Ship Lifecycle Software Solutions (SHIPLYS)

Project Deliverable Report

D6.4 Overview of SHIPLYS rapid virtual design and production process prototyping functionality

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EXECUTIVE SUMMARY

This Deliverable is a report providing a user-level overview of the software modules selected and developed in WP6 titled "Implement rapid virtual design and production process prototyping generators" of the SHIPLYS project.

Based on the requirements identified in WP3 "Specify requirements for integration of rapid virtual prototyping and life cycle tool", several software modules (called SHIPLYS Applications) were developed with the purpose of them being used in an integrated manner through the SHIPLYS platform.

This report provides an overview of such Applications with focus on Applications developed within the project. However, in the interest of showing how an activity can be completed, other Applications (pre-existing, off-the-shelf available) are also mentioned. An activity, mentioned as 'Activity' in the text of this document, in the current context is a task that is typically carried out during the very early design or production planning stage of ship new-build or retrofitting projects.

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ABBREVIATIONS

AHP	Analytical Hierarchy Process
CAPEX	Capital Expenditure
EEDI	Energy Efficiency Design Index
EI	Environmental impact
ELECTRE	Elimination Et Choix Traduisant la REalité
EEOI	Energy Efficiency Operational Index
ILLC	International Load Lines Convention
IMO	International Maritime Organization
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
MCDA	Multi-criteria decision analysis
MARPOL	International Convention for the Prevention of Pollution from Ships
MAVT	Multi-Attribute Value Theory
NVP	Net Present Value
OPEX	Operational and Voyage Costs
PPT	Production Planning Tool
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RIT	Requirement Identification Tool
TOPSIS	Technique for the Order of Prioritisation by Similarity to Ideal Solution

1 Introduction

The SHIPLYS (Ship life cycle software solutions) project is in response to needs of SME naval architects, shipbuilders and ship-owners, who, in order to survive in the world market, need to improve their capability to reduce the time and costs of design and production, to be able to reliably produce better ship concepts through virtual prototyping and to meet the increasing requirements for LCCA (Life Cycle Cost Analysis), environmental assessments, risk assessments and end-of-life considerations as differentiators.

Key tasks in the project include the development of:
• A platform enabling the integration of a variety of Applications[1] (software modules/ tools) used in early ship design
• Rapid early design and production simulation Applications
• LCCA, environmental and risk assessment software Applications for fast and cost effective evaluation of alternatives
• The development of multi-criteria decision analysis techniques to support decision making across the short/ long term, based on explicit user defined decision criteria.

The content of this Deliverable includes a description of all the tools selected and developed to achieve a rapid prototyping of the ship taking account of life cycle costs, environmental impacts and risk. The challenge in the development of such Applications is that they need to be able to work with limited data available at the early design stages.

The Applications are divided into the following categories:
- Operational profile definition and vessel configuration tools, which were developed in WP5 "Development of tools for Operational Profile definition and Vessel configuration".
  - ShipLCA
  - RiskSHIP
  - Multi Decision Tool
- Rapid prototyping tools, which were selected and developed in task 6.2 "Development of Rapid Prototyping Tools".
  - RIT
  - ConceptSHIP
  - RSET
  - CAFE
  - LR SEASAFE
  - RulesCalc
- Production analysis and planning tools, which were developed in task 6.3 "Development of Production Analysis and Planning tools".
  - Production Planning Tools (PPT)

For the benefit of readers with no prior knowledge of the SHIPLYS Project, the following terms used in this report and other SHIPLYS documents, have special meaning as described here:

SHIPLYS Platform: Software developed within the project to enable the integrated use of a variety of software modules (or Applications) that have a 'glue code' (a short software program) allowing for such integration.

SHIPLYS Applications: These are software modules developed within SHIPLYS project, or enhanced versions of existing software owned by SHIPLYS Consortium members or third parties. Apart from RSET, CAFE, SeaSafe, RulesCalc that pre-existed and for which 'glue code' was written and/or certain enhancements made during the project, the other Applications were developed within the project.

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[1] Software modules or tools are 'Applications'. We have tried to be consistent in using 'Applications' but in many cases some of these software have 'tools' in the name itself, for example the Production Planning Tool. Thus, tools as mentioned in this report are software modules, synonymous with software Applications.

SHIPLYS Scenarios[2]: These are issues posed by the three Shipyards present in the SHIPLYS Consortium that the project addresses. There are three SHIPLYS Scenarios, one requiring the optimisation of hybrid propulsion system used in a short route ferry ship (Scenario 1), another requiring support during early design stages of new building ship through inputs from risk based life cycle assessments (Scenario 2), and the third requiring support during early planning and costing of ship retrofitting accounting for life cycle costs and risk assessments. These three Scenarios were mooted by Ferguson Marine Engineering Ltd (UK), Varna Marine Engineering Ltd (Bulgaria) and Astilleros de Santander SA (Spain) respectively.

It must be noted that not all Applications are equally applicable to all Scenarios because of inherent differences in the Scenarios. Applications are applied to those Scenarios where they are most applicable and where their full functionality can be demonstrated within the project.

2   RIT

The Requirement Identification Tool (RIT) software component within SHIPLYS can define the design requirements and the operational profile of a vessel in order to support early new building design or early planning of retrofitting/ repair activities (thus applicable to Scenarios 2 and 3 as described in the Introduction section of this document). The type of profiling data that RIT can process includes a wide range of design parameters that are used to determine design goals such as transport capacity, service speed, operating cost and many more. Such data, often specified in the tender provided by Owners, would typically feed into the early design process/ retrofitting or repair planning in a shipyard.

RIT is a custom software solution developed for the identification and processing of requirements, usually expressed in documents. The tool also provides functionality to process other requirements depending on two different modes: the "New Building Design Mode" and the "Retrofitting Mode".
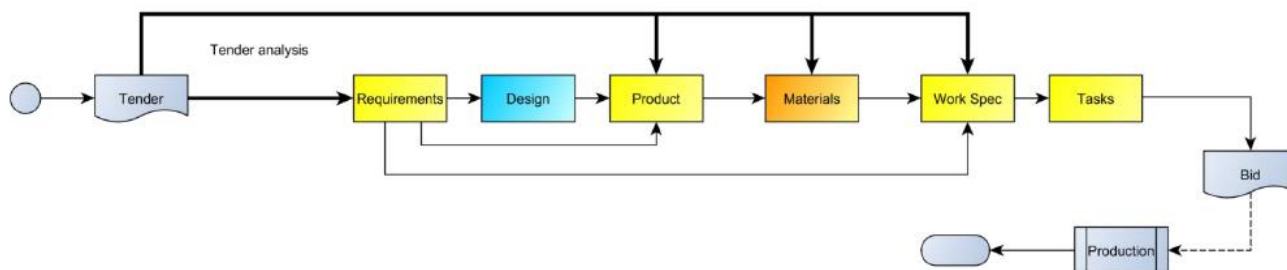
Figure 1: General RIT workflow

Figure 1 represents the general workflow beginning with a tender document provided by the owner.

In general, the following assumptions can be made regarding the newbuilding and the retrofitting projects.

For newbuilding projects:
- Design step is mandatory.
- Work specification is mostly auto-generated.

For retrofitting projects:
- Requirements are usually more limited.
- Design step is optional.
- Work specification requires more user input.

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[2] More information about the Scenarios and background to the project can be found https://www.twi-global.com/technical-knowledge/published-papers/ship-lifecycle-software-solutions-shiplys-an-overview-of-the-project-its-first-phase-of-development-and-challenges

2.1 New Building Design Mode

Normally the conceptual design phase for a newbuilding project starts with the identification of product requirements, which are specified intender documents. The RIT supports this task by creating a storable and automatically evaluable representation of the requirement.

Before the RIT can be used, a project must be created within the SHIPLYS framework, which the tool can address.

A typical workflow would then be to start the RIT and connect to a project/ context / database, then either load a document into the list of registered documents or select a registered document. Loading/selecting a registered document opens a window showing the document. When the user identifies a requirement, he selects the corresponding text passage and defines a requirement data object or refines an existing requirement. The RIT also supports the definition of design loading conditions since some tender/specification documents may contain loading conditions. In order to implement this efficiently the loading conditions should be predefined in the initial stage i.e. during the first processing of the document. Documentations containing specific information such as product and component specifications will give an indication of the dependencies on other products/components, which can also be documented using the RIT. Figure 2 shows the key attributes of RIT.
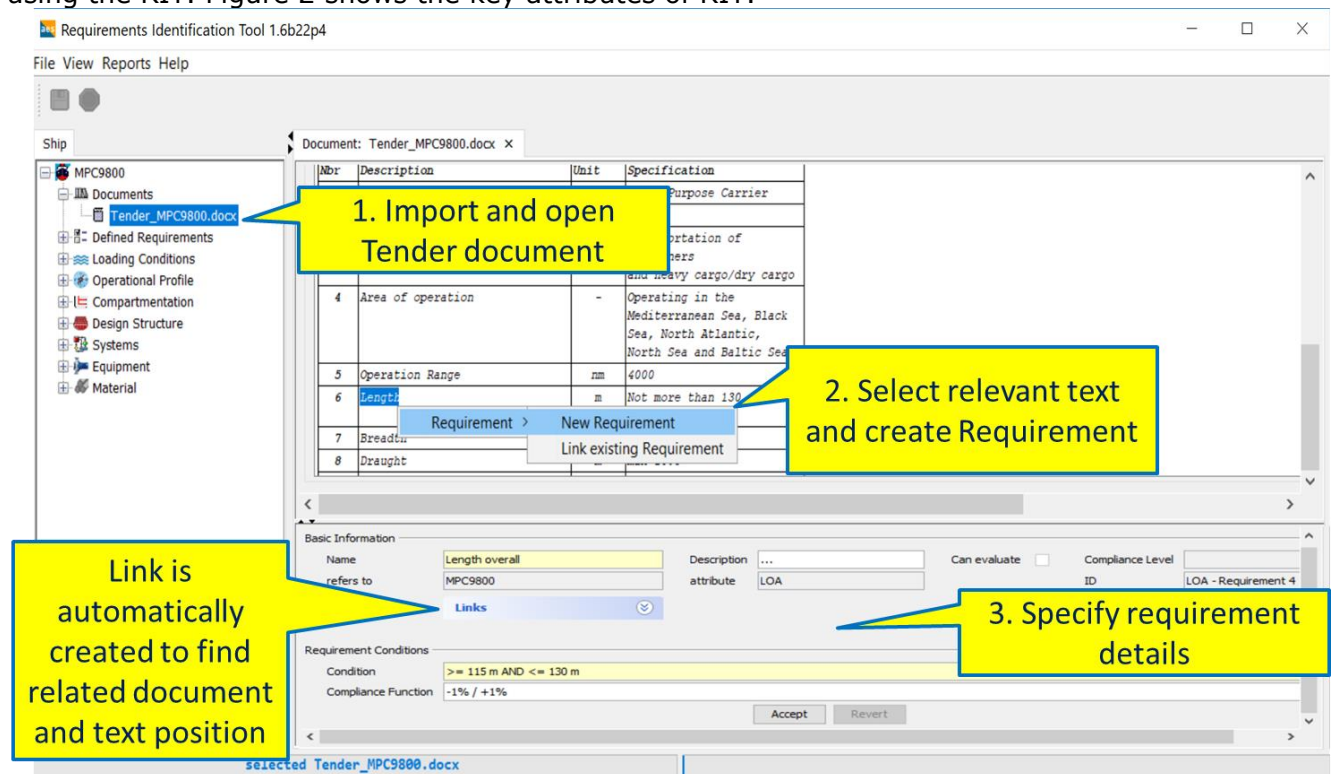
Figure 2: Key features of RIT

2.2 Retrofitting Mode

Repairing and retrofitting projects differ substantially from long term new building projects in the shipyards. An important aspect of typical repair and retrofitting projects is their much higher level of dynamic changes during execution of the project that are expected to occur in comparison to typical new-building scenarios. Due to the high number of dynamic changes (unplanned work, missing resources etc.) and the complexity of the activity dependencies (amongst others, safety related issues), the generated plans at the beginning of the repair and retrofitting projects are not accurate enough. Thus, significant effort is required during the execution phase of the project by those responsible for manufacturing control in order to carry out unplanned work in the required timescale.

The RIT can be run in the retrofitting mode enabling to define retrofitting tasks based on specification documents provided by the owner. By the use of the tool the effort required for the generation of retrofitting plan containing tasks and their sequences is reduced and the accuracy is improved. Therefore, the following main objectives of retrofitting projects are supported:

- Respond as quickly as possible
- Create a technically and financially sound proposal

3   ShipLCA

The main aim of work package 5 of the SHIPLYS project was to develop a life cycle tool, which could be easily used by relatively inexperienced staff at end-users such as shipyards and ship owners . According to the methodology described in D5.1 "SHIPLYS LCCA and environmental assessment software module" (Oguz *et al.*, 2018) all relevant approaches are included such as modularity, LCA, LCCA and multi-criteria decision making and assessment. The scope of the project's Scenario 1 was to carry out analysis on a short route ferry operated in Scotland (built by Ferguson Marine) and targeting specifically the main engines and battery packs. As such the ShipLCA tool focuses on the LCA and LCCA of the ship propulsion system.

In addition to LCA and LCCA, the tool also performs risk assessment for the ship propulsion system. All results are presented with their respective units and also as converted to monetary values, which then can be combined and used for the multi-criteria decision analysis.

The data and parameters required from the preliminary design are mainly the vessel main particulars, the design geometry and the main system selection with their specification. An operation profile and a maintenance plan are also necessary to comprehensively consider the life cycle impacts from the perspective of cost, environment and risk. To complete an LCA analysis, scrapping details are acquired to cover the impacts during the end of life stage.

The software is not limited to activities related to the propulsion system, since activities relating to hull and outfitting are also included. ShipLCA will not only fulfil the required assessment in Scenario 1 but also provide further support and assessment to shipyards, ship owners and operators on the selection of different alternatives.

Figure 3: ShipLCA welcome page
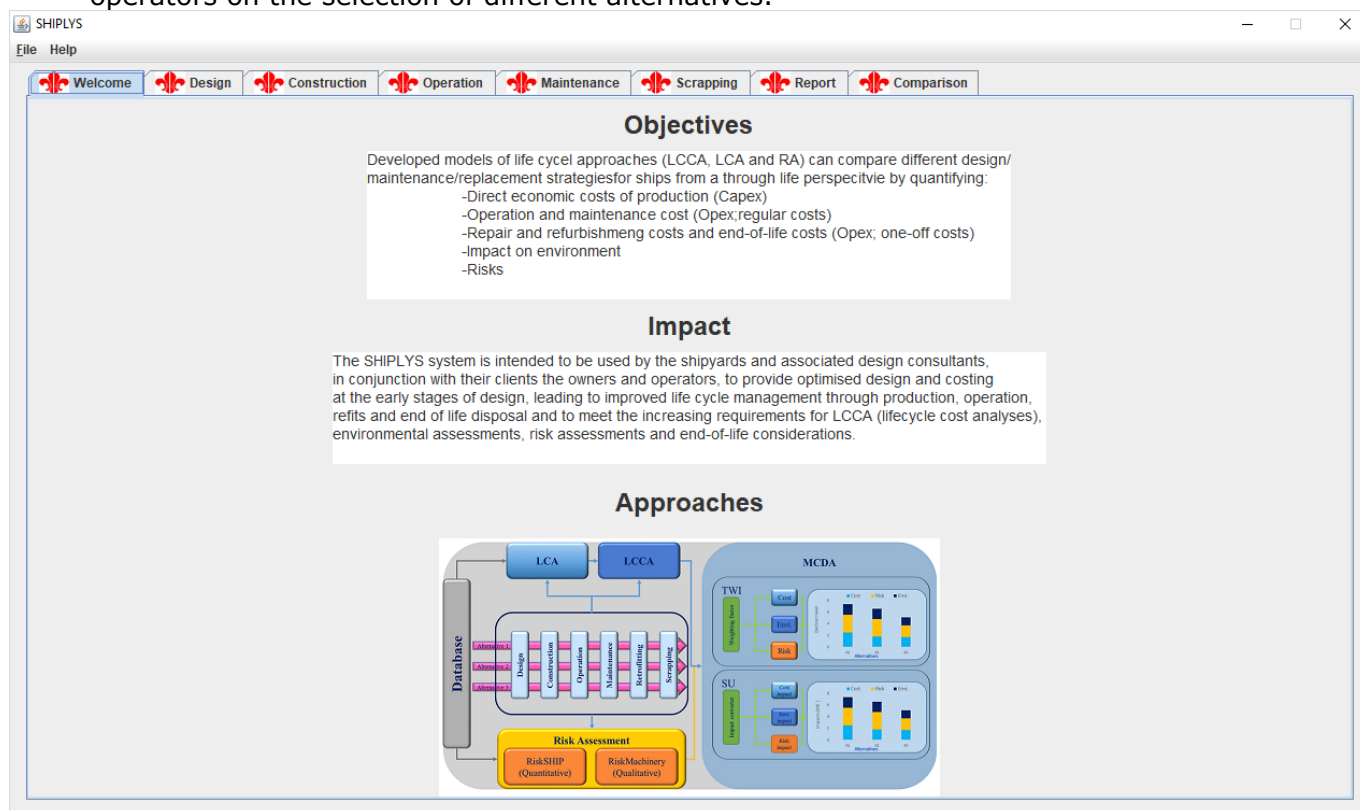
The ShipLCA tool can be used as a "standalone tool", as in the case of data that is already available from different projects, or it can be used within the SHIPLYS platform, where the output from ConceptSHIP, the operational profile and maintenance plan, will be used to calculate the results. The output from ShipLCA will be used as an input for the Multi Decision Tool (MCDA) developed by TWI.

Figure 3 shows the welcome page for the ShipLCA software, further information on the methodologies used and details of the software can be found in Deliverables 5.1, 5.2 and 5.3 (Oguz *et al.*, 2018, Garbatov, 2018 and Cui, 2019) of the SHIPLYS project.

4   RiskSHIP

RiskSHIP is a software tool that allows to calculate the probability of failure and risk associated with a ship model and to analyse its economic value. The first step is based on the calculation of the reliability index and probability of failure, where the solution is obtained adopting First Order Reliability Method (FORM) techniques (Hasofer and Lind, 1974). For this purpose, the main dimensions, net and gross net-sectional areas and midship sectional modulus are required as inputs to calculate the associated probability of failure.

The second step performs an economic analysis leading to a risk estimate, where the costs of failure are related to the costs of implementing a safety measure (Horte *et al.*, 2007, Garbatov and Sisci, 2018 and Garbatov *et al.*, 2018) based on the FSA as stipulated by IMO (2005a, 2006a,b, 2007, 2008, 2013, 2015). The output of this step is the total risk.

Inputs for this procedure are obtained from the software tool ConceptSHIP and RulesCalc, as explained in the tables below. In the presented tables, if an input value is not yet available in the SHIPLYS DataModel a new name will be suggested.

Inputs defined in the ConceptSHIP software tool are given in
Table 1:

Table 1: Inputs defined in ConceptSHIP

Name	SHIPLYS attribute/suggestion	Measure Type	Description
Lpp	lpp	Length_Measure	Length between perpendiculars
Breadth	boa	Length_Measure	Maximum breadth of the ship
Depth	doa	Length_Measure	Maximum vertical distance from baseline to the uppermost deck
Draught	draught	Length_Measure	Draught to which the ship has been designed to operate
Block Coefficient	blockCoefficient	Ratio_Measure	Ratio between moulded displacement and block with dimensions L*B*T
Service speed	designSpeedAhead	Speed_Measure	Forward velocity at which the ship is designed to operate
Steel weight	steelMass	Mass_Measure	Total weight of steel
Lightship weight	LightshipMass	Mass_Measure	The complete lightship mass
Fuel weight	fuelMass	Mass_Measure	Weight of general fuel
num TEU	unitCargo	Count	number of unit cargo loaded per voyage
num Crew	unitCrew	Count	number of crew members and passengers
CAPEX	ownerCost	Cost	Owner's cost

Inputs that are provided by the RulesCalc procedure are shown in Table 2:

Table 2: Inputs from RulesCalc

Name	SHIPLYS attribute/suggestion	Measure Type	Description
step DMF	stepDMF	Real	Fixed step considered for alternative designs considered by RulesCalc
Ult.BM net	netUltimateMoment	Moment3d	Ultimate bending moment calculated at the transverse cross-section amidships for net design
Ult.BM gross	grossUltimateMoment	Moment3d	Ultimate bending moment calculated at the transverse cross-section amidships for gross design

In this tool, net design refers to the structural model without thickness addition due to corrosion while the gross design takes into account the corrosion thickness as well.

More data are needed by the RiskSHIP software, which assumes some default values. Nonetheless, if the user wants to define these explicitly, it is possible by updating their value. The attributes are shown in Table 3.

Table 3: Extra data required by RiskSHIP

Name	SHIPLYS attribute/suggestion	Measure Type	Description
CATS	CATS	Cost	Cost of averting a ton of oil spilt
steelwork cost	steelworkCost	Cost	cost of steelwork per ton of steel
probl. Oil spill	problSpillOil	Ratio_Measure	Probability of oil spill
probl. Oil at coast	problSpillCoast	Ratio_Measure	Probability of spilt oil to reach the coastline
dicount rate	discountRate	Ratio_Measure	Discount rate of initial investment
steelscrap cost	steelscrapCost	Cost	Cost of steel per ton by scrapping
TEU cost	unitcargoCost	Cost	Cost of unit cargo
ICAF	ICAF	Cost	Implied cost of averting a fatality
probl. Loss life	problLossLife	Ratio_Measure	Probability of loss of life of a crew member

The outputs produced from the first step are shown in Table 4. Still water and wave induced bending moments are obtained as given by the classification society (IACS, 2015) and the sensitivity factors are relative to the limit state function (Garbatov and Georgiev, 2017).

Table 4: First step outputs

Name	SHIPLYS attribute/suggestion	Unit	Description
SW BM	swMomentCs	Moment3d	Still water bm as calculated by classification society
WV BM	wvMomentCs	Moment3d	Wave-induced bm as calculated by classification society
sensitivity factors	sensitivityFact	List of real	Sensitivity factors for each of the variables included in FORM
Reliability indexes	relIndex	Real	Reliability indexes calculated through FORM
Probability failure	problFailure	Ratio_Measure	Probabilities of failure calculated from reliability indexes

The second step analyses the risk-related costs and it depends on the previous step, as it needs the probability of failure relative to each design solution. The outputs produced by the second step are shown in Table 5.

Table 5: Second step outputs

Name	SHIPLYS attribute/suggestion	Unit	Description
Ship failure cost	failureCost	Cost	Cost implied with the failure of the ship
Safety measure cost	safetyMeasureCost	Cost	Cost to modify the structure by a specific DMF
Total risk cost	riskCost	Cost	Sum between failureCost and safetyMeasureCost for each DMF

This software tool is meant for initial design, as the ship model is not yet fully described and presents flexibility in the definition of some design parameters. As the software tool proposes a fast estimation of the risk, it is possible to run the software tool modifying the design parameters of interest to observe the influence of these. Also, the software tool analyses different design solutions based on the same ship model and compares them based on their probability of failure and risk. In this way, it is possible to rank the available design solutions and the user can select the one with the lowest risk.

Moreover, a list of sensitivity factors of the variables involved in the FORM will be provided together with the values for still water and wave-induced bending moments.

5   Multi-Criteria Decision Tool

SHIPLYS MCDA is a multi-criteria decision support tool developed within the SHIPLYS project.
The objective of this tool is to determine the optimal design option by comparing their performance regarding life cycle cost (LCC), environmental impact (EI) and risks. The detailed information on the development of SHIPLYS MCDA is reported in Deliverable D5.3 "SHIPLYS multi-criteria decision support software module" (Cui, 2019). In the following paragraphs, a summary is provided.

In the SHIPLYS workflow, the inputs to MCDA are the outputs from the upstream software (such as ShipLCA and RiskSHIP) in the form of Figure 4. This input table can either be automatically filled when it is integrated into the SHIPLYS platform, or manually completed when it is used on its own.

Depending on the user's requirement, the MCDA can be performed with or without the weighting factors. In the SHIPLYS MCDA, these factors are designed to weight the importance or preference level of three measurement criteria, i.e. LCC, LCA and risk. To define the value of the weighting factor the user will have three options:

1.   No weighting factor applied to any score (i.e. results are compared directly)
2.   The user directly inputs the weighting factor (i.e. customised weighting factor)
3.   Using pair-wise comparison method to compute the weighting factor

In Figure 4 below, a design alternative template is showed.

Design Alternative 1				
	Design	Production	O&M	End of Life	Total
LCC					
LCA					
Risk					
Total					

Figure 4: Input parameters of SHIPLYS MCDA

With the intention of being flexible to satisfy the requirements from different stakeholders, various MCDA mathematical models have been implemented in the SHIPLYS MCDA Tool, including:
- Multi-Attribute Value Theory (MAVT)
- Analytical Hierarchy Process (AHP)
- Outranking:
  - Elimination Et Choix Traduisant la REalité(ELECTRE) - Elimination and Choice Expressing the Reality
  - Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE I / II)
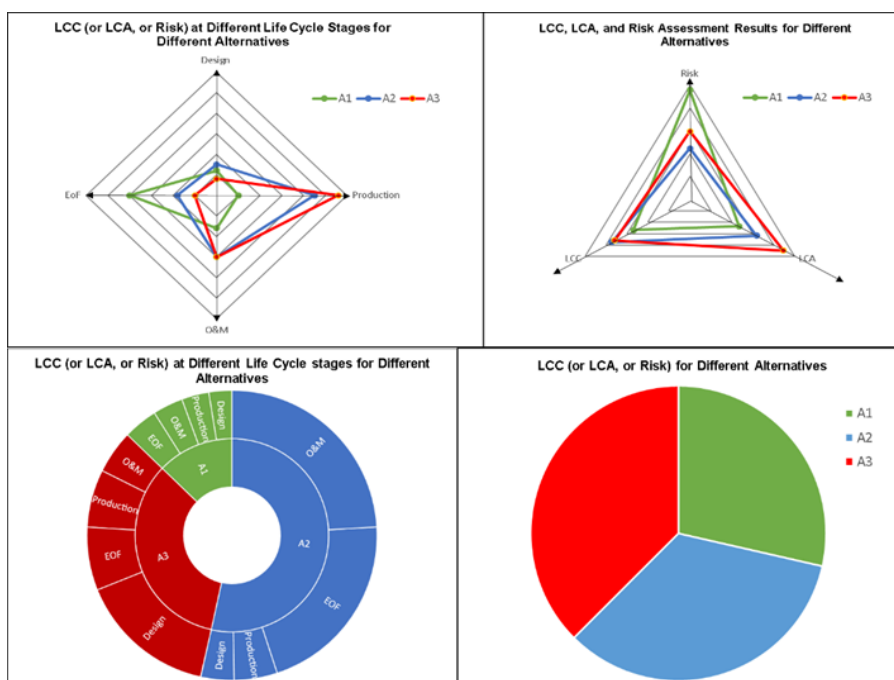 - Technique for the Order of Prioritisation by Similarity to Ideal Solution (TOPSIS)

Figure 5: Visualisation of results from LCC, LCA, risk assessment modules

The expected outcome from the SHIPLYS MCDA is the rank of different alternatives based on the comprehensive evaluation of their performance in LCC, EI and risks. Depending on which MCDA model is used to carry out the assessment the outcome will be presented differently, as seen in Figure 6 to Figure 8.
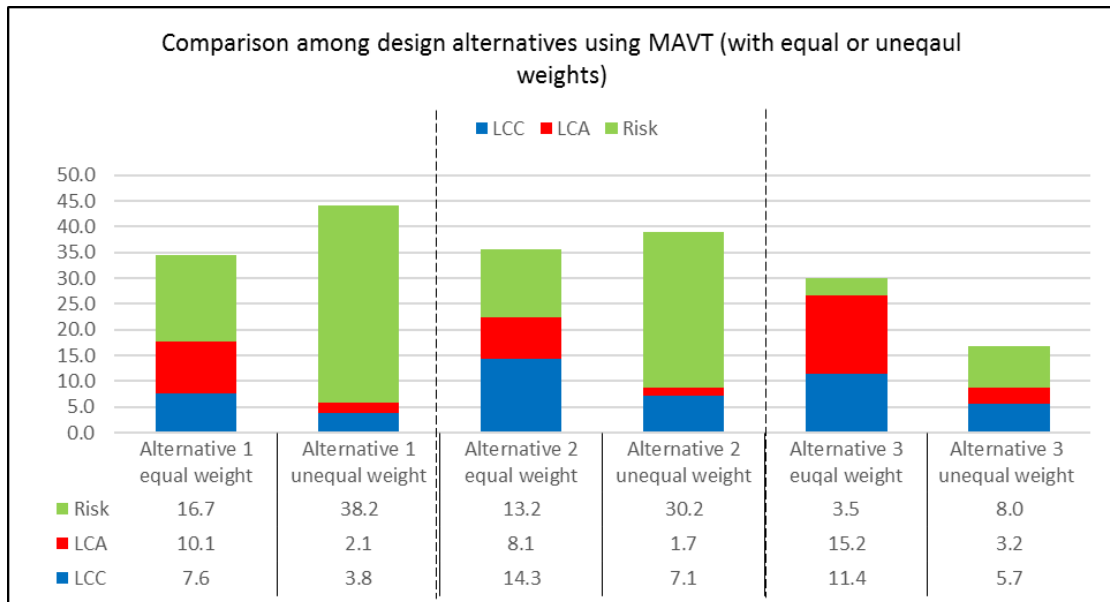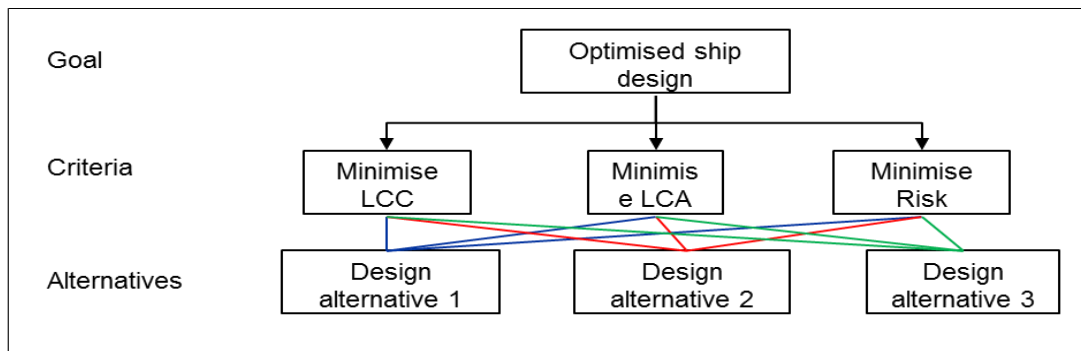
Figure 6: Example of MAVT results demonstration

	Alternative 1 equal weight	Alternative 1 unequal weight	Alternative 2 equal weight	Alternative 2 unequal weight	Alternative 3 euqal weight	Alternative 3 unequal weight
Risk	16.7	38.2	13.2	30.2	3.5	8.0
LCA	10.1	2.1	8.1	1.7	15.2	3.2
LCC	7.6	3.8	14.3	7.1	11.4	5.7

Priority vector/ Final score	Alternative 1	Alternative 2	Alternative 3	CR
LCC	0.229	0.429	0.343	0.000
LCA	0.432	0.346	0.222	-0.666
Risk	0.500	0.395	0.105	0.000
Final score (with equal weights)	0.387	0.390	0.223	-0.068
Final score (with unequal weights)	0.450	0.397	0.153	0.020

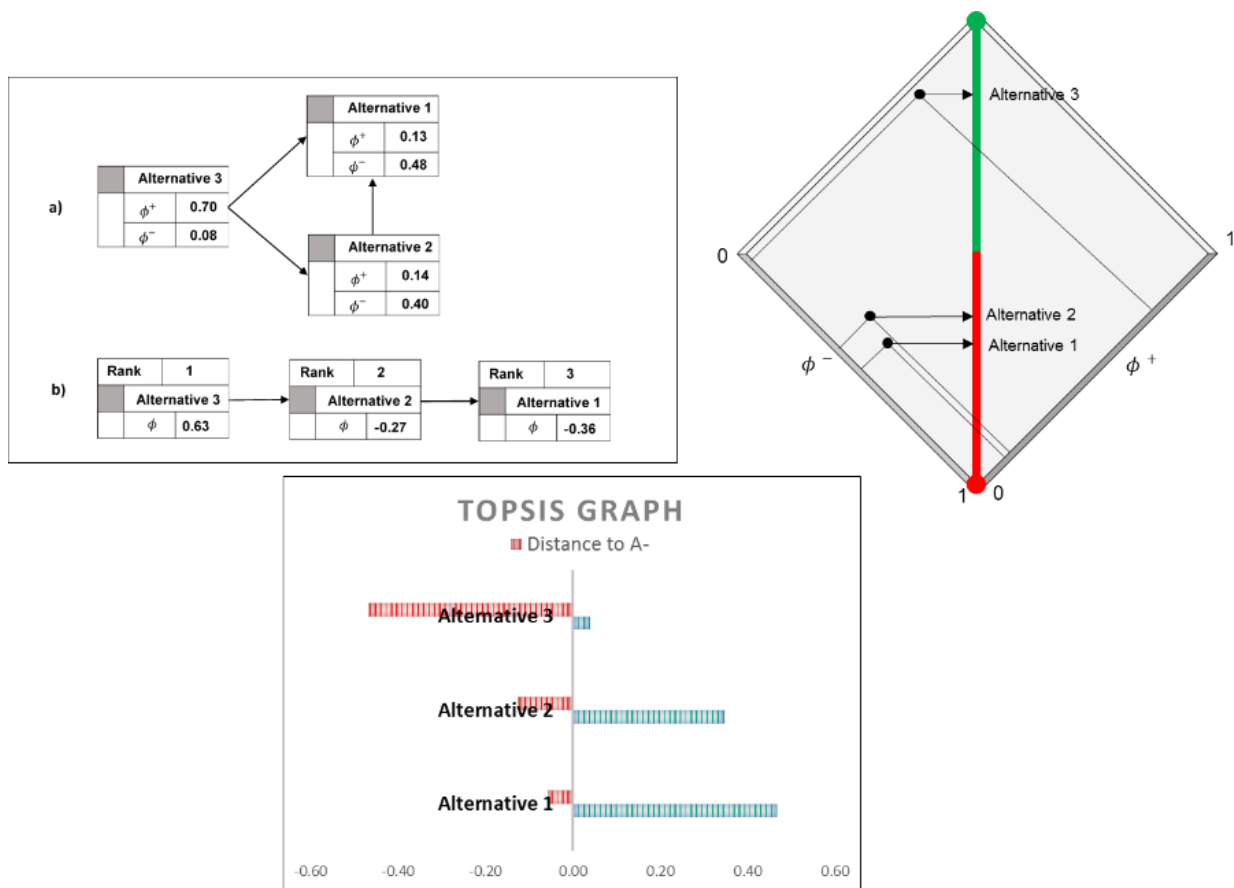**Figure 7: Example of AHP results demonstration**

Figure 8: Example of outranking results demonstration

6 ConceptSHIP

6.1 Overview

ConceptSHIP is a software tool for the early stages of ship design and implemented as an add-in to Excel® spreadsheets. The main objectives of such a choice are to take advantage of the familiarity of naval architects with this type of software, reducing the learning process, to enable the immediate evaluation of the impact of changes in some basic parameters in the global characteristics of the ship ("what if" type of assessment). In addition, as all the data introduced and computed is directly available, it can be exchanged with most software tools used for posterior development of the design. Functionalities for the direct export, in commonly used file formats, of extensive numeric data related to hull form and compartments definitions are also included.

The tool is organized in two stages, concept and basic design, and can be used either in the initial dimensioning of a merchant ship, and/or in the simulation and technical-financial analysis of an operational Scenario; the round-trip voyage of one specified ship. At the end of the process, the resulting workbook is comprised of a number of worksheets that present a repository of all the computations and evaluations carried out for the ship.

At the initial concept stage of design, the purpose is to obtain the initial dimensions and general characteristics of a ship as a response to a set of owner requirements. In ConceptSHIP, based on the ship type, intended cargo capacity and speed, a numeric model is developed that establishes a set of relations in between the main hull dimensions, and the target properties. This model produces a large set of characteristics of the ship, which allow its assessment in terms of propulsion, stability, EEDI, finalizing with the estimate of the shipbuilding cost and CAPEX value. In order to provide some type of lifecycle assessment of the performance of the ship it is necessary to take into consideration its operational life. For this purpose, the mission of the ship can be formally described by a typical round-trip voyage. This Voyage Model is used to account for the times and costs spent in the ports and in the connecting voyage legs, producing more detailed data to support financial and economical assessment of the ship operation.

After the determination of the basic ship characteristics described above, ConceptSHIP proceeds to the next step, basic design, which is initiated by the generation of an initial hull form. This hull form, although very rough, provides support for a subsequent set of numeric computations (unlike the estimates used in the first stage) concerning hydrostatic, stability and compartment properties.

In the following sections the main functionalities of ConceptSHIP are described.

6.2 Ship Model

The above summarized ship model is mainly based on empirical and statistic relations and some simplified calculations. IMO requirements and Classification Society recommendations are taken into consideration where applicable. In this context, the tool can assist the designer in the following estimates:

- Main hull dimensions.
- Hydrostatic properties.
- Freeboard, according to the ILLC.
- Lightweight and longitudinal distribution.
- Resistance and propulsion.
- Cargo and ballast capacities.
- EEDI compliance verification.
- Ship building costs and financial costs associated with a loan (if any).

To improve the accuracy of the above estimates, the system has functionalities for:
- Parametric description of the hull internal layout.
- Simplified modelling of the superstructure.

The parametric description of the main hull areas (cargo, ballast, machinery) is also used in the basic design stage for the actual computation of volumes and centres of volume. The simplified model of the superstructure allows capacity estimates for passengers and RoRo spaces, if any. This Ship Model can be used for parametric studies or in optimisation procedures to determine the characteristics of an optimum ship. Currently two single objective optimisation algorithms provided by Excel Solver can be used. A fast automatic optimisation procedure is provided by the system including not only the basic technical constraints from IMO conventions such as compliance with freeboard (ILLC) and EEDI (MARPOL) but also allowing the specification of any physical constraints to the main dimensions concerning the length, breadth or draught of the ship.

6.3 Voyage Model

The clear statement of the mission is a major requirement for the ship design process. In ConceptSHIP the concept of Voyage Model is used to characterize an operational Scenario for the assessment of economic and environmental aspects.

In this system, a data model is developed to specify the classes of entities used in a marine transport, their attributes and associations. The main entities considered are the ship, the ports and the voyage legs.

The *Port/Terminal* entity data includes mainly attributes for the determination of the time in port and the associated costs. The port costs include the port fees and others such as pilotage and towing. The port fees have different structures in the different ports but in general they are mainly estimated as a function of the ship type and of the gross tonnage.

The total time in port consists of time for manoeuvring, time waiting for berth and the total time at the berth. The time at berth is the one used to compute the port fees and can be further analysed in service time (mooring and un-mooring), the time spent in cargo handling and the time waiting at berth.

The cargo handling rates are considered separately for loading and unloading to cover the possibility of different types of equipment used (cranes, gantry cranes), with different unit costs. The actual volume of cargo handled can be specified either as a percentage of the ship total capacity or as a number of cargo units (TEU, tons, vehicles), for each port call.

The *VoyageLeg* entity consists of a set of attributes necessary for the evaluation of the time at sea and of the overall fuel consumption due to its major contribution to the operating costs but also for the levels of emissions.

A voyage leg is initially considered as the route between two consecutive ports. However, it may be further split in as many legs as needed to characterize any different restrictions or conditions that affect the time at sea, the costs or the emissions. The same logic applies when modelling a part of the route with specific characteristics of sea state or water depth conditions which can originate added resistance.

In addition to the leg length, the water density and water depth type are also specified so that sailing in inland waterways can be modelled. The service speed can be specified for each leg or identical for the entire voyage.

The cargo loaded and unloaded at each port can be specified, as well as the status of the consumables (departure, mid-voyage, arrival) and ballast. The load condition at the exit of each port is the base for the estimation of the propulsive power required for the specified ship speed, improving the accuracy of the estimates of the fuel consumption and emissions, from both propulsion and electric power generation, during the next voyage leg.

Summarising, the voyage model supports the determination of the following aspects:
- Operational and Voyage Costs (OPEX)
- Emissions in operation (CO_2, NOx, SOx)
- Energy Efficiency Operational Index (EEOI)

6.4 Economic Assessment

Based on the ship and voyage models data, ConceptSHIP provides the means to determine some economic measures of merit of the investment. The relations between the freight value and the resulting net present value (NPV) and internal rate of return (IRR) can be explored, either as input or as target values, and estimates of the cash flow during the operational life of the ship can be also carried out.

6.5 Basic Design

The second stage of ConceptSHIP, the basic design, starts with the creation of a hull form complying with the main characteristics and form coefficients from the conceptual study. The hull form is described by a set of cross-sections, each defined by a number of points (polylines) (Figure 9).
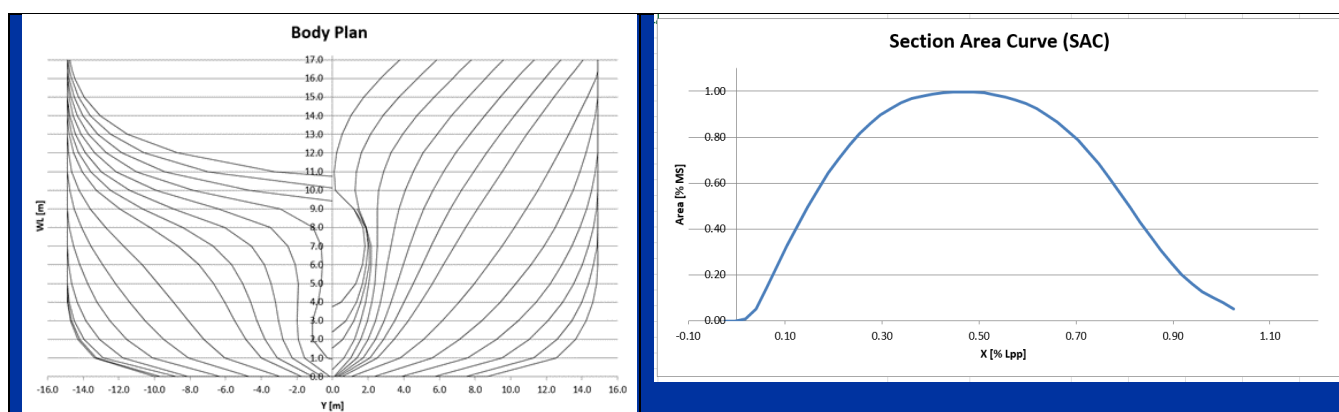

Figure 9: Body Plan and Sectional Area Curve generated

This simplified geometric representation (Figure 10) allows not only a faster handling of the shape but also facilitates the export to other naval architecture and CAD applications for further development. The export formats currently implemented are DXF, GF, CSV.

Although based on linear representation of hull shape, the accuracy is enough to compute the actual hydrostatic properties (even keel) and intact stability at large angles as well as the geometric properties of the main compartments of the hull.

Compartments are defined by sets of closed cross-sections using the sample simplified geometric description used for the hull form.
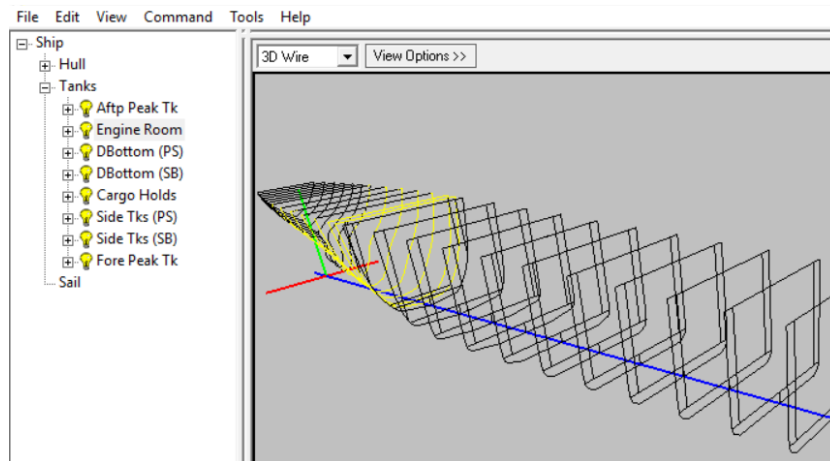
Figure 10: Geometric representation of hull and compartments

Volumes and centre of volume coordinates are computed and the results can be presented grouped as a function of the type of content (machinery space(s), cargo, ballast, consumables). Summarising, the functionalities available in ConceptSHIP are:

- Generation of the hull form.
- Hydrostatic calculations (even keel).
- Intact stability calculations (even keel).
- Righting lever curve (GZ curve).
- Verification of the compliance with IMO Stability Code criteria.
- Parametric definition of the main hull compartments.
- Calculation of the main hull compartments' capacities and centers of volume.
- 3D visualization of the compartments.
- Detailed calculation of the freeboard.
- Selection of a main engine from a database.
- Selection of propeller characteristics.
- Determination of the propulsion shafts diameters.
- Selection of anchoring and mooring equipment.
- Detailed lightweight database and longitudinal distribution.

6.6 Connection to SHIPLYS Platform

Once the optimum ship's main design parameters are determined, the user stores them in the SHIPLYS platform database on the server.

Through a menu, the user can define the address of the TopGallant server, create a new instance of a Ship entity, and finally post to that entity the obtained ship data such as main dimensions of the hull, the CAPEX value and the set of cross-sections that defines the hull form of the ship.
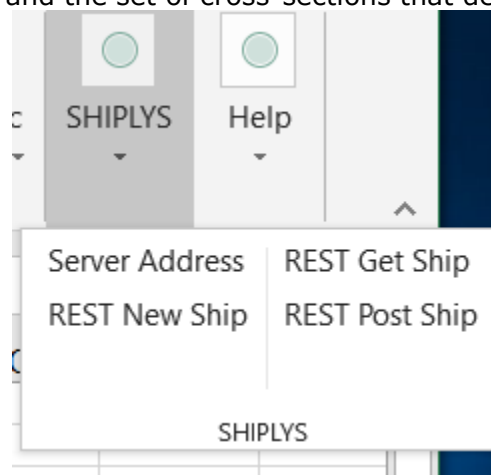

Figure 11: Menu for integrated TopGallant functionalities

7   RSET

7.1   Overview

The Rapid Ship Evaluation Tool (RSET) is a system that allows users to rapidly explore the design space of general arrangement in the early stages of ship design. Given a hull form, RSET allows the user to import or generate bulkheads, decks, and superstructure, as well as detail a list of chambers for arrangement within the compartments of the ship.

A set of user-defined constraints for chamber placement allows RSET to automatically generate a general arrangement that satisfies design requirements, facilitating the rapid evaluation of various constraints and layouts. Employing a 3D view of the general arrangement, RSET allows a user to visualise and experiment with combinations of chambers and constraints to meet various design objectives, such as maximising utilisation of compartment space, minimising hull form size, or reducing construction cost.

7.2   Ship model

A hull form in triangle mesh representation can be imported into RSET via the SHIPLYS Platform, then scaled as desired. If available, decks, bulkheads, and the basic superstructure envelope can also be imported, otherwise these can be created within RSET. Together, these constitute the basic ship model within which the compartments will be arranged.

Figure 12, below, shows the visualisation of the ship model displayed in RSET.
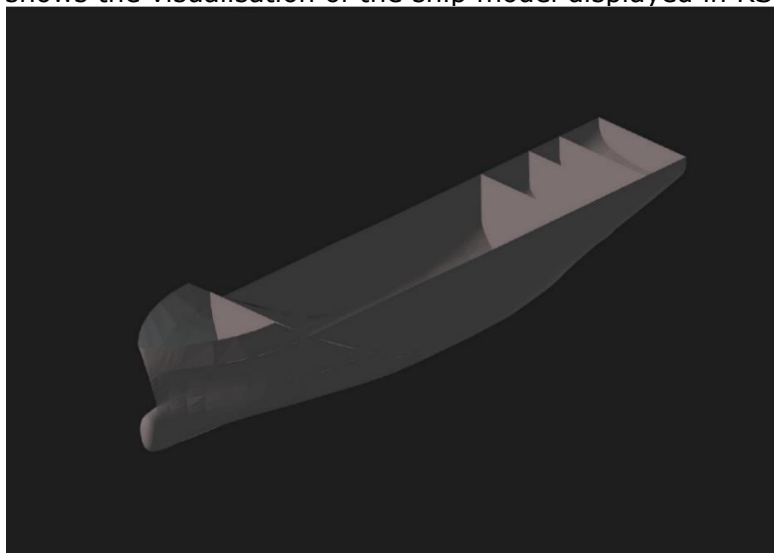

Figure 12: Imported hull with bulkheads

7.3   Compartments and constraints

In addition to the ship model, the user must specify the compartments to be arranged and a set of constraints, which describe the compartments' required positions. Constraints can specify:

- The absolute location of a compartment relative to the ship model (e.g. on the uppermost deck of the superstructure).
- The maximum or minimum separation between compartments (e.g. zero distance between compartments that should be adjacent).
- The location of compartments relative to other compartments, in terms of decks and longitudinal "zones" between adjacent bulkheads (e.g. one compartment should be on a lower deck than another).

By combining these constraint types, practically any compartment placement requirement can be defined (though care must be taken not to define mutually incompatible constraints).

7.4   SHIPLYS output

Once the ship model, compartments and constraints have all been defined, the user can proceed to run the arrangement solver of RSET to create a general arrangement. An example

arrangement is shown below in Figure 13. The updated ship model, now containing the compartments, can then be saved back to the SHIPLYS Platform, where it is then available for use by other tools in the platform.
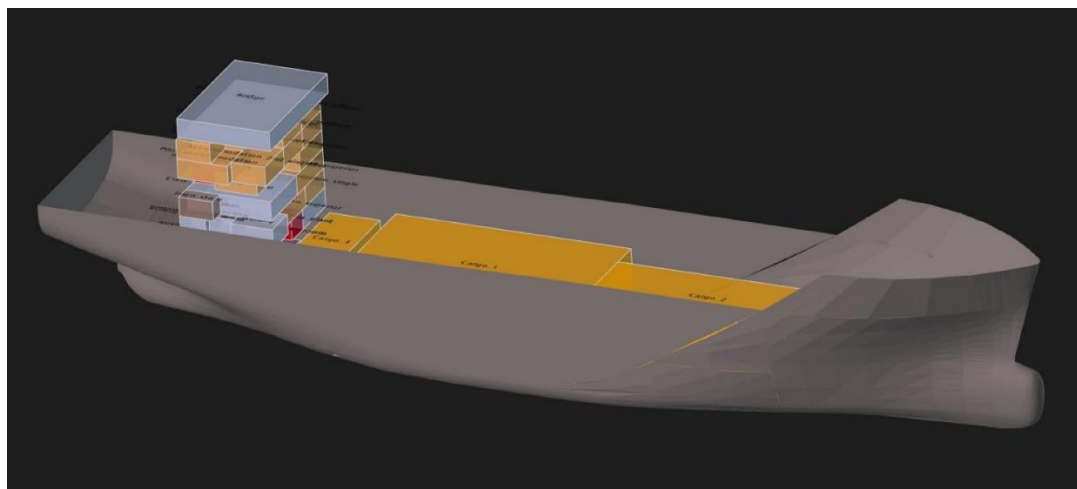

Figure 13: An example general arrangement

8   CAFE

8.1   Overview

CAFE is a ship modelling software that will serve for fast developing of preliminary ship structure and positioning of the main equipment in order to obtain a preliminary estimate of the lightship weight and centre of gravity, provide the structural design that will be checked according to the classification societies' rules and input needed for calculating preliminary trim and stability. In addition, CAFE will generate a list of equipment and bill of materials.

8.2   Hull form

Hull form can be imported from another software in an iges/step file format, created by using imported hull lines from ConceptSHIP or other tools, or created in CAFE based on the same imported hull lines, as it has an ability for generation and manipulation of complex surfaces (Figure 14).
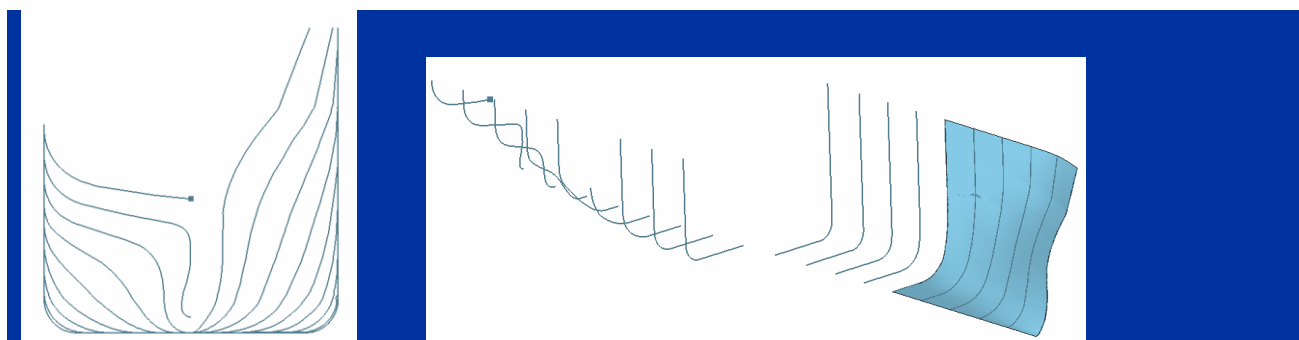

Figure 14: Imported hull lines and creation of surfaces in CAFE

8.3   Structural properties

To estimate the weight of the ship structure, material and structural properties have to be assigned to modelled surfaces (see Figure 15). A pre-set database containing material, plate and profiles properties can be imported into CAFE and customised according to the designer's needs.
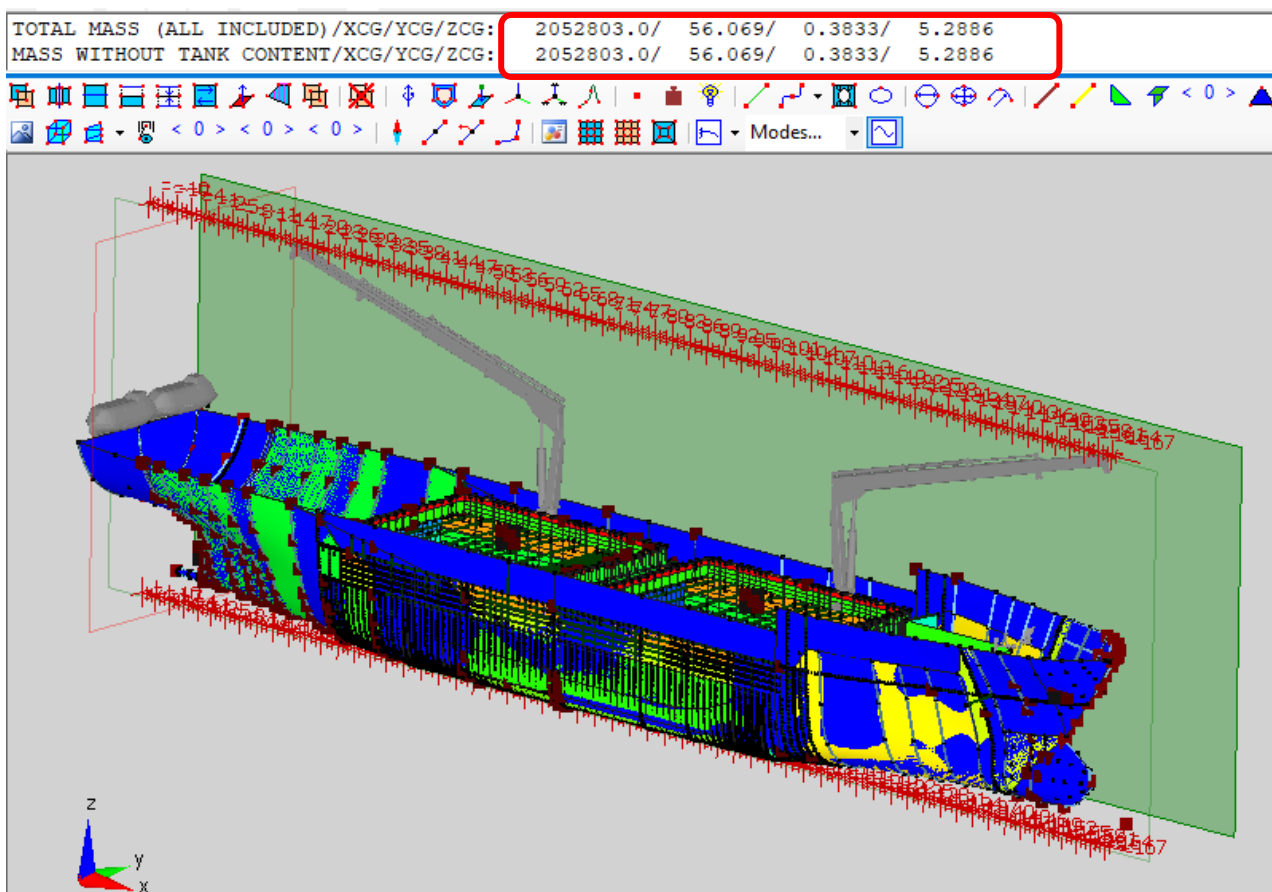
Figure 15: Visualisation of Ship model in CAFE and obtaining the mass properties

8.4 SHIPLYS output

CAFE can automatically produce a SHIPLYS log file containing necessary information on the ship model's total mass and centre of gravity, list of equipment and bill of materials (however, only a preliminary estimate of total material used, not a document ready for the production phase). All the data will be saved into the SHIPLYS database and ready to be used by other tools in the platform.

9 SEASAFE

LR SEASAFE provides powerful, modern statutory compliance tools for design, operation and cargo planning. It enables you to verify the stability, longitudinal strength and other naval architectural aspects of all vessel types from passenger ships, heavy-lift vessels and FPSOs to offshore structures, semi-submersibles and jack-up rigs. The software is available for use by designers and builders, consultants, ship owners, ship officers and fleet operators. It can also be fully customised to meet different users' precise requirements.

LR SEASAFE offers valuable integration with other systems (Figure 16), as well as operating as a standalone system.

LR SEASAFE software has a built in feature dedicated to the exchange of any defined loading condition(s) and related data or database items between assets and the shore-based office to support cargo planning and support the on-board user with other operational decision making.

LR SEASAFE Professional is a fully integrated CAD type, graphics-driven naval architectural calculations package specifically created for the designer, naval architect consultant and shipbuilder. It helps the user to rapidly develop a 3D vessel model of the ship's hull and compartments, from which you can run accurate, consistent and repeatable stability and longitudinal strength calculations.
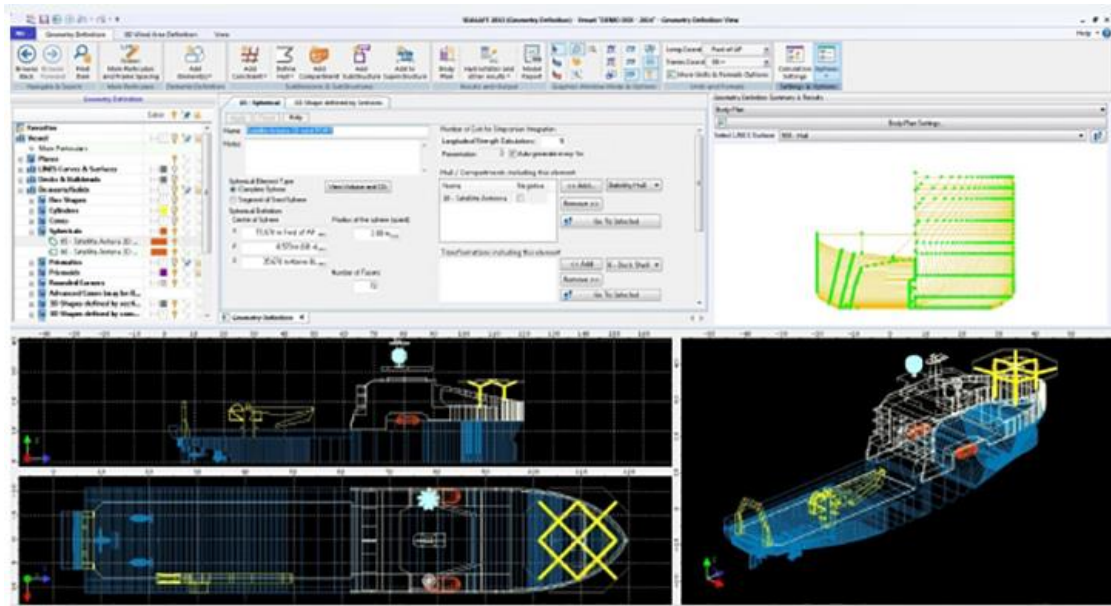
Figure 16: SEASAFE interface

All the commands and functions in the software are presented in a user-friendly and accessible way through well-organized and structured sets of options, context-sensitive menus and other graphical controls directly on the screen; this way the software does not require the user to memorize any commands or write any scripts in order to run the calculations and produce the necessary output. The report function is highly configurable with a number of useful pre-sets following the industry standards (Figure 17).
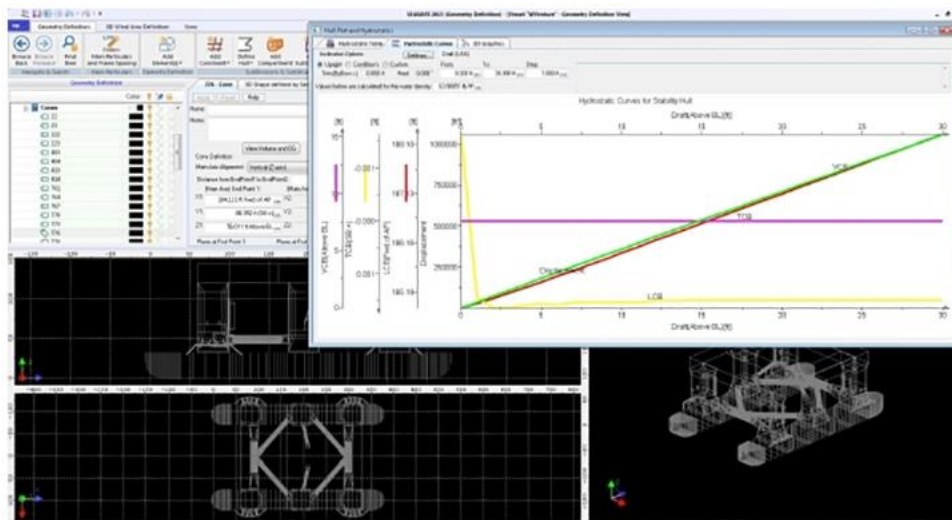

Figure 17: SEASAFE view

9.1 3D Model and Database

The hull form, if faired, is normally modelled using a set of longitudinal curves built up of B-Splines. The non-faired hull shapes (such as those of jack-up rigs and semi-submersible offshore platforms) or parts of the hull such as hull appendages (rudders, propellers and their shafts etc.) or spaces open to the sea (sea chests, thruster holes) are normally modelled using a set of basic shapes and other parametric shapes that allow definition of most complicated buoyant parts of any type of vessel.

The compartments are modelled using constraints such as the hull, the longitudinal and transverse bulkheads and decks, as well as basic shapes and other parametric shapes (Figure 18).

The LR SEASAFE Professional system focuses on rapid development of the 3D vessel model, which is suitable for running the necessary calculations for the production of related T&S

Booklets and Marine Operations Manuals. A 3D wind model can also be created in the software to calculate how the wind affects the vessel's stability, which is mostly used for offshore structures.

Additional information is added to the database depending on the type of calculations that need to be run on that vessel model. This can include the reference points, such as unprotected or weathertight opening, the intact and damage stability criteria (all standard stability criteria are predefined), the wind areas and wind pressure profiles, the lightweight distributions for longitudinal strength - together with their associated allowable shear force and bending moments, the external moments such as lifting or towing to support statutory stability criteria evaluation. Also, loadable areas and devices such as cranes, deck areas, container bays, RoRo vehicle decks, hatches and tweendeck panels, timber decks etc. can be defined to support the required loading operations and other calculations.
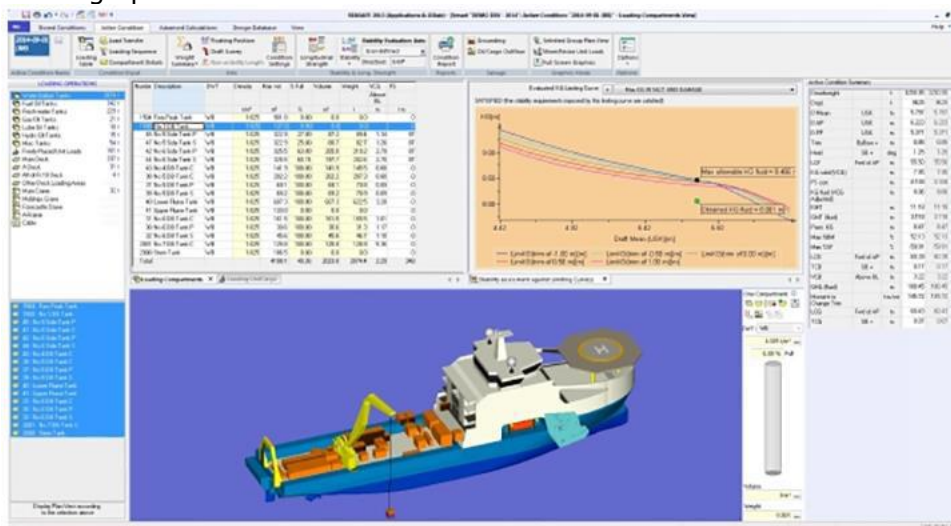

Figure 18: SEASAFE data model

9.2 Functionality

LR SEASAFE Professional has a comprehensive range of features, some of which are listed below:

- 3D modelling of faired hulls and surfaces, using lines plan, offset tables, or data imported from 3rd party software via DXF, IGES, STEP and other formats. The faired surfaces can, if needed, be combined with advanced parametric shapes for rapid modelling of appendages such as rudders, propellers, etc. or for modelling of vessel's superstructure and the hulls and other parts of offshore structures.
- Body plan, offset tables, cross sections and other hull related output.
- Hydrostatics for hull and compartments, Bonjean curves, curves of areas, cross curves of stability etc.
- Production of Ullage / Sounding tables.
- Analysis of Loading Conditions.
- Detailed Intact and Damage Stability analysis for any loading condition (against all current regulations such as IMO, SOLAS, MAPOL etc).
- Limiting KG/GM Curves generation: Intact and damage stability for ranges of conditions (sets of draughts/trims or displacements/trims, against all current regulations such as IMO, SOLAS, MARPOL etc). For offshore structures, the calculations can be done with respect to any direction of wind and evaluation axis 360° around the vessel.
- Probabilistic damage stability (SOLAS 2009 or Harmonized Probabilistic Damage Stability calculations - Latest Revision of SOLAS Chapter II-1, Parts A, B and B1) and SPS Code for the ships whose keel is laid after 1 January 2009.
- Also, available are the old probabilistic calculations for the older passenger and dry cargo ships.
- Grain Stability: generation of Grain Shift Moments in grain compartments and calculation of Allowable Grain Heeling Moments for Stability.
- Timber Stability: for vessels carrying timber.

- 360° Stability calculations as required for Offshore Structures such as semi-submersible offshore platforms and jack-up rigs.
- Longitudinal strength (sheer forces, also shear force correction, bending and torsion moments).
- Grounding calculations (single, two point and shelf grounding).
- Oil Outflow calculations.
- Advanced Reporting Functionality for production of Booklets directly from the software in PDF or MS Word formats.

10   RULESCALC

Manually checking against LR Ship Rules is complex and time-consuming. RulesCalc automatically, swiftly and systematically verifies that your vessel's structural design conforms to LR Ship Rules. By pinpointing any non-compliant elements along with the relevant rule requirements, it then helps you rapidly track down problem areas and action modifications. Figure 19 shows an example of graphical output from RulesCalc.

Confirming compliance while still in the design phase helps meet project deadlines and reduces staff workload. The only software on the market to codify LR's interpretation of its Ship Rules, RulesCalc is a vital tool for all major shipbuilders and ship designers.

The main features of RulesCalc are the following:

- Covers all ship types in the Rules and Regulations for the Classification of Ships, as well as LNG and LPG carriers and bulk carriers for service on the Great Lakes and River St. Lawrence.
- Can be used as a standalone system or in conjunction with other design software packages, including NAPA, Tribon and Lloyd's Register's ShipRight SDA.

Using RulesCalc, the assessment can be integrated within the design phase, which means that the efficiency of the design process will be increased, and the workload significantly reduced.

In short, RulesCalc enables the user to do the following:

- Verify Rules compliance.
- Track down Rule failures.
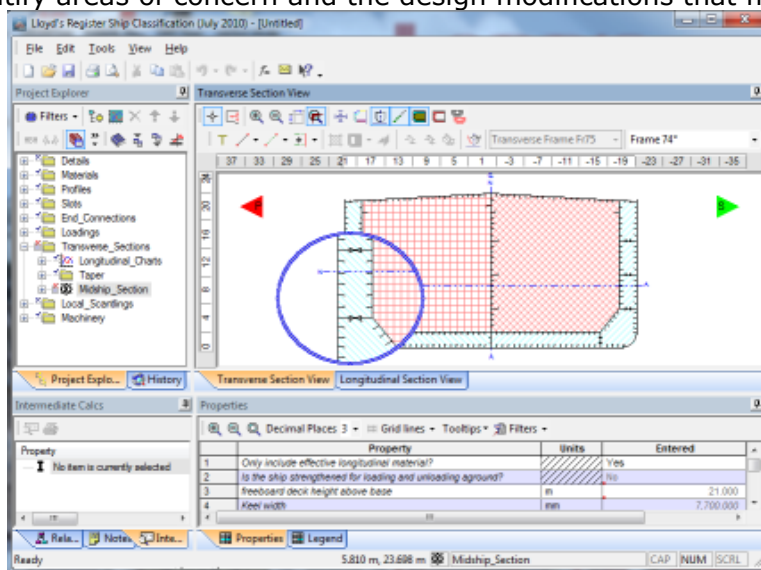- Rapidly identify areas of concern and the design modifications that might be required.

Figure 19: RULESCALC viewer

11 PPT (Production Planning Tool)

The following sections of this Deliverable include a summary of the rapid prototyping and production simulation tools, showing an overview as well as those parts of greater interest that are collected in more detail in D6.3 "Development of Production Analysis and Planning Tools ".

11.1 Rapid data generation tools for production

Production tools will generate technical information and relevant data concerning:
- Product (work breakdown) structure.
- Material content.
- Work content.

11.2 Rapid workflow prototyping

The following workflow in Figure 20, shows the general sequence of activities to be carried out in order to define the initial schedule and use more sophisticated optimization and/or simulation components.
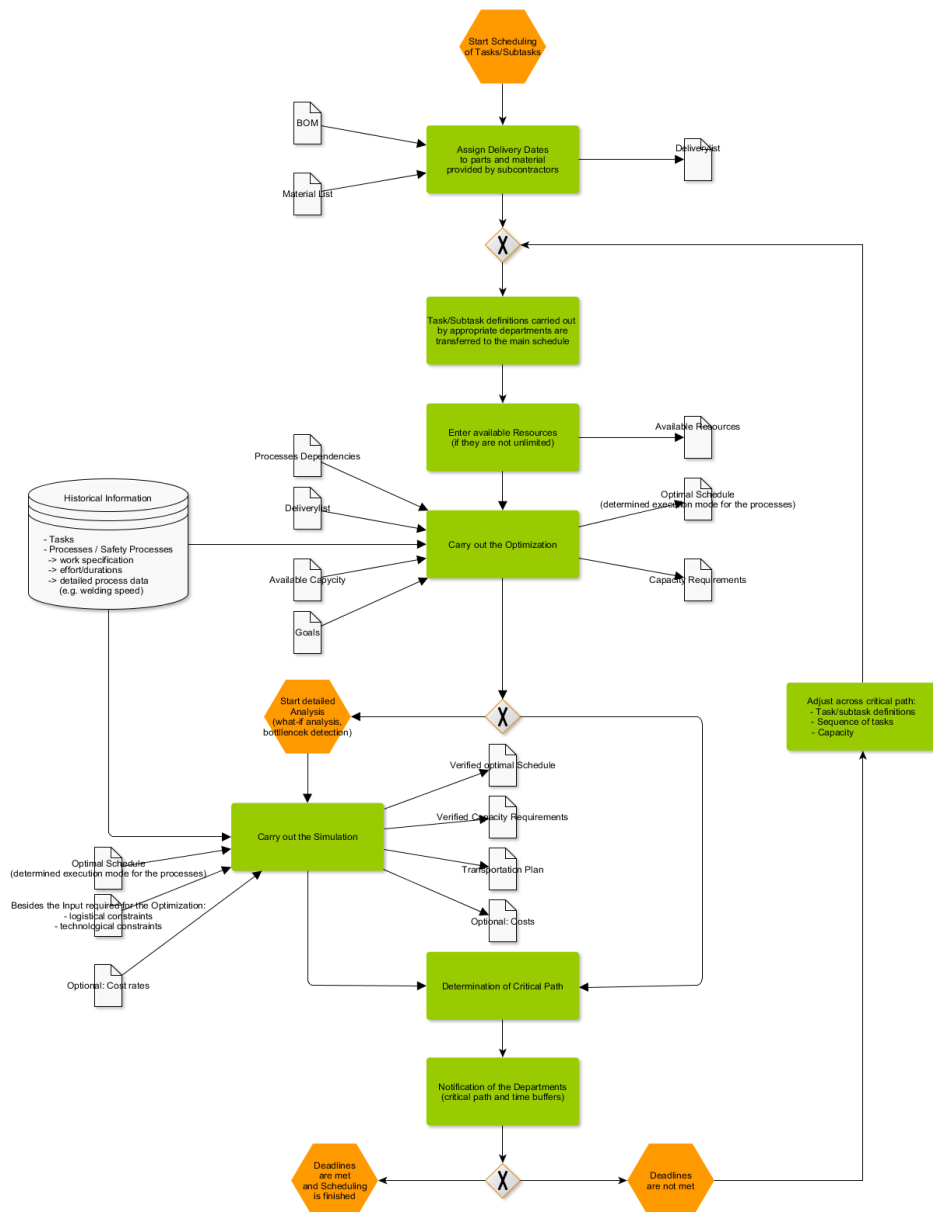

Figure 20: Rapid Prototyping Workflow

11.3 Functionality

11.3.1 Catalogue Data Management

Catalogue data represents data which:
- Can be used across projects.
- Does not change often.
- Can be specified for current project.

Furthermore, the data managed within catalogues can be used as <u>templates</u> or <u>references</u> within projects. In Figure 21, three different example catalogues are shown:
- Material and Equipment.
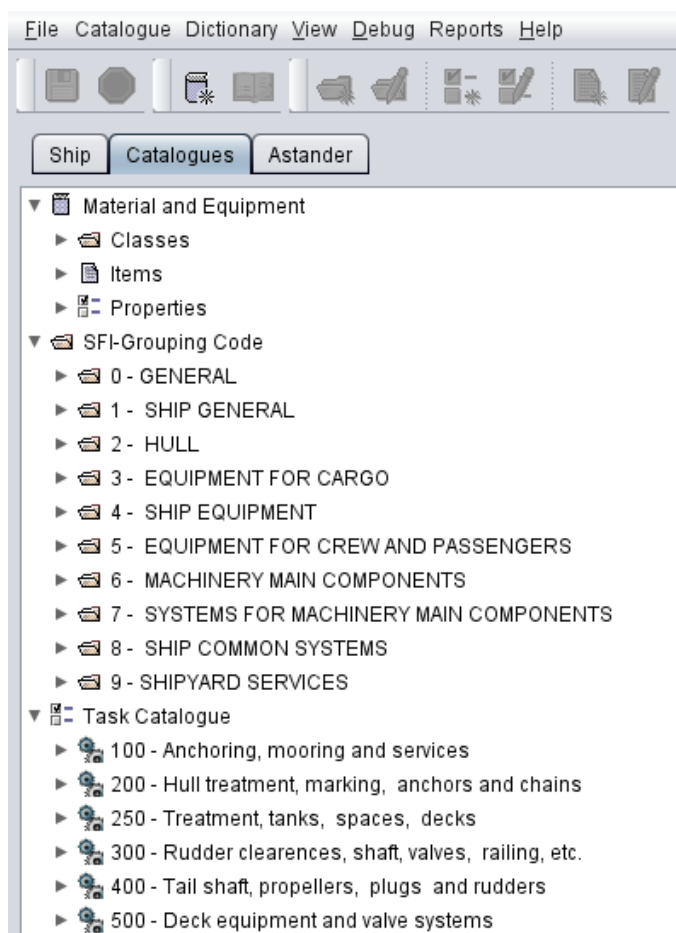- SFI-Grouping Codes.
- Tasks.

Figure 21: Catalogues: three types

Since the data managed by "Material and Equipment" and "Task" catalogue used for a specific project can be revised if needed, these catalogues are used as templates. On the other hand, SFI-Grouping Codes can be referenced by project specific material, equipment and task definitions allowing SFI-code based reports to be generated.

Using the catalogue functionality provides the following advantages:

- Common data needs to be specified only once
- Project specific data can be specified easier and faster

11.3.2 Rapid definition of Equipment

Figure 22, shows step by step how project-specific equipment can be defined. SFI code and equipment catalogue item can be easily found within the appropriate catalogues and assigned to the actual project specific equipment. During step 4, properties of equipment catalogue item are automatically added to the current equipment and can be revised if required (see red marked box).
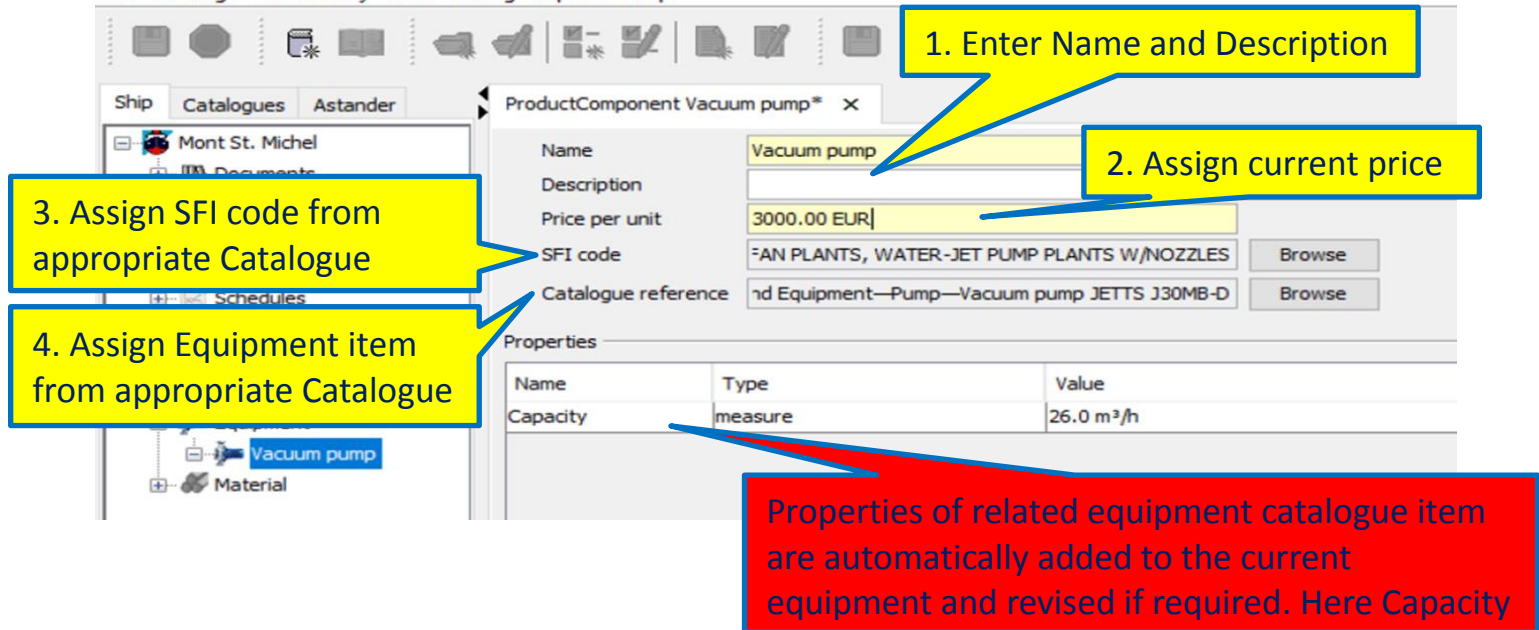

Figure 22: Rapid Equipment Definition

11.3.3 Rapid definition of raw material

<u>Product structure based raw material definition</u>
Once the work breakdown structure and the corresponding interim product structure has been derived based on the early ship design, the related raw material requirements can then be derived.

The current implemented functionality supports a rough estimation of raw material such as raw steel plates. Consideration of raw material implies further tasks (e.g. burning parts, delivery dates and costs) and is therefore important in order to derive a more precise schedule and overall production costs.

The mechanism for rough raw material estimation determines bounding boxes around the parts and summarizes afterwards the areas of the bounding boxes.

Advanced estimation for the raw material is described in chapter "Future Developments".

<u>Catalogue based raw material definition</u>
Similar to the catalogue-based equipment definition described in the previous chapter, the raw material can be defined in the same manner. Especially in retrofitting projects where the interim product structure plays a minor role, it is a requirement to define raw material for various retrofitting jobs. By browsing the catalogues for SFI code and appropriate material catalogue items, the required information can be easily found and assigned to the actual project specific material. During step 3, the predefined properties of selected material catalogue item are assigned automatically (see Figure 23).
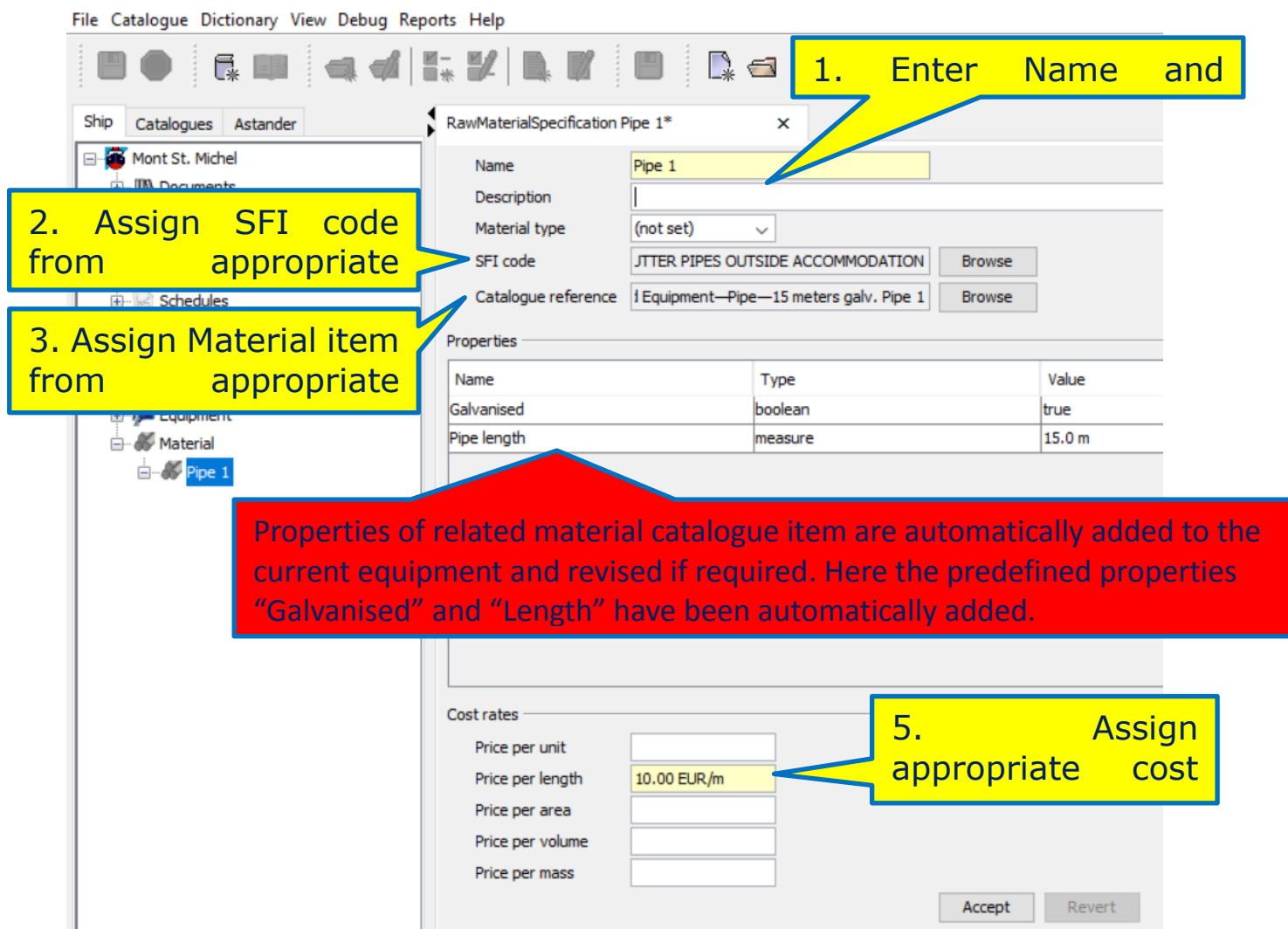
Figure 23: Rapid Raw material Definition

11.3.4 Rapid definition of Tasks

In the same way as described in the previous chapter, tasks can be easily defined using predefined catalogue containing task templates. By selecting and assigning the appropriate task template during step 2, the red marked data is added automatically and can be revised afterwards if needed (see Figure 24).

Within the detailed activity description amongst others, the work content can be defined or revised in case it has been already predefined in the assigned task template. Work content is a qualitative description of work to be done (e.g. work rate = 10m²/h and area to be painted is 60 m² and a specific colour has to be used). Once the work content has been defined, the next step is to derive the quantitative amount of work.

By assigning tasks to the product structure, the work effort is determined; where some tasks may have an explicit duration assigned (e.g. ship docking) or have defined work effort (e.g. assembly of a component) which is independent from the product structure.

A simple example where the work effort depends on the dimensions of the product is for instance the painting task. For the painting task, a work rate can be specified and by considering the related surface area to be covered, the work effort can be derived (e.g. in case of work rate = 10m²/h and the area to be painted is 60 m² → work effort = 6 h).

Once the work content has been specified, and the related work effort has been derived, the appropriate work duration is determined for each of the tasks by considering the available resources and constraints such as space limitations, so that in the next step the scheduling of the tasks can be carried out (see next chapter).
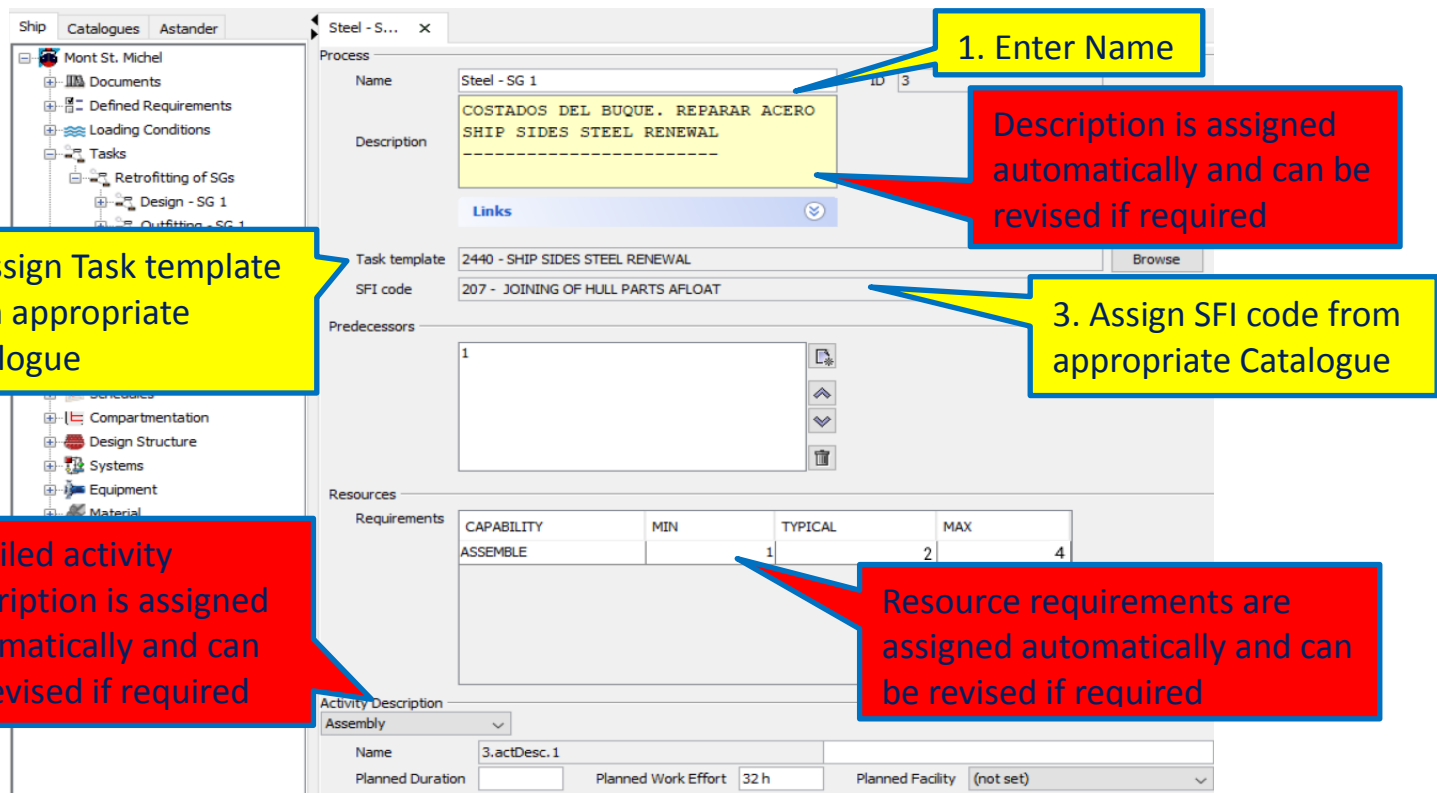
Figure 24: Rapid Task Definition

11.3.5 Scheduling

Overview

Once requirements and tasks have been defined (see D6.1, section 4.3.2) including the work content (see 3.3.2 Generation of Work Content), the next logical step is to schedule the tasks. In case of new building project, a hull erection plan is derived by backward scheduling, starting with the delivery date of a ship and by considering the sequence strategy in which the blocks are erected. In doing so, the predecessor and successor relations between tasks of different blocks are determined.

Unlike new building projects, for retrofitting projects which are quite task orientated, the consideration of the product structure usually does not play an important role. By carrying out forward scheduling the start and end dates for each task are calculated by considering the predefined predecessor and successor relations between the tasks and their durations, whereas the typical predefined number of resources is taken as default to determine durations for tasks where work efforts instead of explicit durations are defined. The schedule is represented as a Gantt chart and provides the first estimate of the overall project duration. At this stage, the resource availability is not considered and only space related restrictions are taken into account. Nevertheless, as a lot of work is subcontracted nowadays, the shipyards may use this information to get an initial idea of how long the whole project would take assuming that the required resources will be available. The possibility to consider limited resources is described in the following chapters using the optimization and simulation component. The consideration of limited resources becomes important in case a shipyard cannot assume that all required resources would be available e.g. due to cost considerations.

Selection of tasks to be scheduled

After adding the schedule plug-in, the tree will show a further node "Schedules", see Figure 25. By creating a new schedule the user can specify first of all within the following dialog the tasks to be scheduled (see Figure 26). This gives the highest flexibility to the user in case not all predefined tasks can be considered for the time being or different schedules have to be evaluated. If a parent task is selected, as shown in the example, then all the subtasks are automatically scheduled.
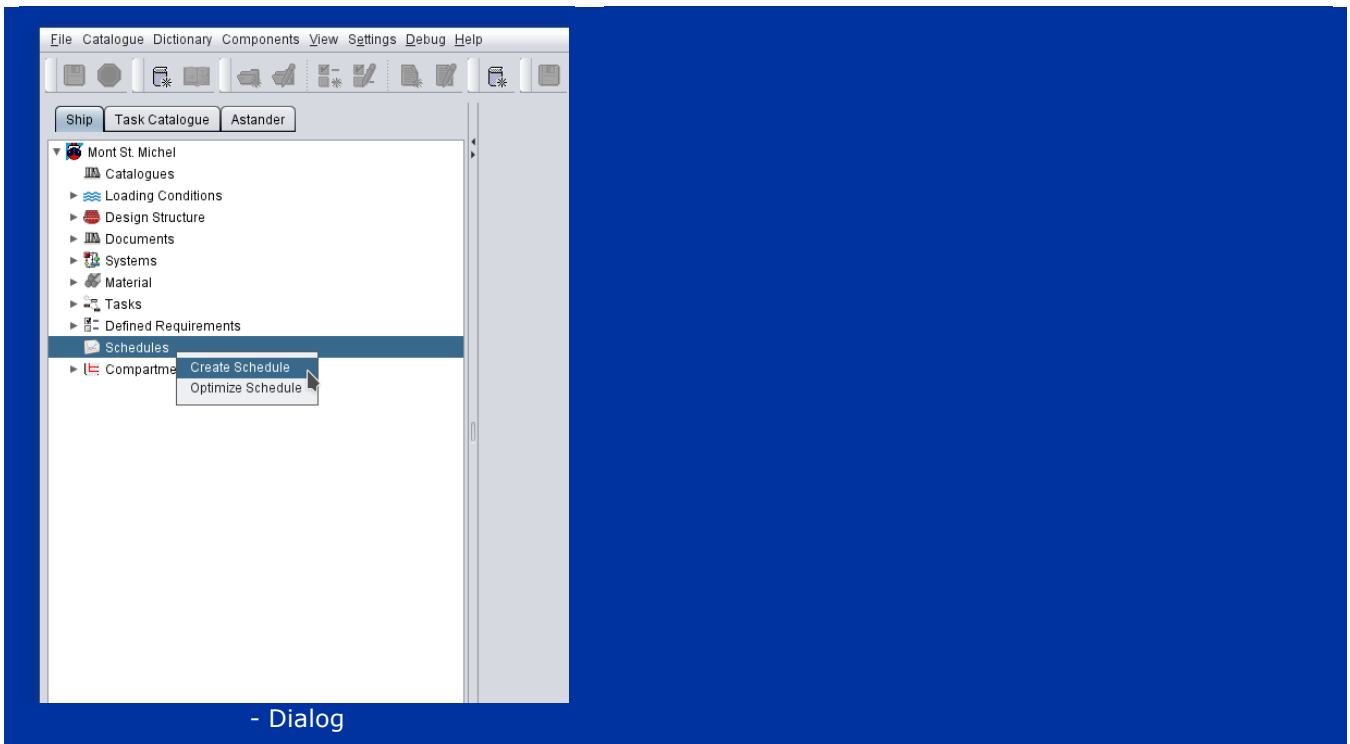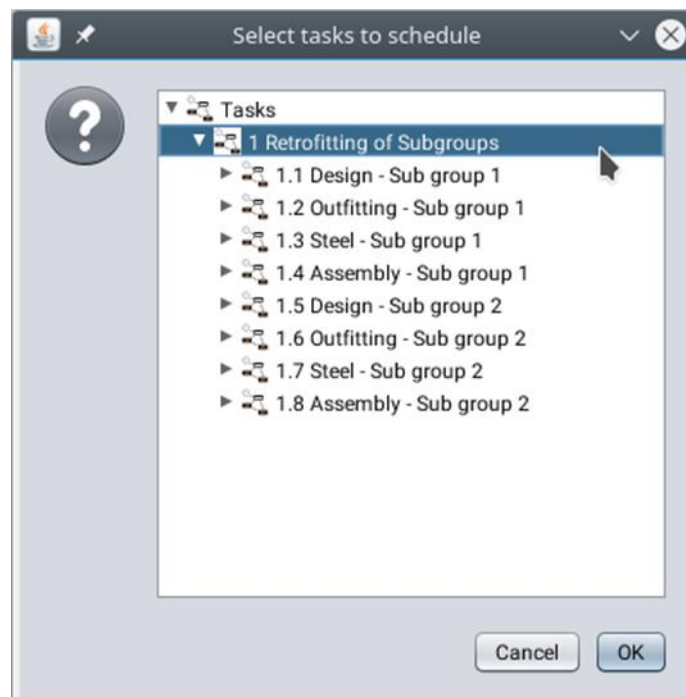
29

- Dialog

Figure 25: Create Schedule

Figure 26: Task Selection

Schedule editor

Figure 27 shows the schedule of several tasks related to retrofitting. The tasks can be edited interactively. For example, the sequence or the start and end dates can be changed just by dragging the tasks within the chart after selecting appropriate actions in the tool bar. By selecting a task within the Gantt chart, the related task details are shown below and can be also edited by the user. This combination between the Gantt chart and an editor supports the usability and provides an advantage over other systems like MS Project.
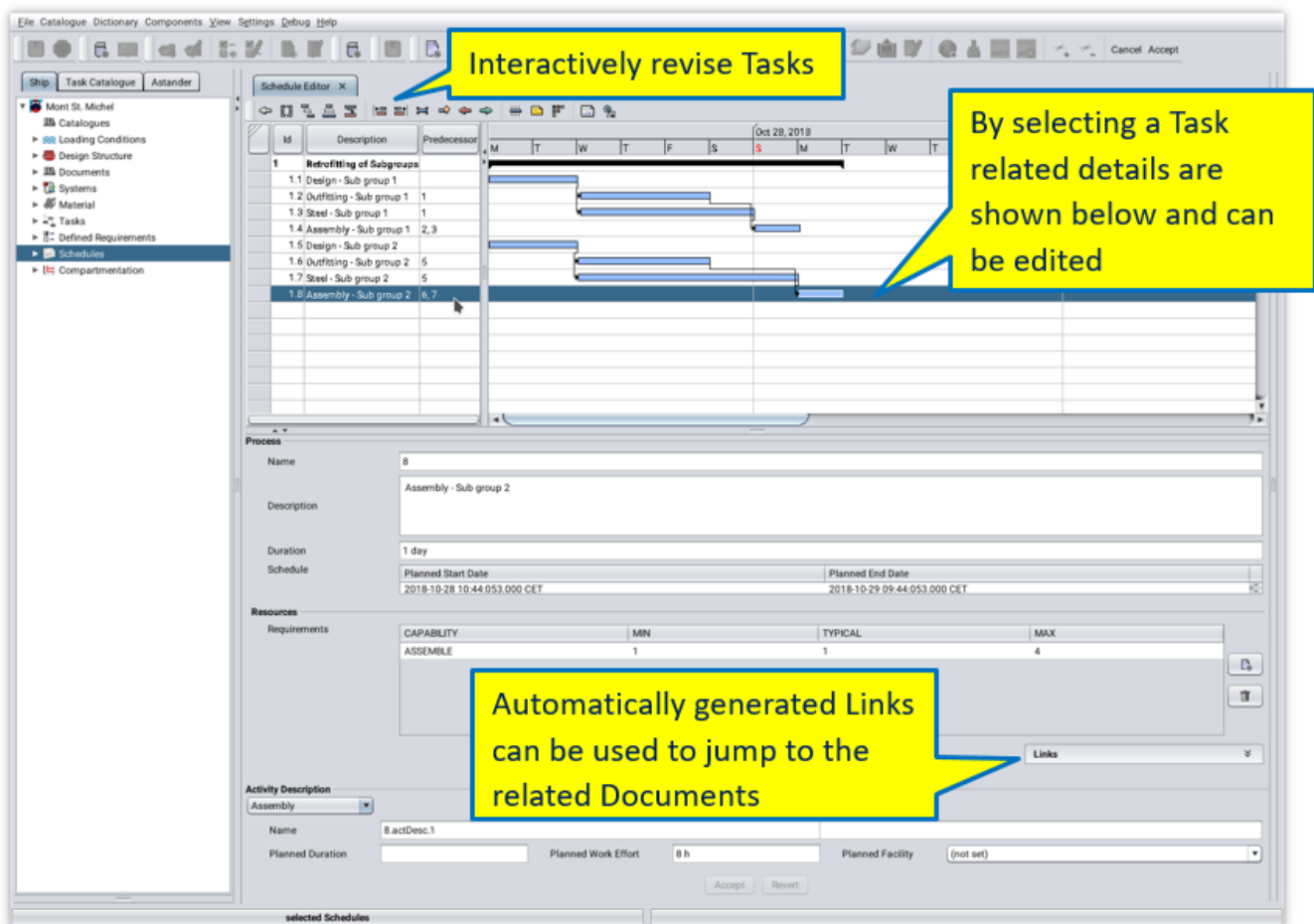
Figure 27: Schedule Editor

The editor also offers the opportunity to refer back to the related documents, e.g. to a specification provided by the owner, in order to check for further details as needed.

11.3.6 Schedule Optimization

Overview

▪ **What is optimized?**
  ▪ Main objective is to shorten the overall <u>Project Duration </u>considering limited resources.
  ▪ Second objective is to minimize the resource related costs.

▪ **How is it optimized?**
  ▪ By varying the <u>sequence</u> of tasks.
  ▪ By varying the <u>execution mode</u> of tasks.
  ▪ By varying the resources and related <u>costs.</u>

The result of an optimization run determines a start time and execution mode for each of the tasks, whereas the execution mode determines the number of specific resources to be used and related costs. Depending on the number of resources a task can be executed slower or faster. The following simple example demonstrates the optimization procedure. The initial possible but not optimized solution has an overall project duration of 13 days (Figure 28). It is assumed that there are two subgroups and for each of them 4 different tasks has to be executed considering predefined sequence. The limited resources consist of one designer and two general workers who can carry out outfitting, steel and assembly works. Furthermore, the "Design" task can be finished within one day if an additional expensive subcontracted designer is used. All the other tasks shall have an explicit duration.
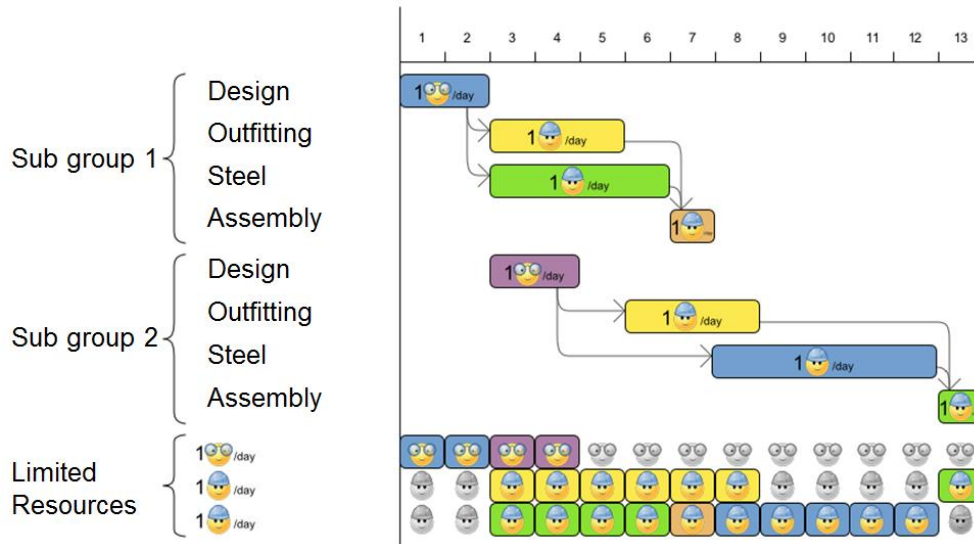
Figure 28: Initial Schedule

Figure 29 shows an optimal solution. The overall project duration has been reduced from 13 to 10 days. This has been achieved by varying the sequence of the tasks "Outfitting" and "Steel" works of "Sub group 2" which results in a saving of 2 days. Furthermore, another execution mode has been assigned to the "Design" task of "Sub group 1" resulting in a saving of 1 day. Since the second optimization objective is the minimization of costs and the assignment of the subcontracted designer to the "Design" task of "Sub group 2" would only cause additional costs and no further reduction of the project duration, the subcontractor is only used for the first design task.
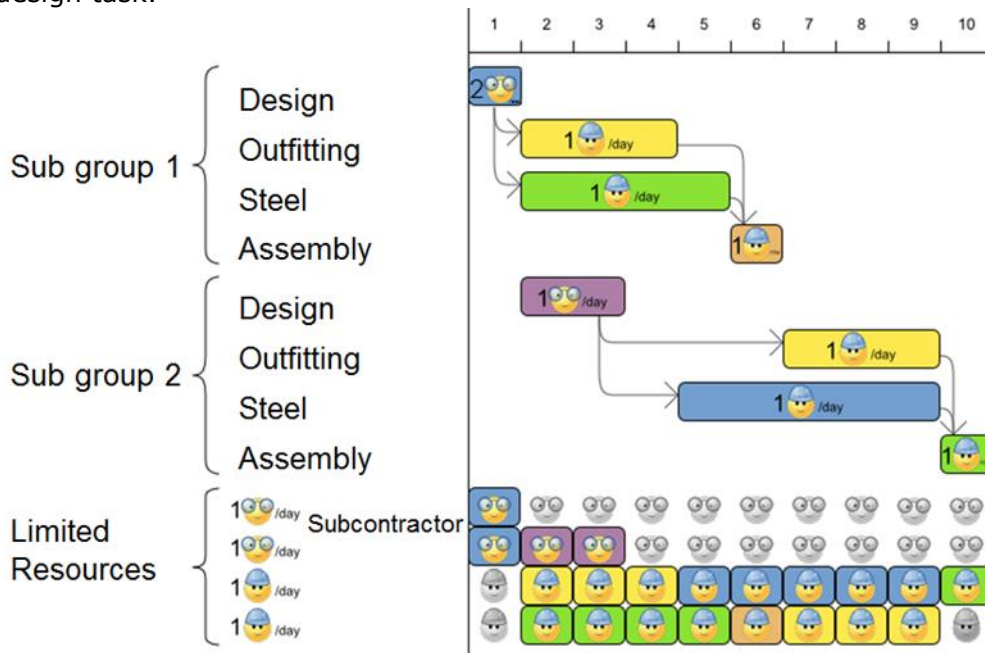

Figure 29: Optimized Schedule

Precautions for schedule optimization

Since the optimization engine considers limited resources, the first step is to define the available resources and related capabilities (see Figure 30).
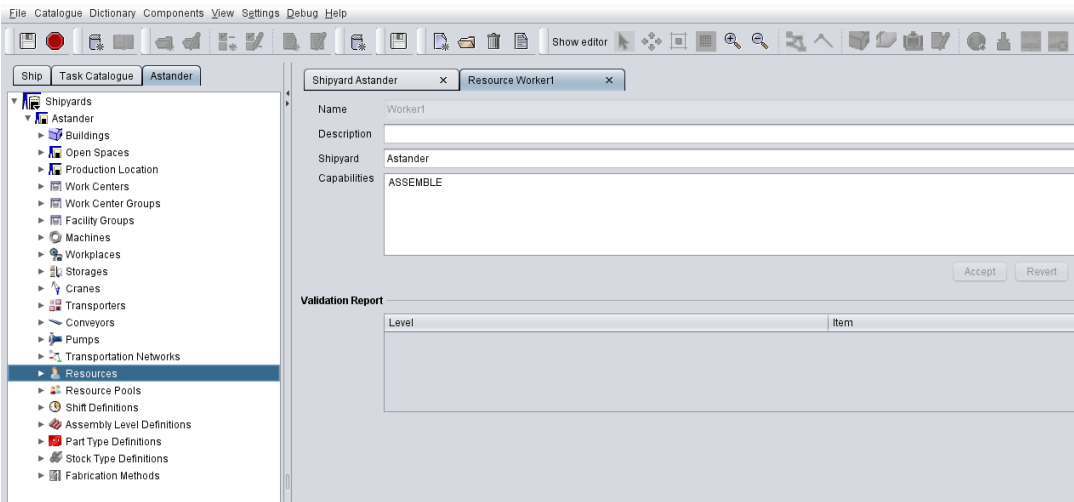
Figure 30: Resource Editor

Once the available resources have been defined, they can be added to a specific resource pool, where it is possible to define a general cost rate and a shift plan specifically for each of the resources if required (see Figure 31).
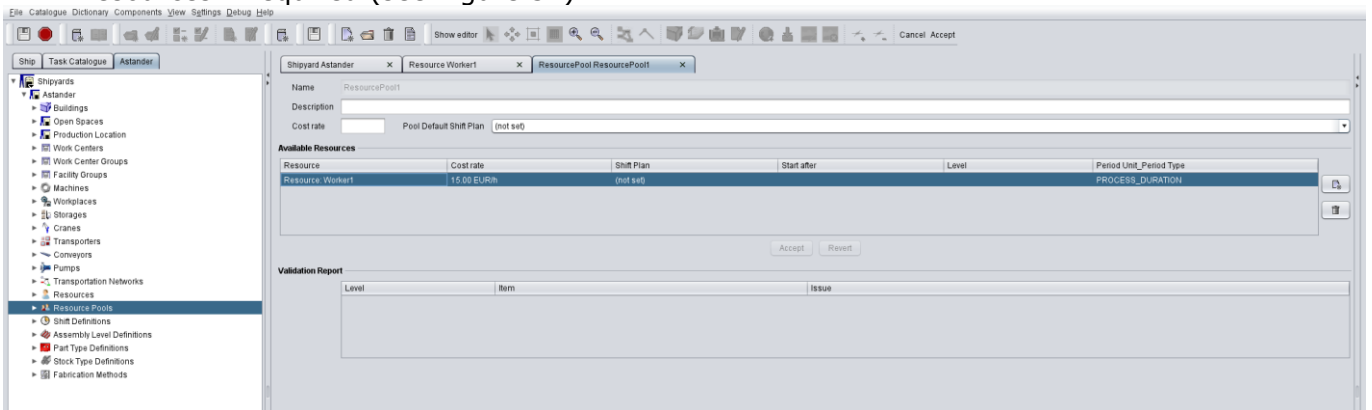

Figure 31: Resource Pool Editor

After the resources have been defined, the next step is similar to the procedure already described for creating a standard non-optimized schedule shown in Figure 32 and in Figure 33.
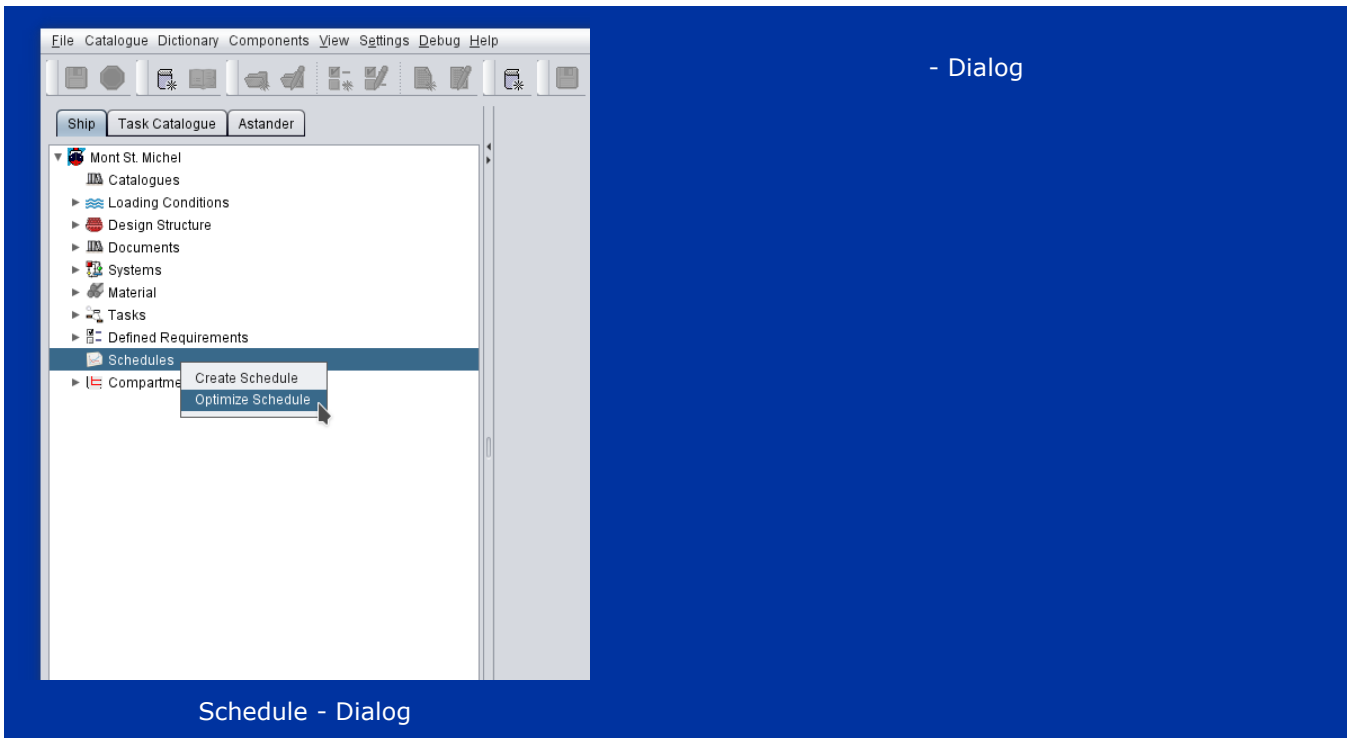
Schedule - Dialog

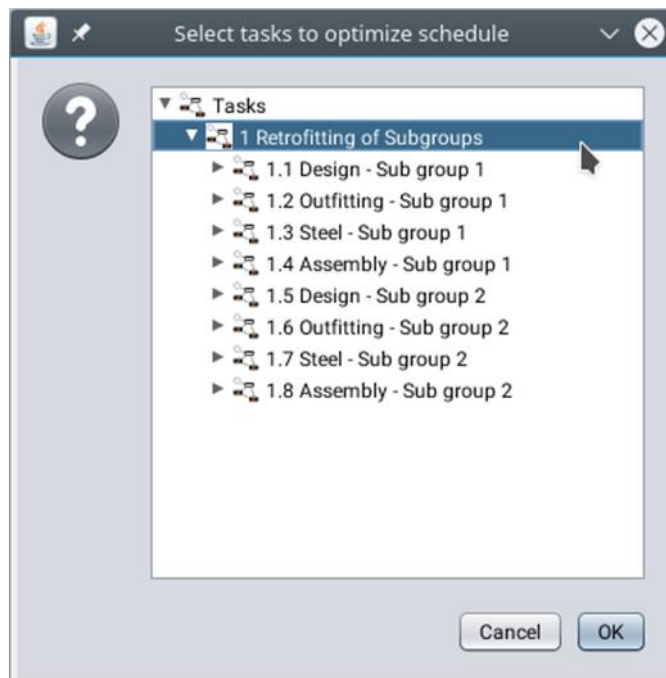**Figure 32: Optimise Schedule**

Figure 33: Task Selection

Optimization editor

After the tasks to be used for the optimized schedule have been selected the optimization editor (shown in Figure 34) is displayed. By pushing the "Solve" button, it is possible to start and terminate interactively the optimization run. After a desired score is achieved it is possible to save the optimized schedule and display it within the schedule editor (see Figure 27).

Figure 34: Optimization Editor

11.3.7 Shipyard Production Simulation

The biggest challenge regarding the use of simulation is the huge amount of data required in order to better reflect the reality and therefore obtain more realistic results. PPT helps to overcome this hurdle so that rapidly generated product data, task and resource definitions can be used by the simulation component in order to provide further benefits such as locating of bottlenecks, investigation of technical aspects of production process (e.g. evaluation of laser welding), and to minimize production risks by doing what-if analysis. Furthermore, LCA/LCCA relevant data such as footprint and consumables for the facilities and related costs can be determined in a more detailed way. In case an optimized schedule has been generated using PPT, the resulting optimal task and resource allocation can also be considered during the simulation run by higher prioritisation of tasks to be carried out first. Figure 35 shows the main general steps required for simulation runs, whereas the second step is the most time consuming since it has to be carried out for each project and now can be supported by PPT.
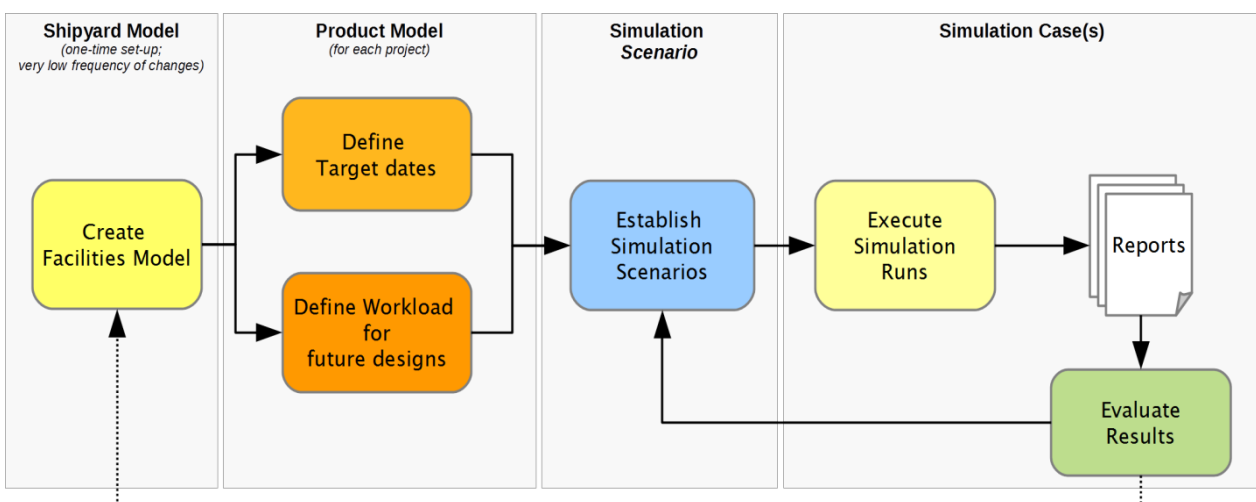

Figure 35: Simulation Procedure

Furthermore, besides human resources option, PPT also contains a facility modeller, which allows the definition of various types of facilities. This can then be directly used by the simulation component, which aids the first step described in previous Figure 35. Figure 36 shows a shipyard model for the Varna Maritime shipyard allowing further investigations by the use of simulation engine.
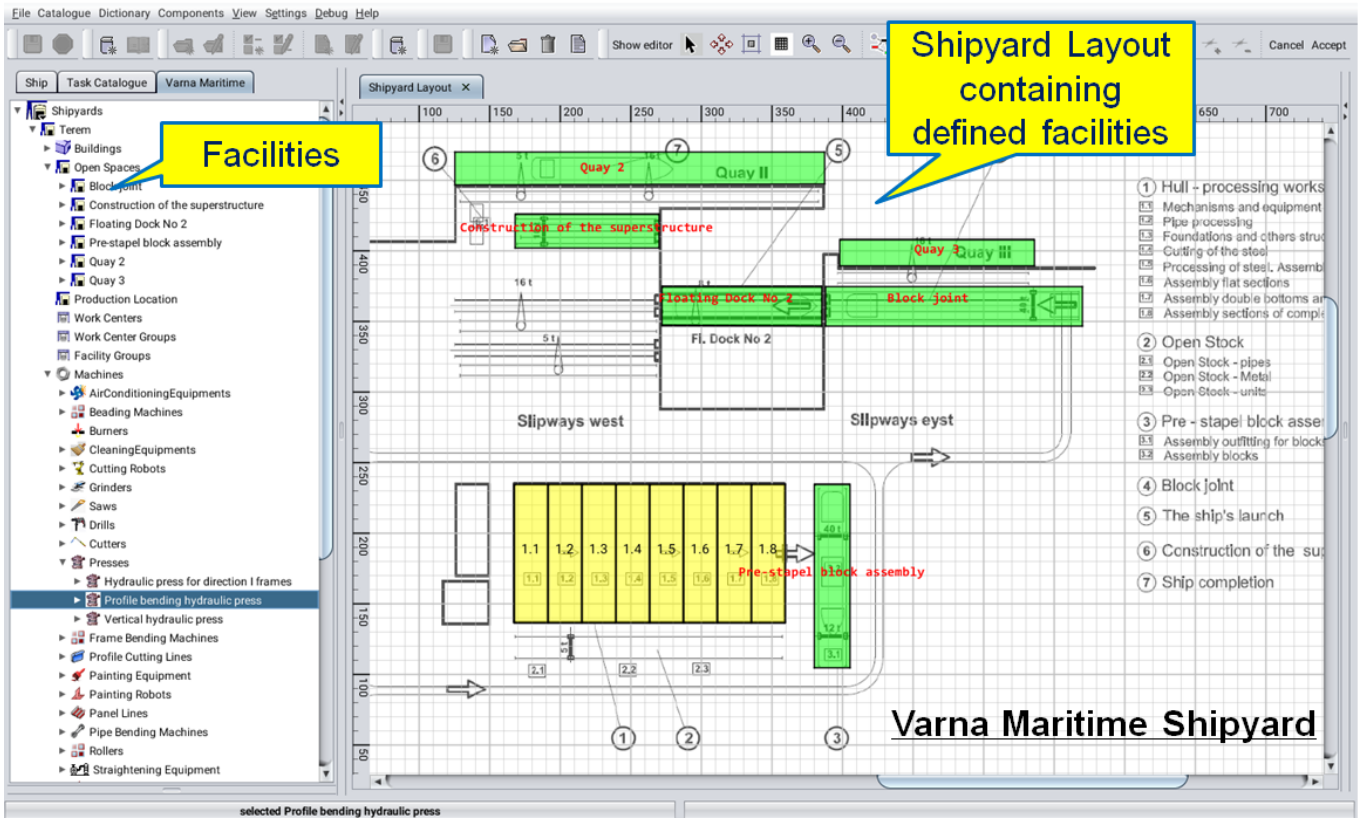
Figure 36: Facility Modeller

Technical "hot-spot"/risk identification

Once the relevant data is provided by PPT to the simulation component, analysis of technical hot-spots and risks can be easily done by investigating what-if Scenarios:

- Ship design changes.
- Special facilities are used.
- Logistics are important to consider.
- Different production sequences are possible.
- External impacts such as weather conditions have to be considered.

Furthermore, availability of facilities, which may break down can be considered using appropriate distributions during simulation run.

After the simulation run is finished, various results are available, as shown in the following figures (Figure 37, Figure 38, and Figure 39) which can be used to detect possible bottlenecks and under-utilization of resources. Afterwards, precautions can be taken to minimize production risks and maintain deadlines.
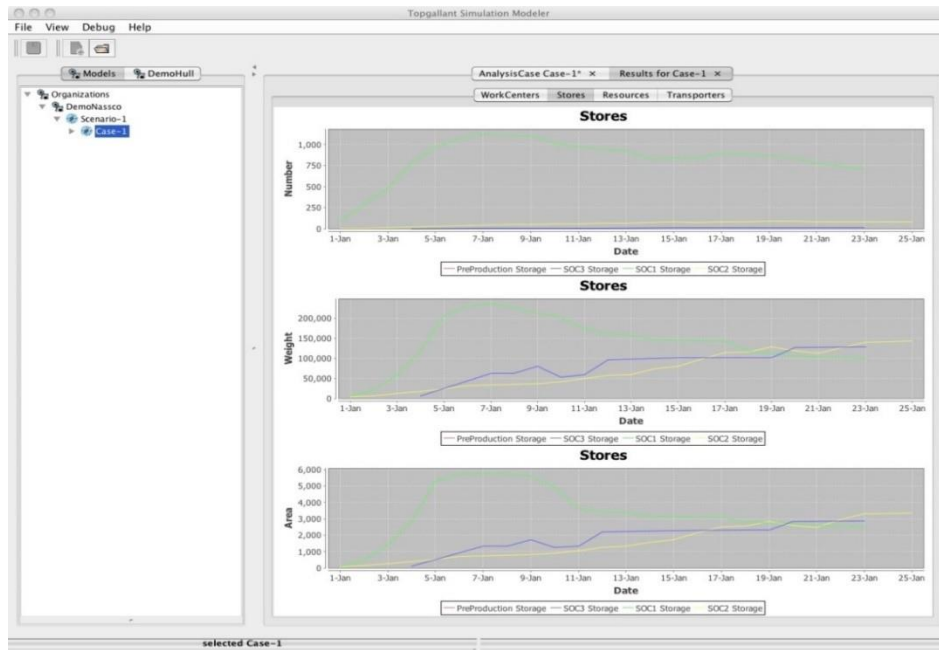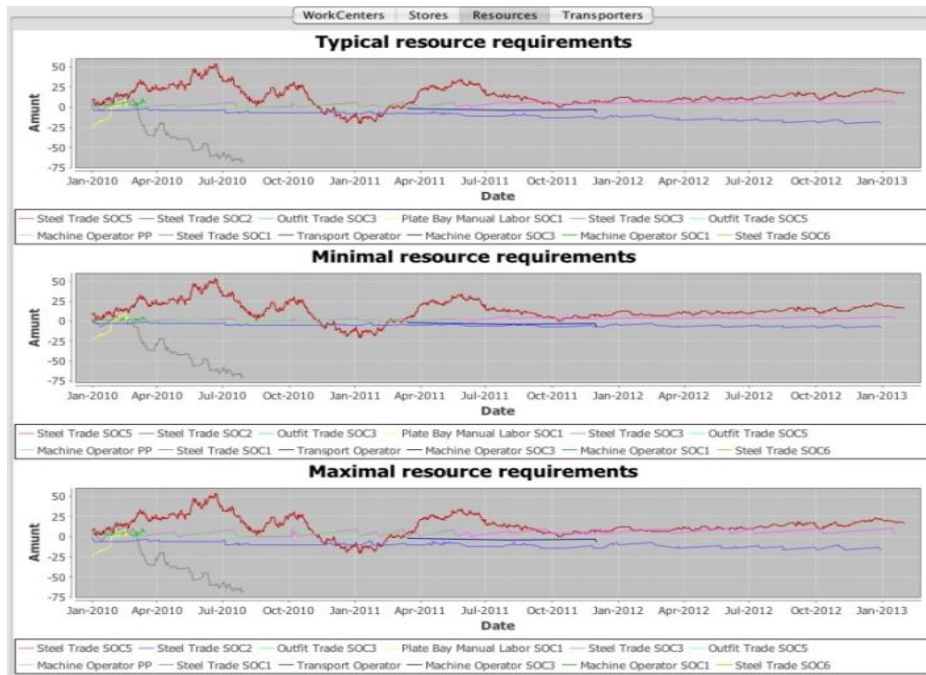
Figure 37: Stores Utilization

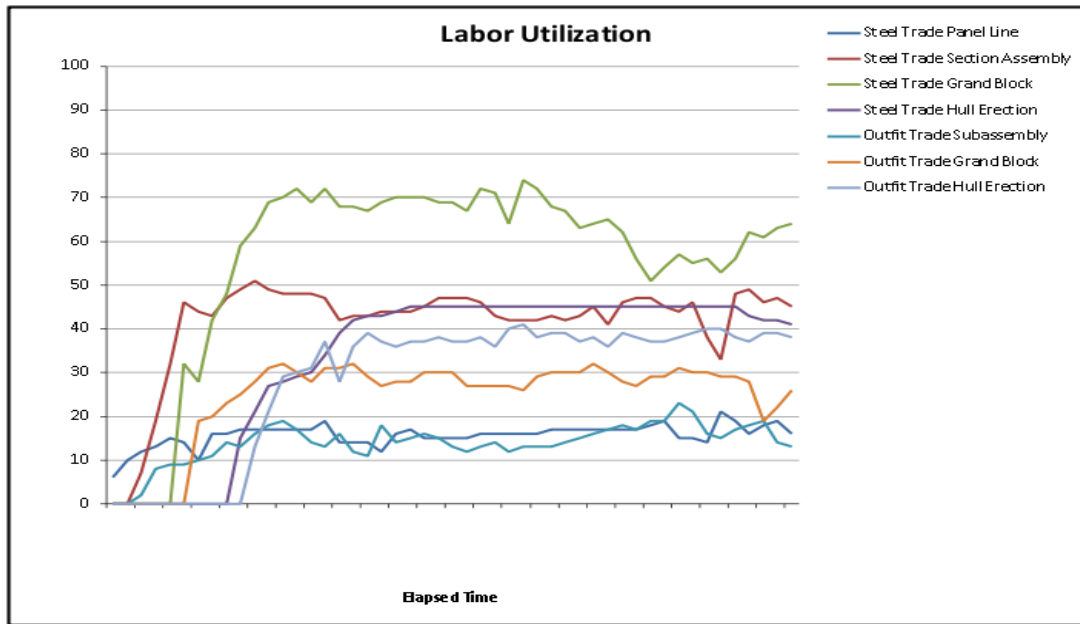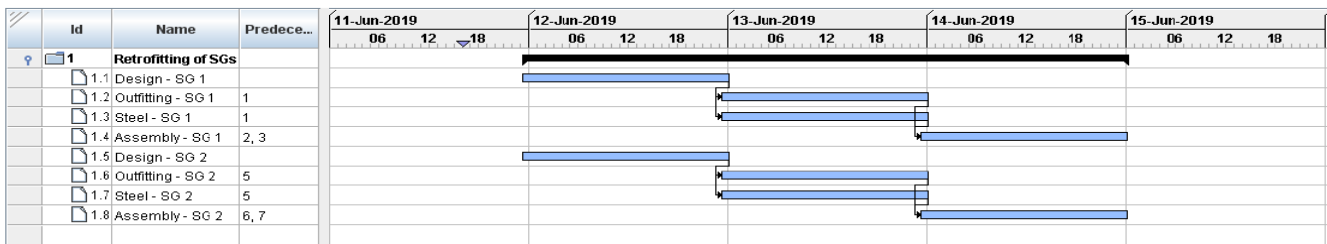
Figure 38: Resource requirements

Figure 39: Labor utilization

11.3.8 Reporting

Reporting is an important functionality in order to support the negotiation with the owner and also internal planning.

Currently a task and a cost report can be automatically generated. The task report contains the schedule and details for each task, as shown in Figure 40, illustrating an example of a design task.

Path Name	1—5
Common Name	5
Aliases	Design - SG 2
Description	Design - Sub group 2
Resource Requirements	DESIGN-> {min=1; typical=1; max=2}
Assigned Resources	
Schedule	Duration=1.0 day; Start=2019-06-12 00:00:00.0; End=2019-06-13 00:00:00.0
Predecessors	
Successors	6, 7

Figure 40: Task Details – Report

Another important report is the cost report, which can be used for bid preparation by the owner. The cost report is structured according to SFI codes and contains costs related to tasks, equipment and material. At the beginning, the report provides an overview of all SFI groups relevant for the current project (see Figure 41).

SFI Grouping Codes

Code	Name	Description
101	CONTRACT/SPECIFIC. WORK, GENERAL DESIGN, MODEL TESTING	Construction/fabrication software Engineering software (CAD, analysis) Maintenance, spare parts and supplies Other construction assistance (cleaning, rigging, stores, support)
211	HULL SECTIONS AND PANELS, AFTERBODY	
221	HULL SECTIONS AND PANELS, ENGINE AREA	
252	MAST, PUMP, FAN AND WINCH HOUSES, COMPANION WAYS	
268	FUNNELS	
292	FLAME CUTTING	
577	CENTRAL HEATING SYSTEMS W/RADIATORS	Boilers, burners and incinerators Heat exchangers & steam generation
627	FAN PLANTS, WATER-JET PUMP PLANTS W/NOZZLES	Turbines & waterjet units

SFI Grouping Code Details

101

Tasks

1

Common Name	1
Aliases	Design - SG 1
Description	Design - Sub group 1
Resource Requirements	DESIGN → {min=1; typical=1; max=2}
Costs	16.0 h x 5.0 €/h = 80.0 €

5

Common Name	5
Aliases	Design - SG 2
Description	Design - Sub group 2
Resource Requirements	DESIGN → {min=1; typical=1; max=2}
Costs	16.0 h x 5.0 €/h = 80.0 €

SFI Grouping Code Details

627

Equipment

Sewage treatment plant

Common Name	Sewage treatment plant
Description	...
Price	8500.0 €

Vacuum pump

Common Name	Vacuum pump
Description	...
Price	3000.0 €

Figure 41: Cost report

12   Conclusion

This report provides a user-level overview of the software modules selected and developed in WP6 titled "Implement rapid virtual design and production process prototyping generators" of the SHIPLYS project.

Based on the requirements identified in WP3 "Specify requirements for integration of rapid virtual prototyping and life cycle tool", several software modules (called SHIPLYS Applications) were developed with the purpose of them being used in an integrated manner through the SHIPLYS platform.

This report focuses on Applications developed within the project. However, in the interest of showing how an activity can be completed other Applications (pre-existing, off-the-shelf available) are also mentioned.