.

Finally, the results are established based on the experience performing the tasks and comparison is carried out based on four criteria in concern: exchange, re-modelling, restrictions of constraints, structure importance.

The methodology was applied to a simplified PSV (Figure 5). The 3D model of the PSV hull divided by modules was used from the EMIS project (Andrade, et al., 2015) and adapted to this certain case. The ship is already designed by modules so the ship design application in NX couldn't be used due to the assembly structure of the model which is not supported by this application. Moreover, this case study doesn't require an exact model of a vessel but focuses on the concept of modelling and reuse, and how the systems are interacting between the modules and different systems across the ship.

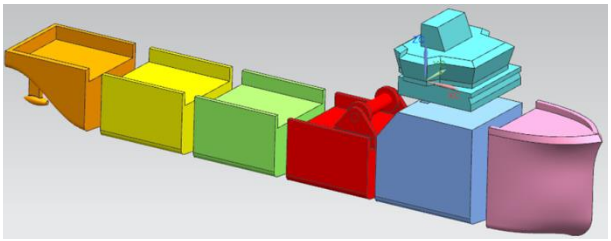

Figure 5. Simplified PSV (Exploded view)

PRODUCT TAXONOMY

Ship as a product contains millions of parts which need to be grouped into systems and subsystems to ease the 3D modelling process. This kind of division of a product into sections is called taxonomy. The breakdown can be done by following different rules and approaches adapted or most suitable for certain maritime company.

There is a number of taxonomies currently used in industry. This paper shortly discusses three taxonomies which are the most common for ship design: functional, spatial and modular.

Functional organisational breakdown divides a vessel based on function of the systems, for example, HVAC, piping, mission oriented, propulsion systems, etc. Each of the system includes sub-systems which are composed of assemblies. The functional division is an efficient structure to define detailed drawings and models of the routing systems and are particularly useful for the routing specialists. However, the interaction between the systems becomes complex and makes the model rigid as the assemblies in the conventional assembly approach is only viewed in hierarchy.

Another taxonomy published as ISA research in Daniels & Parsons (2008) and discussed in Andrews, *et al*. (2009) is the spatial organisational breakdown of a vessel. It divides the product by zones and areas (rooms, decks, etc.). The spatial divisions concerns the arrangement of the vessel by pre-defined structural zones which are fixed and are further divided by major bulkheads and appropriate decks. The spatial taxonomy permits the view on the vessel based on specific area to which a component belongs to. It gives a neat representation of the vessel due to clear relations between the spaces but requires well established positioning of the extensive components.

The modular organisational breakdown in ship design was discussed by (Chaves, et al., 2015) where the preliminary modular ship division was proposed. The modular taxonomy is defined based on maritime company's business processes and might be unique in each case. This division aids creating product variations, improving re-use, and managing the complexity of a vessel. The modules are created by decomposing a vessel into certain modules, sub-modules, etc. (Figure 6). The division of a product depends on the final use which is why certain boundary criteria have to be established by the maritime company. Modular taxonomy is widely used in ship design due to flexible breakdown of a vessel which is adjusted to individual needs.

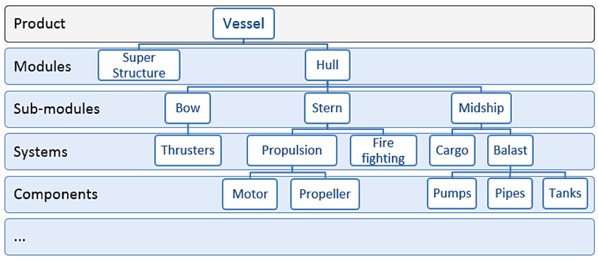

Figure 6. Modular taxonomy (Chaves, et al., 2015)

In the conventional assembly approach the taxonomy is significant because it is used through the entire lifecycle and it should meet the needs of each designer and stakeholder. Therefore, the division of a product is defined in the very beginning of designing process. The same division is followed up in the 3D modelling of a vessel which means that 3D parts and units can only be divided and viewed in relation to their parent systems as defined in the conceptual design phase. It restrains the view to the product from other perspectives and restricts the designers from different departments to one rigid breakdown.

4GD APPLIED TO SHIP DESIGN

In order to investigate the 4GD approach, the same methodology was applied to the conventional assembly approach and non-conventional (4GD) approach. This method provided the view on the same actions and problems from two points of view. As this paper concerns the 4GD application to ship design, only the 4GD case is described further.

The 4GD approach provides the possibility of multiple organisational breakdowns which might be defined prior the process or during the design. In this case study, three divisions of a PSV were created as partition schemes in the PLM software and were after used to search and define subsets. The divisions selected for this case study are functional, modular and physical which examples is given in Figure 7. Here, a vessel is divided by physical locations that are rear, centre and front of the vessel. Each of these blocks further consists of sub-assemblies and components. .

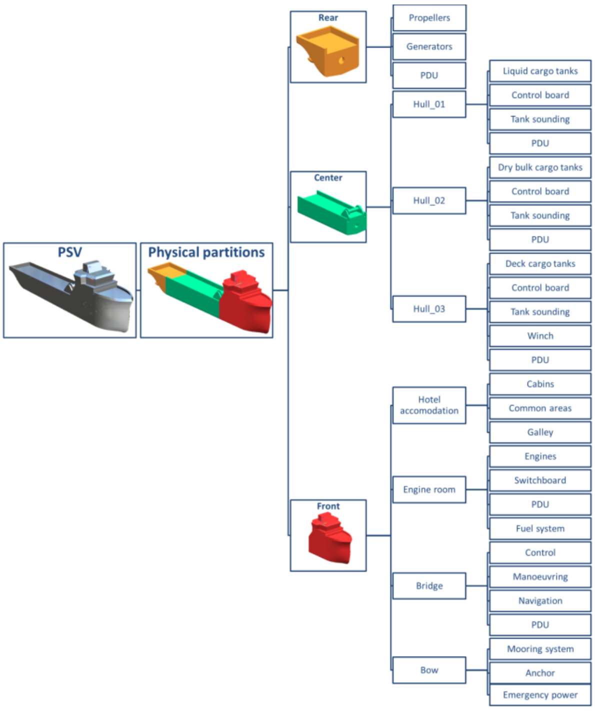

Figure 7. Physical partition of the PSV

Following, the adaptation of a PSV 3D model to 4GD environment was performed. The overall assembly was introduced as a collaborative design, the division objects as partitions and components as the design elements in 4GD. The 3D models were imported directly to the created design elements which automatically converted the part into reusable design element. During this process there were some issues related to the import of assemblies and introducing them as design elements. The problems aroused due to misconfiguration of the software which requires customisation. Consequently, the design elements were assigned to the appropriate partitions to have multiple organisational breakdown of the PSV. These operations are performed in PLM software and following steps are done in 3D modelling environment.

First of all, a workset is created which consist of the whole PSV 3D model. To have all the components of the assembly in one working environment, a subset is created to which the entire partitions in the collaborative design are included. As the partitions to add were defined, the 3D modelling software executed the search and displayed all the components within the PSV. The elements were located randomly as they were created in PLM software. Therefore, the positioning of each DE was performed by moving parts and located them in accordance to the surrounding parts. There are no assembly constraints in 4GD which is why there is no necessity to restrict the parts by three axes.

So finally, as all of the 4GD design objects were established, defined and correctly positioned the 3D model of a PSV was completed and could be viewed by from three points of view. As an example, Figure 8 displays the PSV 3D model divided by physical partitions established in Figure 7.

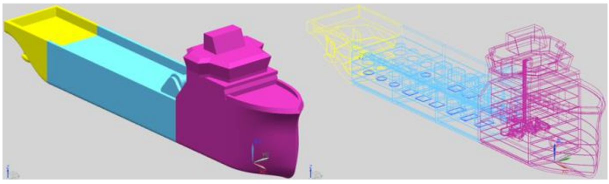

Figure 8. PSV (physical organizational breakdown)

Subsequently, the change case of this research was performed by completing four change assumptions defined in the methodology.

First of all, the stern was exchanged using the 'Replace source part' function which replaces the source part of reusable. 4GD locates the exchanged part at the same location as previous part was which means that it he coordinate axis coincide. It's a useful feature if the designs are only slightly different which makes the part in required position without a need of relocation.

Secondly, additional engine and generator were introduced in the 3D model. Specific subset for particular design context was defined where the procedure was performed. The parts were created as new design element which uses the source part from the previous models. Both new parts were manually assigned to certain partitions which will add the parts to the overall PSV model. The position of the new parts was defined by simply moving the parts into required position.

Thirdly, the remodelling was performed which means that all the influenced parts due to changes above are corrected. Some routing parts, switchboard and distributing units were adapted to fit with the 4 engine room. The remodelling was smoothly performed by design-in-context and the changes were updated in the overall vessel.

Finally, two different configurations for the PSV were created. It was done by using the effectivity solution which is a specific feature in 4GD. It allows creating different configurations or layout of a product within the same single file. For this case study, a 2 cargo hull and 3 cargo hull vessels were required and therefore, the effectivity was employed. First of all, the effectivity was set in the subset which means that any further actions are assigned as certain effectivity and are valid only for this certain model. If the primary vessel model needs to be viewed, the effectivity has to be redefined which issues the primary vessel. Then, as the effectivity was set, the 2 cargo hull was configured by deleting the unnecessary module and introducing necessary routing objects.

Using the effectivity concept, two different configurations of PSV were generated in one single CD and are subject of choice and necessity for certain customer. Figure 9 illustrates how the two configurations are distinguished by effectivity specification.

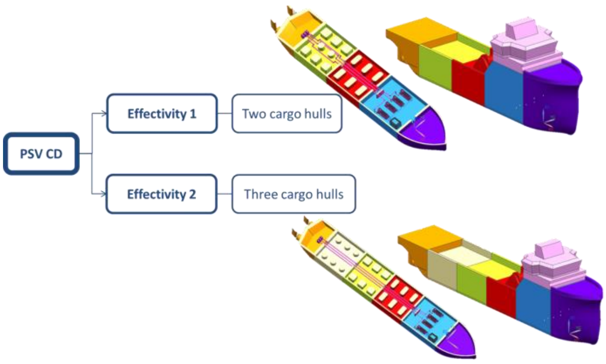

Figure 9. Effectivity solution for different configurations

RESULTS FROM COMPARISON

As the case study was performed a comparison analysis of the conventional assembly and non-conventional approaches was carried out. The results are described further in this chapter.

First of all, the exchange done using the two approaches is compared. In both cases, particular functions were used to exchange one part by another. The difference here is that the traditional assembly approach positions and constraints the new part to the particular location where the 4GD places a new part depending on the components coordinate axes. This means that 4GD allows free movement and allocation of the new part when traditional assembly approach restricts it due to certain constraints and requires readjustment if there is movement in need. However, the function ‘Replace component’ in the traditional assembly approach is mainly used to replace parts by revisions and is not always applicable for exchange. For example, the exchange of the parent part in an assembly can’t be accomplished as the children parts are lost in this case. So, it can be concluded that 4GD improves the exchange due to automatic positioning, no constraints or hierarchical assembly restrictions.

Secondly, remodelling was performed in both approaches, and the results show that design-in-context was straightforward in both cases. The only difference is that the traditional assembly approach requires working with the precise assembly where the design is performed, unlike the 4GD where the design-in-context is performed straight in the whole assembly or certain subset. Due to the partitions which sort the design data but do not constrain it, the components can be modelled first and just then assigned to the particular partition. Plus, to remodel relevant part in the sub-assembly the parent and children components are loaded into NX session where in 4GD only the necessary set of data might be used in the NX session. In large scale products, it exposes a big advantage over the traditional assembly approach because the working environment is not overloaded, contains only the significant components and requires only a few parts being checked out. Plus, an effectivity solution might be employed instead of remodelling in 4GD by creating an equivalent model in the same file which contains the same information and is different where needed.

Thirdly, the restriction of constraints turned out to be unusually high in the traditional assembly approach. The positioning of the components is always defined by the constraints so any movement, modification or exchanged part issues constraints errors and demands for alterations. On the one hand, the constraints make the assemblies well-structured and parts are moving together as fixed structure but on the other hand, it makes the assembly very rigid and any change influences surrounding parts and constraints whereas 4GD makes the assembly a flexible structure which also retains the position of objects. Plus, 4GD allows the assembly constraints at some level if needed. Moreover, the constraints overload the assembly because the reused sub-assembly comes with the existent constraints and might mix up with the assembly constraints of the primary model. It can be seen, that, in this case, the 4GD exposes an advantage over the traditional assembly due to the absence of constraints system.

Finally, the importance of the structure in the two approaches is compared. This research verified that the hierarchical structure in the traditional assembly method is of high importance and influences entire design process. Assembly structure needs to be pre-defined to follow it while modelling a large-scale product. Due to the high amount of data, the structure of assemblies and sub-assemblies has to be clear and meet the requirements of different design teams whereas 4GD allows a flat assembly structure where the parts don't have to be the dependent one to each other but is an option. Using this approach allows deciding the structure at the beginning or during the design process due to multiple organisational breakdowns and search capabilities to load only relevant data for design teams.

This case study was performed to investigate whether the 4GD improves exchange and facilitates the 3D reuse, so it’s necessary to discuss what the comparison of the traditional assembly approach and 4GD exposed in the context of these features.

Taking into account the comparison of the traditional assembly approach and the 4GD, the exchange improvement and 3D reuse facilitation will be discussed in this chapter. The four criteria for the comparison of the two methods were defined to reflect how the exchange and 3D reuse might improve using 4GD.

Due to the multiple organisational breakdowns and flat assembly structure where each DE is independent, the 4GD provides a more flexible assembly structure of a product which means that there are no constraints and very few restrictions to position components in the assembly which make it easy to exchange. Even the top level element which couldn't be exchanged in traditional assembly approach is exchangeable in 4GD and doesn't influence the parts below.

As described in theory, a class of vessel needs to contain the same configuration or have the same outfitting which integration must fit with all the vessels in the same class. The results showed that due to the effectivity solution it is possible to create a series of ships with the same hull or the same propulsion system within the same collaborative design file. In this way, the same configuration is reused across the vessel family. Plus, as the reusable DEs are widely used in the 4GD models, the previous designs can be directly reused in a new design ship. These features bring the highest influence to facilitate the 3D reuse across the vessels.

CONCLUDING REMARKS

The main goal of this research was to implement and study the 4GD framework in ship design in comparison to the traditional structuring approach. Therefore, several design and change cases, emphasising particular challenges in ship design like an exchange, re-modelling, alternatives and re-use across the vessels, were assumed and established as the framework for this analysis. The method proved to be a powerful tool for this research to verify whether the 4GD improves the exchange and facilitates the 3D re-use.

The case study showed that the 4GD approach requires different thinking on the assemblies and designing process as the components and features are distinct from the traditional assembly approach. Due to the absence of assembly constraints together with flat assembly structure in 4GD, the positioning of the parts becomes straightforward, and changes are accomplished smoothly. These features influence the exchange of the parts which is non-restrictive and fluent process in comparison to the traditional assembly approach. Plus, the effectivity in 4GD proved to be an efficient solution for alternative vessels or various ship configurations across the vessel family. It aids the designers to avoid remodelling and instead, re-use the 3D models of previous products. In ship design, it is a powerful tool which is innovative, cost effective, and time saving.

However, this master thesis scratched only the surface of the 4GD framework from novice user point of view. 4GD is a highly advanced approach to work and organise the design data which requires high competence in programming, configuring and working with Teamcenter and Siemens NX to gain significant benefit out of this approach. Plus, it requires well established needs and requirements to the software of the company to efficiently employ 4GD to the business processes. The installation and configuration must be well set and customized. To verify whether 4GD is a beneficial approach for continuous improvement in shipbuilding industry it has to be implemented and tested out in real maritime business and products. Therefore, it can be concluded that even applied to a simplified PSV, the 4GD exposes advantages over the conventional assembly approach but significant improvement of the exchange and 3D re-use across the vessel weren't observed. This is why the thesis requires further investigation of this case study applied to a more complex vessel.

Further work

The benefits of 4GD against the traditional assembly approach are already noticeable from this research, but there is always room for improvement.

This case study was carried out from the 3D designer point of view, but there are so many people working with different tasks not only in Siemens NX which is why the further step in the analysis should be the investigation of the 4GD capabilities in the Teamcenter. The data management, structuring, views on the BOMs, the search of data, etc. are maintained in 4GD Designer environment in Teamcenter which is unlike the traditional data management in Teamcenter.

Another important matter for future analysis is a large amount of data. This case study was performed on a simplified PSV with several sub-assemblies and components, but it's nowhere near the level of data in a real vessel. Therefore, to verify if the flat assembly structure, effectivity, absence of assembly constraints and other differences in 4GD are beneficial for a maritime company, the approach has to be applied to a fully equipped vessel.

Finally, to continue with this case study of change in the traditional assembly approach and 4GD a dedicated function in Teamcenter should be employed. For working with changes in the vessel which might influence several components, design tasks and designer, the Change Management feature in TC should be used. The change management tool used together with 4GD might expose even greater advantages and development possibilities in comparison to the traditional assembly approach.

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