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Creating and Processing Ship Design Data for Sheet Metal Cutting

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Preface

This report is the result of my Master's thesis in Product and System Design, written for the Department of Maritime Technology and Operations at The Norwegian University of Science and Technology (NTNU), located in Ålesund, Norway. As of the end of May 2016, I have for the past eight months been preparing, researching and completing the assigned project.

Initially, the goal of the thesis was to analyse the current process of fabricating the foundation used for sheet metal cutting, with focus on the preparation of cutting data/information in 3DEXPERIENCE, improvement of nesting by using ALMA instead of Nestix, and finally how to perform the procedure with purchased data which is not native to 3DEXPERIENCE (imported data).

It is safe to say that the topics of the thesis has slightly changed since the beginning, resulting in the development of a new method, instead of improving the current one. The investigation and experiments performed during the thesis is accomplished solely with the use of the tools Kleven currently possesses. Thus the method is regarded as a best practice, and can actually be implemented at the shipyard and provide covet benefits.

The investigation and analyse of purchased data has unfortunately been left out. However, I will continue to work on the topic after graduating, as I have been offered an engineering position at Kleven, with prefabrication processes as a main discipline.

The thesis has given me much deeper insight in the shipbuilding process and digital manufacturing. I look forward to continue my work in this area, and hope to contribute to the development of technology within the industry in the future.

I would like to thank Dr. Henrik Kihlman of Prodtex and Chalmers Institute of Technology who has supervised the project externally, for software support and helpful guidance throughout the past months.

I would also like to thank associate professor Ola Jon Mork of NTNU Ålesund who has been the projects internal supervisor, for motivation and good follow-up on the thesis.

Finally I would like to thank my co-workers at Kleven for invitations to workshops and providing me with relevant information not available anywhere else.

Ålesund, 3rd June 2016

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Summary

The process from the creation of a design to the initiation of production in the shipbuilding industry is a complex procedure. Recently more and more shipyards has started moving away from traditional shipbuilding methods. Production processes are being automated, and engineering and design digitalized.

Kleven is a company that is investing a great amount in modernization and automatization of the shipyard's production facility, and is currently working on moving much of the engineering work onto the digital PLM platform, *3DEXPERIENCE*. The development is still a project in progress, yet much is successfully operational today.

One of the remaining challenges is to figure out to connect 3DEXPEIENCE with the process of sheet metal cutting on the production floor. Through the development of work methodology for modelling, digital manufacturing and CAM processing of ship design data, where the output is documentation intended for the sheet metal cutting of plates; the initial stage of hull production.

By using state of the art digital tools, a best practice is developed, bringing Kleven one small step closer to their goal of reducing manual labour in the production and to gain highly valuable competitive benefits.

TABLE OF CONTENTS

TERMINOLOGY

CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CNC	Computer Numerical Control
NC	Numerical Command
MCU	Machine Control Unit
PLM	Product Lifecycle Management
MOG	Marine and Offshore Manufacturing Planning
EKL	Enterprise Knowledge Language
EBOM	Engineering Bill Of Materials
MBOM	Manufacturing Bill Of Materials
DWG	Drawing
DPR	Drafter Document (ALMA)
IGES	Initial Graphics Exchange Specification
DXF	Drawing Exchange Format
XML	Extensible Markup Language

1. INTRODUCTION

Kleven is a company located in the Sunnmøre region, Norway. In other words, it is located in the middle of one of the largest cluster of maritime industry in the world. Kleven was primarily founded in 1915, and has since then been a solid brand name within the shipping industry. Today the company provides both aftermarket service and newbuilding of advanced offshore vessels in two shipyards, Kleven Verft and Myklebust Verft (Gursken). The company has approximately 720 employees.

Figure 1: Kleven Shipyard

For the time being, parts of the hull manufacturing is outsourced to shipyards in Poland and Romania, and shipped as modules/sections to Norway for assembly. This is done for economic reasons, but poor quality, policies, other difficulties has made it less profitable than earlier.

With suppliers, ship designers and competing shipyards as the closest neighbours, competitive advantages is crucial to maintain sustainability. For the recent years, Kleven has started research and investing in automation and robotization. Their main objective is to automate parts of the hull production, and utilize the advantages of this technology to “bring back” more the production to Norway.

As a part of this development, a fundamental PLM platform is required. After extensive testing and offers from software suppliers, a selection of the platform software was made. The choice fell on Dassault Systèmes’ state of the art PLM solution; *3DEXPERIENCE*. Mainly because Dassault Systèmes has come furthest in the development of a virtual cross-department collaboration platform for the shipbuilding industry.

1.1. Project background

Today, Kleven is purchasing complete design packages from external design companies such as Marin Teknikk, Rolls-Royce, Salt, Wärtsilä, etc. These packages include all the required design data such as basic design[1], detail design, piping, outfitting, etc. In other words, Kleven is not producing any design themselves. But this is about to change; the management of Kleven has decided that the company shall purchase only basic design packages from external vendors, and perform the rest of the design and digital manufacturing processes internally. This leads to various challenges for the company. First of all, it requires a reliable and custom tailored 3D design tool with the ability to ensure reliable and flexible/adaptable design. Secondly a digital manufacturing platform capable of simulating the shipyard's manufacturing facility is required. Kleven decided on the design and digital manufacturing tools *CATIA* and *DELMIA*, which is a part of the 3DEXPERIENCE platform, a state of the art PLM solution developed by Dassault Systèmes.

Once these tools were introduced and running smoothly, an interface between the manufacturing equipment had to be implemented. This is where the foundation of this thesis lie; if Kleven no longer is going to purchase complete design packages, they will no longer be provided with the data required for cutting sheet metal parts. Kleven's current approach is to purchase separate packages which includes the cutting data, complete with nesting and NC-codes[2] for the CNC-cutting machine[3]. If Kleven will produce their own detailed design work they will have to generate the input for the cutting machine themselves by using data from designs created internally.

The main challenge is to develop a method describing how the data can be created, prepared for production and transferred to the CAM software for nesting and sequencing of the sheet metal cutting. This whole process needs to result in generated workshop documentation and NC programs for the sheet metal cutting operation on the work floor.

If Kleven is able to use this information to create their own cutting machine input for cutting sheet metal parts, this will both contribute to greater corporate independency and economic benefits.

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[1] Class approved design data: Arrangement of spaces, structural design, stability analysis, etc.
[2] Numerical Control – Common denomination for machine programming language.
[3] Computer Numerical Controlled cutting machine – A cutting machine which has its actions/operations controlled by NC-codes (programs)

1.2. Problem formulation

Kleven is facing challenges regarding preparing and processing internally created design data so that it becomes compatible with the interfaces of computer aided manufacturing (CAM) software that is used for managing the sheet metal cutting. A secondary challenge is that the output data from the CAM software (NC program) is not compatible with the interface of the cutting machine "as is".

The lack of a fundamental method describing each process from design to production initiation is hampering the progress of going live with the design and digital manufacturing solutions the company has purchased.

In order to arrive at a satisfactory best practice, the problem needs to be divided into sub-problems, and addressed one by one. The problem is divided into four sub-problems focusing on the different stages of the process, in chronological order.

- Firstly a design model needs to be established by using 3DEXPERIENCE. The design has to have be flexible, meaning that it can rapidly be modified in case of possible revisions and specification changes. In order to replicate a "live" design project, all relevant design features needs to be included in the model.
- Further the design model has to undergo assembly planning and manufacture preparation, also by using 3DEXPERIENCE. The assembly process must be planned in such a manner that it is adaptable to Kleven's production facility. The elements in the assembly also needs to have manufacturing features applied before it can be further processed in the CAM software.
- How to transfer the data between 3DEXPERIENCE and ALMA must be investigated. Compatible file formats, complexity of export/import processes and the quality of exported data must be evaluated to determine the most convenient transfer method.
- Finally the data must be processed in the CAM software, ALMA. Imported data must be prepared for nesting, raw material must be assigned and cutting sequences must be planned. Further, output in the form of workshop documentation and NC programs must be generated.

1.3. Thesis objectives

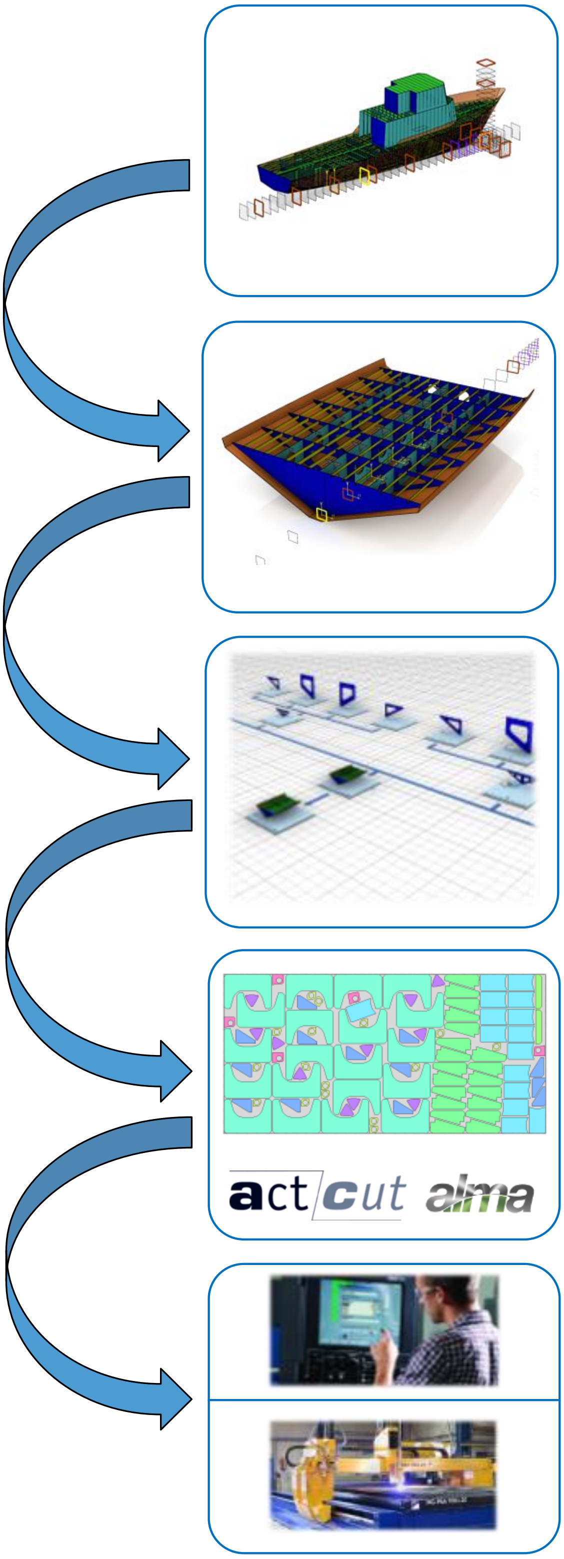
In this thesis, it is assumed that all design tasks is performed by Kleven, apart from the creation of hull geometry, which is supplied by an external design company. This means that all data that will be processed is native to 3DEXPERIENCE, and not imported data which is native to third party design platforms such as Nupas, Aveva, etc. Most imported data has information, attributes and properties that are incompatible with 3DEXPERIENCE, so handling this data has proven to be somewhat problematic. Especially when it comes to manufacture preparation.

The main objective for the thesis is to investigate methods on how to create a design unit from scratch, and processing it in the digital manufacturing platform that Kleven is operating on today. Experiments focusing on the creation, processing and preparation of the design data which will be used as input data in the process of sheet metal cutting is to be performed in order to establish reliable methods. In order to obtain the most accurate view of the different processes, all involved processes are to be performed from start to finish.

A generic 3D model of ship section is to be modelled. Further, the section needs to be broken down into the data which will be used for sheet metal cutting. The data is then to be exported into formats which is compatible with the nesting software. Different export methods is to be investigated and evaluated in terms of complexity, time consumption and quality of the exported data. This will conclude the experiments on the 3DEXPERIENCE platform, and verify if it is a viable solution for the task.

Once the data is exported into the desired format, it is to be imported into the nesting software, where further processing is to be investigated and explained. At this stage it is important that all the necessary information is included in the import data (export data from 3DEXPERIENCE). This information will be discussed later in the report. Nesting, adjustments, preparation, etc. is then performed in order to generate the NC-program required to operate the CNC-cutting machine. It is also here important that the output data (NC-program) is compatible and in accordance with the interface/programming language of the cutting machine.

Figure 2, presented on the next page describes the work flow which is desired to achieve once both the design platform and nesting software is fully operational.



BASIC DESIGN

- Fully defined, simplified representation
- Structural design
- Space arrangement
- Analyses
- Documentation

DETAIL ENGINEERING

- Division by blocks
- Detail design
- System design
- Steel outfitting
- Documentation

ASSEMBLY PLANNING

- Assembly sequence
- Weld planning
- Edge preparation
- Shrinkage planning
- Export part geometry data for cutting preparation

CUTTING PREPARATION

- Import part geometry data into nesting software
- Minor corrections of data (if required)
- Nesting of parts
- Sequencing
- Generate NC-code
- Post processing of NC

PRODUCTION INITIATION

- Input machine compatible NC
- Preparation of machine/workshop
- Start cutting/marking

Figure 2: Design workflow

1.4. Research and literature review

In order to determine what information is available on the respective topics, systematic methods of obtaining this information is performed. Information is obtained by performing subject relevant searches in various electronic databases. Among the databases are scientific electronic databases such as Google Scholar, NTNU BIBSYS and various databases provided by international universities. Also common electronic sites such as Google search and online libraries has provided helpful information. Searches is performed by using thesis specific search phrases such as *plasma cutting, hull production, digital ship design, manufacturing, CAD data formats* only to mention a few.

The most valued information is provided by the software providers themselves; 3DEXPERIENCE and ALMA. Both provide help documentation on the software's tools and features. 3DEXPERIENCE provides the information through an online service called *3DEXPERIENCE User Assistance*, which requires a personal user account (*3DPassport*) to access [1]. ALMA utilizes a more traditional approach, by integrating the information into their software as *HTML Help* documentation. The help documentation for both 3DEXPERIENCE and ALMA can easily be accessed by pressing *F1* on the keyboard, upon selecting the tool or function desired one desires to know more about.

Obtaining the information more informative external information on 3DEXPERIENCE proved to be very challenging. Apparently, very little documentation apart from the user assistance data base is available for the public, due to Dassault Systèmes' strict business confidentiality policy. However, by consulting the project supervisor and Kleven, beneficial training and course material has been obtained. Also through an informative practical workshop together with Kleven and Dassault Systèmes many questions were enlightened. During this workshop, professional relations were established between the thesis candidate and DS, opening up for more direct communication between the parts.

The same challenge were experienced with ALMA. Even though the software is fairly known in various businesses, relevant information were not available for public use. By consulting ALMA's software distributor, useful training material were obtained, helping the candidate to establish sufficient knowledge on how to operate the software. [2]

Another valued source of information is the University Library, which has provided informative literature regarding ship building. The book "Ship Construction" authored by George Bruce and David Eyres [3] is considered as one of the most superior guides in the shipbuilding industry. It covers the complete construction process including the development of ship types, materials and strengths, welding, cutting and shipyard processes. Every subject is clearly described by using descriptive diagrams and figures.

To summarize information obtained through the performed research, brief descriptions of the findings are categorized and presented below.

Ship design and building process:

The subjects welding distortion, edge preparation and general sheet metal cutting (CNC) has been very much enlightened by G. Bruce and D. Eyres book *Ship Construction.* The book has also provided an informative overview of how traditional ship building is executed. Also through previous work experience and co-operation with Kleven's production department, the thesis candidate has been able to connect the textbook theory with today's existing procedures.

3DEXPERIENCE platform:

Various training and course material developed by Dassault Systèmes (regarded as confidential information) has proven itself useful in some cases. However, the material is very general, and does not go into detail on important subjects, such as software configuration and data management. The online user assistance provide a useful encyclopaedia on the 3DEXPERIENCE platform's applications and features. It includes a full-text search engine, guides and tutorials. Also in this case, previous wort experience and co-operation with Kleven's detail engineering department, has contributed to valuable knowledge.

ALMA Act/Cut:

Like 3DEXPERIENCE, ALMA has its user assistance easily available (literally by a keystroke), and provide very informative documentation on the user interface and applications within the software. In order to obtain the information on how to perform a realistic simulation of a CAM processing situation, ALMA were contacted and provided helpful training material, including a tutorial for the software. Not all tools and function available are described in the documentation, but enough were provided to implement a pilot project for the thesis.

2. METHODS

To solve the challenges and reach the objective discussed in the previous chapter, appropriate methods are to be used. The methods discussed in the report will be software based, which means that all tasks will be performed inside the various software that is being investigated. Though there is little available information on the subjects, the theory concerning “trial and error” will be put into practice.

With this fundamental method for solving problems, various attempts of success is practiced until satisfactory results are achieved. [4]

Experimental learning or “learning-by-doing” is also a valued method throughout the progress of the project. The goal is to build as much competence and knowledge on the topics as possible, and highlight features and functions which is not well documented by others. This method will not only build the necessary knowledge, but also help verify the results in the process. It will also highlight weaknesses/flaws in the different software’s interface.

A case study is an efficient tool used to obtain a deeper and detailed understanding of the topic(s). It is an account of an activity, event or problem that contains a real or hypothetical situation and includes the complexities one would encounter at the workplace. [5]

The case study illustrates real life issues and challenges that the Kleven is up against today. For the thesis, this regards processing and preparing the design data through the design- and manufacture preparation phases, and at the end being able to use the data for generating usable output data in the form of NC-programs and workshop documentation for sheet metal cutting.

2.1. *Case study - Kleven*

As mentioned, the thesis will reflect upon the manufacture preparation methods concerning plate/sheet metal cutting in Kleven's hull production line. More specifically; interfaces and compatibility between the design platform (3DEXPERIENCE), nesting software (ALMA) and cutting machine input data. In order to obtain the most realistic overview of the design process, a ship section model is to be established by using the available tools that Kleven is planning to use. Once the model is established, assembly planning is performed so that the assembly process is adapted to Kleven's production facility. Further, manufacture preparation is performed in order to apply the correct manufacturing features to the model.

The designed model of the ship section is of a generic character, which means that the design data will not be put into production. However, the data are to be treated as a real design project, and include various ship design elements such as plating, brackets, openings, girders, etc. The more elements included, the more realistic the case. Listed in table 1 is elements and design features which are commonly included in a structural design model of a ship section. In this case, most of these features will be included in order to simulate a realistic case.

Plate types	Stiffeners/girders	Opening types	Details
Shell plates	Vertical	Manholes Lightening holes Access openings Penetration/slot	Brackets End cuts Face plates Collars Plate thickness Material
	Horizontal		
Decks	Longitudinal		
	Transversal		
Longitudinal bulkheads	Vertical		
	Horizontal		
Transversal bulkheads	Vertical		
	Horizontal		

Table 1: Structural design features

Once the structural design model is established and the variety of design features is satisfactory, the data processing can commence to the assembly planning and manufacture preparation stages. Finally, the data is transferred to the CAM processing software where nesting and sequencing is performed, and NC-programs and workshop documentation is generated. The methods for each stage and the data export/import process between CAD and CAM software is explained in detail later in the report.

3. TECHNOLOGY AND TOOLS

This chapter will discuss the different technologies and tools that are used in throughout the project. Technology concerns the theory around nesting and G-code programming[4], and tools concerns the main software solutions utilized. The 3DEXPERIENCE platform and ALMA Act/Cut are also given detailed descriptions. For the software, the overall functionalities and interfaces are described. The design and digital manufacturing solutions in 3DEXPERIENCE that are relevant to the thesis will also be given brief descriptions.

3.1. Nesting

Nesting is generally referred to as *fitting an object (or objects) inside a larger one*. In this case it concerns the process of fitting the maximum amount of plates inside a standard sized rectangular steel sheet, and at the same time minimizing the scrap raw material produced when cutting. In other words; optimizing the sheet metal cutting process. This may seem like a simple task when addressing only rectangular profiles, but this is not the case in the shipbuilding industry. Various structural elements such as brackets, collars, girders, etc. may have complex and odd shapes. The procedure is performed by a computer, through a software which specializes on optimized nesting. The input can be 2D, 3D or coded data, and the software utilizes advanced algorithms in order to determine how to lay out the parts in such a way on the sheet that most of the raw material is utilized, and at the same time the correct amount of parts is produced. An example of a sheet with nested parts assigned is presented in figure 3:

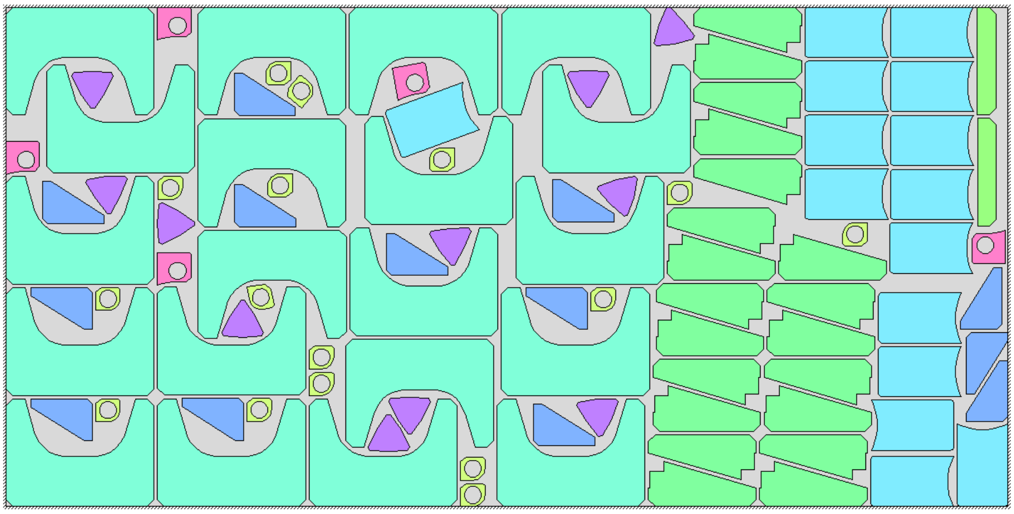


Figure 3: Nested sheet metal parts

[4] Most common NC programming language

Many machine manufacturers develop their own nesting software which can be customized accordingly to the specific cutting machine. This helps the machine operator/programmer to take full advantage of the machine’s features. Also nesting software developed by third party-vendors is preferred by some fabricators. This is common if the fabricator operates two or more machines, from different machine brands. The operator/programmer then only needs to deal with one common customized software rather than various machine dependent software.

3.2. Computer Numerical Control

CNC, or Computer Numerical Control is a system which is used to control advanced machines. The technology can be used for machining centres such as lathes, drill presses and milling machines. It can also be used for sheet metal processing such as plasma/laser cutting, punching, etc. The machines is controlled by a NC-program which contains coded alphanumerical data. The program controls the motions of the workpiece, tool/torch, feed rate, depth of cuts, speeds and all other machine functions. The only thing which is limiting the programming is basically the capabilities of the machine.

The CNC system consists of three basic components:

3.2.1. NC-program

The NC-program is a detailed set of commands to be followed by the machine tool/torch. Each command specifies a position according to the Cartesian coordinate system[5], a motion, machining parameters or on/off functions. The program can be written manually according to production drawings, or it can be generated from design data, and is performed in a CAM software. Such software can also automatically generate complete NC-programs for the machine, given that the software is equipped with the correct post processor[6]. The post processor edits the "raw" program in so that it is readable both for the user and the machine. The most common language for a NC-program is called *G-code* or *G-programming language*. A typical simple program for cutting in a straight line can look like as presented in figure 4 below:

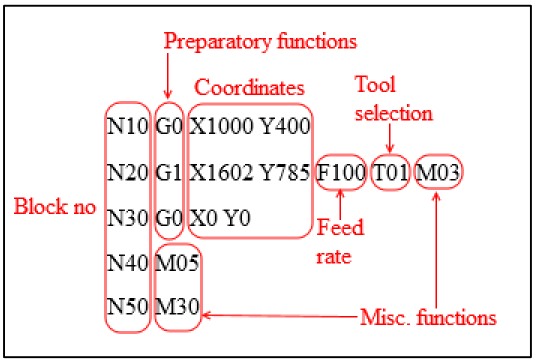


Figure 4: Example of a simple NC-program

[5] A coordinate system that specifies each point uniquely in a plane or space by numerical coordinates. Coordinates are relative to the origin of the system.

[6] An extension from the nesting software which processes and edits the automatically generated NC-program so that it is compatible with the specified machine.

The block numbers, also known as sequence numbers is to identify the specific machine operation throughout the program. Preferably the block numbers is in chronological order, but it is possible to rearrange the blocks as desired. Following the block numbers is *G-codes* and *M-codes*, or preparatory- and miscellaneous functions. The G-codes prepares the machine to perform a specific machining operation. The M-codes concerns more “internal” machine functions such as torch on/off, temporary stop, end/loop program, etc.

Following these functions is the coordinates relative to the origin of the work piece/sheet metal, feed rate, and tool/torch selection.

3.2.2. Machine Control Unit (MCU)

The MCU is the machines internal computer. It interpret and stores the NC-program, and executes the commands into actions performed by the tool/torch. It includes the system software and user interface, calculation algorithms and translation software which translate the G-code to a format that the can be processed by the machine. Sensors monitor all actuators and tools, and give highly accurate feedback to the MCU during all actions. The operator can inspect and survey all this information on a monitor connected to the MCU.

3.2.3. Machine tools

A CNC plasma cutting machine is always equipped with a plasma cutting torch. However, various accessories can be equipped to improve the functionality of the machine. Examples of this equipment is tool rotators, tilters, multi torch systems, drilling- and marking tools, vision- and scanning systems. All this equipment can be controlled in the NC-program or manually at the machine control station. A selection of plasma cutting machine tools provided by the machine vendor Microstep is presented in figure 5 below.

Figure 5: Various plasma cutting machine tools

3.3. The 3DEXPERIENCE platform

In the highly dispersed and interconnected marine and offshore landscape, the struggle to stay competitive is intense. Innovative and sustainable concepts, on-time and on-budget delivery, compliance with strict safety and environmental regulations, and greater design, manufacturing and operational efficiencies are some of many challenges organizations has to overcome if they want to stay relevant. The challenges are many, but so are the opportunities. Safer, cleaner, greener vessels and offshore structures, as well as new sources of energy, require a whole new way of thinking. The possibilities are as boundless as the oceans themselves. Leveraging over 30 years of expertise across 12 industries, Dassault Systèmes helps progressive naval architects, designers, shipyards and suppliers successfully transform their practices to create unique value for their customers. [6]

Dassault Systèmes, the company behind major CAD/CAE, CAM and PLM software such as CATIA, DELMIA, SOLIDWORKS and more introduced the 3DEXPERIENCE platform in 2013. They call it a *Business Experience Platform*, because it provide software solutions for all organizations/departments within a company. Dassault direct the platform towards a variety of industries such as transportation, aerospace, marine and offshore, industrial equipment, finance, consumer goods retail, just to mention a few. Through a cloud-based[7] service, the platform provide its industry-leading applications; Design and engineering, manufacturing and production, simulation, governance and lifecycle.

The user interface of 3DEXPERIENCE is quite different from any of Dassault Systèmes' other software. Where their previous software have completely different interfaces among themselves, 3DEXPERIENCE offers a common interface that ties all these software together in the same environment. All the applications are cloud based, which means that only the 3DEXPERIENCE client software has to be installed on the user's computer. The user's available applications are available through hosted services, and require specific licenses in order to be launched.

The access to the applications are found under the characteristic *3DEXPERIENCE Compass*. Four different categories (north, west, south and east) divides the applications into their respective quadrants of the compass.

[7] "On-demand computing": Internet based storage solutions which provide users and enterprises with various capabilities to store and process their data.

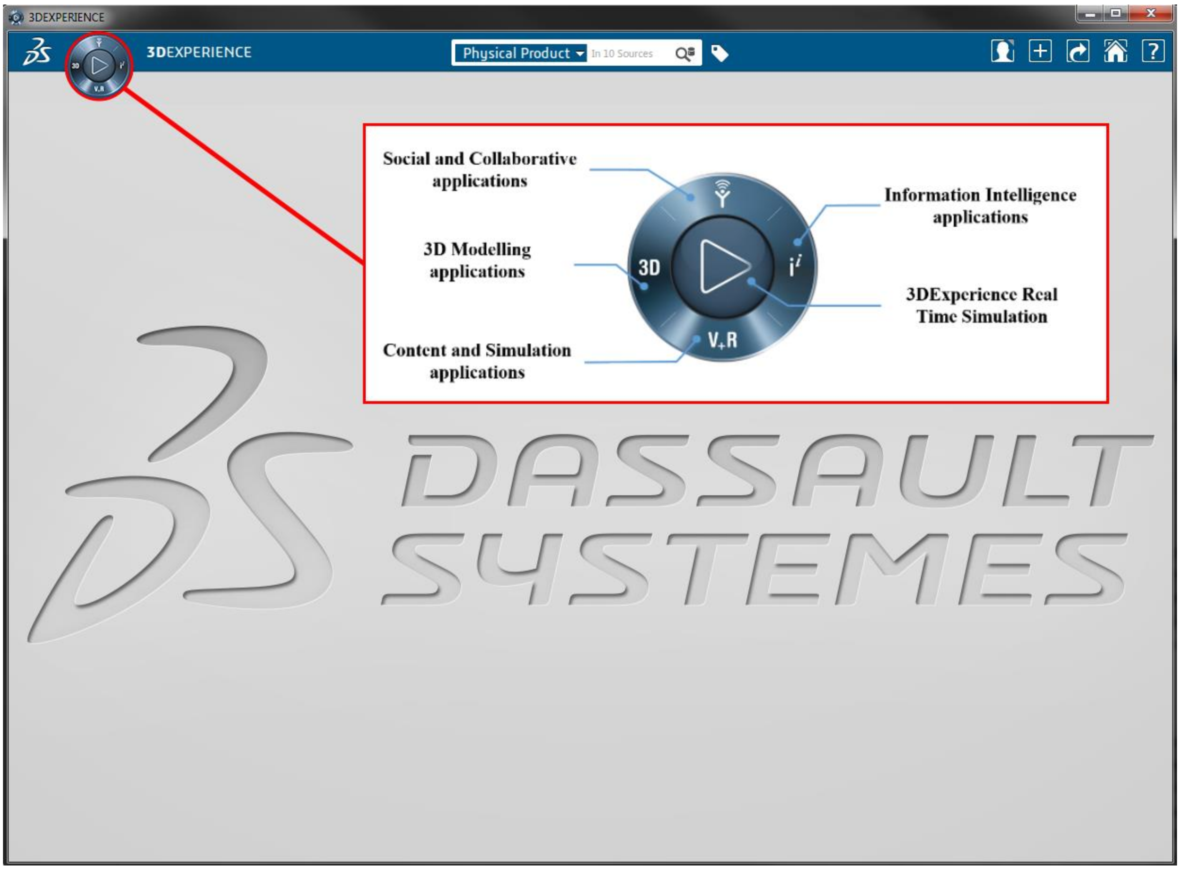


Figure 6: 3DEXPERIENCE dashboard

Social and Collaborative applications

Provides a comprehensive set of user experiences to enterprise users across the product lifecycle, from product planners, designers, and program managers to manufacturing planners, purchasing agents, suppliers, and compliancy managers that allows them to collaborate with each other in the overall context of the product data. Social and Collaborative applications provide functionality for businesses related to product planning, configuration management, design management, engineering management and manufacturing management.

3D Modelling applications

Offers a set of digital engineering and design applications. CATIA applications offers a full spectrum of next generation solutions design, engineering, systems modelling and architecture, electrical and electronic systems. SOLIDWORKS offers a conceptual mechanical design solution that merges the benefits of history, parametrics, and editing into a single interface.

Content and Simulation applications

Applications in this category explore the boundaries between the virtual and real world. They reduce physical prototyping, increase confidence in product performance, accurate design decisions, and enhance knowledge of real world behaviour in a virtual environment. DELMIA offers solutions that enable planning and simulation of manufacturing processes. Key functionalities are optimization of processes, mapping of human factor issues and resource planning. SIMULIA provides a full spectrum of solutions for simulating the behaviour of designs in a multiphysics environment, including finite element analyses (structural, thermal and fluid dynamics).

Information Intelligence applications

These applications enable any employee in a company to collect, connect, discover consolidate and understand information from the platform's wide selection of functionalities.

[1]

3.3.1. CATIA

CATIA is an advanced 3D product lifecycle management software, and the main 3D-modelling solution in 3DEXPERIENCE. CATIA offers a vast selection of industry specific *workbenches*, which provides multiple stages of product development. CATIA can be applied to a wide variety of industries, but this thesis will focus on the ship design solution for CATIA. This solution is one of the leading 3D tools when it comes to marine and offshore construction. This is a powerful design tool that provides the user with intuitive and easy-to-use functionalities, covering all processes from conceptual design to a complete detailed design.

3DS CATIA

3.3.2. DELMIA

DELMIA is the digital manufacturing solution in 3DEXPERIENCE platform. It enables manufacturers in any industry to efficiently plan, manage and optimize their industrial operations. This includes process- and assembly planning, work instructions planning, and robotic programming. By performing digital simulation of manufacture processes at an early stage, the fabricator is able to evaluate "what-if-scenarios", perform modifications/corrections, optimize floor operations, and identify and eliminate expensive errors and poor design. DELMIA Marine and Offshore Manufacturing Planning (MOG) provide the foundation for all shipbuilding manufacturing solutions of 3DEXPERIENCE. With a unified data model and a single workbench/environment MOG enables all manufacturing disciplines to collaborate.

3DS DELMIA

3.3.3. ENOVIA

ENOVIA provides the collaborative management part of 3DEXPERIENCE. It is a framework for collaboration between the different departments in a company. It is an online environment which involves designers, programmers and work floor employees in the product lifecycle. Fully integrated with other solutions from Dassault Systèmes, ENOVIA's intuitive user interface offers powerful capabilities via a standard web browser. It is ready to be used "out of the box", so the benefits of effective collaboration, project management and planning can rapidly be achieved.

3DS ENOVIA

3.4. *ALMA and Act/Cut for shipbuilding*

Sheet metal cutting is a key link in a shipyards manufacturing process. It can be either a bottleneck hampering the whole production, or a huge productivity and profit booster. In order to achieve the maximum potential efficiency of the sheet metal cutting machines, the programming system must perfectly answer the needs of the production. The software *Act/Cut* developed by the company *ALMA* promises to deliver a solution to these challenges.

In addition to maximizing the material utilization, the programming system must manage the plasma technology as well as the specific processes in the industry, adapt to existing processes, and reduce to a minimum the necessary preparation and production kick-off time as well as the machine's cycle time.

ALMA Act/Cut is a complete, craft-oriented solution for cutting machine programming. It supports a variety of cutting technologies, such as plasma, laser, oxy-cutting and punching. It has specialized on all the shipbuilding specific functions; edge preparation management, symmetrical dual sheet cutting and marking. Also included in the software is powerful nesting- and material optimization tools. It also has the capability to be perform many tasks automatically.

Compatibility with shipyard-dedicated design solutions is also an important feature included in ALMA Act/Cut. In addition to 2D DWG/DXF[8] data import, the software is also capable of importing and managing native 3D data from different brands such as CATIA, SmartMarine and Tribon M3, and XML-coded data.

The software's user interface is fairly simple and straightforward. As shown in figure 7 on the next page, both 2D- and 3D data can be imported into Act/Cut, as well as coded data. Further the imported data is translated into a native format called DPR. The parts, now translated into .dpr, are then processed in various applications. Before the final output (NC program and workshop docs.) can be generated, all the parts geometries has to be analysed and defects corrected. When the geometry is satisfactory, the nesting process can commence. This is can be done automatically, partially automatic or manually. Further the sequence of the cutting process needs to be planned before the NC program is automatically generated.

[8] 2D data formats

Figure 7, below shows the data flow between the PLM and CAM system, production management and production floor. The processing in ALMA Act/Cut is briefly explained.

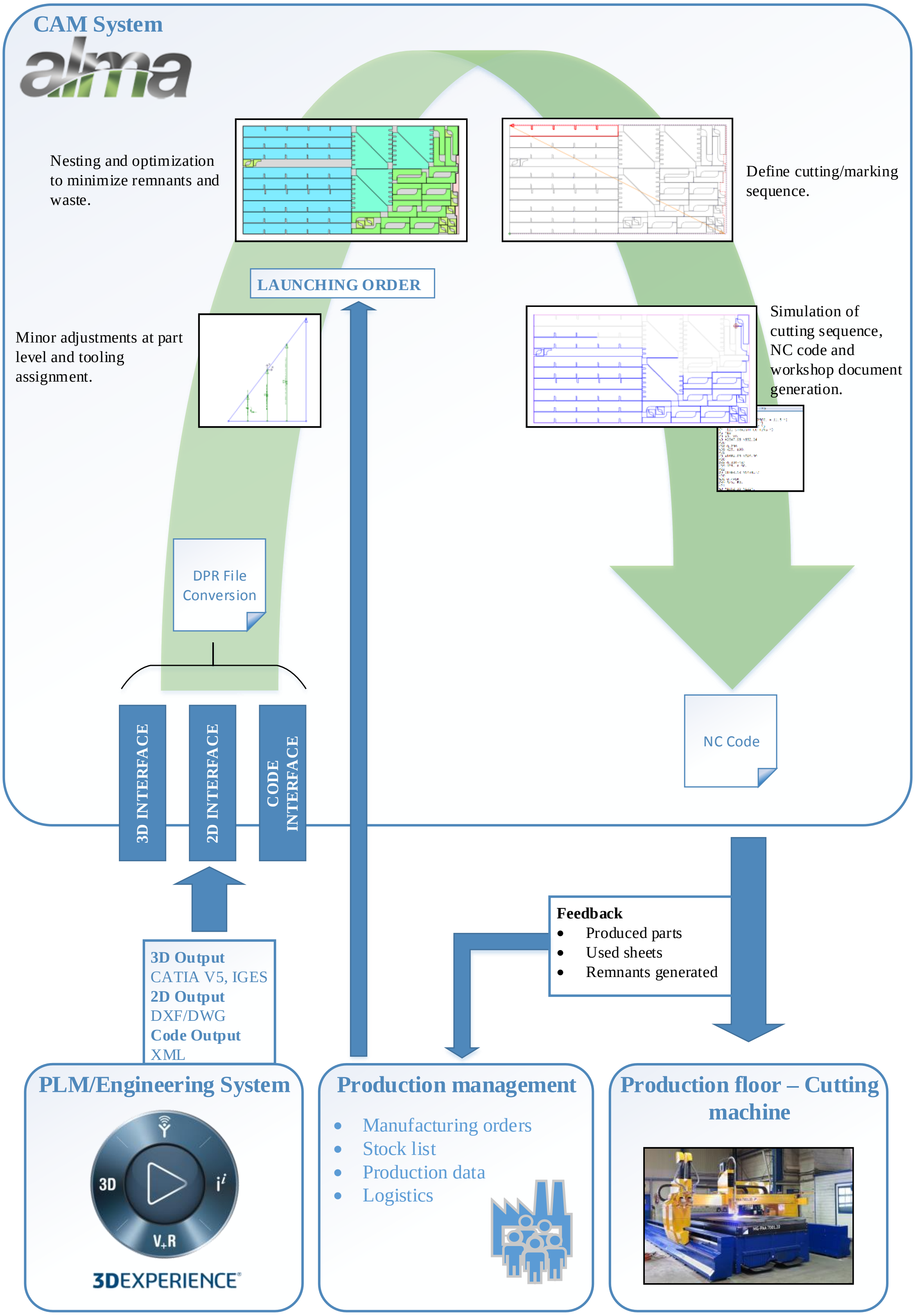


Figure 7: Data flow through the departments

4. INVESTIGATION OF MANUFACTURING FEATURES

Before establishing the design unit, a few manufacturing features needs to be discussed. These are important features that must be understood before starting the modelling: Compensation for welding distortion, edge preparation and marking of parts.

4.1. Compensation for welding distortion

During the welding process of steel structures the metal is subjected to highly localized heating, which causes the material surrounding the welding area to expand, and then contract upon cooldown. This inconvenience is called weld distortion, and is basically shrinkage of the welded plate. Distortion from arc welding is a common challenge, and is a major cause of extra work during the assembly and construction of a ship. The need for adjusting parts so that they will fit together correctly can take considerable time and effort.

Uniform stresses are introduced due to the expansion and contraction of the heated material. Initially, compressive stresses are created in the cooler material surrounding the weld pool due to thermal expansion of the heated material in the HAZ.[9] Further, tensile stresses occur when the material is cooling down, and the weld metal will start contracting, while the HAZ is resisted by the surrounding cold material. The magnitude of these thermal stresses can be seen by the volume change in the weld area on solidification and subsequent cooldown to room temperature. If the stresses exceeds the yield strength of the material, localized plastic deformation of the material occurs. This results in distortion and permanent reduction in the structures component dimensions.

For repeatable processes, which are very common in shipbuilding, the shrinkage of the plates can be measured, documented and collected in order to predict the behaviour of a plate when welded. Computer-aided design systems (CAD) take advantage of these measurements and allows the designer/modeller to compensate for the shrinkage at an early stage of the design process and include the modifications in the plate cutting information. The plates are then cut oversized and the shrinkage after welding brings it to the correct fit. This prediction method can also be applied to more complex parts such as stiffeners and structural webs with face plates. [3]

[9] Heat Affected Zone – the heat affected area adjacent to the weld pool

Figure 8 visualizes the most common distortion types on two simple butt welded steel plates. These types of distortion is called *transverse shrinkage* and *longitudinal shrinkage*. Other types of distortion can also occur in a welded plate. These are known as longitudinal bending, rotational-, angular- and buckling distortion. However, these will not be considered in this case.

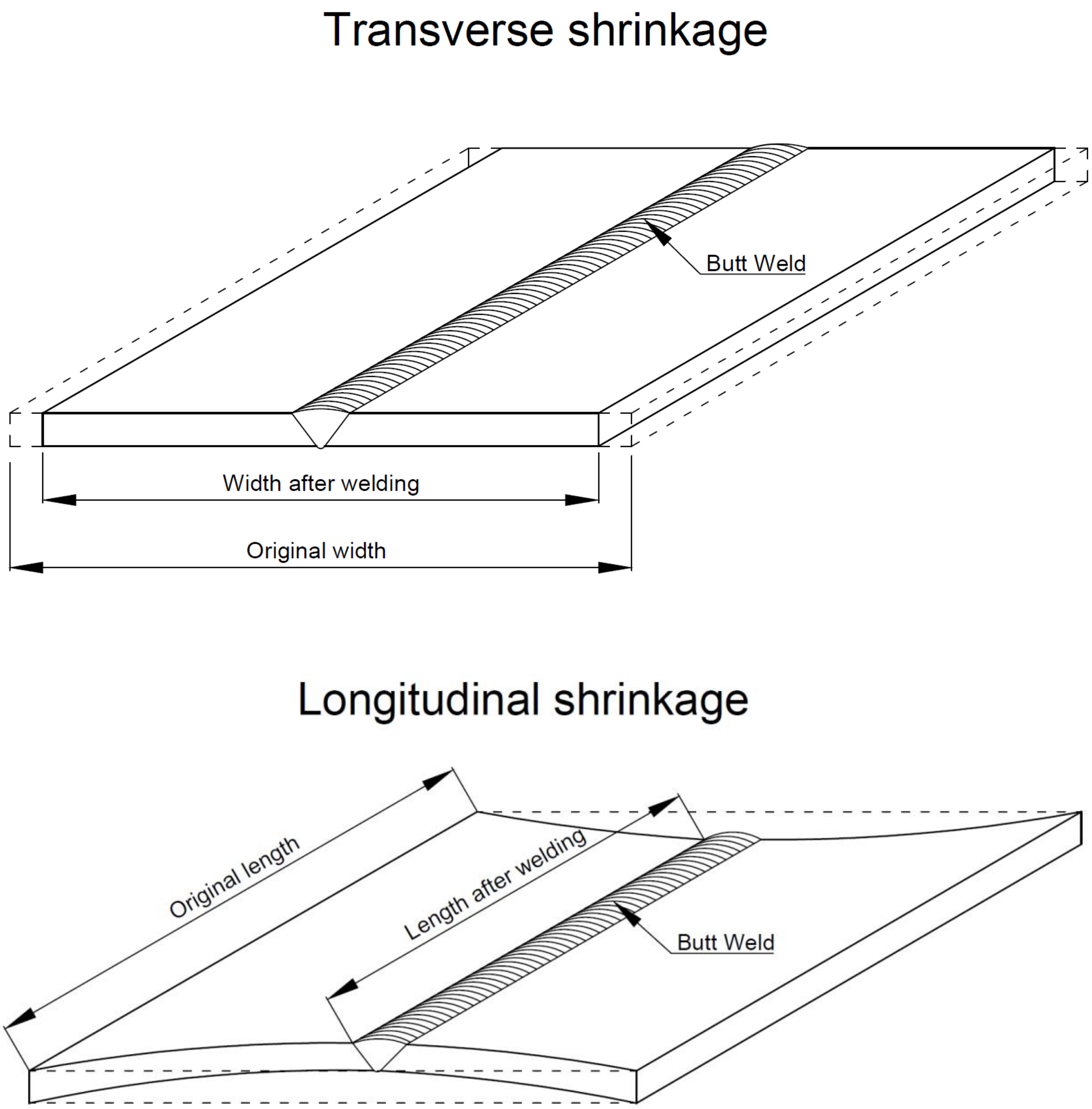


Figure 8: Weld distortion (shrinkage)

These deformations needs to be taken into consideration at an early stage, before the plate cutting is initiated. 3DEXPERIENCE offers a tool called *Shrinkage Planning*, which allows the user to input the shrinkage of the plates by scaling the plate's dimensions. This is done inside the application which governs the manufacture preparation of the section.

4.2. Edge preparation

On thick plates it becomes necessary to bevel[10] the connecting edges of plates that are to be welded together. This is done in order to achieve complete penetration of the weld metal and sufficient strength in the connection. There are various methods on how to create the bevels, such as machining, grinding or by performing it at the plasma (or similar) cutting stage. For plates of a larger dimension such as those used in shipbuilding, the most convenient method for creating bevels would be during the plasma cutting. For the cutting machine to be able to perform this task it is necessary that it is equipped with nozzles out of phase that can be set at a different angle. This is the method which will be focused on in this thesis. In figure 9 different types of edge preparation is shown. [3]

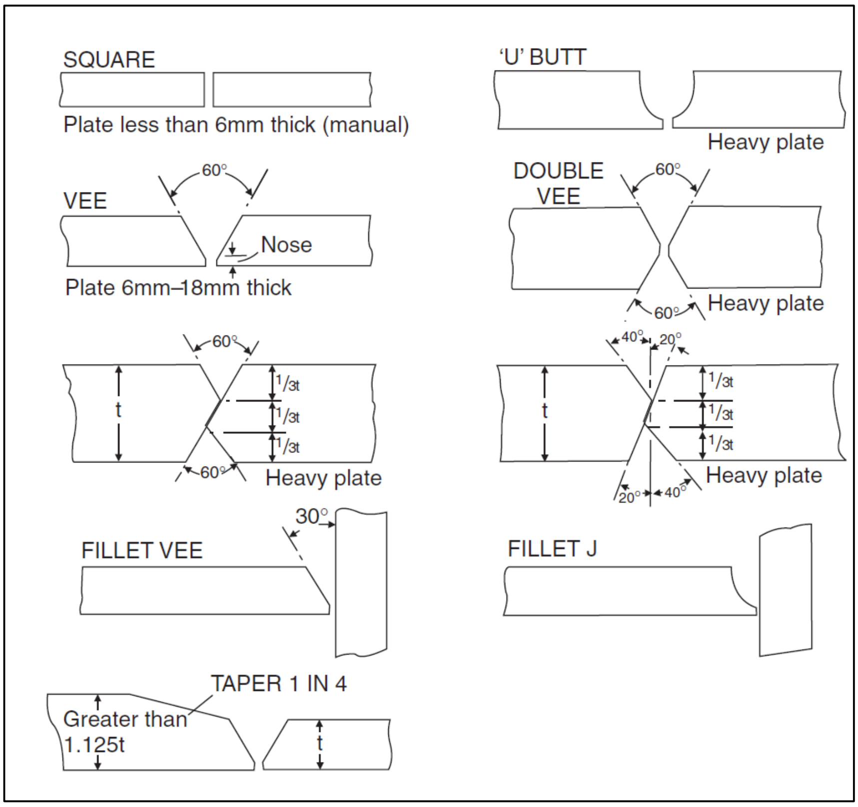


Figure 9: Edge preparation types

[10] Trim or chamfer along the edge of a plate resulting in a non-perpendicular transition between the plates faces.

4.3. Marking

Marking of the plates will aid the manufacturing process both in logistics and assembly. By marking each plate physically with a part identification number, such as a position number, it can easily be identified on the work floor and transported to the correct place. Convenient enough, the plasma cutting machine is able to mark plates with both numbers and letters by using the torch or a special marking/grinding tool. One way of marking the plates is by the current vessels build number, following by the position or part number of the current plate.

Marking also proves itself useful when assembling parts. Attachment lines for stiffeners can be marked physically onto the plates, reducing measurement errors drastically when welding the stiffeners to the plate.

Figure 10, below shows an example of a plate labelled with a part identification number and marked stiffener attachment lines. The stiffeners' orientation is also included and visualized with semi-circular symbols on the lines' centre mark.

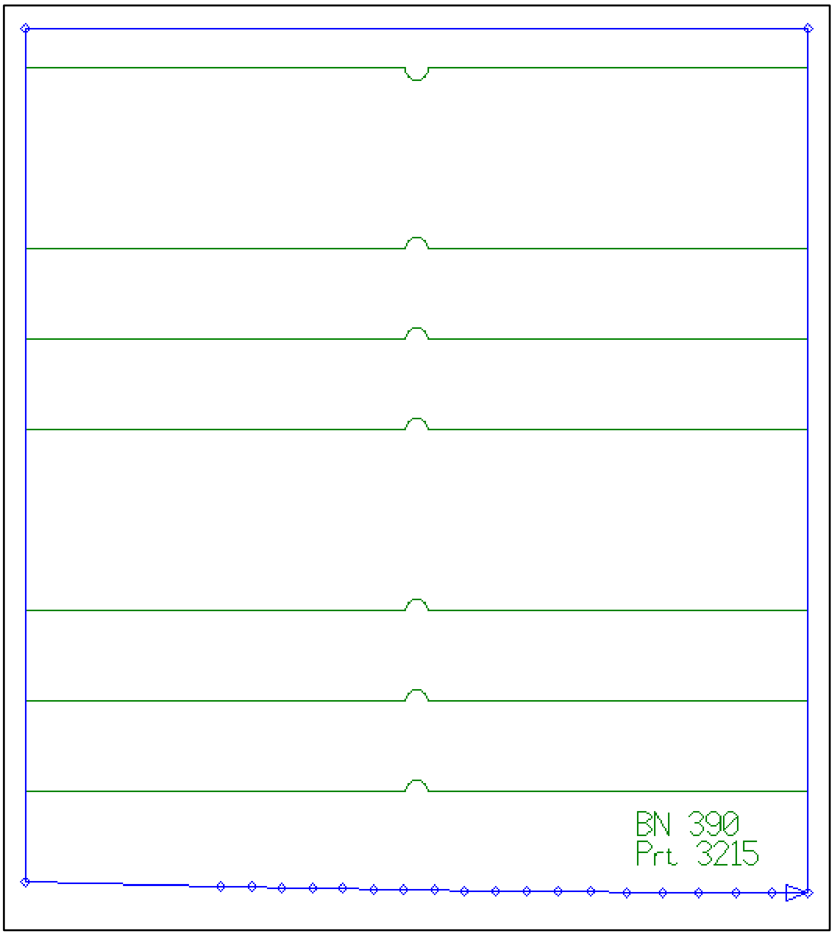


Figure 10: Plate marked with ID number and stiffener attachment lines

5. CONFIGURING THE COLLABORATIVE SPACE

The applications of 3DEXPERIENCE rely on standards and resources that must be predefined prior to the project start-up. These resources are governed by a separate application called *Data Setup*. Here an administrator can customize and associate resources with the project's work environment. Such an environment is assigned to all projects, and is called a *Collaborative Space* in 3DEXPERIENCE. [1]

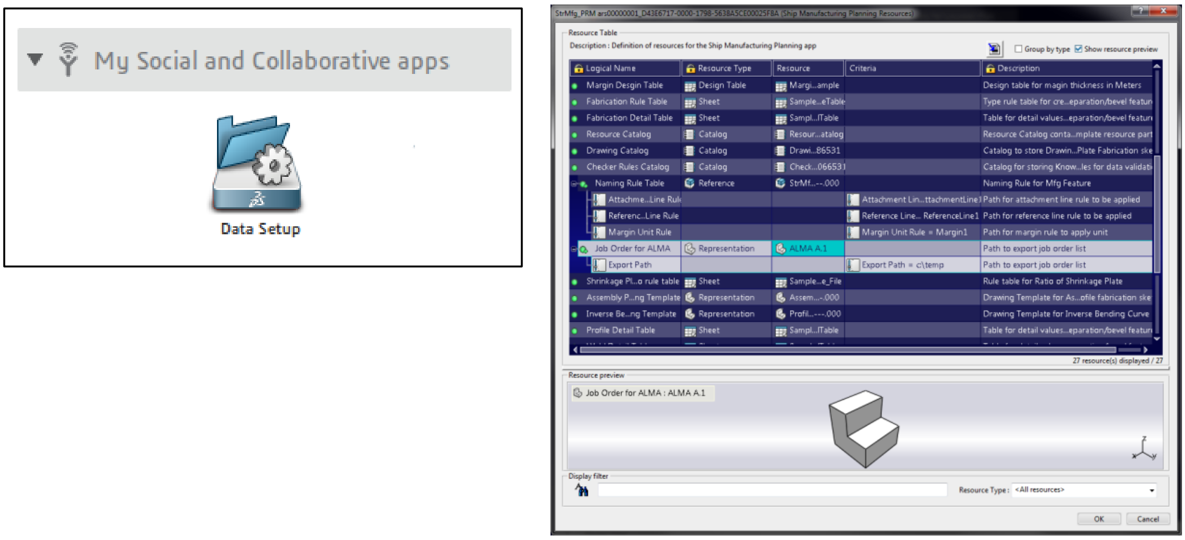


Figure 11: Data setup

The collaborative space contains resource tables and resource sets that holds project relevant information such as naming rules, design tables, hull forms, plane systems, end cut tables, material tables, macros and templates. These sets of resources is required by both the designer and manufacturing engineer in order to eliminate unnecessary manual work, and for certain operations to function as intended. The templates for extracting data for sheet metal cutting are also defined here, and is important in order to obtain satisfactory output data.

The format of the resources can be spreadsheet tables, catalogues, XML files, templates, etc. There is one particular kind of resource called *business rule*. A business rule is a piece of logic that will be triggered during the execution of a command to make decisions or prevent an operation. The logic is described using the Enterprise Knowledge Language (EKL) that enables to manipulate almost all the objects within the applications of 3DEXPERIENCE.

According to Dassault Systèmes, the data setup application is not particularly hard to master, however, it is recommended that the administrator responsible for the collaborative space and data setup have some computer programming experience. This is not a relevant subject for this thesis, and therefore case study will rely on a collaborative space and resources, which is already defined by Kleven.

6. MODELLING

Regarding the case study which is the practical foundation of the thesis, the modelling part of the process is an important stage. As mentioned, the 3D modelling applications of 3DEXPERIENCE is represented by CATIA. For ship design, three CATIA applications is required in order to establish the 3D data for the ship unit. These three are called *Space Referential*, *Structure Functional Design* and *Structure Design* and is included in 3DEXPERIENCE's Marine & Offshore solution. This chapter will give a brief explanation of the functions and interfaces of the above mentioned applications. Further, the methods applied (app by app) to the case study will be explained.

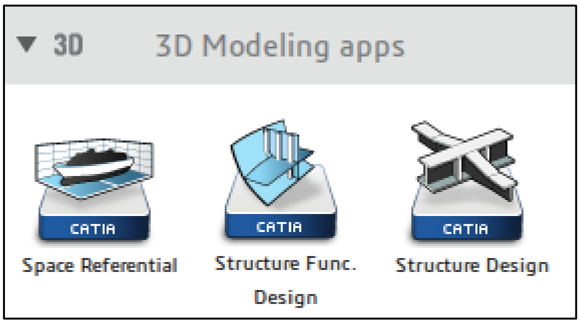


Figure 12: Main modelling applications

Due to the high level of complexity of a ship's unit/section, mistakes will most likely be made during the design stage. Therefore it is crucial that the design is flexible enough so that it is receptive to modifications/corrections without introducing a lot of extra work when edited.

Apart from establishing a 3D model of the vessel, the purpose of the modelling stage is to also establish an *Engineering Bill Of Materials (EBOM).* The EBOM is defined as a structured list of parts and assemblies that constitutes a product definition. It is a link between a part and its sub-parts, containing "as designed" product information which are used later at the manufacturing stage. [1]

It is not much to say about the environment of the modelling applications. However, they are designed with an intuitive and flexible user interface in mind. A customizable toolbar provides the user with all the necessary tools and commands. User assistance for each command/tool is available as online help documentation, which can be accessed by selecting a command and pressing the F1-key on the keyboard. The user assistance web page will then open in the users' web browser. A personal user account[11] has to be created in order to access this database.

[11] DS Passport is a web based service for accessing support, documentation, forums, etc. in Dassault Systèmes database

6.1. Space Referential

Before the modelling can start, a few important design parameters needs to be established. These are reference plane systems. Most ships are designed relative to fixed distances between decks transversal- and longitudinal frames. A reference plane system consists of planes which are placed where design features like bulkheads and decks will be placed. The planes can then be used as design supports for the applied design features.

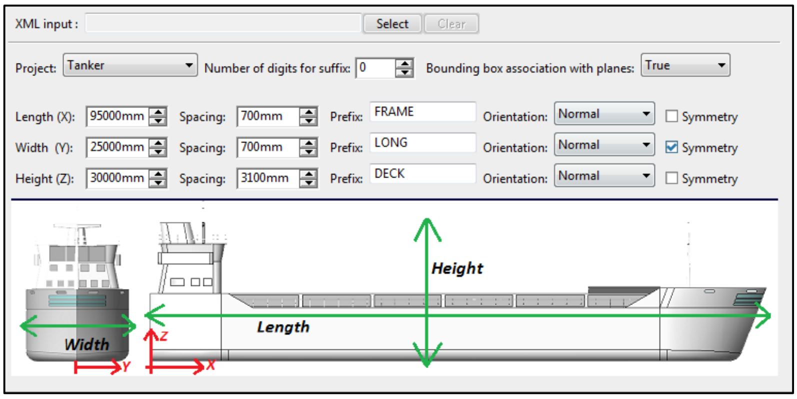


Figure 13: Reference plane system configuration

With the Space Referential application, the user can easily establish the plane system by introducing the length, width and height of the ship. Further, the distance between decks, transversal- and longitudinal bulkheads are set. A plane system as shown in figure 14 is then created (the ship model is only included for visual purposes)

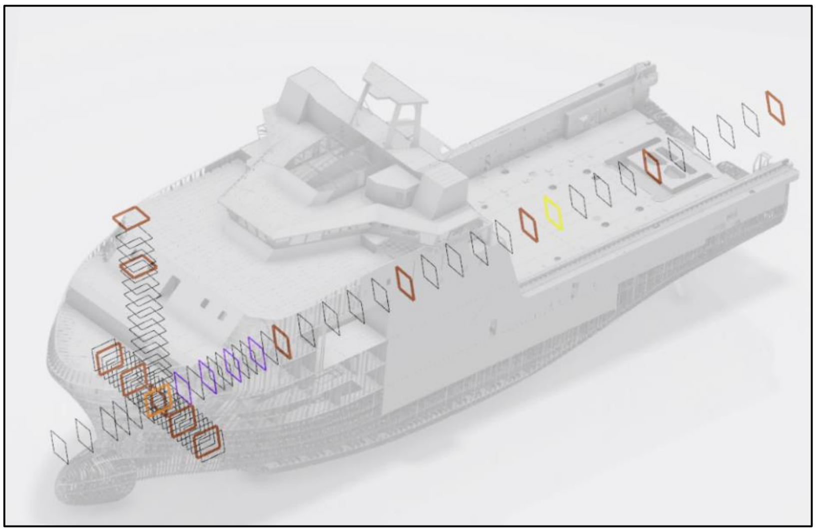


Figure 14: Reference plane system

The plane system is also important when it comes to the naming of the design features. Upon creation of the plane system, the application will add prefixes to all the planes, identifying them as FRAME, LONG or DECK. For example: A transversal bulkhead placed on frame #29, will automatically be given the name *TBhd-Frame.29*.

6.2. *Structure Functional Design*

The Structure Functional Design application is where the first structural design features is applied to the conceptual ship design. The model created in this application is a very lightweight and undemanding in terms of computing power. This is because only surfaces represent all the features created, and the plate thickness is not visualized. The plate thicknesses is instead added as an attribute for the feature. With such a lightweight model the time needed for creation, editing and updating of design features is significantly reduced compared to a more traditional approach where the plate thickness is included.

STEP I – Hull import

The first task on this stage is to import a representation of the already designed hull form. The hull representation's purpose is to act as a support for the shell panel that will be used in the model itself.

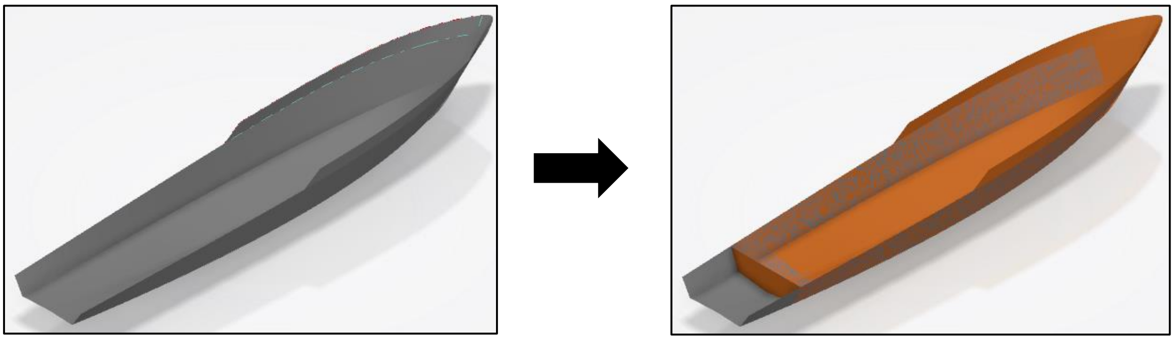


Figure 15: Imported hull form used as shell panel support

STEP II – Decks and bulkheads

When the hull representation is established, bulkhead and deck plates can be created. These use the planes in the reference plane system for support, and needs to be limited by either planes or other design features (plates or sketches). Material, plate thickness and orientation is defined as attributes. Also inclined/angled planes can be used for support.

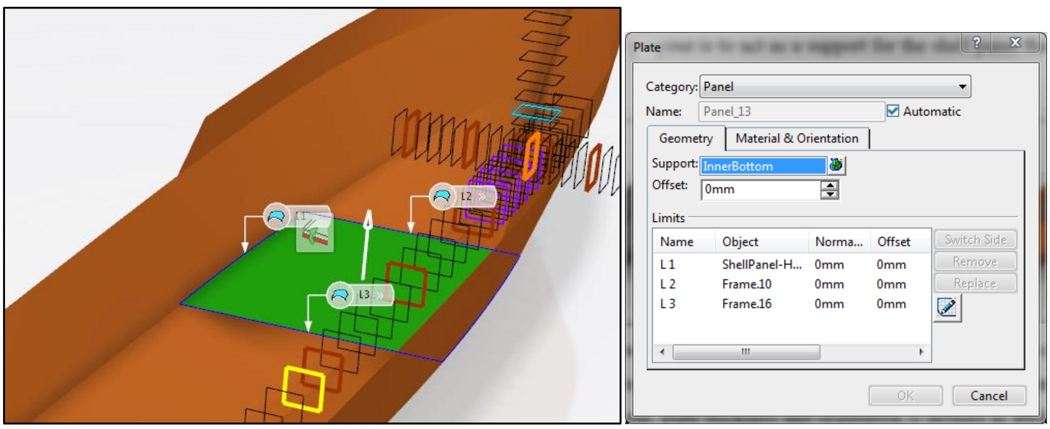


Figure 16: Creating a panel (deck)

STEP III – Seaming/breaking of plates

Once all the fundamental plates are is placed, seams and breaks must be applied. This operation can also be performed at later stages, but may cause difficulties related to the openings which will be applied to the plates in STEP V.

Breaks are added where plates intersect, and once applied, the break will create new independent plate objects. In this case, the transverse bulkheads is split by the longitudinal bulkheads in order to maintain the ship's longitudinal strength.

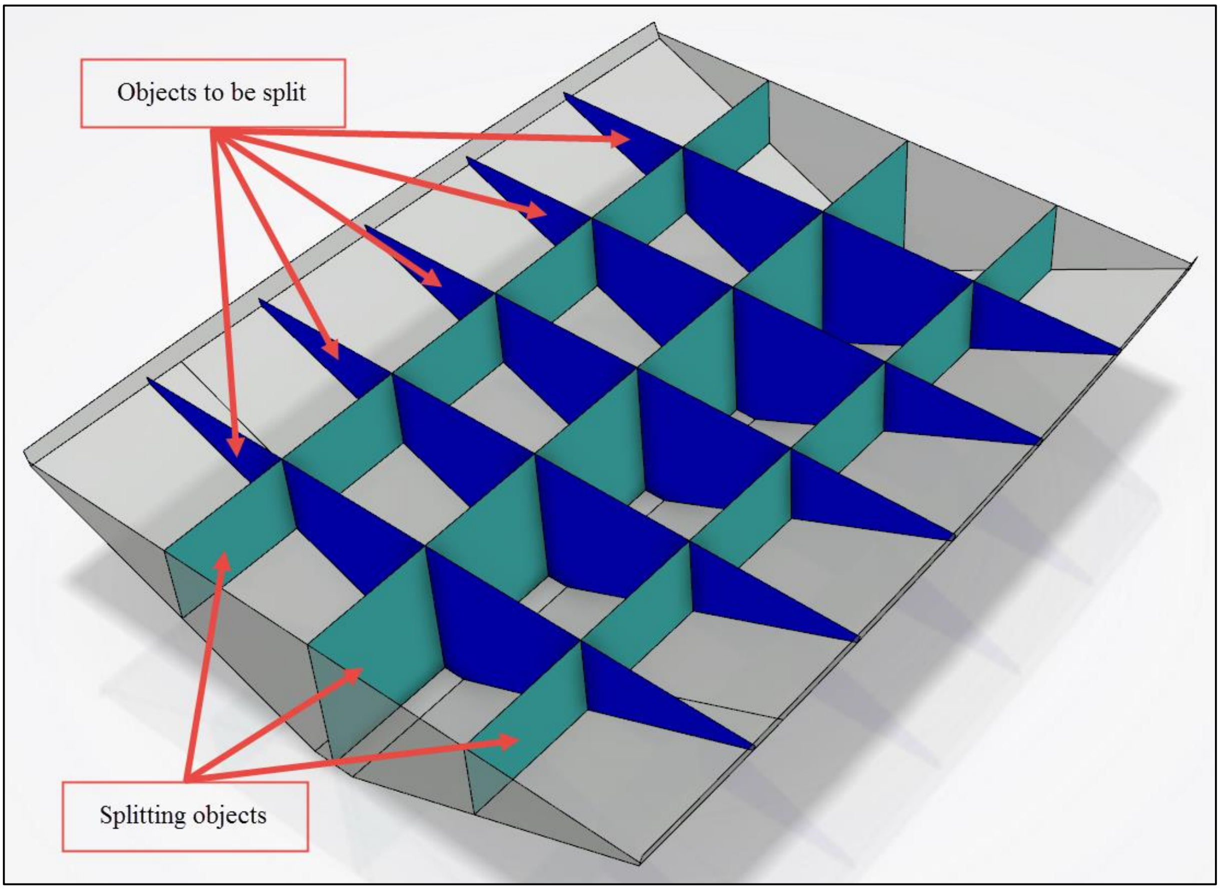


Figure 17: Splitting/breaking of plates (bulkhead)

Panels such as decks may have variable plate thickness along the surface due to placement of heavy machinery or equipment. In that case the panel can be seamed, instead of broken. Unlike breaks, the seam does not create new independent plate objects. Instead, the plate object will be divided into smaller sections with a common plate object. The seaming function can use both plates and sketches as splitting objects. Seams can also be applied to shell panels and bulkheads. The crane capacity and maximum dimension of plates is also decisive when applying seams.

For the case study the tank top deck of the unit is seamed using a sketch.

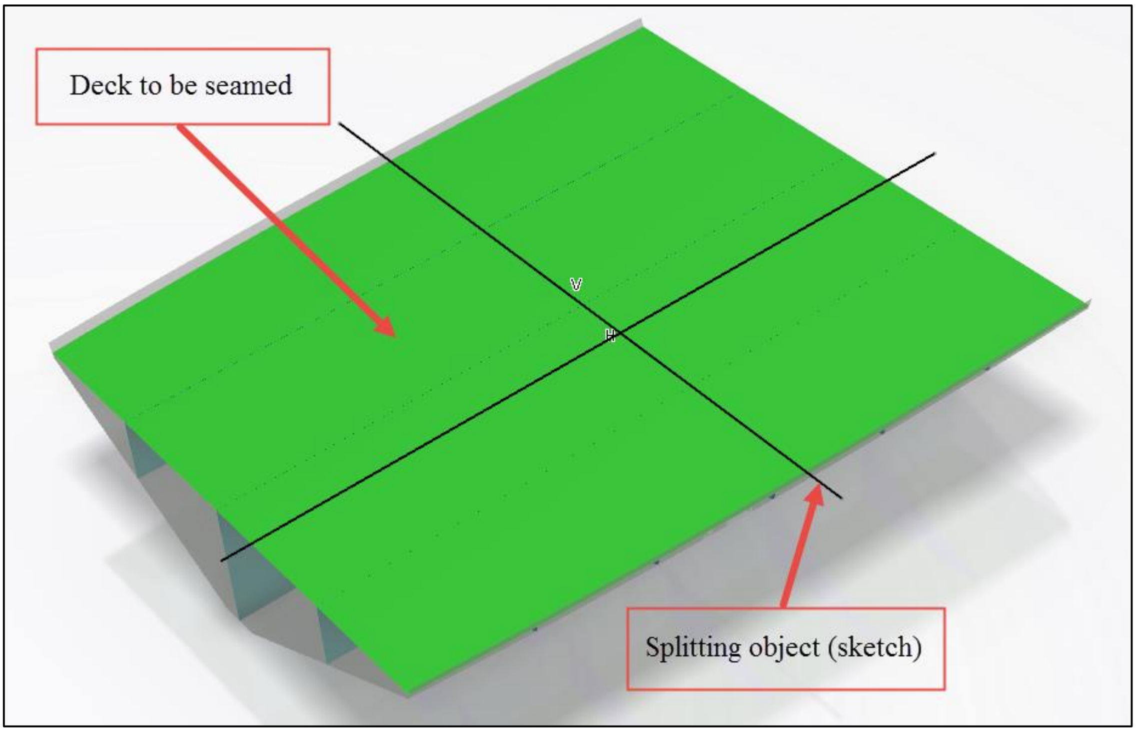


Figure 18: Seaming of a plate (deck)

STEP IV – Stiffeners

Stiffeners is divided into different types according to what kind of plate they are attached to: Shell stiffeners (longitudinal and transverse), transverse bulkhead stiffeners (vertical and horizontal), longitudinal bulkhead stiffeners (vertical and horizontal), and deck stiffeners (transverse and longitudinal). The type needs to be selected before placing the stiffeners on a plate. Similar to creating plates, also stiffeners require both supports and limits. Planes is used for support, and the limits (start/end point of stiffener) can be plate edges, planes, intersecting plates, etc. Material, dimension, plate side, anchor point and orientation is defined as attributes.

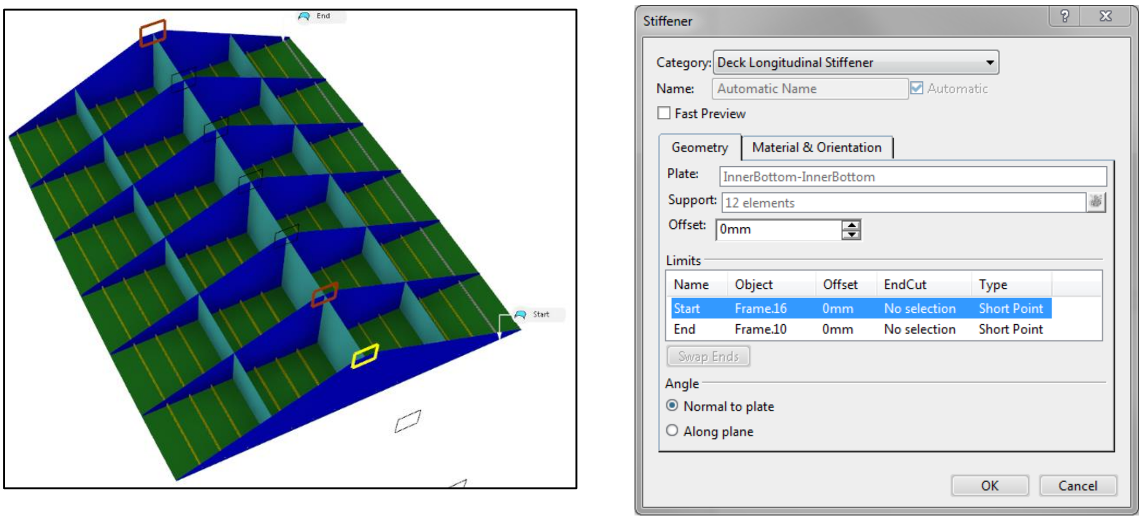


Figure 19: Placing stiffeners

STEP V – Openings

Openings such as manholes, doorways, etc. can easily be added by using standard shapes with parametric dimensions, sketches or 3D objects. Regarding naming, the openings is also categorized depending on the opening's purpose/type.

By using the *Interrupt* command, stiffeners that intersect with the opening will automatically be re-limited with respect to the opening.

For the case study both the standard shapes (manhole 600x400 mm) and sketches are used to create openings.

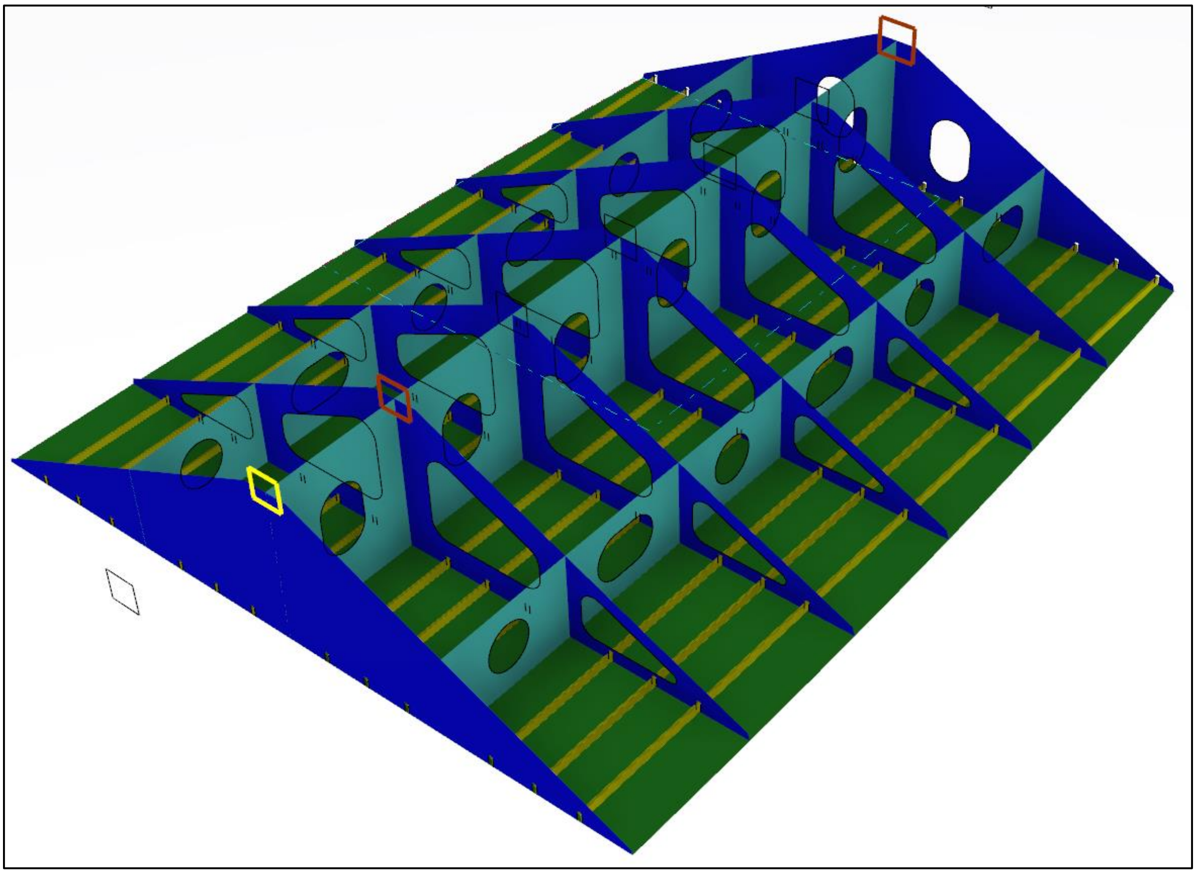


Figure 20: Placing openings

STEP VI – Brackets

Brackets is created from parametric features that should be available as resources in the project's collaborative space. Each project has a library of parametric bracket designs, from which the designer can select the desired type. Brackets needs one support, and 2-4 limiting features depending on the type. The parameters define the dimensions of the bracket.

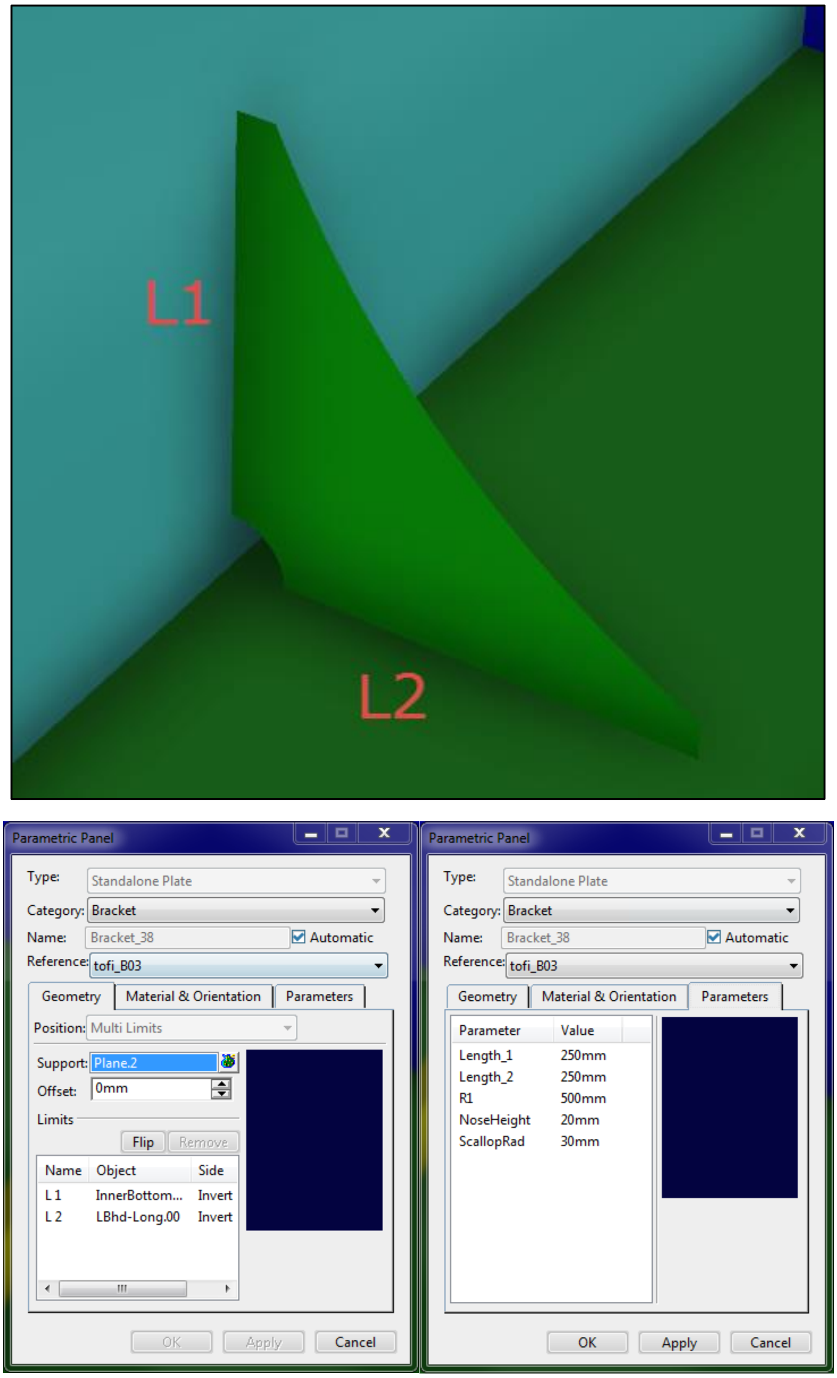


Figure 21: Placing brackets

6.3. Structure Design

The steps described in the previous section concludes the functional design of the unit. In the Structure Design application the unit's structure will be fully finalized. All plates and stiffeners will have their thickness applied, and even more details are added. This include secondary structure, end cuts, slots, openings on profiles, welds, etc.

STEP I – Splitting the vessel

Depending on the shipyard's characteristics such as crane capacities and production facility arrangement/size, the ship is divided into smaller sections. At Kleven, the ship is divided into blocks and sections/units. Figure 22, below shows an example of the division

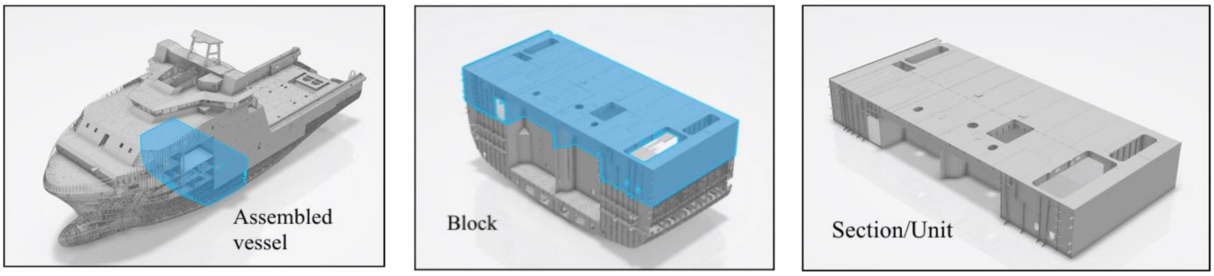


Figure 22: Block & unit division

It is given that the functional model for the whole vessel is established before splitting it. For the case study however, only one unit is designed from start due to the time demanding task of designing a whole vessel. This will not have any impact on the upcoming tasks (other than working with 1 unit instead of multiple). All the components in the design are regenerated as *parts* with their respective thickness applied once the splitting process is completed.

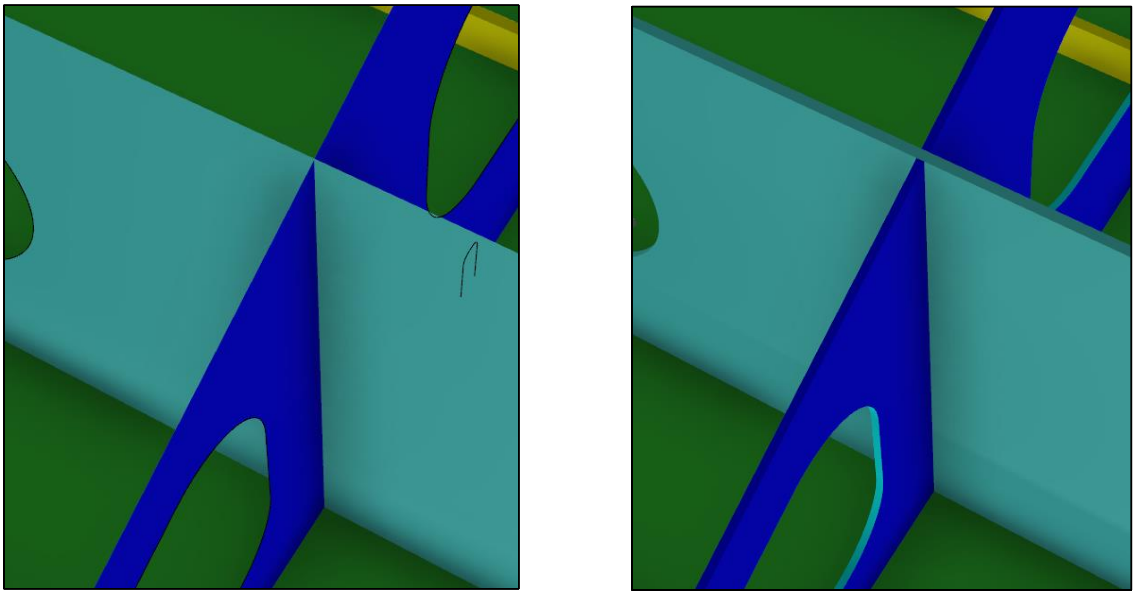


Figure 23: Functional design/structural design comparison

STEP II – Finalizing the design

Once the ship has been split into the desired blocks and units, it is time to add the final details to the design. The Structure Design application provide similar tools and functionalities as the Structure Functional Design, but fully defines the features upon creation (thickness included). Plates, openings, stiffeners, breaks/seams, brackets can also be applied here. The process is however somewhat slower due to more demanding operations for the computer's hardware, but less demanding operations such as placing end cuts, slots and collars is a quick procedure. Once all design features is included and the model is satisfactory it is time to add the connections (welds).

STEP III – Adding connections

Regarding preparation for sheet metal cutting, defining the connections between the design features is important in order for the software to understand where edge preparation, attachment lines and shrinkage compensation is needed during the manufacturing preparation phase.

The Structure Design application features a tool called *Weld Management*. This is a smart tool which allows the user to place apply welds manually, or let the software analyse and apply welds automatically. The project's database contains various types of welds which can be applied where applicable.

For the case study the automatic approach is used. This is done by launching the Weld Management tool and selecting the whole assembly. A list of all "touching" features in the assembly will appear, showing the pilot part and the joined part. The weld type is then automatically computed, and applied to the connection.

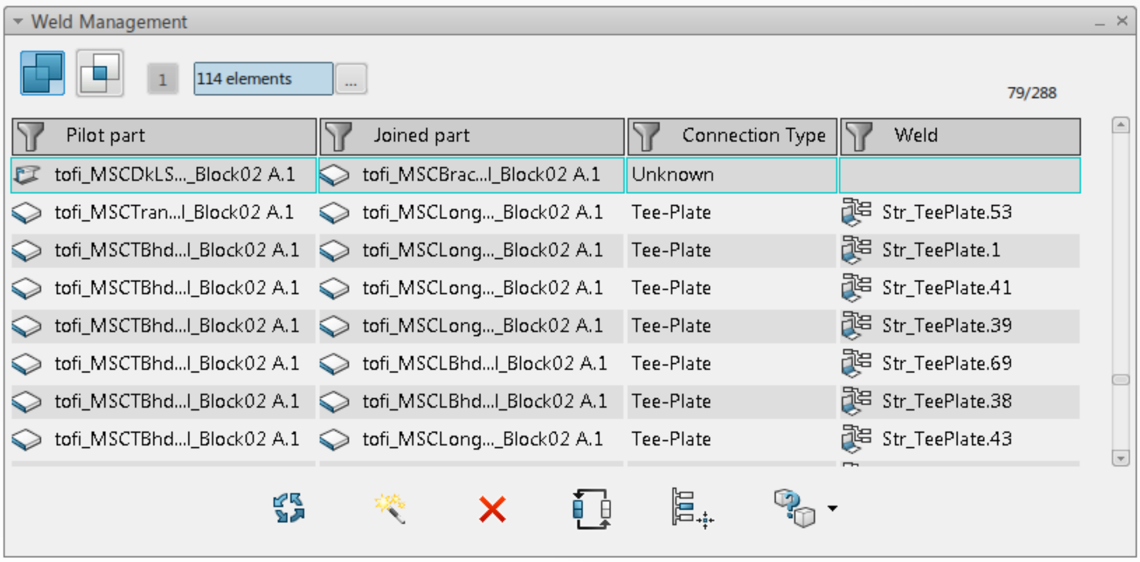


Figure 24: Weld management tool

7. MANUFACTURE PREPARATION

Before the design data is put into production it is necessary to prepare the assembly for the manufacturing process. 3DEXPERIENCE's DELMIA features a collection of applications directed at the shipbuilding industry, called *Marine and Offshore Manufacturing Planning (MOG)*. For the manufacture preparation of plate cutting/sheet metal cutting, MOG features two important and highly useful applications named *Marine Manufacturing* and *Marine Structure Fabrication*. This chapter will give a general description of the applications, their interface and further describe the methodology applied to the case study (app by app). The methodology will be essential in achieving satisfying quality of the output data (sheet metal cutting data).

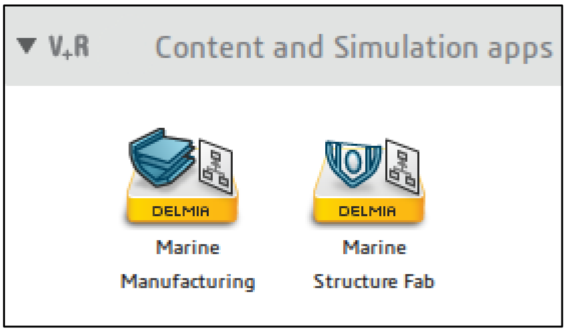


Figure 25: Main manufacture preparation applications

The applications displayed in figure 25 governs digital manufacturing inside a specific manufacturing environment. Theoretically, any production line, work floor or even a whole factory can be experienced in a virtual environment. The applications encourage efficiency by planning and simulating the production processes. This virtual environment allows the manufacturer to easily address and adjust manufacturing processes so that difficulties and delays may be avoided at an early stage.

The digital manufacturing environment is built on the theory of *Manufacturing Bill Of Materials (MBOM)*. The MBOM is derived from the EBOM (explained in chapter 6) and is defined as a list of parts required to manufacture a part or an assembly. It contains all information that is present in the corresponding EBOM such as find numbers[12], reference designators, unit of measure, quantity, description and usage. It also contains additional manufacturing-specific information such as part relation and attachment. [1]

[12] An ID that is used on drawings as a "bubble" callout.

The digital manufacturing environment is very well visualized due to the integration of 3D navigation in the applications. The user has the option to review features either in the 3D environment or more traditionally arranged hierarchically in the tree[13]. Figure 26 shows an example of how an *assembly breakdown structure* is typically visualized in DELMIA.

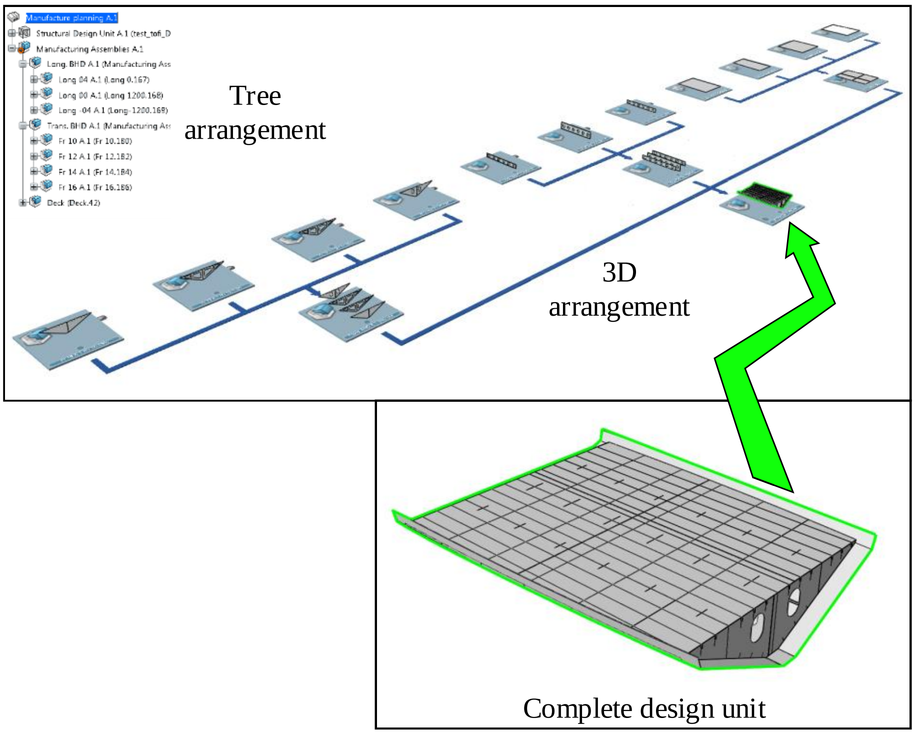


Figure 26: Unit breakdown structure visualized in DELMIA

The intention of a breakdown structure is to establish a hierarchic "recipe" of how the unit can be assembled, and imitates the facility's assembly process. The steps of the assembly is directly visualized in the 3D environment, where parts and sub-assemblies, called *Manufacturing Assemblies*, are placed on square tiles. These represent the "branches" of the tree structure. The structure is fully customizable by the user and can also be automatically generated.

A separate window called an *auxiliary viewer* will open on selecting the different manufacturing assemblies. These can be selected either by navigating in the 3D environment (clicking the "tiles"), or in the tree. The auxiliary viewer displays an enhanced/zoomed in view of the manufacturing assembly's contents, allowing the user to drag and drop the selected parts/components onto the desired tile/manufacturing assembly. The auxiliary viewer also features a powerful filtering tool, which is very convenient for larger assemblies with a large number of parts.

[13] A tree structure where content is arranged hierarchically containing product design specifications, logical blocks, simulation specifications or manufacturing processes.

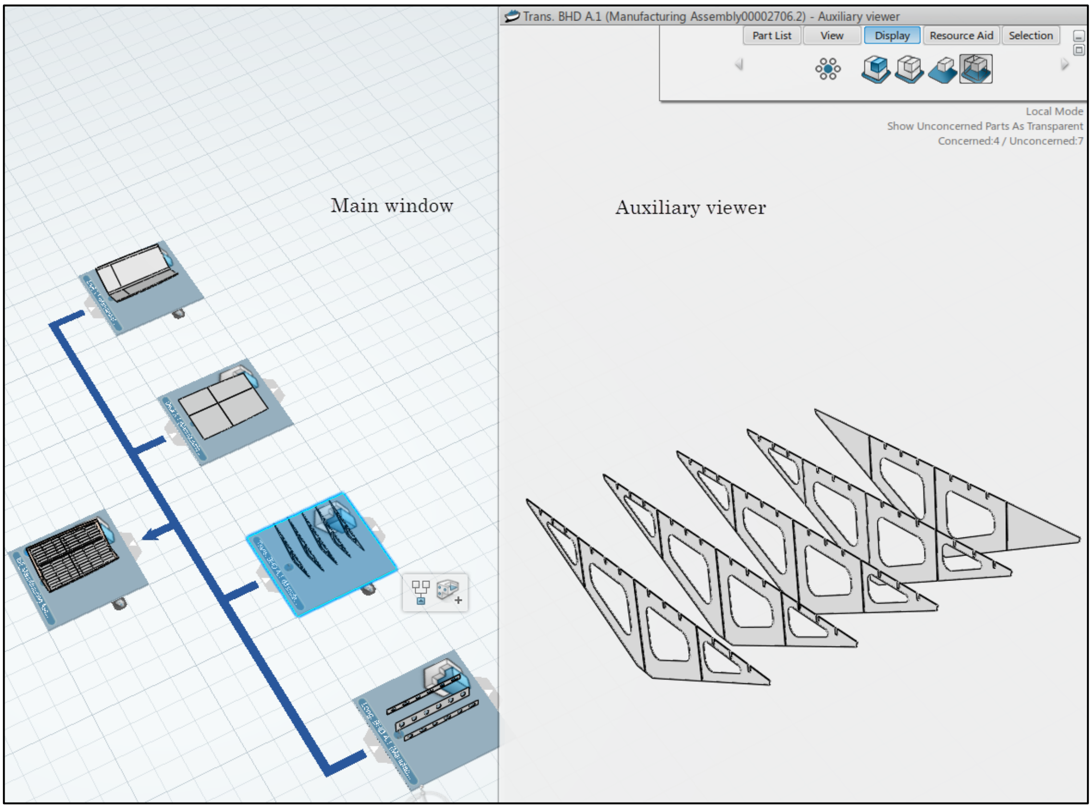


Figure 27: Auxiliary viewer

With a satisfactory breakdown structure established, the user is allowed to edit manufacture features on the part level. These manufacture features includes shrinkage/distortion planning, plate connection, orientation and alignment, attached stiffener/profile management, edge preparation, etc. Some of these features needs to be according to the vessels building standard, and has to be pre-defined in the data setup application, which were discussed earlier in chapter 5.

The breakdown structure also prove itself convenient regarding the extraction of data for sheet metal cutting. This is due to clever naming and categorization capabilities the application provide. With extensive assemblies it can be difficult to keep track of the large amount of parts if the manufacturing assemblies and parts are not categorized or named properly.

It is also within these applications one applies the welds specified in the Structure Design application in the modelling stage (CATIA).

In order to minimize the error and achieve high efficiency during the cutting preparation process, it is necessary divide/sort the different parts of the assembly into an organized assembly breakdown structure, and is a major part in the process planning step of the manufacturing of a ship unit.

The next sections will focus on the case study, and how the features discussed above is applied.

7.1. Marine Manufacturing

The Marine Manufacturing application enables the user to use the design data created in chapter 6 to plan the manufacturing process of the unit. The ship unit is broken down into sub-assemblies and parts, and is organized into a satisfying breakdown structure. As mentioned, the unit basically is broken down in order to find the most advantageous way to assemble it at the shipyard. Also factors such as crane capacities and facility arrangement is taken into consideration when the breakdown is performed.

In figure 28 below, a suggested unit breakdown structure is presented. The assembly process is divided into *tempos* where the unit is gradually assembled through five stages. Intentionally the tempos 1 through 4 is carried out in Kleven's automated hull production line, and parts which require more complex assembly methods such as brackets and profiles is assembled manually between the stages.

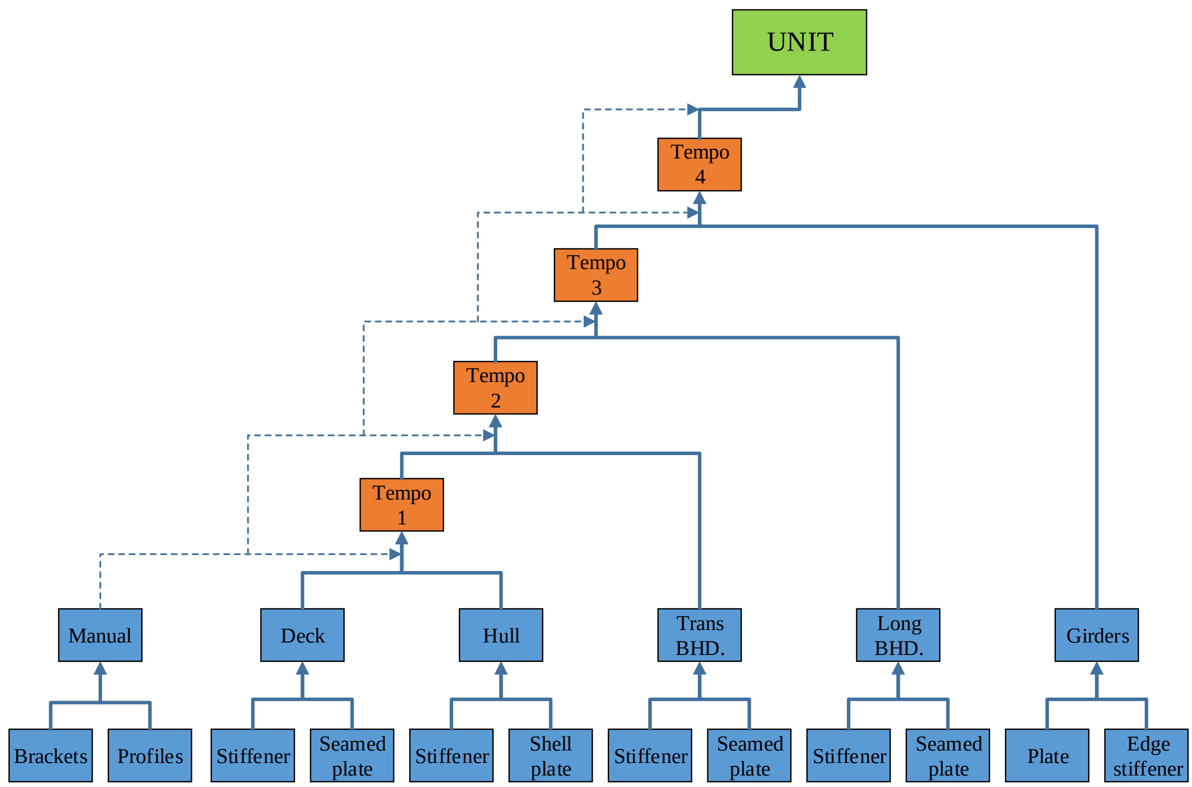


Figure 28: Proposed unit breakdown structure based on Kleven's production line

For the case study, the breakdown structure will be organized as proposed in figure 28. The process performed in 3DEXPERIENCE (DELMIA) will be explained stepwise.

STEP I – Setting up the environment

The design unit established in chapter 6 is found by searching for the unit's name in the search field. Upon right clicking on the design unit, select the option saying *Open in PPR* (short for Product, Process and Resource). The design unit will then be opened inside the DELMIA application Marine Manufacturing., with the first level of the breakdown structure, displaying the fully assembled unit, already placed.

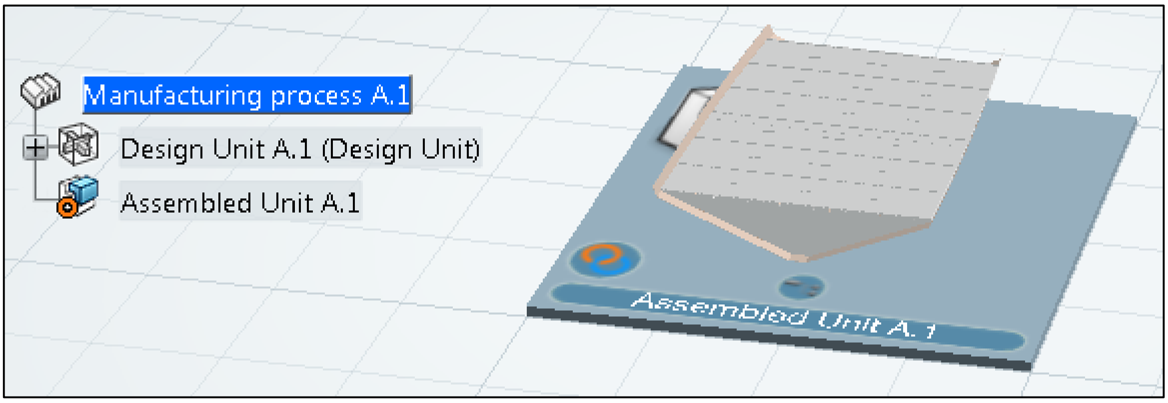


Figure 29: Design unit in DELMIA's environment

STEP II – Creating manufacturing assemblies (branches)

The branches of the breakdown structure is created by using *Manufacturing Assembly* command, found on the application's toolbar. Further, select the manufacturing assembly (tile) which is to be broken down. A new window will open, giving the opportunity to give the manufacturing assembly a title, name and description. If nothing is typed in, a default generic title and name is applied. These can be easily altered later, simply by accessing the properties of the manufacturing assembly. It is highly recommended that each manufacturing assembly is given specific titles in order to keep track of large and complex assemblies.

The process of creating new manufacturing assemblies is continued until the structure satisfies the requirement of the proposal presented in figure 28. Note that the outmost tiles of the branches contains only single parts, and is the "highest" level of the breakdown structure. These are called manufactured parts (names can be changed), rather than manufacturing assemblies.

Manufacturing assembly

Manufactured part

If the assembly does not have one or more of the listed features (girders, brackets, etc.), the current manufacturing assembly (branch) can be neglected. However, if a standardized structure is preferred for each project, simply leave the manufacturing assembly empty if no features falls under the current category.

By accessing the auxiliary viewer explained in the previous section, one can simply drag and drop design features onto their respective manufacturing assemblies (tiles). Once all features of the assembly has been assigned to their correct manufacturing assembly, the breakdown of the unit is completed. The manufacture planning can then be continued in the next application, Marine Structure Fabrication.

Figure 30 shows how the breakdown structure of the designed unit in DELMIA. As mentioned, leaving a manufacturing assembly empty has no impact on further work. As the figure shows this design has no girders included, but the manufacturing assembly named *Girders* is added in case these will be added in a design revision.

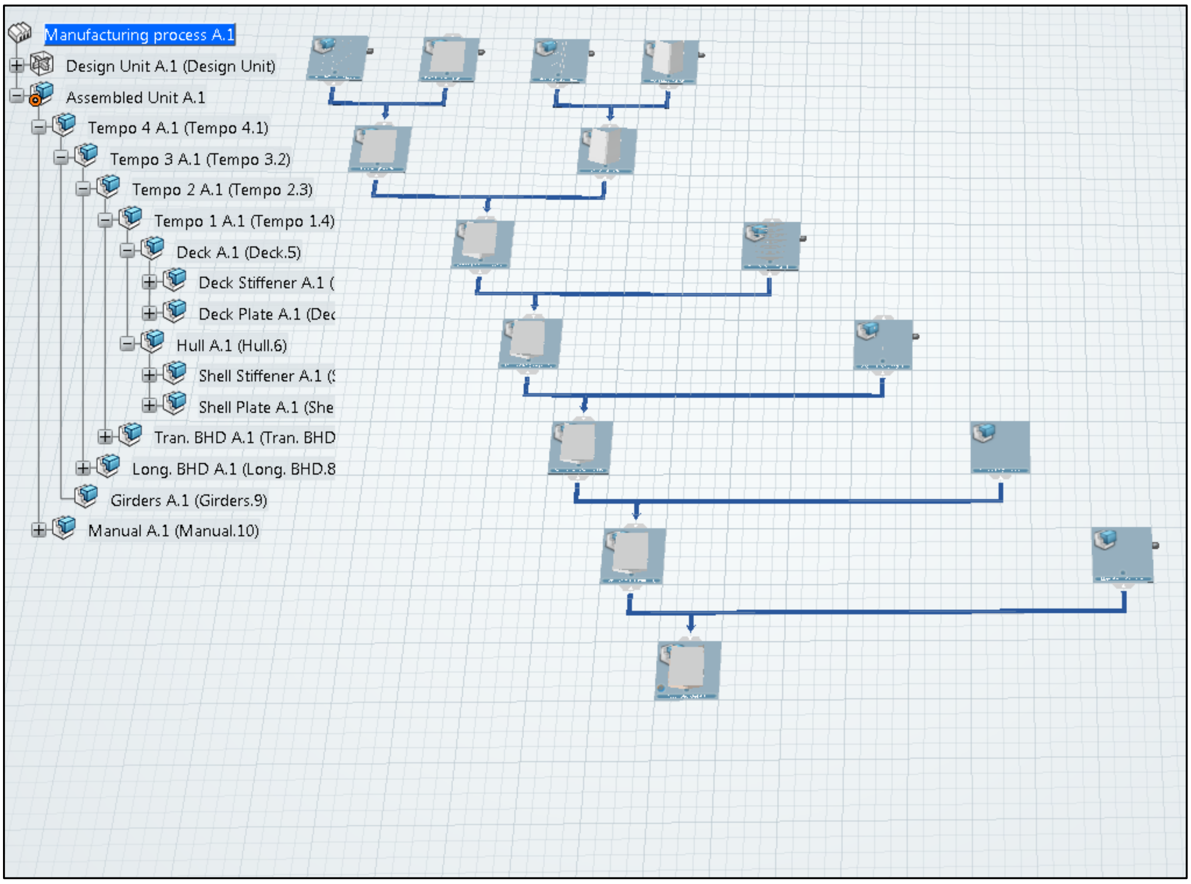


Figure 30: Unit with the applied breakdown structure – 3D and tree visualization

7.2. *Marine Structure Fabrication*

The final stage of editing the design unit in 3DEXPERIENCE is done in the Marine Structure Fabrication application. This application allows the user to perform more complex production planning. Preparations is made on the part level of the assembly, and covers shrinkage and weld planning, edge preparation, marking and management of structural resources (e.g. pin-jigs). Once all preparations is complete, commands for extraction of workshop documents such as drawings (DXF) and plate representations (IGES, XML-code) can be executed. The extraction of data can include fully defined assembly drawings of the unit, or more relevant in this case; the plate contours/outline and marking for later import and processing in the nesting/CAM software.

The appearance and layout of this application is very much similar to the Marine Manufacturing application. The toolbar, however features a different set of tools, used specifically for the addition of manufacturing features, managing structural resources and generating documentation of the sub-assemblies and parts that are to be fabricated.

The following steps will explain how to apply the manufacturing features.

STEP I – Applying welds and updating the manufacturing assemblies

The welds applied to the unit in the Structure Design application is by default not loaded in the Marine Structure Fabrication application. By launching the *Weld Planning* tool, the created welds are applied to the manufacturing assemblies. The welds can be seen in the tree.

Once the welds are loaded, the manufacturing assemblies needs to be updated. This is done by running the command called *Update In-Process Models*. This will prepare all the manufacturing assemblies for the manufacturing features that will further be applied. Once the update is complete, the appearance of the manufacturing assemblies will change, as seen in figure 31 below.

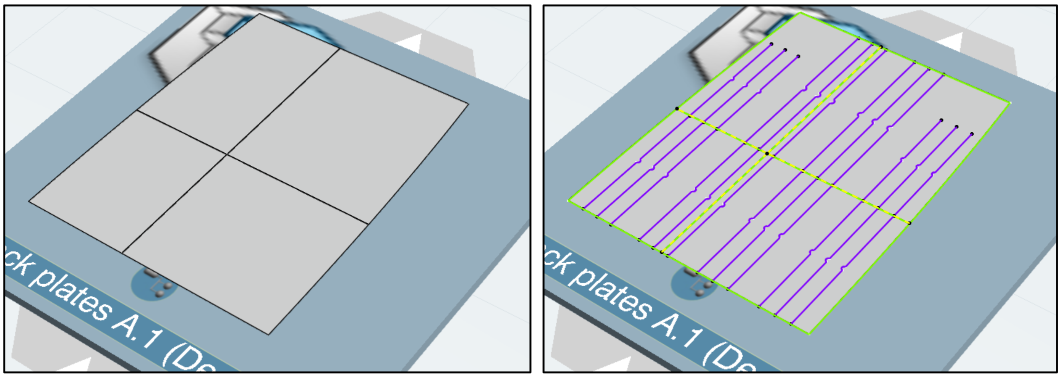


Figure 31: Appearance on updated manufacturing assembly

As shown in figure 31 different coloured lines appears upon updating the manufacturing assemblies. The colour of the lines represent different types of features. These are as follows:

Colour	Linetype	Representation
Green	Continuous	Part contour
Pink	Dashed	Openings/cut-outs
Yellow	Dashed	Connection lines
Purple	Continuous	Attachment lines
Purple	Dashed	Alignment lines

Table 2: Linetypes in Marine Structure Fabrication

3DEXPERIENCE applies these manufacturing features automatically depending on how "completed" the design are. For example, if the welds had not been applied correctly, the stiffener's attachment lines would not have been visible. However, these lines can be applied manually by editing the features of the manufacturing assembly

STEP II – Shrinkage compensation

Shrinkage compensated parts are created by launching the *Shrinkage Planning* command. A selection window requires selection of one or more manufacturing assemblies that are to be shrinkage compensated. The command will create a "step" between the manufactured parts and the first manufacturing assembly in the breakdown structure. This step will have the name *Shrinkage Part* by default.

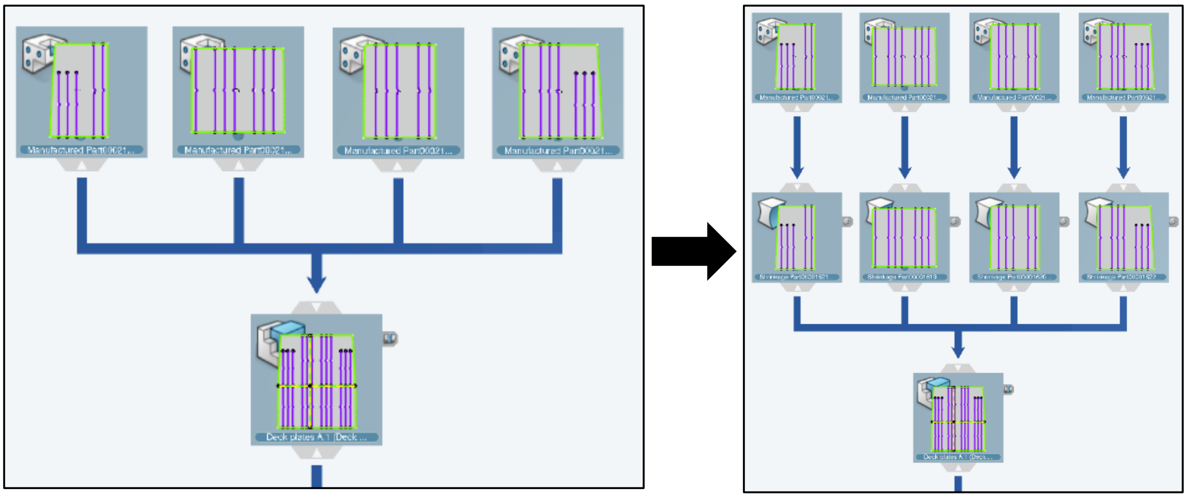


Figure 32: Adding shrinkage steps

Once the shrinkage compensation tiles are placed the shrinkage features needs to be adjusted. By launching the Edit Features command the auxiliary viewer will display the available options. These include outer contour compensation, opening compensation and stiffener compensation. The shrinkage compensation is adjusted by using ratios relative to the original dimensions of the plate. The ratios are labelled U and V, and represent the length and width of the compensated part. E.g. for a deck, U and V represent respectively longitudinal and transversal compensation ratios.

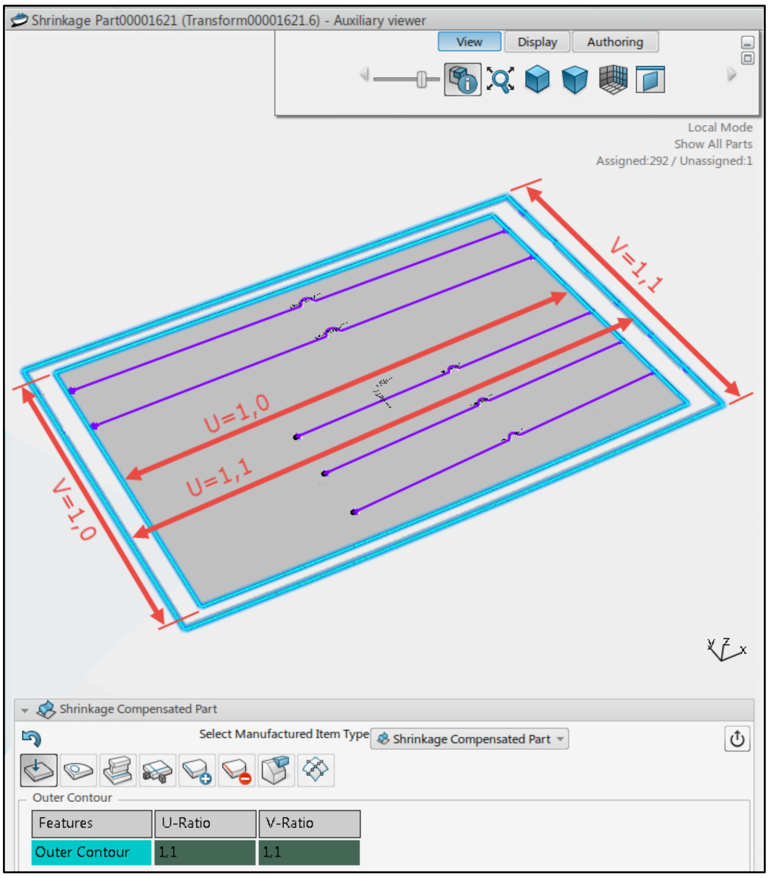


Figure 33: Shrinkage compensated plate (ratio = 1,1 in both directions)

Ref. appendix A-1 for comparison of non-compensated plate vs compensated plate.

STEP III – Edge preparation

Application of edge preparation features is can performed on both the manufacturing assembly level and the manufactured part level. This is optional, and has the same outcome. By launching the Edit Features command again and selecting the desired assembly/part, it will appear in the auxiliary viewer. In the auxiliary viewer, a tool called Edge Preparation is available.

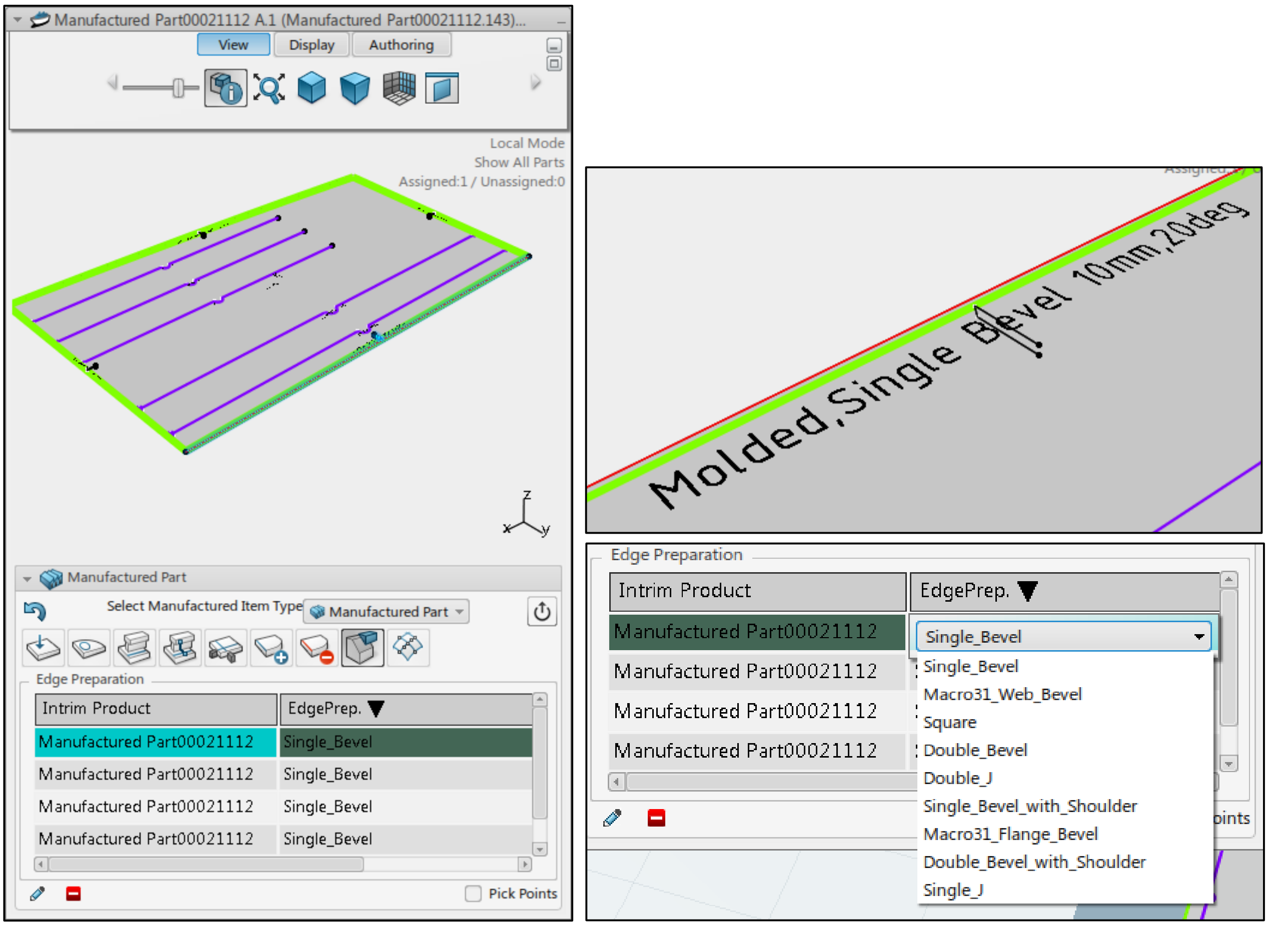


Figure 34: Edge preparation

Upon selecting the edges of the plate they will highlight, and the default edge preparation type is applied to the plate's edge. There are various types of edge preparation available, depending on which that have been made available in the project's collaborative space (configured in the Data Setup application). Similar to the brackets discussed in chapter 6, the edge preparation types are also parametric, so they can easily be edited in a separate window.

STEP III – Editing and applying markings

The features of the assembly will have markings such as attachment lines and labels automatically generated when features are applied. The automatically generated labels are often generic, and does not provide much information. In that case they have to be edited. For example; a stiffener may be labelled with only "Deck stiffener". Then it will be more convenient to give it a more informative label, for example "Deck Longitudinal Stiffener, HP100x8". The labels can be edited by using the *Modify/Delete texts* tool, when editing features in the auxiliary viewer. This tools opens a separate window, displaying the concerned part or assembly. All the visible labels can be edited, deleted and moved to a desired position. The changes are saved upon closing the window.

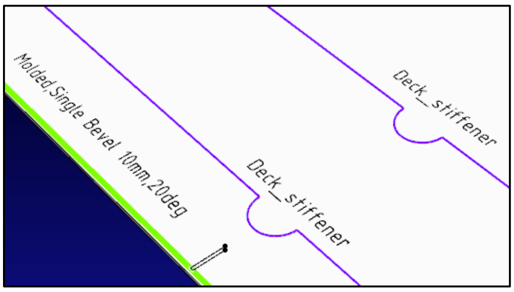


Figure 35: Automatically generated labels

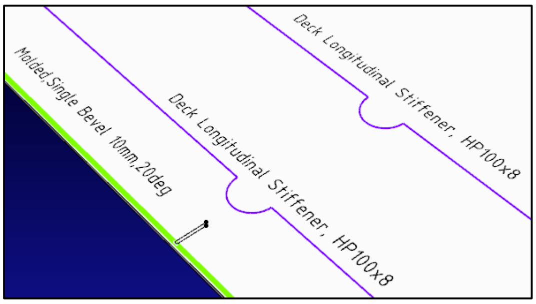


Figure 36: Customized labels

Labels is helpful information which can be included in workshop documentation. If included in the plate cutting program, the labels can also be marked physically on the plates when they are cut (by the cutting machine's torch or marking tool). Typical marked labelling is identification numbers such as position/part numbers or similar.

The attachment lines for stiffeners can be convenient to include on both in the workshop documentation and physically on the plates. It will aid welders in placing the stiffener correctly when assembling the panel. Similar to the labelling, these lines can also be included in the cutting machines CNC program, and marked by the cutting machine's marking tool.

8. DATA EXPORT & IMPORT FOR PROCESSING IN CAM SOFTWARE

The steps explained in the previous chapter concludes the manufacture preparation stage of the process. The next task is to export the plate data into a format which is compatible the nesting software Kleven intends to use (ALMA). This chapter focuses on the formats which can be used when transferring data from 3DEXPERIENCE to ALMA. Chapter 3.4 explained that ALMA can import formats with 2D, 3D and code interfaces. The file formats IGES (3D), DXF (2D) and XML (code), and the methods used for export/import is explained and evaluated in terms of complexity of the export method and the quality of exported data. For description of export/import procedures see appendix A-2.

8.1. IGES

Initial Graphics Exchange Specification (IGES) is an ANSI based and vendor-neutral file format designed for the exchange of 2D and 3D data between dissimilar CAD systems. Data with this format can be full three-dimensional models with associated drawing views and dimensions. [7]

3DEXPERIENCE can export parts into the IGES file format without problems. For a large ship unit assembly consisting of many plates, the export process is very time demanding. This is because each part needs to be opened in a separate model view and be exported one at the time.

ALMA is compatible with the IGES format. When a plate exported into the IGES file format is imported into ALMA, the both the geometry and thickness of the plate is included.

This export format is suitable only for single plates. If an assembly is exported, ALMA is will interpret the assembly as one solid, instead of an assembly of multiple parts. Manufacturing features such as attachment lines, markings/labels and edge preparation will not be included in the export, resulting in that ALMA only interprets the plate contour (including openings)

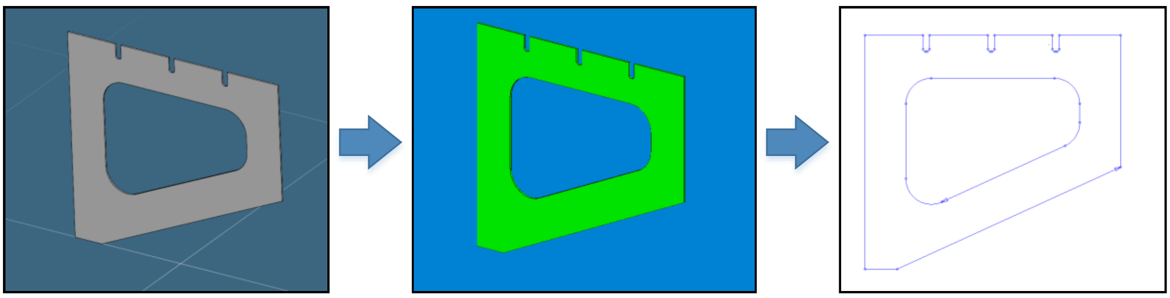


Plate model in 3DExperience | Plate model exported to IGES format | Plate in IGES format converted to DPR format

Figure 37: IGES representation

8.2. DXF

Drawing Exchange Format (DXF) is a 2D CAD data file format developed by Autodesk[14]. Much like the IGES, the purpose of the format is to enable data compatibility between different CAD software. The superiority of CAD software supports DXF, which allows users to exchange drawings even if they are running different software. [8]

The downside of the files with the DXF-format extracted from 3DEXPERIENCE is that it only includes 2D-geometry, and no plate thickness. This requires manual input of all plate thicknesses upon import. The format is however “out-of-the-box” compatible with ALMA, which means that no further processing before import to ALMA is necessary.

3DEXPERIENCE has features a function which allows extraction of multiple DXF-files of the plates in an assembly in one operation. This makes the DXF-file extraction from 3DEXPERIENCE a lot more efficient than the extraction to the IGES-format. This format includes markings/labels and attachment lines, but due to the lack of thickness it does not include edge preparation, other than the labels describing the feature. Yet, ALMA features simple functionality to apply edge preparation manually, so this is not a problem.

The labelling of the plates with for example identification numbers will provide the necessary information such as plate thickness and plate material. The information is located under the specific identification number in the workshop documentation (typically the bill of materials).

The batch-extraction of data makes this method very efficient compared to the time demanding method used to export plates in the IGES format. The exported files are lightweight in terms of file size, and the whole export process is a fairly rapid operation.

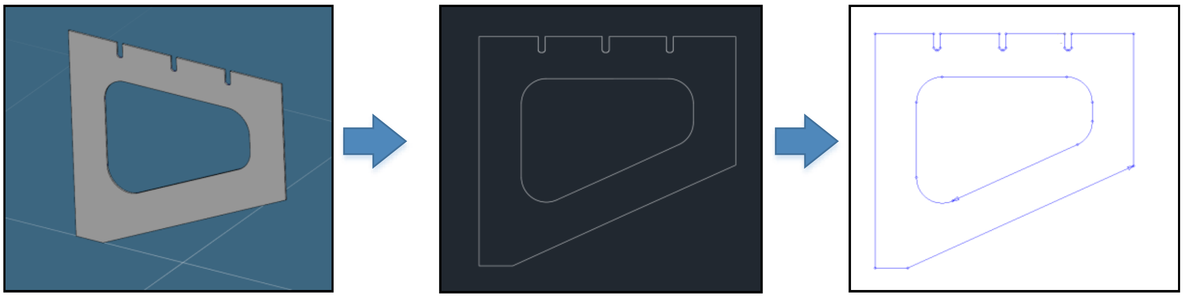


Figure 38: DXF representation

[14] A company that makes software specialized for the architecture, engineering and construction industry (AutoCAD, Inventor, etc.)

8.3. XML

Extensible Markup Language (XML) is a markup language that defines a set of rules for encoding documents in a format which is both human-readable and machine-readable. The design goals of XML emphasize simplicity, generality and usability across IT-platforms. The format is based on text supported by Unicode. Although the design of XML focuses on documents, it is widely used for the representation of arbitrary data structures. However, representations of CAD geometry is not very common, but it is possible. [9]

Within the data setup of 3DEXPERIENCE it is possible to add a special XML generator. This generator extracts XML-files of any selected plate of an assembly or sub-assembly, and includes information about the time of extraction, plate identification and name, material, plate thickness, markings/labels and most importantly; a representation of the plate geometry (contours). This is very convenient because ALMA has an integrated function which can import this kind of XML representation. The software interprets the code in the document, and returns the contour of the plate, including markings. DPR files are automatically created from the XML and placed in an automatically generated project library.

Also here, as with the DXF, edge preparation is not applied to the plate, but the label describing the feature is included.

Also this methods allows export of multiple parts in one operation, making it a very efficient method for transferring data between the software.

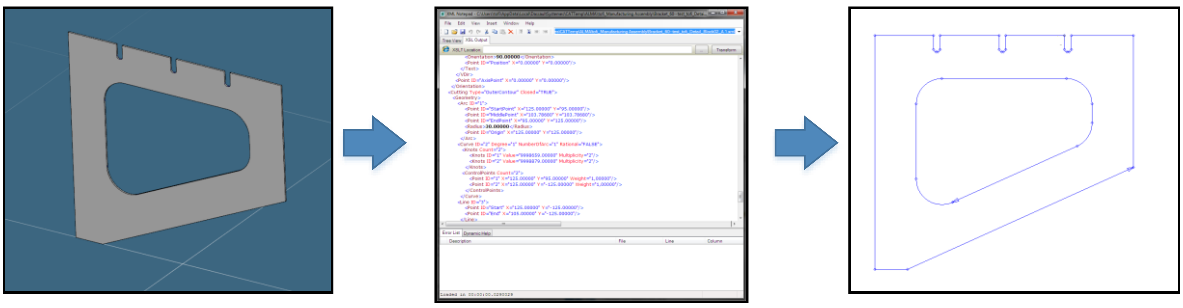


Plate model in 3DExperience

Plate model exported to code representation (XML)

XML representation converted to DPR format

Figure 39: XML representation

9. CAM PROCESSING

With all data is successfully transferred from 3DEXPERIENCE to the DPR format (required in ALMA), the work in 3DEXPERIENCE is completed and further processing is to advance in the CAM software, ALMA.

The CAM processing is done in five steps, given that the import explained in appendix A-2 is done. The steps involve part preparation, launching order creation, nesting, cutting sequence creation, and NC program and workshop document creation.

This chapter will explain the processing method through steps I to V in ALMA, where the design from the case study is used as input data.

STEP I – Preparing parts for processing

Before the processing can begin some modification may be required. The data exported from 3DEXPERIENCE is not always completely as desired and parts may require some "cleaning". The cleaning involves removing excessive labelling (markings), closing open curves and trimming away unwanted lines. Cutting lines may also be mistaken for marking lines, and opposite. These issues is easily fixed in the Drafter application.

Edge preparation is also applied at this stage, and is applied according to the edge preparation information labelled on the plate. By default these informative labels are set as *Marking*. These can also be set to *Text*, so that they are not physically marked on the plate.

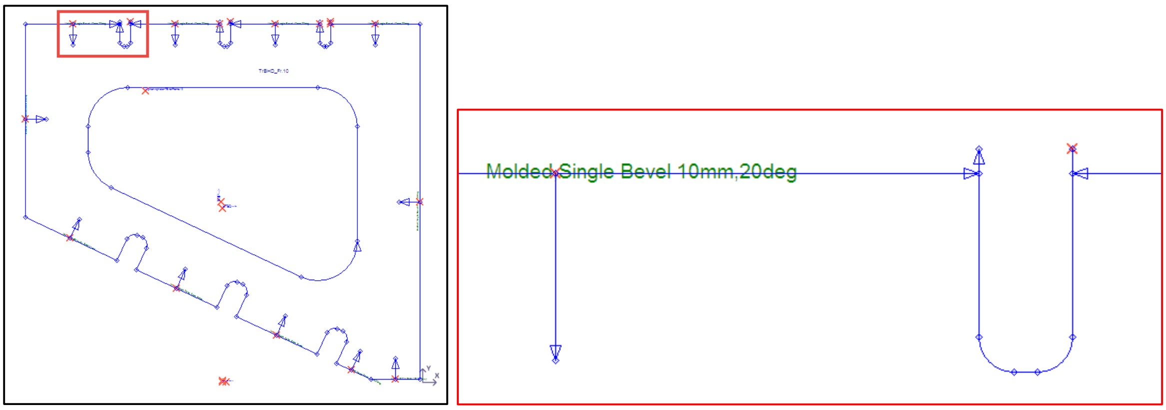


Figure 40: Unedited geometry

As figure 40 shows, the export has included some of the unwanted features discussed above. Figure 41 shows the "cleaned" version of the same part where edge preparation is added, curves are closed, overextended lines are trimmed and excessive markings removed (marking information is turned into *text* which is only visible in the DPR).

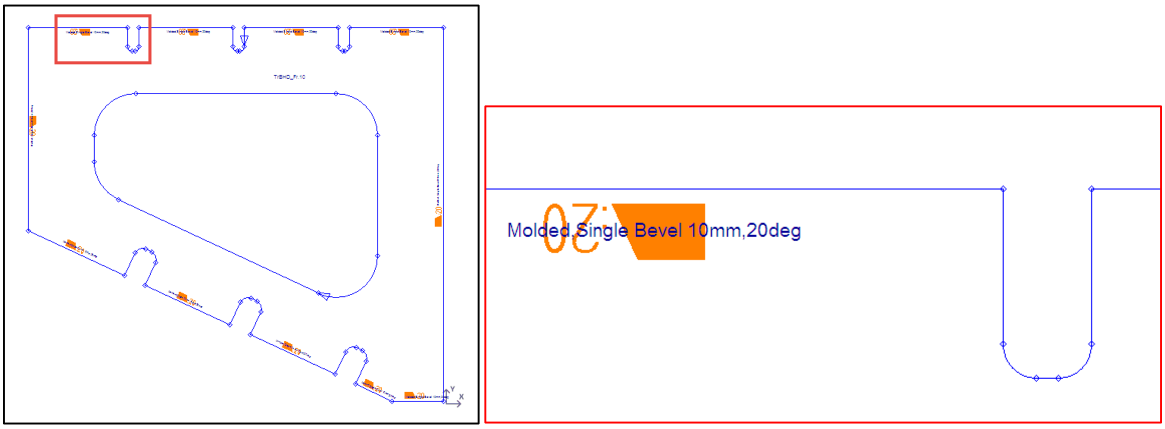


Figure 41: "Cleaned" geometry

NOTE: Remember to save the modifications frequently!

These modifications must be performed on all parts (where necessary) of the assembly before advancing to the next step.

STEP II – Creating the launching order

Launching orders is needed for separating parts with different thickness or material quality. In the launching order, raw material (sheets) is added and configured (material and dimensions). A standard dimension on sheet metal for cutting is selected as 8000x3500 mm, material grading NVA36.

Launching orders are created by selecting the *Launching Order* icon, and simply press INS (insert) on the keyboard. The *New launching order*-window is displayed. The launching order is named according to plate thickness. Once created, the new launching order will appear under the *Launching Order*-category in the tree with the sub-categories: *Parts*, *shee*ts and *Kit*.

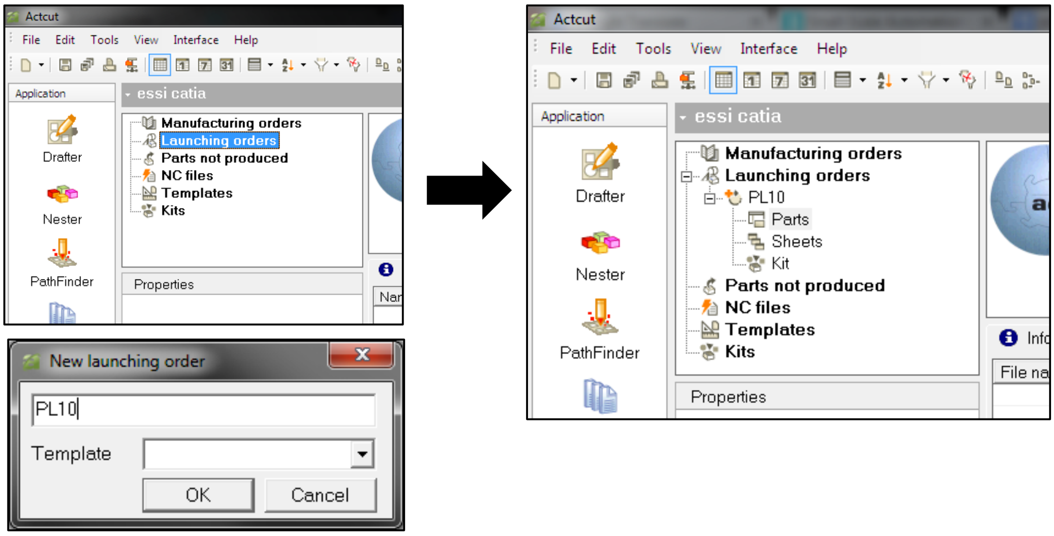


Figure 42: Creation of a launching order

When the launching order is established, the parts corresponding to the plate thickness of the order is assigned. This is done by selecting the *Parts*-icon and pressing INS (insert) on the keyboard. The *Add parts* window is displayed. The parts are assigned to the launching order by selecting and opening (multiple selection is possible).

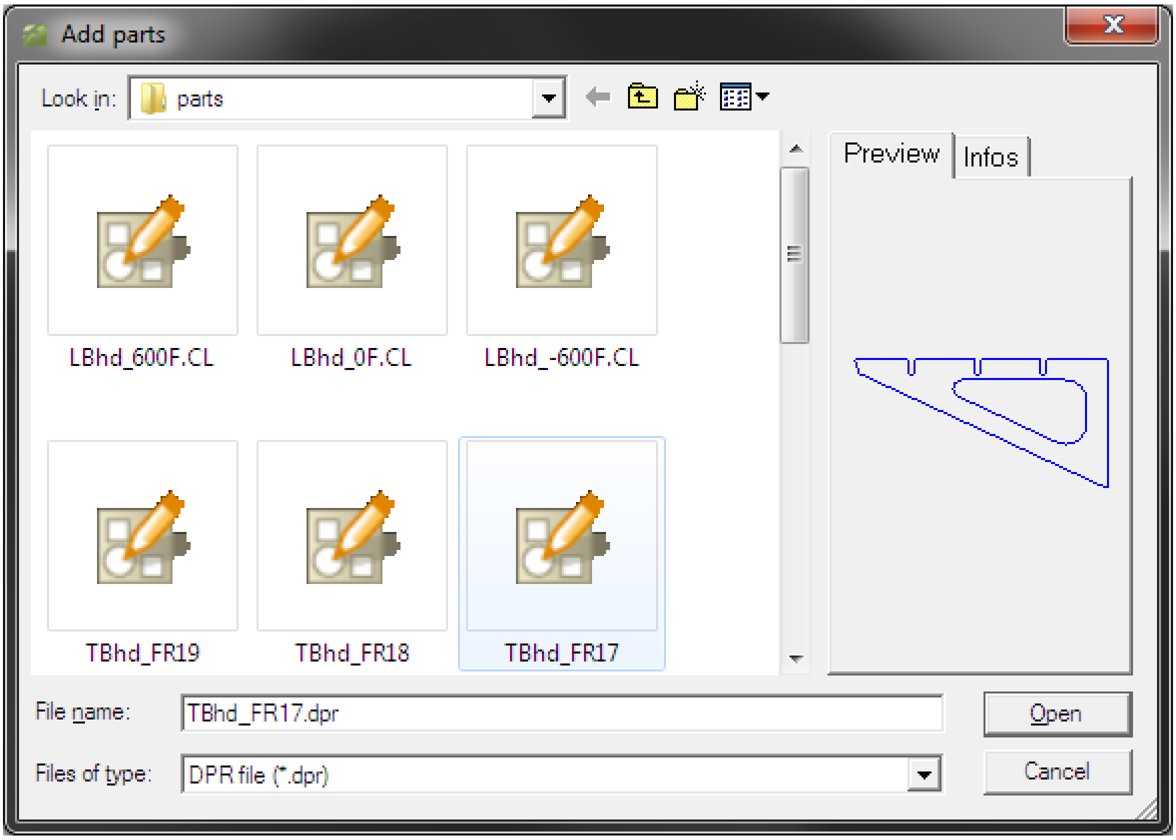


Figure 43: Assigning parts

The assigned parts is displayed under the launching order with filenames, quantities, material and thickness displayed.

When assigning sheets, select the *Sheets*-icon in the tree and press INS (insert) on the keyboard. A sheet appears in the spreadsheet window displaying the parameters plate ID, length, width and quantity. These parameters can be edited in the properties area. The material and thickness parameters is automatically inherited from the assigned parts.

This procedure is repeated until launching orders is created for all plate thicknesses in the assembly.

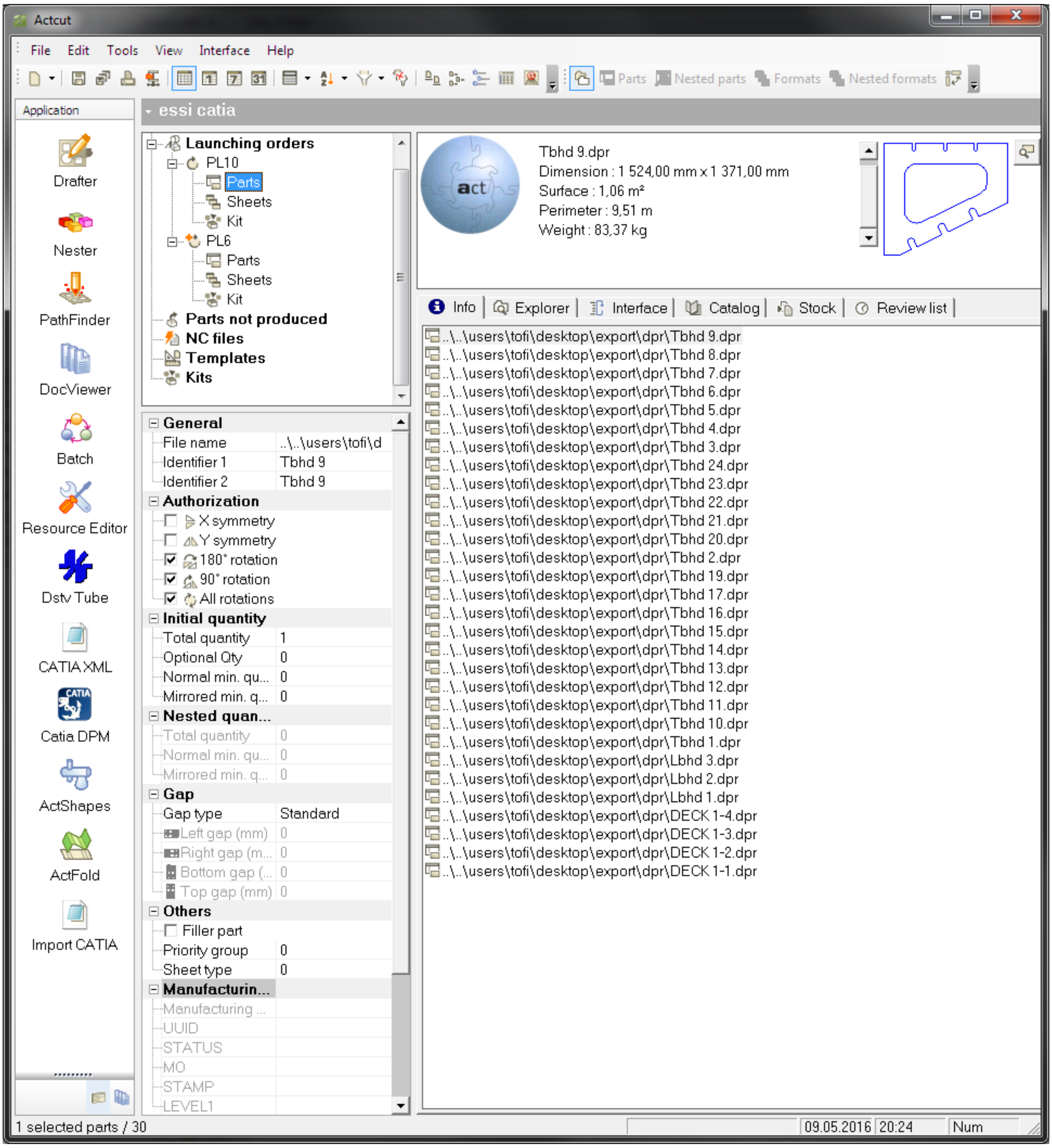


Figure 44: Created launching orders with assigned parts and sheets

STEP III – Nesting

Nesting is a key procedure of the CAM processing. ALMA provide a powerful nesting tool, believed to be one of the most efficient and optimal on the market.

Nester is the tool used for this operation, and is found in the application window of ALMA. Once a launching order is selected and Nester is launched, the application's window will appear displaying the 1st empty sheet in the top window and the assigned parts (including quantity) in the window below.

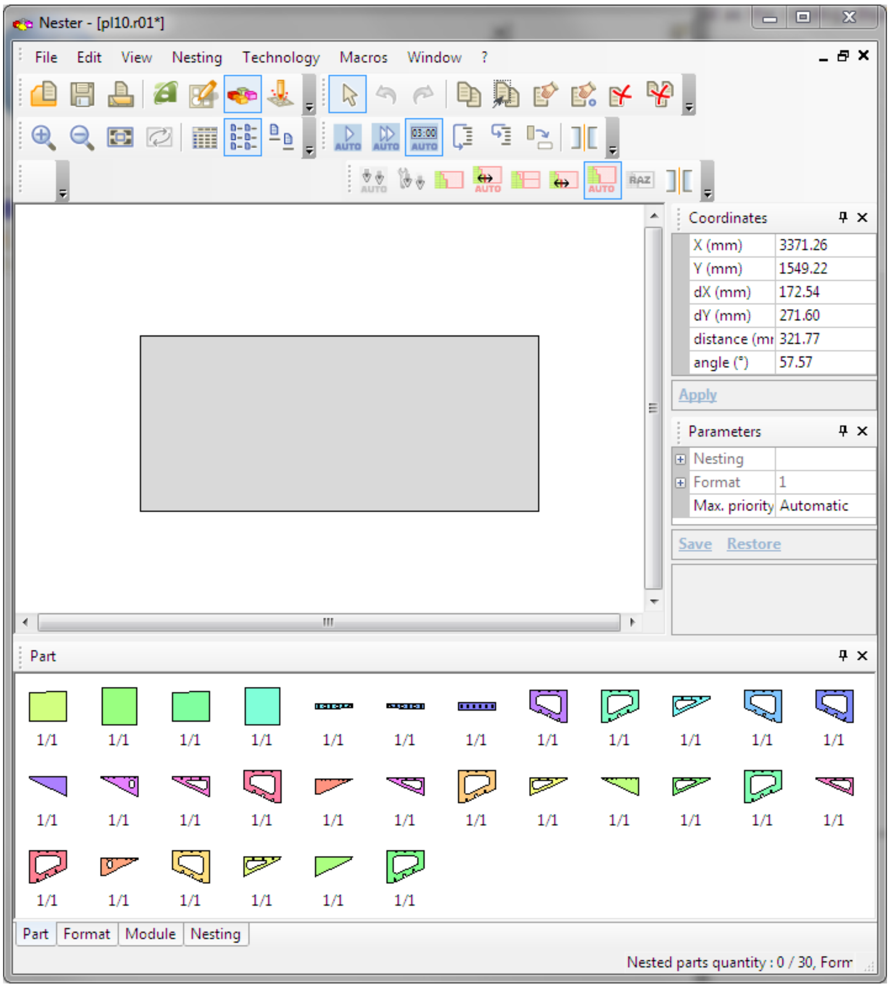
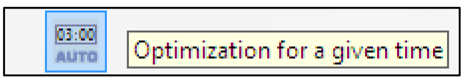
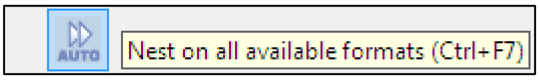


Figure 45: Launching order loaded in Nester

The nesting process can be performed both manually and automatically. In this case, automatic nesting is used. It is possible to perform complete the nesting process almost instantly, but then the application has no time for optimization. Therefore, before initiating the automatic nesting the application is given a maximum of 60 seconds for optimization. This time value is entered in the parameters of the optimization tool, which must be active during the nesting process.



Once the optimization time value is set, the automatic nesting is initiated by executing the automatic nesting command. It is possible to nest on one sheet at the time, or on all sheets at once (one operation). In this case, the nesting on all available sheets is perfromed in one operation.



Once the nesting process starts it will take approx. 60 seconds for both the nesting and optimization to complete. A popup window indicates the progress.

When the nesting process is complete the results can be reviewed. Information available is number of nested parts, remnant (%), used sheets. The nesting itself is displayed in the main window.

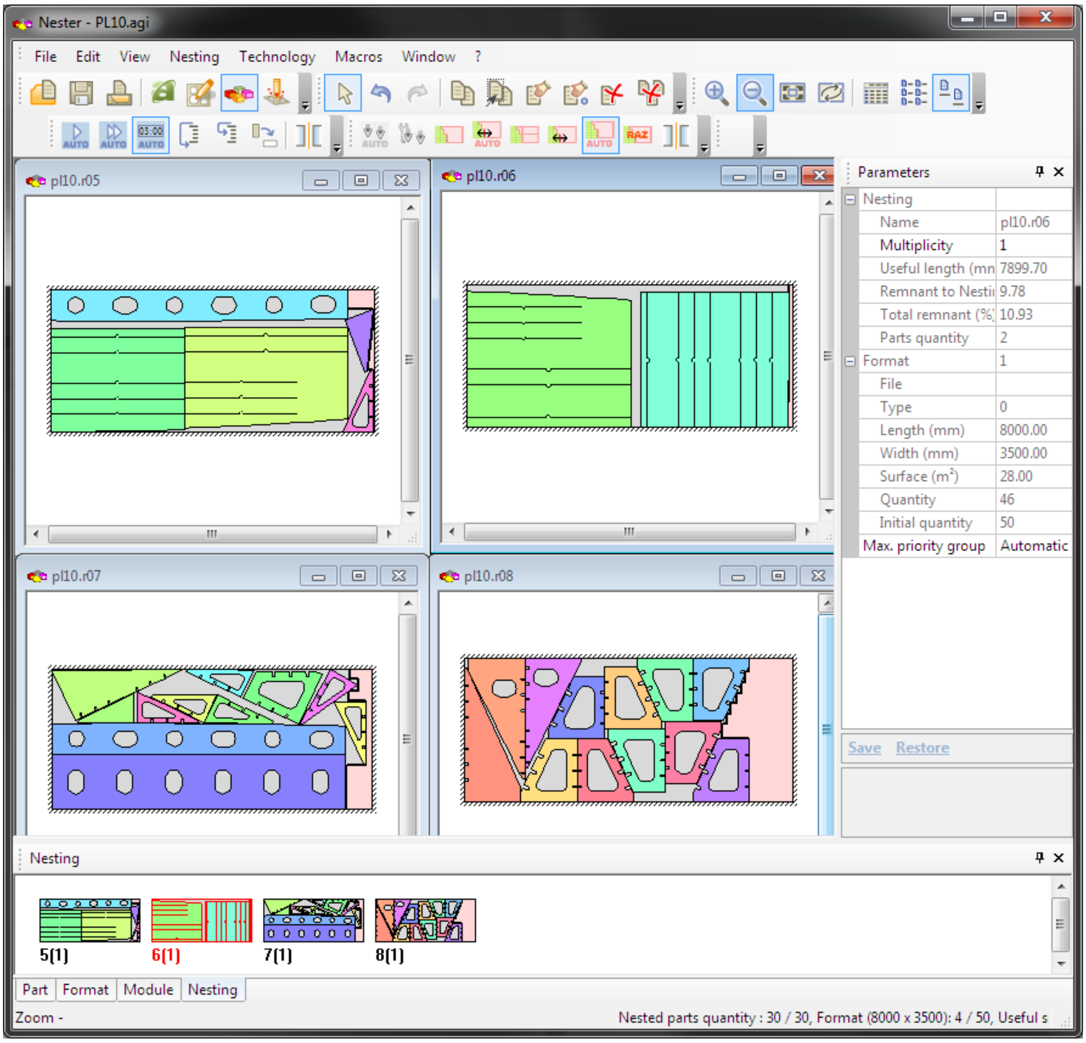


Figure 46: Nesting results

Once a satisfying nesting result is achieved, select *File – Save*, and close the application. The same procedure is performed on all launching orders.

STEP IV – Cutting sequence planning

After nesting, sequencing is the second most important step in the part machining and cutting preparation. Sequencing, which precedes the numerical command (NC) program generation, specifies the cut sequence, which is basically the order in which nested parts are to be cut. Support bridges[15] and connections are also applied here.

The application *Pathfinder* allows both automatic and manual application of the cutting sequence. Once a cutting sequence is applied, Pathfinder also allows simulation of the sequence and adjusting the results if necessary.

Pathfinder is launched by selecting the Pathfinder-icon in the application window. The selected launching order including the corresponding nesting file(s) is displayed in the Pathfinder window. By default, a sequence is already applied once the application is launched.

Bridges is the first feature that is applied to the sequence. Bridges can be placed both manually and automatically. These allows for cutting of multiple parts in one operation, and helps reducing sheet piercing, heat development and machining time. By default, bridges are applied automatically, but can be modified manually.

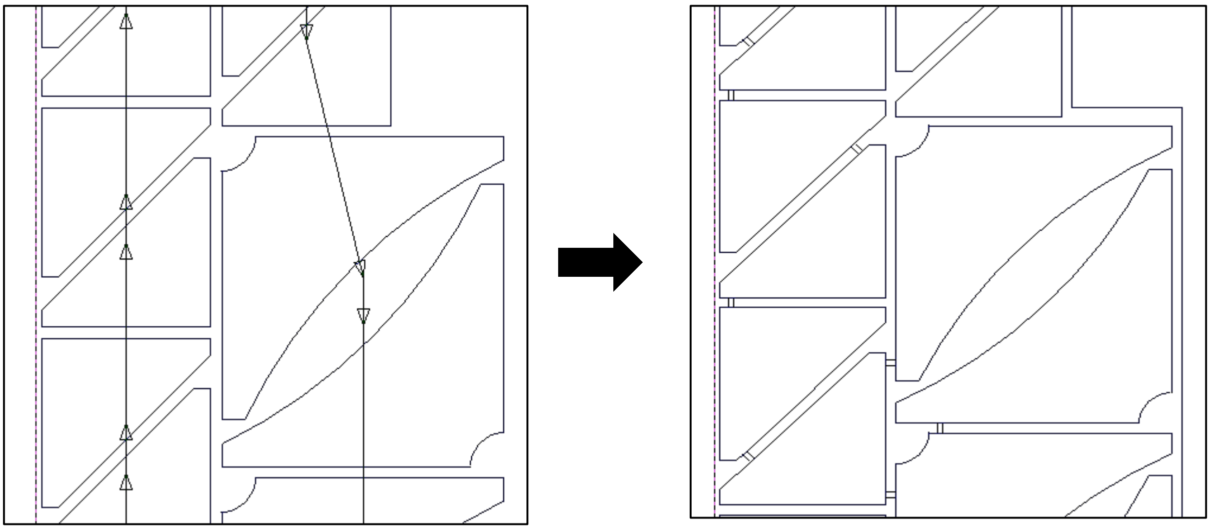


Figure 47: Bridges applied

[15] A piece of material connecting two or more parts, allowing cutting of multiple parts in one operation. This minimizes sheet piercing, time and energy consumption, heat.

The next step is adding connections to the skeleton[16]. These are manually applied to each part, and will keep the whole nested sheet fixed together once the cutting operation is completed. This is helpful when the parts must be removed quickly from the machines cutting table in one lift. Connections are applied by activating the *Connection* tool and simply selecting one or more edges of the nested parts.

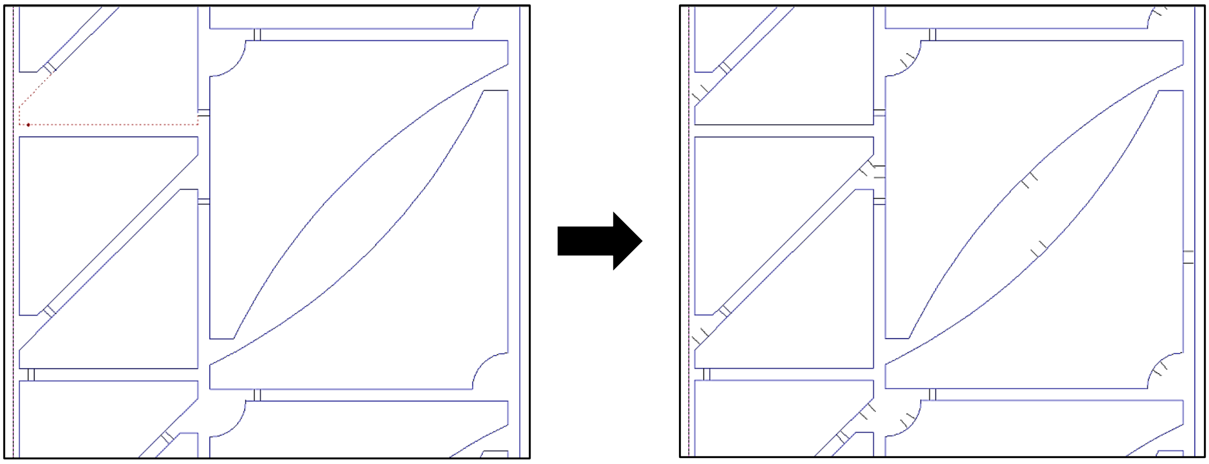
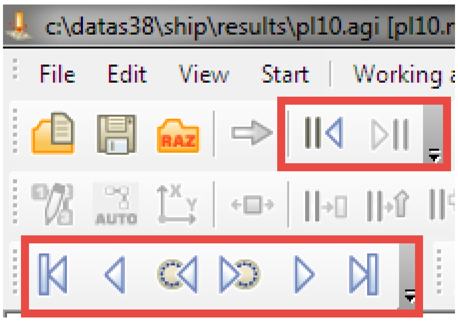


Figure 48: Connections applied

Once bridges and connections is established it is time to review the sequence. Using the navigation tools found in the top toolbar, each operation of the sequence can be reviewed step by step.



When navigating through the sequence, notice that marking of the stiffeners' attachment lines is the first elements to be processed before moving on to cutting the plates.

[16] The «leftover» sheet metal surrounding the nested parts. Also called waste.

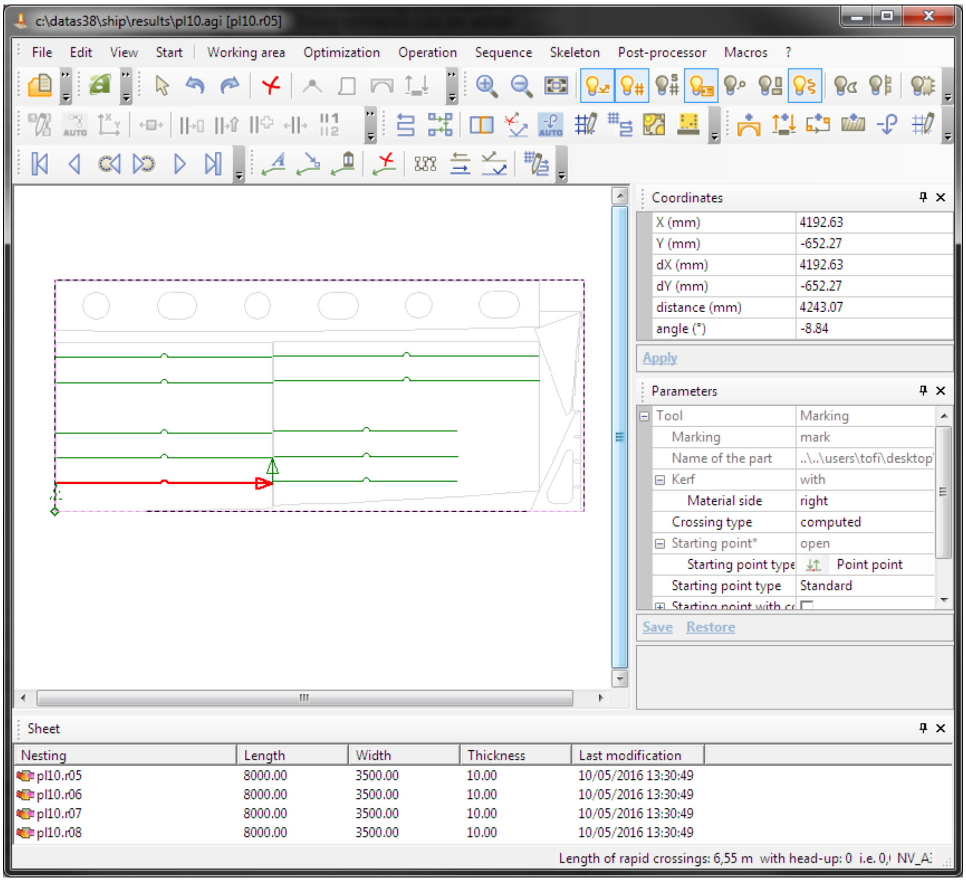


Figure 49: Default cutting sequence

Once a satisfactory cutting sequence is established, the sequence is simulated. While simulating, the software will automatically generate the NC-program. This has to be done separately for each nested sheet in the launching order.

Initiate the simulation by selecting the *Post Processor - Simulation*-icon found on the top toolbar. The progress throughout the sequence is visualized by the tool path.

When the simulation is completed, save the sequence and close the Pathfinder application. The NC-program is found under *NC files* in the tree in ALMA's main window and can be reviewed and edited in Notepad (*right click on file – Open in Notepad*). A NC-program viewer can also be used to review the program.

STEP V – Generate workshop documents

Workshop documents can be created from the launching orders. These hold information about basically the whole launching order such as nested parts, sheet dimensions, NC-program number, cutting length, machining time, bevels, etc.

The document is automatically created by selecting a launching order, and launching the application *DocViewer*. See appendix A-3 for a generated workshop document.

9.1. *Post processing the NC-program*

To cut parts from a sheet metal plate using a CNC cutting machine, regardless of cutting technology, the machine has to be programmed with the path of the desired shape or nest of shapes. Most parts are originally designed using a CAD software such as AutoCAD, SOLIDWORKS, CATIA, or similar software where one can export data in a CAD format. But the exported CAD data cannot be sent directly to the CNC cutting machine without proper processing. First of all, the data has to be processed by a nesting software, which again generate the NC-code. This generated NC is somewhat "generic", and is unreadable to the human eye. For the NC to be readable, it has to be translated into a language which both the machine and the programmer can understand. G-code is the most common language, and is described in section 3.2 earlier in the report.

The "raw" NC-program obtained from the CAM processing in ALMA, is of the generic type, and needs processing. This output is not configured for any specific machine, and does not follow the correct syntax.

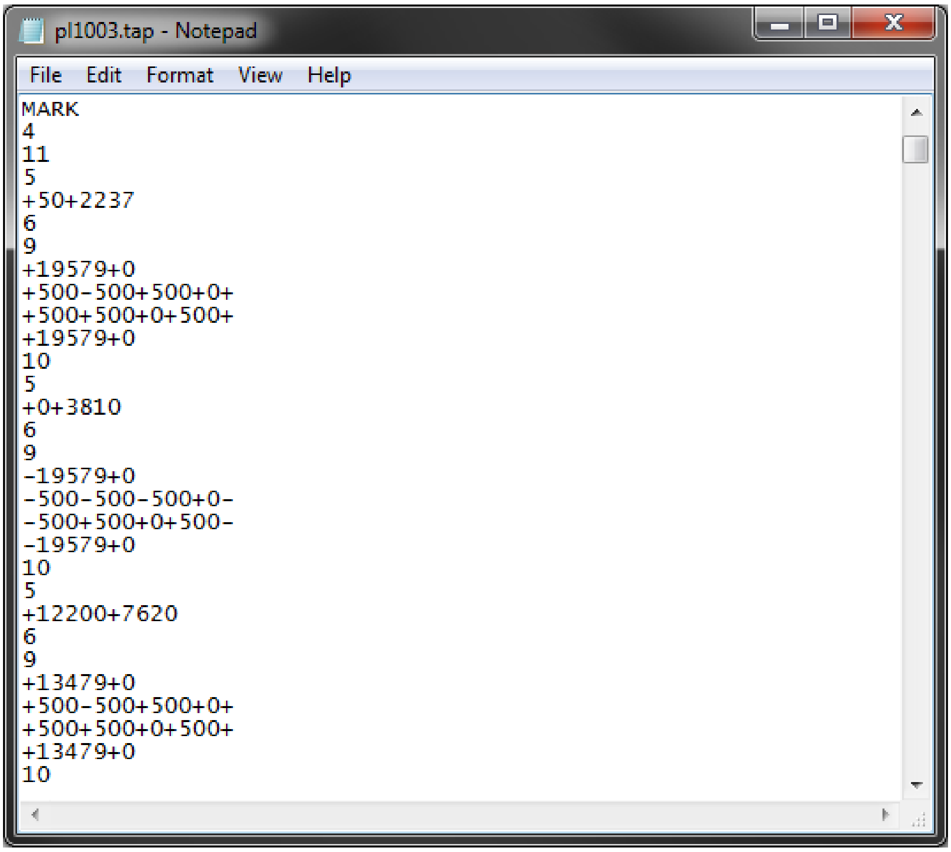


Figure 50: Raw NC-program generated in ALMA

A NC-program viewer can however ensure that the required information is included in the code. The software *Essi Viewer* is here used to confirm that the program satisfies the contents of the generated NC-program

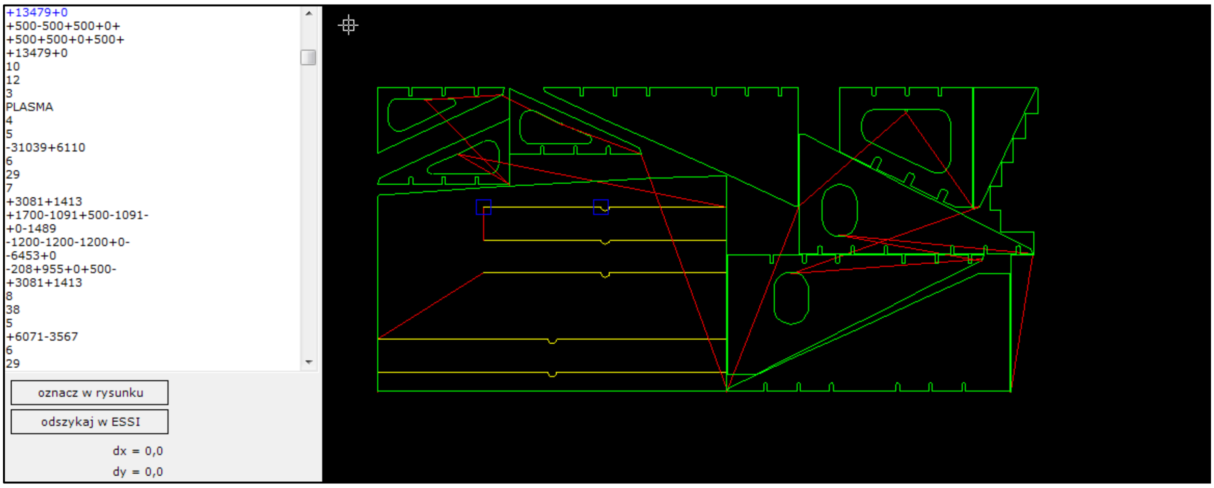


Figure 51: NC-program reviewed in Essi Viewer

Green lines represent cutting, yellow represent marking and red represent rapid torch positioning.

In ALMA's Resource Manager it is possible to configure the software to generate machine specific NC-programs in G-code that is directly compatible with the cutting machine's interface and syntax. This is called post processing, and the program performing the operation is called a post processor. Through dialogue with the distributor of ALMA, it was stated that development of a post processor is done in cooperation with ALMA and the customer, provided that the customer has purchased the software (in this thesis a free trial version has been used).

It is also possible to run the NC-program through post processor from an external software provider. The cutting machine vendors usually offers both nesting and post processing software alongside with the machines they distribute.

10. DISCUSSION

This chapter discuss the resulting method reached in the preceding chapters. In particular, the discussion will focus on three areas: Firstly the methods concerning establishing a design, planning the assembly and manufacture preparation in 3DEXPERIENCE. Secondly the challenges around data export and import. Finally the CAM processing of the data in ALMA.

10.1. Design , assembly planning and manufacture preparation

The data creation during this project is performed using Dassault Systèmes' 3DEXPERIENCE as both a design and digital manufacturing tool, respectively CATIA and DELMIA. A more or less realistic design model is established, including the structural details which is commonly found in a ship unit. However, in order to achieve an even more realistic case, a functional design of the whole vessel can be established before moving on to the Structure Design stage. This would have enlighten possible challenges upon the block and unit division of the model. In this thesis only a single unit of a vessel is designed, making the division process absent.

Slots and collars are important design features that are to be included in any structural design model. These are parametric features available in various types, and is found in the project's resource library. However, in Kleven's design environment these design features are not working properly at the moment, because they have not been configured yet. They should have been included in the established design, and would have added some extra complexity to the exported data. Yet, custom made slots is included. These are created with sketches, which is a very time consuming process. However, they has the same function as the intentional parametric slots. Collars can also be created using this method (even more time consuming).

Other than these issues, the design process in 3DEXPEIENCE is very intuitive and easy to operate. The user interface is simple, yet advanced enough for taking on the demanding task of designing a vessel, and includes the tools and applications to apply all elements required.

The well visualized appearance and simple user interface is present also in 3DEXPERIENCE's other applications as well, which can be seen upon the transition from CATIA to DELMIA. In DELMIA the assembly planning and manufacture preparation is performed. The assembly planning can be performed automatically, but it is recommended that this is done manually in order to establish the breakdown structure or assembly procedure which replicates the real life procedure at the shipyard. If an automatic approach is preferred, the algorithm/program creating the breakdown structure needs to be altered to output a more desirable structure, standardized for the company's newbuilding projects and their production facility.

When applying manufacturing features, some of the weak sides of 3DEXPERIENCE is revealed. The software occasionally crashes, and needs to be restarted. Upon restarting a restore function offers to restore the previous session. This function does not work, and the software crashes upon restoring as well. If saving the session is done frequently, this is not a big issue. However, if not saved, repeating a great amount of the work is the only option. What causes the crashes is unknown. It may sometimes be experienced upon deleting features, exporting data or simply just occur.

The shrinkage planning tool may seem a bit “simple”. This considering the compensating is done by adjusting ratios or the proportionality of the plate size. Integrating a smarter tool which considers the variables of applied heat, material and dimensions, and then calculates the required compensation may be more convenient.

Some visual “bugs” is also experienced. Upon applying shrinkage compensation on a plate, the change is not visualized on the plate’s geometry. But when comparing the original with the compensated plate (measuring) it is confirmed that the function works as intended.

Apart from these issues, the used digital manufacturing tools in 3DEXPERIENCE performs very well.

10.2. Data export/import

The manufacture prepared design data is exported from 3DEXPERIENCE using built in tools. The first challenge is to identify the data formats which is compatible with both 3DEXPERIENCE and the CAM software (ALMA Act/Cut). These has proven to be IGES (3D), DXF (2D) and XML (code). The three formats has been evaluated in terms of data quality and the complexity of export/import.

IGES export proved to be the least advantageous. Firstly, the process of exporting is highly complex, and very time demanding due to the lack of batch export options. Upon import to ALMA, manufacturing features is not included either. Yet, as this is a 3D format, the plate thickness is included.

Export in the XML format is a more promising story. Marine Structure Fabrication features a tool intended for the export in this format, and ALMA features a corresponding tool for the data import. The whole export operation can be performed in one operation, making it a very efficient method. Import to ALMA is also performed in one operation, and at the same time the data is converted to the DPR format (native file format in ALMA). Plate thickness is applied automatically. However, the quality of the imported data is not satisfactory. Many plates are missing contour, and only showing openings and text marking. Yet, parametric plates such as brackets is fully defined upon import, which is a bit strange. This may be due to a faulty XML code generator, which needs to be re-programmed.

DXF proved to be a satisfying export format regarding the data transfer. Also here Marine Structure Fabrication features a tool for exporting DXF representations of the plates. With a multiple selection option and lightweight format, the export process is very efficient. The quality of the data upon import is currently far better than the other formats, but the plate thickness needs to be applied manually. Some “cleaning” of the imported data is required, such as removing excessive marking and lines.

10.3. CAM processing

The CAM processing is as mentioned performed in the software ALMA Act/Cut. Much like 3DEXPERIENCE, ALMA offers features applications for various types of technologies, but for Kleven’s case, plasma cutting is the applicable one. Three applications within this technology is relevant: Drafter, Nester and Pathfinder.

Drafter is a drafting tool used for import of DXF data, “cleaning” the geometry, applying thickness and material, and finally saving data in the DPR format. This is a bottleneck process because all parts of the assembly needs undergo this procedure. However, an algorithm or a program may be developed to automatically transform the DXF files into DPR

Nester is the where parts with common thickness and material is nested onto their respected steel sheets. Powerful algorithms ensures that parts are automatically nested in the most optimal manner, reducing the raw material waste to a minimum. Manual nesting is also an option, and is recommended in some specific cases.

Pathfinder allows the user to plan the cutting sequence, apply bridges and connections. A cutting sequence that is the least time consuming and heat developing is applied automatically. The sequence can also be applied and edited manually. Further, a simulation of the sequence is launched, and the NC-program and workshop documentation is generated at the same time. The NC-code output is not readable as is, and will require post processing in order to be used as machine input. This can be done by modifying ALMA, adding an internal post processor within the software. ALMA’s distributor informs that this is a task usually performed by their company once the customer has purchased their product.

10.4. Further work

Kleven is currently still running pilot projects on implementing the 3DEXPERIENCE platform and it is reasonable to believe that it will take some time before they are ready to fully operate the platform in live newbuilding projects. This means that they will still be working with purchased design data for a few more years. If this data can be prepared for manufacturing internally, Kleven will only have to purchase the design, and not the manufacturing data (NC programs and documentation). Eliminating this major cost element will cause both economic benefits, and reduce the work of re-processing unsatisfactory data (common with purchased nesting data).

Manufacture preparation of data that is not native to 3DEXPERIENCE has not yet been tested. However, purchased data has been used for robot programming for a few years at Kleven. This is performed in a former version of DELMIA, and has proven to be a feasible solution. With that in mind, it is absolutely worth the effort to investigate the options of performing manufacture preparation on this kind of data.

11. CONCLUSION

This thesis has focused on developing an applicable method or procedure for design, digital manufacturing and CAM processing. This in order to establish the information required for the initiation of sheet metal cutting on the work floor. Through practical research in form of a realistic case study, focused on Kleven Shipyard’s current situation, a descriptive method has been developed. Essential variables such as planning for welding distortion, informative marking of parts and edge preparation has been taken into consideration.

Also data management has been investigated and evaluated. This concerns the export and import of file formats that have compatibility between the respective software used. Three formats were evaluated, IGES, DXF and XML. IGES proved to be the least beneficial file format, due to the complexity of the export operation and lack of included information in the data. Regarding the XML format, a malfunction in the code generator prevented any applicable results (however, a successful export using this method has been demonstrated by DS during the workshop at Kleven). The DXF format proved to be the most feasible export format. It includes sufficient information and the export of data is a rapid operation.

The results of implementing the methods described in this thesis will bring Kleven one step closer to performing the respective processes more independently. As the company is today relying on purchased data from vendors, the method will also contribute to economic benefits by reducing the cost of purchasing these services. At the same time it will contribute in educating personnel on the technology and tools the company currently possesses.

In the current case of sheet metal cutting, Kleven has had troubles with the purchased NC-programs. The nesting has been of a poor quality, forcing them to redo the procedure internally by using a software called Nestix (compatible with the vendor’s design data). By implementing the presented method, it is expected that CAM processing in ALMA will bring more desirable/successful outcome, because it is to be performed by internal personnel which is familiar with Kleven’s technology, tools and procedures.

The work performed throughout this thesis has been highly educational for the candidate, and has enlightened areas of digital manufacturing which has earlier been unclear. The resulting method that is established will hopefully help with contribution to economic benefits and increased knowledge not only for Kleven and the shipbuilding industry, but also other instances or industries that may consider 3DEXPERIENCE and ALMA as software solutions.

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APPENDIX

A-1 Comparison of shrinkage compensated and original plate

The comparison is done on exported plate data (DXF), and is compensated with a factor of 1,1 in both U and V direction. The comparison is done in AutoCAD 2016.

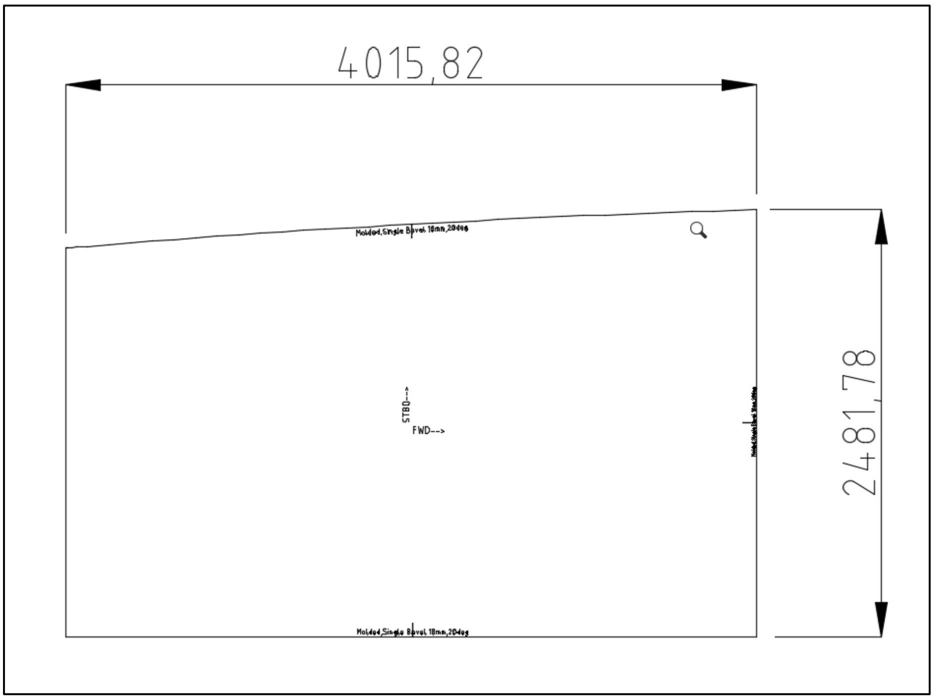


Figure 52: Original plate (no compensation)

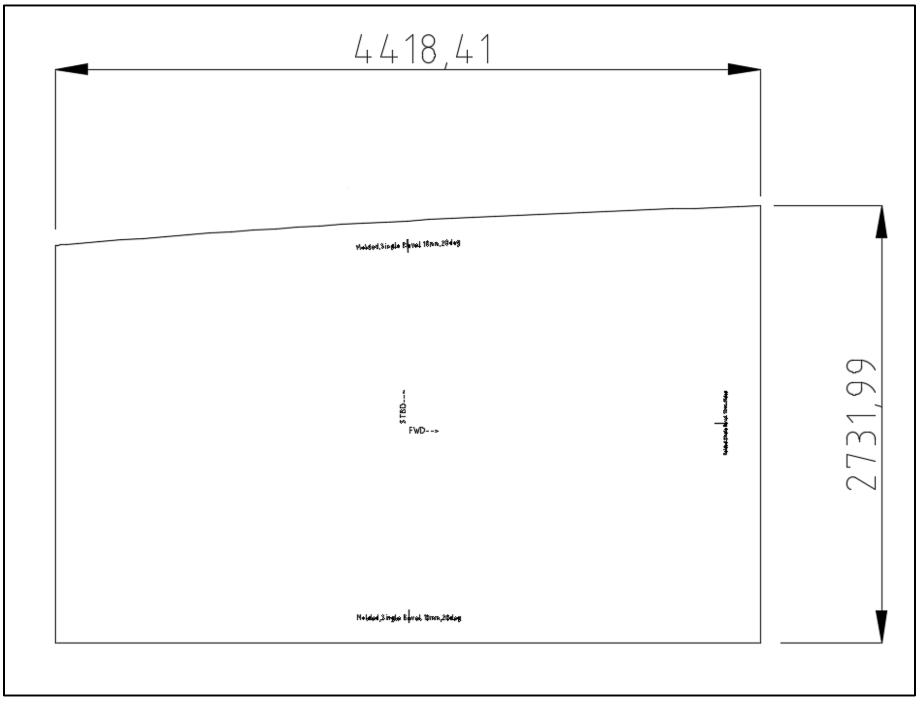


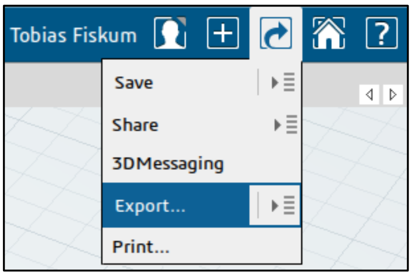
Figure 53: Shrinkage compensated plate

A-2 *Process description: Export and import of parts*

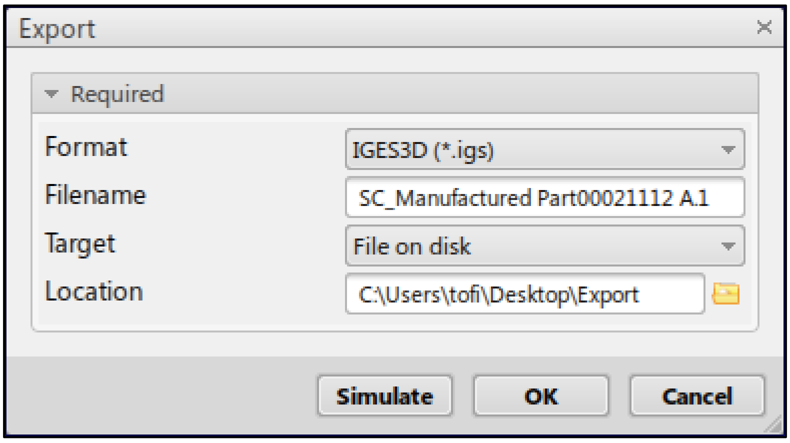
IGES export from 3DEXPERIENCE

1. Make sure the current workbench is DELMIA - Marine Structure Fabrication.
2. Select the desired manufactured part in the breakdown structure. Note: ALMA does not interpret assemblies/sub-assemblies correctly, so single parts must be selected (manufactured parts).
3. Select the command called *Open Resulting Product*. The part will open in a separate tab.

4. Select the *Share* function followed by *Export*.



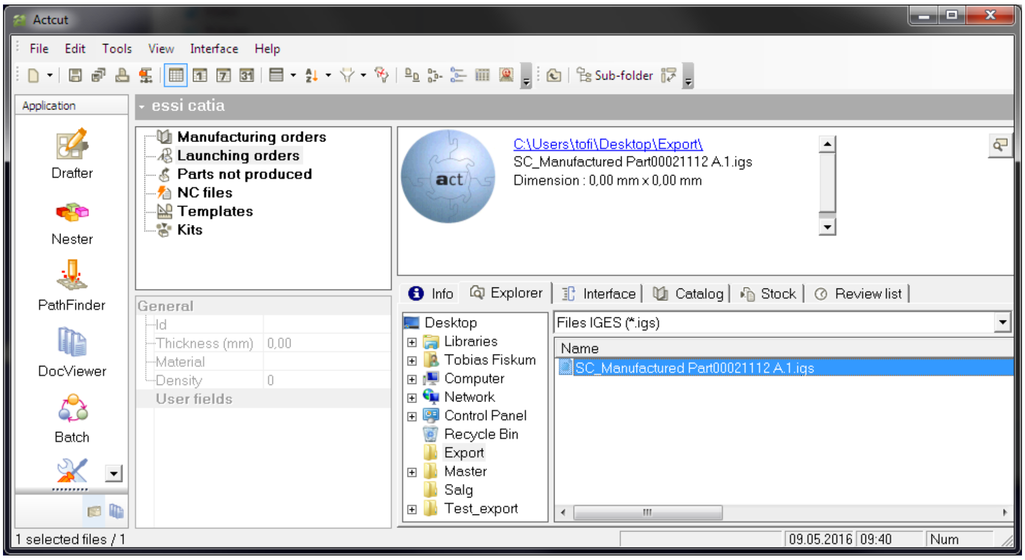
5. When the export window appears, select IGES3D as format. The file can be exported to a local directory, or an exchange space (cloud). Select OK. Note: The name of the file will be assigned a default name, and it is recommended to change this to a more project specific name.



6. Once the operation is completed, the exported data is found in the target location.

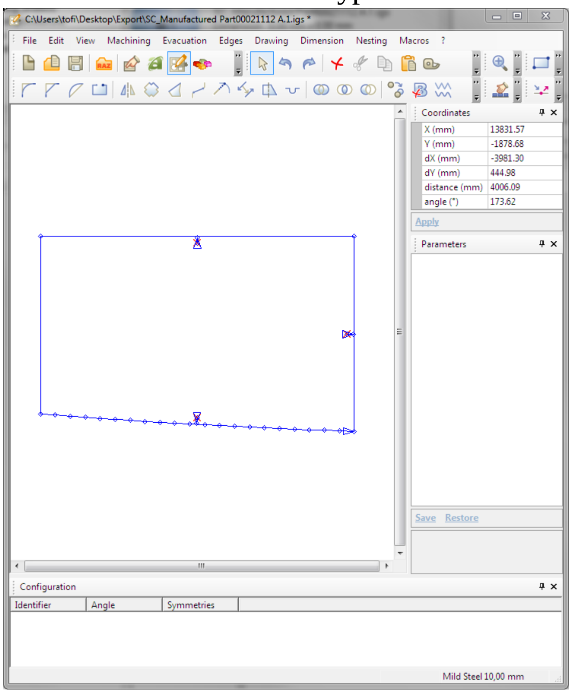
IGES import to ALMA

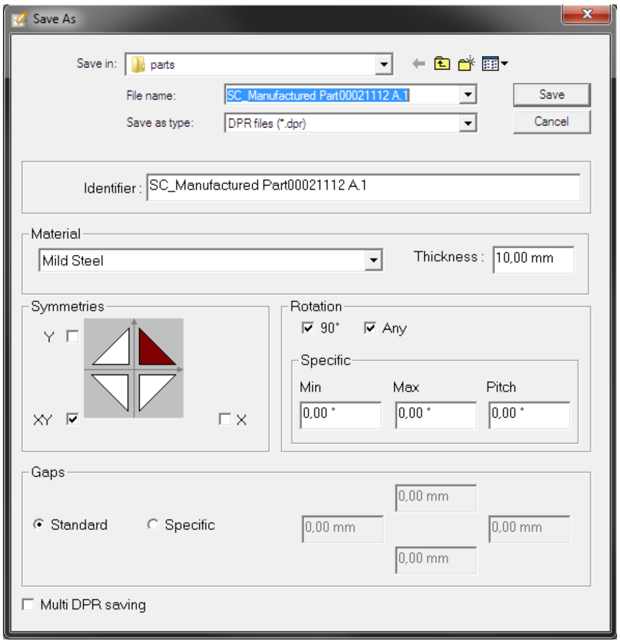
1. Launch ALMA Act/Cut software. In the main window select the *Explorer* tab and navigate to the export target location. Make sure file type is set to IGES. The exported file will appear in the *Explorer* window.



2. Right click on the IGES-file, and select *Open with → Drafter*. The drafter application will start. The part is shown in Drafter.

3. If needed, perform modifications of the part in Drafter. When ready, select *File → Save As*. Select desired save directory and type in a desired identifier (name) for the part, and select DPR as filetype. The material and thickness is automatically applied. Click save.



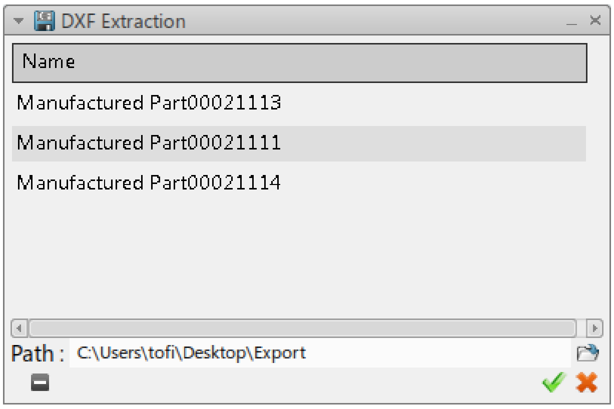


The DPR file is created and saved under the selected directory.

DXF export from 3DEXPERIENCE

1. Make sure the current workbench is DELMIA - Marine Structure Fabrication.
2. Select the command called *Extract DXF Documents*. A selection window will appear.

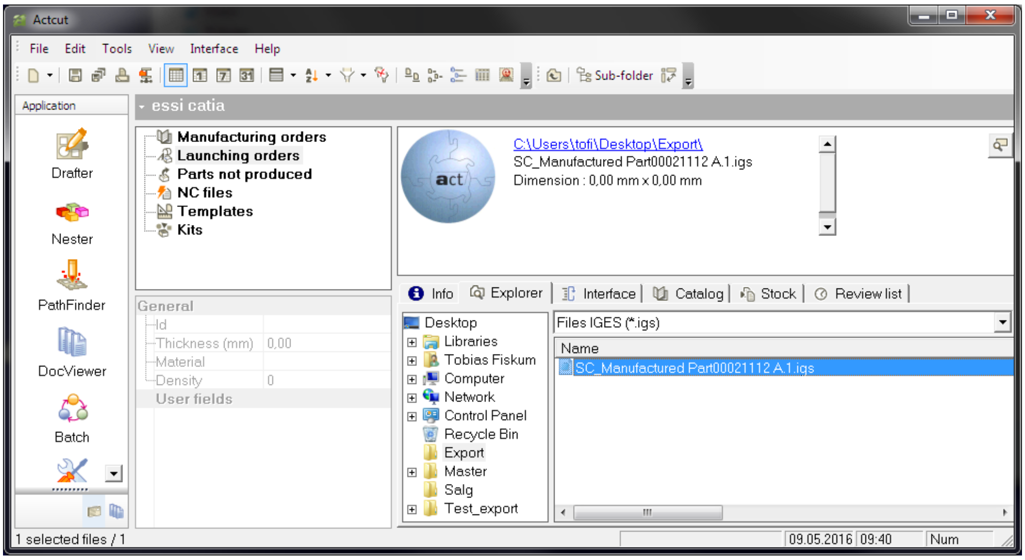
3. Select the desired manufacturing assembly (sub-assembly) or manufactured part (single plate) in the breakdown structure. Multiple selections is possible. Specify the directory path where the exported files shall be saved, and click the *Launch*-button 



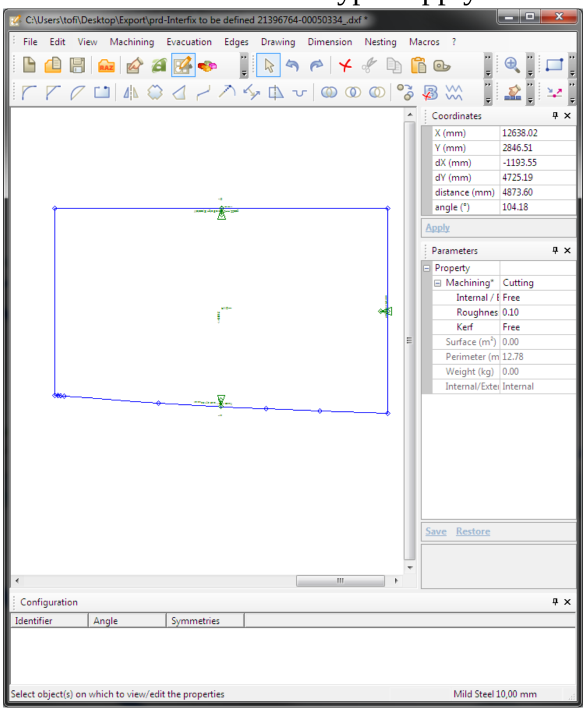
4. Once the operation is completed, the exported data is found in the target location (path).

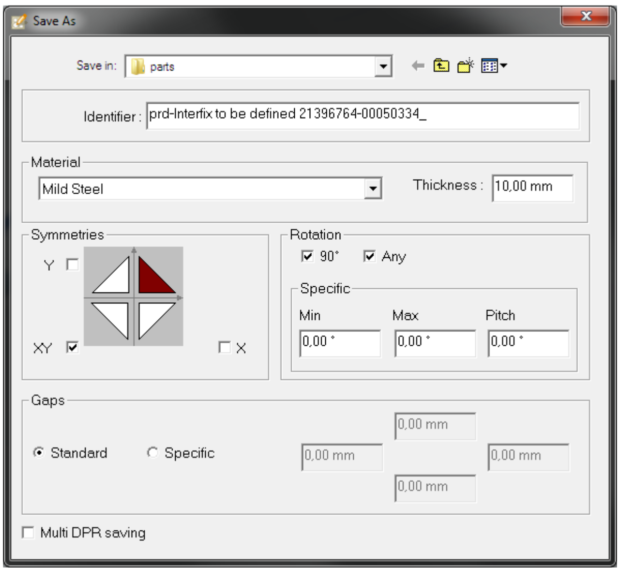
DXF import to ALMA

1. Launch ALMA Act/Cut software. In the main window select the *Explorer* tab and navigate to the export target location. Make sure file type is set to DXF. The exported file will appear in the *Explorer* window.



2. Right click on the DXF-file, and select *Open with → Drafter*. The drafter application will start. The part is shown in Drafter.
3. If needed, perform modifications of the part in Drafter. When ready, select *File → Save As*. Select desired save directory and type in a desired identifier (name) for the part, and select DPR as filetype. Apply material type and thickness manually. Click save.



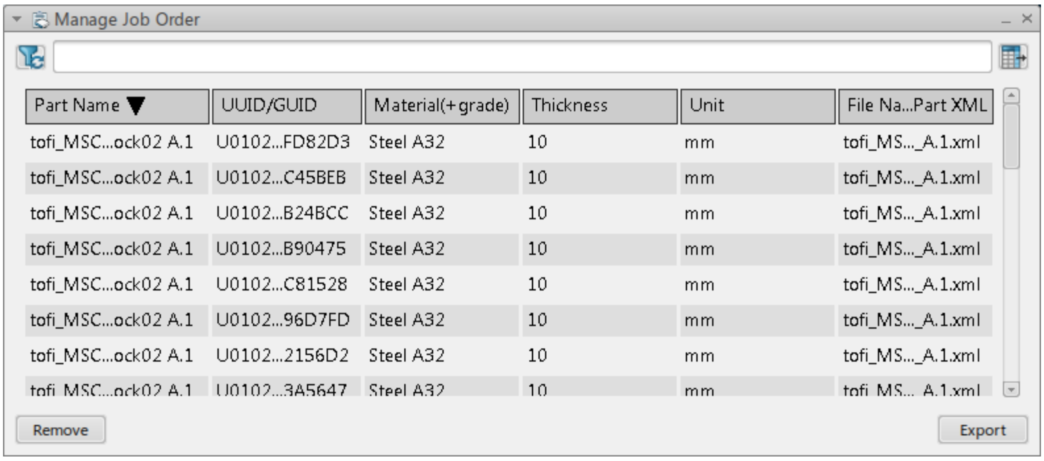


4. The DPR file is created and saved under the selected directory

XML export from 3DEXPERIENCE

1. Make sure the current workbench is DELMIA - Marine Structure Fabrication.
2. Select the command called *Plate Job Order List*. A selection window will appear.

3. Select the desired manufacturing assembly (sub-assembly) or manufactured part (single plate) in the breakdown structure. Multiple selections is possible. The fully assembled unit can also be selected, if all plates are to be exported. The selected plates will appear on the list, showing the plates' name, ID number, material, thickness, etc. There is no selection of target directory for this function. When ready, select *Launch.*

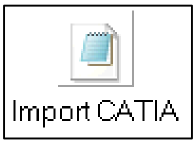


4. Once the operation is completed, the exported data is found under the directory: *C:\Users\Username\AppData\Local\DassaultSystemes\CATTemp\ALMA\Project title*. Also a spreadsheet containing information on the exported data is automatically generated and placed in the same directory.

XML import to ALMA

1. Navigate to the project's XML export location. Select all files and copy (include CopyOut.csv). Navigate to the following directory and paste all copied files: *C:\Datas38\import.*

2. Launch ALMA Act/Cut software. Run the application named *Import CATIA*, found in the application area. The application will start importing the XML files, and automatically creates generates the DPR files.



3. The import progress is shown in a popup window. If errors occur upon importing, an error message is displayed together with a log file.

4. The generated DPR files are now located under the following directory: *C:\Datas38\Project title.* The imported XML files are moved to the directory: *C:\Datas38\import\treated.*

5. In the main window select the *Explorer* tab and navigate to the import target location. Make sure file type is set to DPR. Open the DPR files in *Drafter* and make necessary modifications. Save files once the data is satisfactory.

A-3 Generated workshop document (ALMA)

pl10.n03 1 / 2

Nesting name	PL10.R03	NC program no.	89
Machine	PLASMA	Nesting no.	3 / 4

SHEET

Dimensions	**8000 X 3500 X 10 mm**
Weight	**2198.0 kg**
Identifier	
Material	**NV_A36**
Remnant	

EFFICIENCY

Useful dims.	**7600 X 3504 mm**
Multiplicity	**1**
Total waste	**25.91 %**
Front Remnant	**19.05 %**

MACHINING TIME

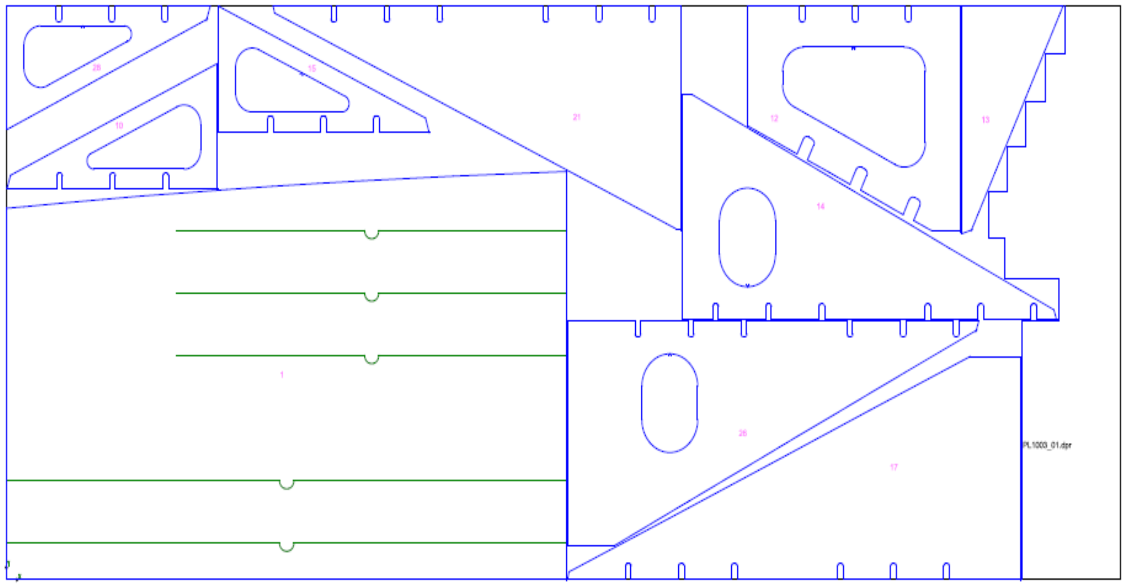
Rapid crossings length	29.051 m	00:00:24
Nb markings	5	
Marking length	16.705 m	00:03:20
Nb starting points	17	00:00:00
Cutting length	88.660 m	00:44:20
Nb pos/neg bridges	0 / 0	
Nb stops	0	00:00:00
Machining time		**00:48:05**

BEVELS

Type	Length	Time
I	88.660 m	00:44:20

SEQUENCE

Sequence	Number of heads	Gap



PARTS LIST

No.	Name	Qty	Reference	Dimensions	Surface	Weight
1	DECK 1-1	1	DECK 1-1	4016 X 2482 mm	9.589 m²	752.7 kg
10	Tbhd 11	1	Tbhd 11	1509 X 763 mm	0.410 m²	32.2 kg
12	Tbhd 13	1	Tbhd 13	1524 X 1371 mm	1.062 m²	83.4 kg
13	Tbhd 14	1	Tbhd 14	1389 X 731 mm	0.550 m²	43.2 kg
14	Tbhd 15	1	Tbhd 15	2686 X 1371 mm	1.716 m²	134.7 kg

PARTS LIST

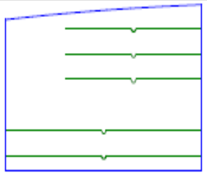
No.	Name	Qty	Reference	Dimensions	Surface	Weight
15	Tbhd 16	1	Tbhd 16	1509 X 763 mm	0.410 m²	32.2 kg
17	Tbhd 19	1	Tbhd 19	3253 X 1356 mm	2.480 m²	194.7 kg
21	Tbhd 22	1	Tbhd 22	2933 X 1356 mm	2.046 m²	160.6 kg
26	Tbhd 5	1	Tbhd 5	2956 X 1371 mm	2.086 m²	163.7 kg
28	Tbhd 7	1	Tbhd 7	1459 X 751 mm	0.396 m²	31.1 kg

pl10.n03

Nesting name	**PL10.R03**	NC program no.	**89**
Machine	**PLASMA**	Nesting no.	**3 / 4**

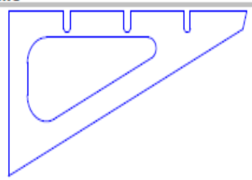
PARTS DETAILS

Name DECK 1-1



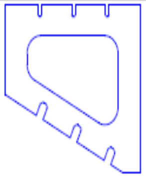
Reference	DECK 1-1
No.	1
Qty	1
Dimensions	4016 X 2482 mm
Perimeter	12778 mm
Surface	9.589 m²
Weight	752.7 kg
Time	00:07:22

Name Tbhd 11



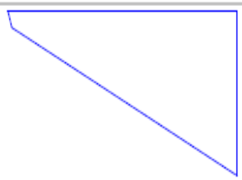
Reference	Tbhd 11
No.	10
Qty	1
Dimensions	1509 X 763 mm
Perimeter	6560 mm
Surface	0.410 m²
Weight	32.2 kg
Time	00:03:47

Name Tbhd 13



Reference	Tbhd 13
No.	12
Qty	1
Dimensions	1524 X 1371 mm
Perimeter	9511 mm
Surface	1.062 m²
Weight	83.4 kg
Time	00:05:29

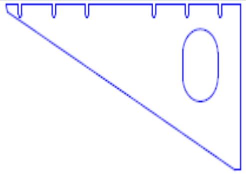
Name Tbhd 14



Reference	Tbhd 14
No.	13
Qty	1
Dimensions	1389 X 731 mm
Perimeter	3712 mm
Surface	0.550 m²
Weight	43.2 kg
Time	00:02:08

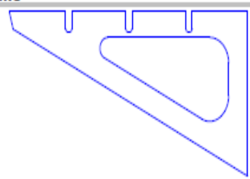
PARTS DETAILS

Name Tbhd 15



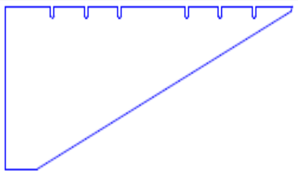
Reference	Tbhd 15
No.	14
Qty	1
Dimensions	2686 X 1371 mm
Perimeter	9817 mm
Surface	1.716 m²
Weight	134.7 kg
Time	00:05:39

Name Tbhd 16



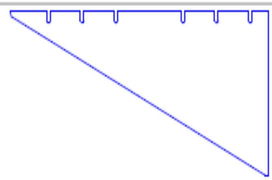
Reference	Tbhd 16
No.	15
Qty	1
Dimensions	1509 X 763 mm
Perimeter	6560 mm
Surface	0.410 m²
Weight	32.2 kg
Time	00:03:47

Name Tbhd 19



Reference	Tbhd 19
No.	17
Qty	1
Dimensions	3253 X 1356 mm
Perimeter	9242 mm
Surface	2.480 m²
Weight	194.7 kg
Time	00:05:19

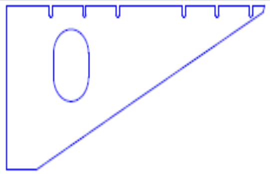
Name Tbhd 22



Reference	Tbhd 22
No.	21
Qty	1
Dimensions	2933 X 1356 mm
Perimeter	8602 mm
Surface	2.046 m²
Weight	160.6 kg
Time	00:04:57

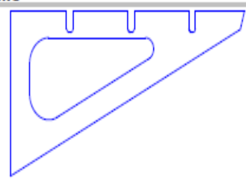
PARTS DETAILS

Name Tbhd 5



Reference	Tbhd 5
No.	26
Qty	1
Dimensions	2956 X 1371 mm
Perimeter	10356 mm
Surface	2.086 m²
Weight	163.7 kg
Time	00:05:58

Name Tbhd 7



Reference	Tbhd 7
No.	28
Qty	1
Dimensions	1459 X 751 mm
Perimeter	6342 mm
Surface	0.396 m²
Weight	31.1 kg
Time	00:03:39

A-4 Article draft: Creating and processing ship design data for sheet metal cutting

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Abstract
The process from the creation of a design to the initiation of production in the shipbuilding industry is a complex procedure. Recently more and more shipyards has started moving away from traditional shipbuilding methods. Production processes are being automated, and engineering and design digitalized.

Kleven is a company that is investing a great amount in modernization and automatization of the shipyard's production facility, and is currently working on moving much of the engineering work onto the digital PLM platform, 3DEXPERIENCE. The development is still a project in progress, yet much is successfully operational today.

One of the remaining challenges is to figure out to connect 3DEXPEIENCE with the process of sheet metal cutting on the production floor. Through the development of work methodology for modelling, digital manufacturing and CAM processing of a ship design data, where the output is documentation intended for the sheet metal cutting of plates; the initial stage of hull production.

By using state of the art digital tools, a best practice is developed, bringing Kleven one small step closer to their goal of reducing manual labour in the production and to gain highly valuable competitive benefits.

1. Introduction

Kleven is a Norwegian shipbuilding company that has for many years outsourced most of the design and engineering tasks involved in the shipbuilding process. Kleven's current approach is to purchase complete design packages from external design companies. Apart from drawings and 3D data, these packages contains NC programs for sheet metal cutting, completed with nesting[17] and sequencing[18]. This cutting documentation has proven to be unsatisfactory, and the work often has to be re-done internally by Kleven's production department.

Kleven is currently investing a great amount of funds in the development and modernization of their production plant and engineering platform. By implementing the PLM tool 3DEXPERIENCE developed by Dassault Systemes, Kleven is thriving to perform more of the design and engineering internally. The implementation is still in development, yet much is

[17] Optimized arrangement of parts to be cut from a sheet of metal. The parts are arranged within the boundaries of the sheet, with a goal of minimizing remnants and waste.
[18] Planning of the cutting sequence. Preferably optimized in terms of short machining time and minimizing of sheet piercing.

operational today. One of the remaining objectives is to eliminate the extra work following the unsatisfactory sheet metal cutting documentation.

This paper focuses on a best practice method on how the shipyard can create ship design data internally, and further process the data so that it can be used as documentation for the sheet metal cutting process. The method is to be compatible with the digital engineering tools that is available at the shipyard; 3DEXPERIENCE as the PLM solution, and ALMA Act/Cut as the CAM[19] solution.

2. Overview of the digital engineering tools

Dassault Systemes' 3DEXPERIENCE is a state of the art engineering platform. Referred to as a *business experience platform*, the software is directed towards a variety of industries such as transportation, aerospace, marine & offshore, industrial equipment, finance, consumer goods retail, just to mention a few. 3DEXPERIENCE provide its industry-leading applications under the brands CATIA (design and engineering), DELMIA (manufacturing and production), SIMULIA (simulation and analysis) and ENOVIA (cloud based data management[20]).

3DEXPERIENCE features a unique user interface, consisting of applications provided by hosted services. These tied together in a single interface, allowing the user to operate all applications in the same digital environment.

Act/Cut is a CAM software developed by ALMA that specializes on cutting technologies. It offers compatibility with various shipyard-dedicated design solutions and is able to import 2D-, 3D- and coded file formats. A simple, yet advanced user interface allows the user to efficiently perform editing, nesting, sequencing and simulation of the sheet metal cutting procedure. Workshop documentation and NC programs is automatically generated by the software.

[19] Computer Aided Manufacturing

[20] "On-demand computing": Internet based storage solutions which provide users and enterprises with various capabilities to store and process their data.

3. Establishing a design

Due to the high level of complexity of a ship's unit/section, mistakes will most likely be made during the design stage. Therefore it is crucial that the design is flexible enough so that it is receptive to modifications/corrections without introducing a lot of extra work when edited.

All 3D modelling is performed in 3DEXPERIENCE by operating applications under the CATIA-domain. Specifically three applications is used:

1. *Space Referential*: Definition of the vessel's main particulars; length, width and height. Establishment of a reference plane system will reference design features correctly according to the vessels global origin.
2. *Structure Functional Design*: Establishing a global model of the vessel in a lightweight format. All structural design features is applied at this stage. The design features is modelled as surfaces (no visualized thickness), making the model very lightweight in terms of computing power. This is very convenient if any design revisions is to be made, which is very common at early stages.
3. *Structure Design*: The functional design model is divided into blocks and units/sections, and more details is applied to each unit. Upon finalizing the design of a unit, plate thicknesses is applied, and plate connections (welds) is defined.

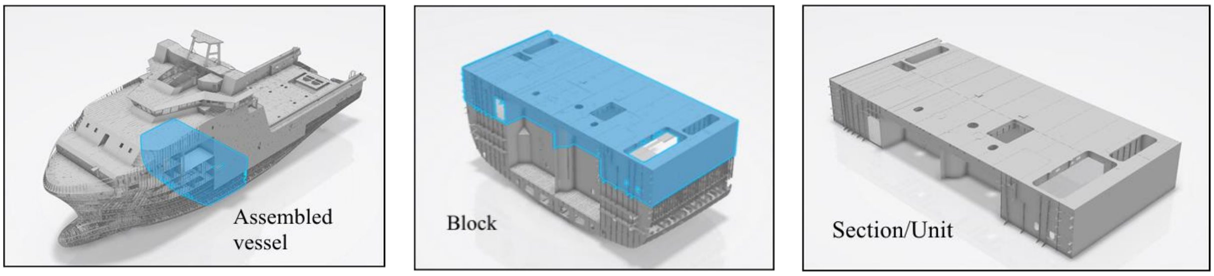

Figure 54: Block & unit division

4. Manufacture preparation

Before the design data is put into production it is necessary to prepare the assembly for the manufacturing process. The assembly process must be planned and manufacturing features must be applied. The DELMIA-domain of 3DEXPERIENCE features a collection of applications called *Marine and Offshore Manufacturing Planning (MOG)*. Theoretically any production line, work floor or even a whole factory can be experienced in a virtual environment. The applications encourage efficiency by planning and simulating the production processes.

Specifically two applications is used for the manufacture preparation:

1. *Marine manufacturing:* A "recipe" on how to assemble the unit is established, and must be in accordance with the physical production line where the assembly is to be done. The designed unit is broken down into sub-assemblies and parts, and organized according to the stages of the assembly process.
2. *Marine Structure Fabrication:* Manufacturing features is applied to the parts. These are edge preparation[21], shrinkage compensation[22] and marking/labelling[23].

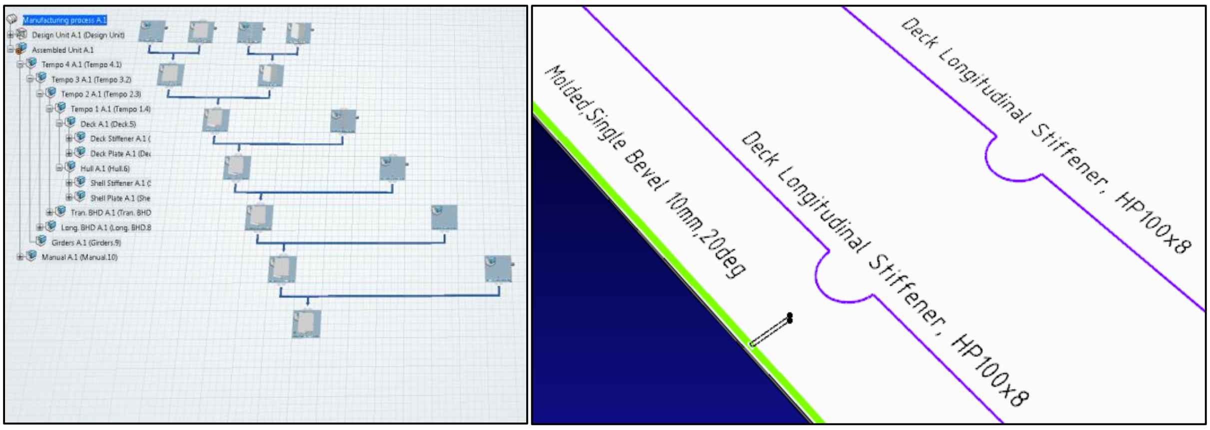

Figure 55: Assembly planning and manufacturing features

5. Data export and import for processing in CAM software

The data processed in ALMA Act/Cut must be in a format called DPR. It is not possible to extract the data created in 3DEXPERIENCE directly into the DPR-format, so different methods must be used. Three applicable methods is investigated when it comes to transferring data from 3DEXPERIENCE to ALMA. The three methods features transfer of data in 3D-, 2D- and coded formats: *IGES, DXF and XML.* These formats are compatible with both 3DEXPERIENCE and ALMA.

The IGES export can only be performed on one part at the time, making it a time demanding operation. Only the plates contour and thickness is included in the export, leaving out the necessary manufacturing features and material information.

[21] Bevel or chamfer edges of a plate to ensure complete penetration of the weld metal.
[22] Compensation for welding distortion/shrinkage by cutting a plate slightly larger than its original size
[23] A convenient method for identifying plates is by marking them with ID numbers. Also attachment lines for stiffeners can be marked physically on the plate, aiding the welder in attaching the stiffeners.

DXF is a very efficient format when it comes to exporting, due to the ability to export multiple parts or even the whole assembly in one operation. Manufacturing features is included, but material and plate thickness must be applied manually in ALMA.

Export of multiple parts is also supported by the XML export function. This format include all the required information required in ALMA, making it a superior method compared to the others.

5. CAM processing and generating cutting documentation

With the data successfully transferred from 3DEXPERIENCE to ALMA, the parts needs to be nested and the cutting process must be planned in order to generate the required documentation (NC program and workshop documentation).

Firstly, it is recommended that all parts exported from 3DEXPERIENCE are checked and edited where it is necessary. The exported files are not always "perfect", so some modifications in ALMA may be required.

Parts with the equivalent thickness and material grading are nested onto their corresponding raw material sheets. In ALMA this can be performed both manually and automatically. The automatic nesting utilizes advance algorithms to nest the parts in the most optimized way, by minimizing material waste.

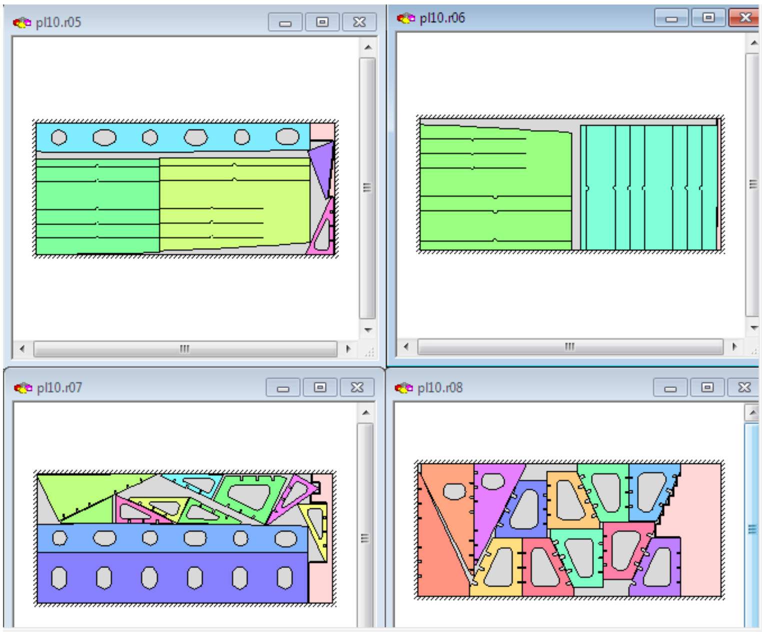

Figure 56: Nested parts in ALMA

Sequencing is applied to achieve the most efficient way of cutting the parts from the metal sheet. This can also be performed manually and automatically. By applying “bridges”, a small connection between the parts, the machine can cut multiple parts in one operation without having to pierce the sheet for every part.

Finally, the sequence is simulated in the software. While the simulation is running, the NC program is generated automatically in the background together with workshop documents. Once the simulation is complete, the documentation can be reviewed.

5. Post processing the NC program

The “raw” NC program obtained from the CAM processing in ALMA, is of the generic type, and needs processing. This output is not configured for any specific machine, and does not follow the correct syntax of the cutting machine.

By running the NC program through a post processing software, it can be translated into the correct programming language required by the cutting machine. The development of this software can be done by a software developer, and is a service that must be purchased.

6. Conclusion

This paper describes briefly an applicable best practice method that can be used for establishing a design, preparing it for manufacturing and generation of documentation intended for sheet metal cutting. The method has been developed through practical research in form of a realistic case study, focusing on the resources that Kleven currently possesses at their shipyard.

Further work include the development of a NC program post processor, and investigation of a similar method for purchased design data (Kleven will continue to purchase design until their engineering platform is fully operational).

The resulting method that is established will hopefully help with contribution to economic benefits and increased knowledge not only for Kleven and the shipbuilding industry, but also other instances or industries that may consider 3DEXPERIENCE and ALMA as software solutions.