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Ship Lifecycle Software Solutions (SHIPLYS)

Project Deliverable Report

D8.2 SHIPLYS Good Practice Guide

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EXECUTIVE SUMMARY

This report presents the outcome of the work under the remit of 'WP8 - Testing, demonstration, verification' of the SHIPLYS Platform and associated suite of software (SHIPLYS Applications) for different ship design applications (SHIPLYS scenarios) in terms of 'a set of SHIPLYS Good Practice Guidelines' under sub task 8.3.

These guidelines are aimed to support the different stakeholders including ship designers, shipyard operators, ship owners, operation and maintenance professionals, repairers, classification bodies, researchers and consultants in the application of the SHIPLYS platform to other software developed to meet their respective ship design requirements. This is achieved by considering their perspectives and demonstrating the application of SHIPLYS platform to different design scenarios.

The document includes guidance on how circular economy can be improved using the approaches developed within SHIPLYS project. The potential for reduction in lifecycle and energy costs using the SHIPLYS tools is also addressed in this report.

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1 Introduction

The SHIPLYS platform and associated software suite (called 'SHIPLYS Applications'), have been developed, verified, tested and applied within the SHIPLYS project. SHIPLYS aims to help the ship designers, shipbuilders and ship-owner members, who, in order to survive in the highly competitive world market, need to:

- improve their capability to reduce the cycle time and costs of design and production,
- obtain adequate estimates of work content, raw materials and costs, as well as adequate production process planning of the work to be carried out.
- reliably produce better ship concepts through virtual prototyping and
- meet the increasing requirements for LCCA (Life Cycle Cost Analysis), environmental assessments, risk assessments and end-of-life considerations as differentiators.

The different SHIPLYS Applications integrated through the SHIPLYS platform are listed in Section 2.

The SHIPLYS project has undertaken the requisite work to test, demonstrate and verify the platform and associated software suites by applying to different ship design scenarios as per the tasks listed below.

- Stakeholder Scenarios
- Specify requirements for integration of rapid virtual prototyping and life cycle Applications
- Data quality assessment and database development
- Develop models for LCCA, environmental & risk assessment and multi-criteria decision making
- Implement rapid virtual design and production process prototyping generators
- Integration and optimization of the rapid virtual prototyping modules and SHIPLYS LCT, and their adaptation for the development of generic models
- Testing, demonstration, verification and development of good practice guidelines

This report presents the outcome of the work undertaken regarding 'WP8 Testing, demonstration, verification' of the SHIPLYS platform and associated suite of software in terms of a set of SHIPLYS good practice guidelines as outlined in Section 3.

These guidelines cover all aspects of the software developed within SHIPLYS including recommendations on the type and format of data required to conduct analyses. It also includes perspectives from all the stakeholders involved including designers, shipyard operators, ship owners, operation and maintenance professionals, repairers, classification bodies, researchers and consultants.

The guidelines include suggestions on specific aspects that are of interest to several stakeholders such as: how circular economy can be improved using the approaches developed in SHIPLYS; and, the potential for reduction in lifecycle and energy costs using the SHIPLYS tools.

In order to facilitate the development of the SHIPLYS tools, an activity model has been composed based on the ship design elements of ISO 10303, the Standard for the Exchange of Product model data (STEP).

This standard allows for the communication between different modules/tools that will be integrated to be explicitly resolved.

The activity model has served as a guide for integration of the various software components to be utilised by the SHIPLYS platform, as it maps the various functions covered by the components and illustrates the input, control and output data flows between them. The functionality, inputs and outputs of each software tool can be used to determine which functions within the activity model the tool facilitates. The activity model can then be used to guide integration and highlight any gaps or overlap in functionality of the software tools, see D3.3 Requirements for the integration of SHIPLYS tools and compatibility with existing tools.

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' allowing for such integration.

SHIPLYS Applications: These are software modules developed within the SHIPLYS project, or enhanced versions of existing software owned by SHIPLYS Consortium members. Table 1 shows these Applications, where apart from RSET, CAFE, SeaSafe, RulesCalc that pre-existed and where 'glue code' and/or certain enhancements were made during the project, the other Applications were developed within the project.

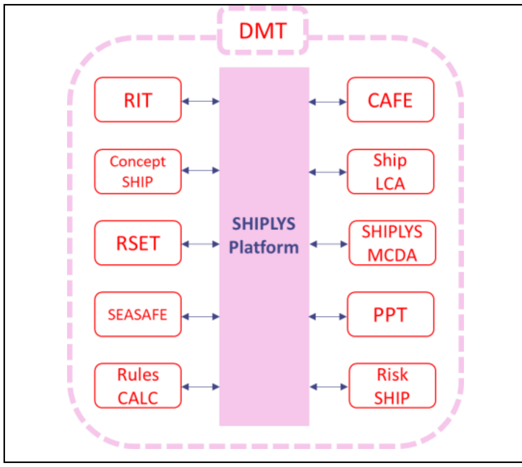
SHIPLYS Scenarios[1]: These are issues posed by the three Shipyards present in the SHIPLYS Consortium that the project addresses. There are three SHIPLYS Scenarios; one requiring the optimisation of hybrid propulsion system used in a short route ferry ship (Scenario 1), another requiring support during 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. Within the project, Applications are applied to those Scenarios where they, in their current state of development, are most applicable i.e. where their full functionality can be demonstrated.

[1] 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 Role of each software within the ship design cycle

The different software applications integrated into the SHIPLYS platform are listed below in Table 1.



Software (Applications)	Developer Organisation
DMT	BMT
SHIPLYS platform	AES
RIT	AES
ConceptShip	IST
RSET	BMT
CAFE	AS2CON
SeaSafe	LR
RulesCalc	LR
PPT	AES
ShipLCA	SU
SHIPLYS MCDA	TWI
RiskShip	IST

Table 1: List of different SHIPLYS Applications

Figure 1: Typical New Build Ship Design Workflow and the related software applications within SHIPLYS platform

Figure 1 shows the typical ship design workflow and the related software Applications to carry out specific activities within the SHIPLYS platform; iterations are possible between software but are not depicted for simplification purposes. It starts with Applications supporting design related activities and ends with an Application supporting the early production planning. The SHIPLYS rapid prototyping Applications are used based on the ISO Activity Model activities as an established workflow methodology[2].

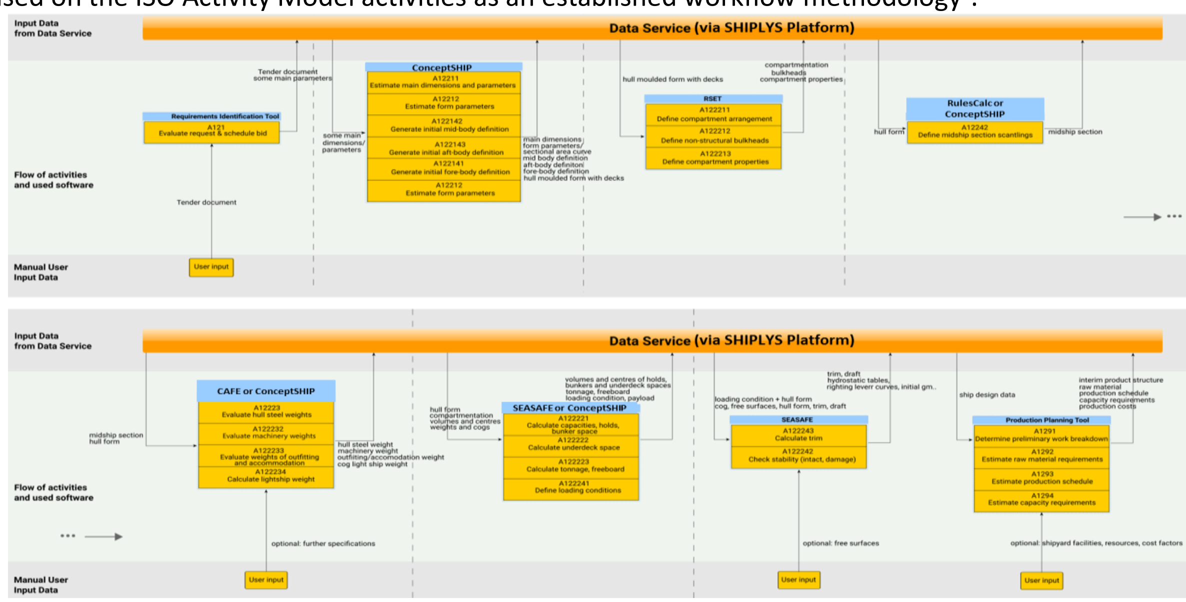


Figure 1: Typical New Build Ship Design Workflow and the related software applications within SHIPLYS platform

[2] More details on the Activity Model used for the purposes of SHIPLYS can be found here: https://www.atlantec-es.com/files/Downloads/Refactoring%20Early%20Ship%20Design%20Methodologies.pdf

2.1 DMT

2.1.1 Description of software

The Design Management Tool (DMT) acts as a user interface entry-point Application to facilitate visual interaction and connection with the SHIPLYS platform for access to local or remote services and resources, including:

- Connecting to the data service (Figure 2)
- Testing availability and connection of required services
- Securely accessing the database as an authenticated user/system
- Listing and accessing available projects within the connected database
- Demonstrating the design state of the project
- Displaying what data is stored in the database for access/usage by integrated software Applications
- Presenting the status and completion of each activity within the activity model
- Detailing and launching available software Applications, both locally and remotely
- Visually highlighting newly created data and changes to activity progress as a result of integrated software Application usage.

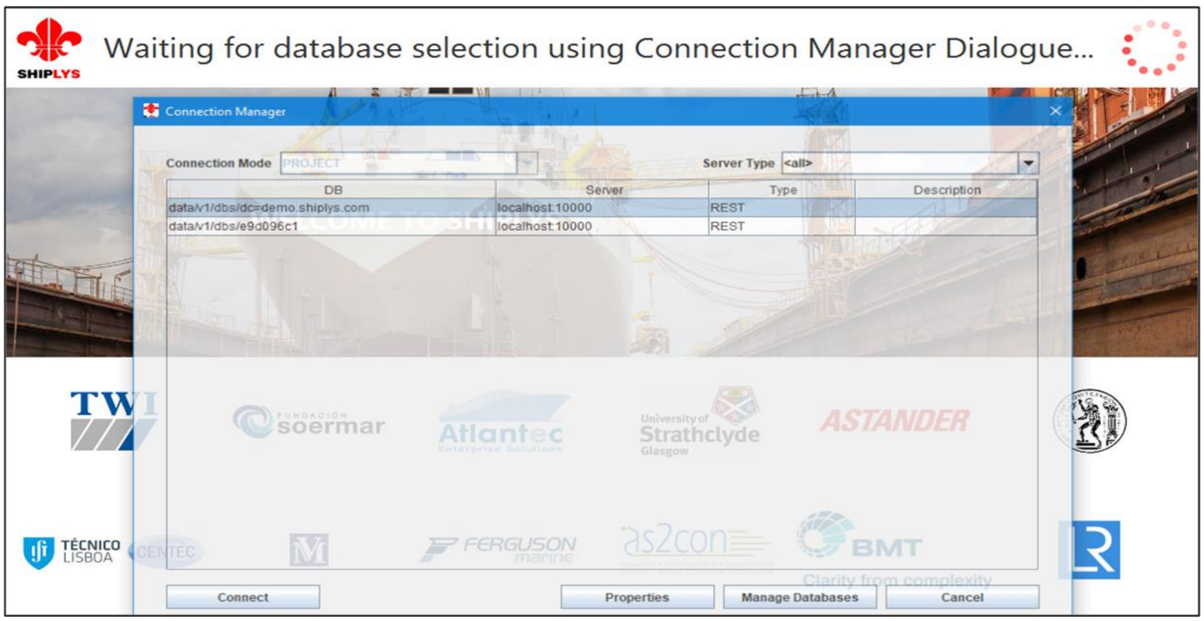


Figure 2: DMT Database Connection Selection View – Waiting for User to Select a Database from a SHIPLYS Platform Data Service

This allows users of the DMT to connect with and access the SHIPLYS platform, and launch the integrated software Applications. The DMT's visual representation of the database containing the SHIPLYS project data and activity models can be used to enable a designer or spectator in accessing the current state of a project.

2.1.2 Scope and limitation of functionality

The DMT will access and display all activities and data within the project database.

2.1.3 Data exchange with SHIPLYS platform

2.1.3.1 Input formats

The URI to the desired SHIPLYS data service and project database is required to connect, as well as the username and password for authorised access to the database.

The DMT can retrieve and graphically display available projects, data stored within the project database, the status of the activity model, accessible local and remote software Applications, and relevant metadata from the SHIPLYS platform, Figure 3.

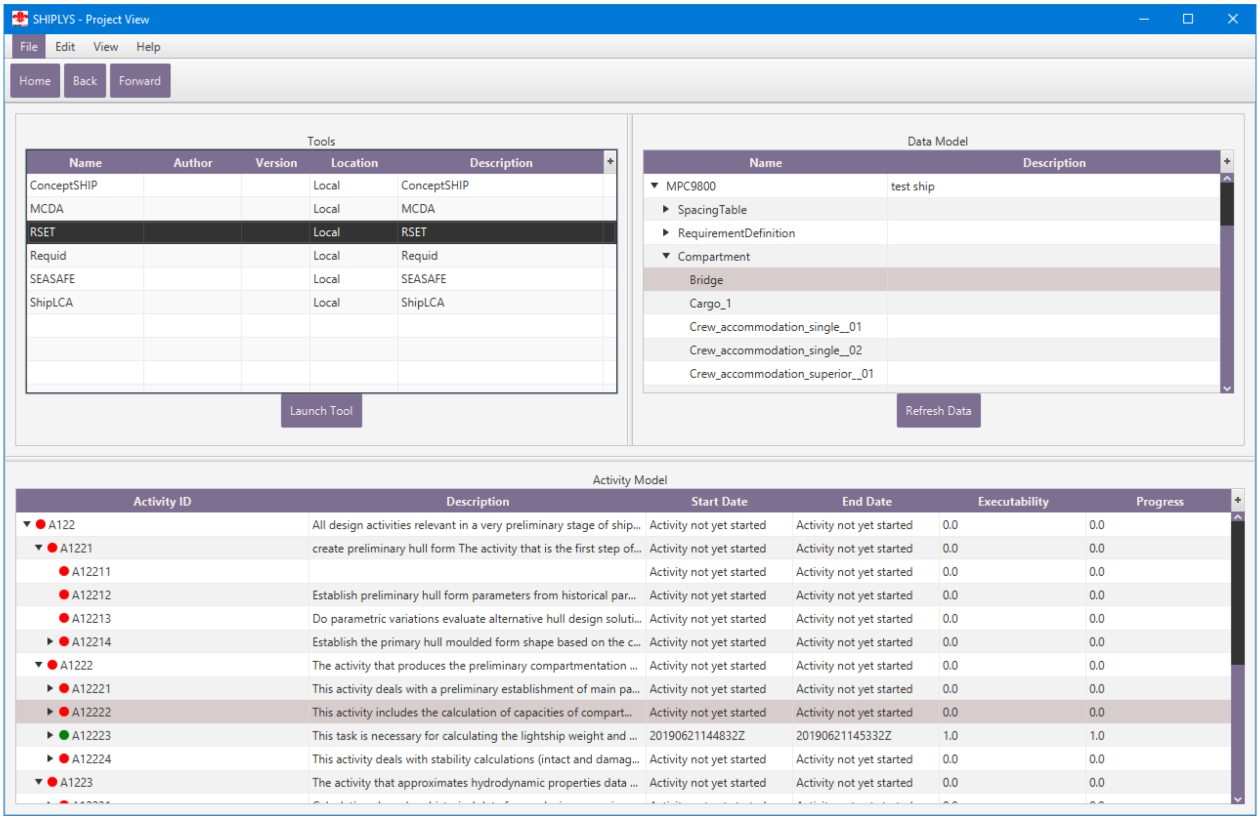


Figure 3: DMT Project View – Main View of Project, Displaying Available Software Applications (Top Left), Database Entries (Top Right), and the Status of the Activity Model (Bottom)

2.1.3.2 Output formats

The DMT does not output data to the SHIPLYS platform.

2.1.4 Setup of software with the SHIPLYS platform

The DMT, as well as the required SHIPLYS platform software modules, must be installed on the user's system.

Locally installed integrated software tools must be added to the DMT's local software registry.

Once installed and launched, the DMT can connect to and access the SHIPLYS platform and software via the user-input URI to the desired database of the data service, as well as the locally installed integrated software Applications that have been defined in the DMT's local software registry.

2.2 RIT

2.2.1 Description of software

The Requirement Identification Tool (RIT) represents the very first step within the whole ship design process and requires therefore only the tender document to be provided by the owner. The tender document can be easily imported into the Application to creating requirements linked to relevant text positions in it. Once the requirements are created, they are machine-readable which provides various advantages described in following chapters.

2.2.2 Scope and limitation of functionality

Scope of RIT is to support “Activity 121 – Evaluate request & schedule bid” within the early ship design process by making requirements machine-readable and in doing so to link them with provided documents by the owner, to track the changes and to make them accessible by other Applications which finally results in time savings.

Time consuming searching for relevant documents and specific text positions within a tender is avoided. Especially if an owner provides several documents or the tender document changes over time, it is required to keep the overview. Due to the linking functionality enabling the user to jump directly to the relevant text positions of a specific document, the linked document is opened automatically, and further details can be examined, which among others also simplifies the negotiation with the owner.

In case the requirements change over time, RIT enables the user to track them due to its versioning functionality. So, there is no need to manage these kind of changes manually (e.g. by using spreadsheet applications like MS Excel).

Furthermore, since the requirements become machine-readable they can be automatically imported by other applications so that entering the data manually is avoided.

A limitation of RIT in its current version is that retrieving the results of ship design Applications and comparing them with the initially defined requirements (via RIT) to ascertain how much of defined requirements have been met is not achievable. Furthermore, more sophisticated text analysis can be considered allowing more or less automatically to find requirements within a tender document e.g. by searching for specific key words.

2.2.3 Data exchange with SHIPLYS platform

RIT requires as an input a tender document containing the requirements specified by the owner (see Figure 4). The tender document can be retrieved from the SHIPLYS platform or if it does not exist yet it can be directly imported into the Application. The main output data is represented by requirement definitions and related links pointing to the position in tender document, which are stored within the Data Service of SHIPLYS platform. Furthermore, the tender document itself is stored in case it did not exist before.

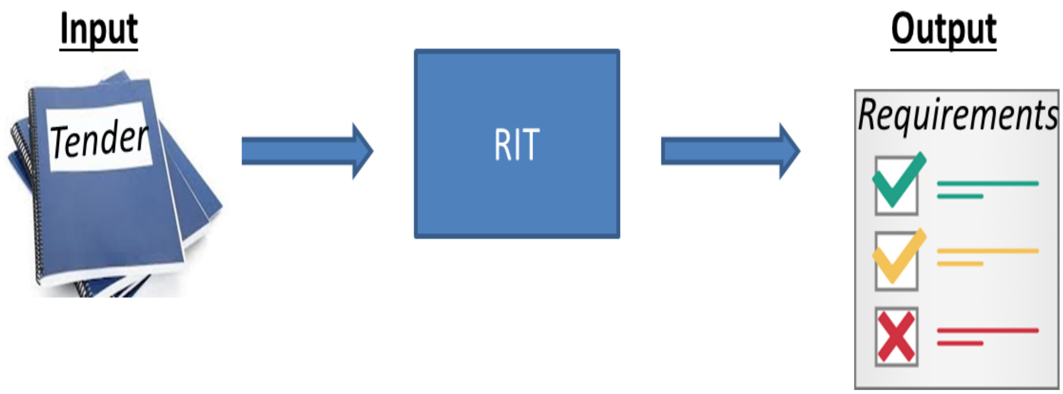


Figure 4: RIT - Input and Output

2.2.3.1 Input Data

According to Figure 4 above, the only required input is the tender document provided by the owner. Currently the Microsoft Word docx format is supported.

2.2.3.2 Output Data

The output represents requirements related to the following main categories, where the categories are selected during the requirement definition procedure:

- General Dimensions
- Operation Profile
- Design Structure
- Compartmentation
- Systems
- Equipment & Outfitting
- Material

2.2.4 Setup of software with SHIPLYS platform

RIT is fully integrated into the SHIPLYS platform using a Java based client for the REST-based communication with the services. Once RIT is installed it can be used as a standalone software or automatically launched from the Design Management Tool (DMT) for a specific project and store its requirements into the Data Service.

2.3 ConceptShip

ConceptSHIP is a software Application for the early stages of ship design and is 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 Applications 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 Application 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 composed by 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 allows its assessment in terms of propulsion, stability, EEDI, finishing 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.

2.3.1 Scope and limitation of functionality

The scope of the Application is for the concept and the basic design stages of merchant ships with a monohull. This Application provides a fast prototyping of both a ship and a voyage model that can be applied either in the initial dimensioning of a merchant ship or in the analysis of the round-trip voyage of one specified ship. The dimensioning of the ship can be obtained by systematic parametric variation or by optimization procedure. Currently the focus is on the four main types of merchant ships: tankers, bulk carriers, container carriers and RoRo vessels. For some of these types, some subtypes are considered that correspond to common hull internal layout configurations.

The Application is implemented as an add-in to Excel® spreadsheets and runs in computers under Windows 10 (32 or 64 bits) operating system and where Excel 2013 or later (32 bit version) is installed.

2.3.2 Data exchange with SHIPLYS platform

The necessary initial inputs to use the system for the initial dimensioning of the ship are those that can be found in an enquiry for a new ship, which are given below.

2.3.2.1 Input Data and its formats

To initiate the process the following data is required:

- Ship type and subtype (oil tanker, bulk carrier, container carrier, RoRo)
- Target Cargo Capacity (required deadweight, TEU or Lane Length)
- Physical restrictions (if any): Loa Max, Breadth Max, Draught Max
- Target ship speed
- Autonomy
- Type of propulsion system
- Number of crew members

The configuration of the hull cargo area requires additional parameters, such as:

- Height of double bottom
- Width of side tanks
- Geometry of hopper and wing tanks (in bulk carriers)

2.3.2.2 Output data and its formats

The data produced includes:

- Hull main dimensions and form coefficients (Loa, Lpp, Breadth, Depth, Draught, Cb, etc.)
- Steel weight
- Lightship weight
- Consumable weights
- Cargo capacity (expressed as volume, deadweight, total TEU number or LaneLength)
- Ballast capacity (in cargo area and in peak tanks)
- Propulsive power (MCR)
- Ship design speed
- Power of auxiliaries (electric power generation)
- Ship building cost and CAPEX
- Simplified hull form, described by a set of transverse sections or stations, each defined by a linear approximation (polyline)

2.3.3 Setup of software with SHIPLYS platform

The support for data exchange with TopGallant software is embedded in ConceptSHIP and is controlled through a menu of options, Figure 5.

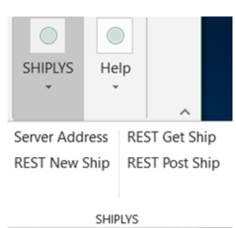


Figure 5: Menu for integrated TopGallant functionalities

Through this 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 ship data produced by ConceptSHIP, such as main dimensions of the hull, the CAPEX value and the set of cross-sections that defines the hull form of the ship.

2.4 RSET

2.4.1 Description of software

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, from ConceptSHIP or an external file, RSET allows the user to import or generate bulkheads, decks, and superstructure, as well as detail a list of functional spaces (compartments) for arrangement within the available spaces defined by the decks and bulkheads of the ship.

A set of user-defined constraints for compartment 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 available space, minimising hull form size, or reducing construction cost.

2.4.2 Scope and limitation of functionality

For the purposes of demonstration of the SHIPLYS approach, RSET will be used to perform activity A122211 (Define compartment arrangement), activity A122212 (Define non-structural bulkhead) and activity A122213 (Define compartment properties).

2.4.3 Data exchange with SHIPLYS platform

2.4.3.1 Input Data and its formats

A hull form can be imported into RSET in STL or OBJ format (triangle mesh). This is contained within a DocumentContent object in the SHIPLYS data model.

2.4.3.2 Output data and its formats

The hull form, superstructure, decks and bulkheads may be exported in OBJ format. Compartments can be exported in the standard Compartment format of the SHIPLYS data model. All of this data is saved to the SHIPLYS database, updating the project contained there with modifications to existing data (e.g. changes to the hull form) and newly created data (e.g. new compartments). See Figure 6 showing RSET Input and Output data.

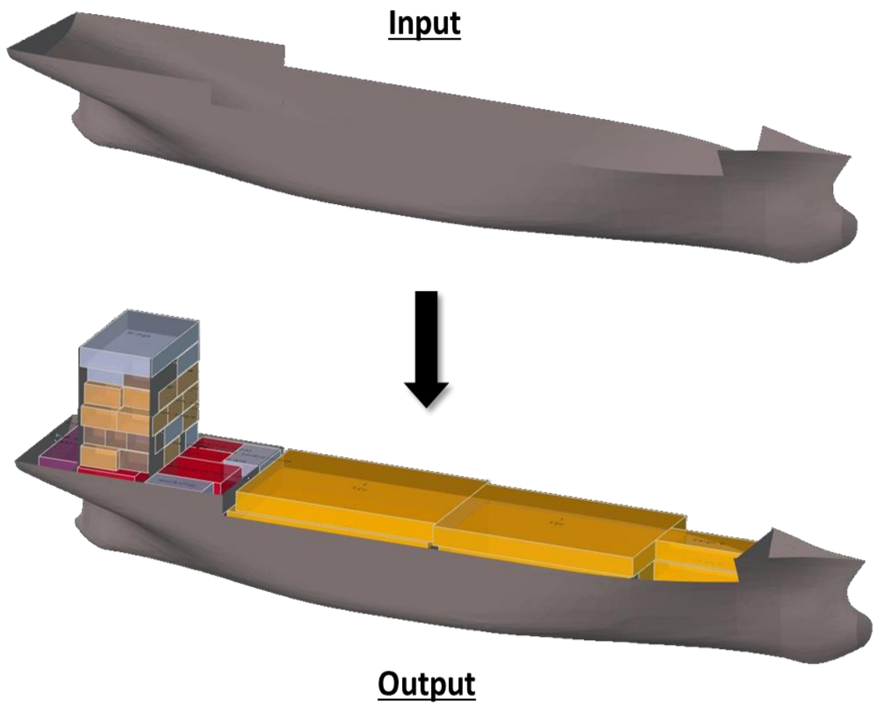


Figure 6: RSET Input and Output

2.4.4 Setup of software with SHIPLYS platform

The RSET executable must be available on the user's system. A local directory with write permissions must be specified, which will be used for reading/writing temporary files during data import/export operations. RSET will be launched via the SHIPLYS Platform interface, whereby the current SHIPLYS project is loaded automatically on start up. Any changes or additions to the ship model created in RSET are saved back to the SHIPLYS platform as requested by the user.

2.5 CAFE

2.5.1 Description of software

CAFE is a ship modelling software for fast developing of preliminary ship structure and positioning of the main equipment in order to obtain a preliminary estimate of the lightship weight, centre of gravity and provide the structural design that will be checked according to the classification societies' rules and input needed for calculating preliminary trim and stability - Figure 7. Also, CAFE generates a list of equipment and bill of materials.

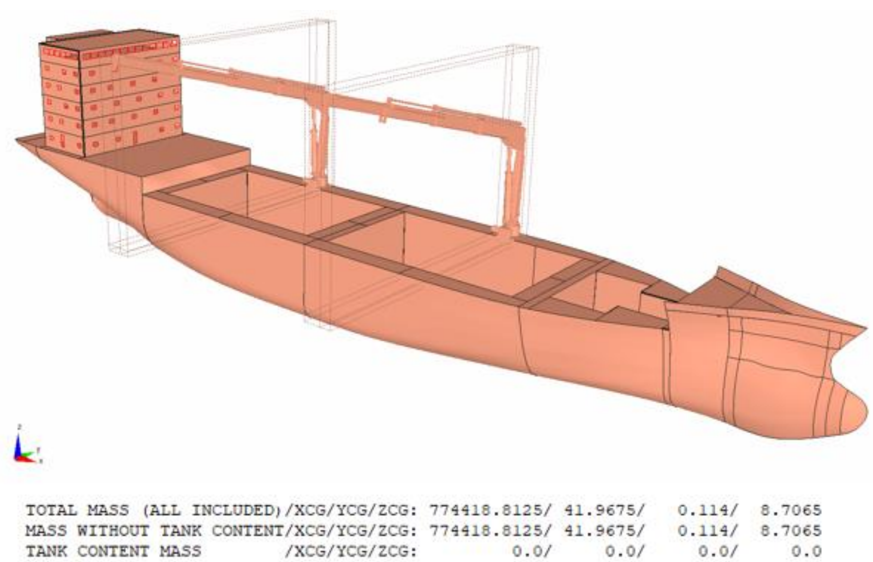


Figure 7: Ship model created in CAFE with estimated mass and centre of gravity

2.5.2 Scope and limitation of functionality

For the purposes of SHIPLYS, CAFE will be used for the following activities:

A12223 – Estimate weight

A1225 – Create preliminary machinery design (refer to a deliverable)

A1226 – Create preliminary outfitting design (refer to a deliverable)

2.5.3 Data exchange with SHIPLYS platform

CAFE software communicates with the SHIPLYS platform through a simple log file that can be automatically produced after the modelling is finished. The log file contains all necessary information on the ship model's total mass and centre of gravity, list of equipment and bill of materials.

2.5.3.1 Input data and its formats

As a starting point for CAFE, the user can import a hull form taken from the SHIPLYS database or created independently in other Applications. The hull form can be imported as a geometry file (iges/step) or it can be created in CAFE using imported hull lines from ConceptSHIP or other Applications.

2.5.3.2 Output data and its formats

Within SHIPLYS platform, CAFE user stores following data into database:

- Ship model's total mass and centre of gravity
- List of equipment including equipment mass and centre of gravity
- Bill of materials (a preliminary estimate of total material used, not a document ready for the production phase) including total amount of plates/profiles (m^2/m) used in the model, type of materials with its properties
- Geometry file of the ship model (in .stl format and CAFE .cpf format)

2.5.4 Setup of software with SHIPLYS platform

CAFE has been integrated into the SHIPLYS platform using Java based client for the REST-based communication with the services. It can be used as a standalone Application or automatically launched from the Design Management Tool (DMT) for a specific project and store its output data into the Data Service.

CAFE software needs to be installed following the basic instructions given in User Manual and D7.2 *SHIPLYS generic software with user instructions*.

The connection with the SHIPLYS platform is based on creating the SHIPLYS log file in CAFE after modelling is completed. The specified log file contains all necessary data needed to be stored in the SHIPLYS platform. These data are, for example, total mass of the model and its centre of gravity, list of equipment, total amount of profiles/plates used with the same property, material specification etc. Figure 8 shows an example of SHIPLYS file. Using Java based client, the SHIPLYS platform reads from this log file and stores the data in the Data Service.

```
//SHIPLYS DATA EXPORT
//MASS PROPERTIES
Total Mass 747.731
Centre of gravity 0.5 0.6966 1.0675
//PLATE PROPERTIES
Plate;PT1;120;1.5;10;A
Plate;PT2;144;1.5;12;A
Plate;PT3;126.4911;1.581138;10;AH32
Plate;PT4;192;2;12;AH32
//PROFILE PROPERTIES
Profile;HP*100*10;17.6;2;1100;A;L;100;10;20;10
Profile;FB*120*12;23.04;2;1440;A;FB;120;12;0;0
Profile;HP*120*10;20.8;2;1300;AH32;L;120;10;20;10
Profile;FB*150*12;28.8;2;1800;AH32;FB;150;12;0;0
//MATERIAL PROPERTIES
Material-0;A;8000;0.3;400;210000;235
Material-1;AH32;8000;0.3;400;320000;235
//MASS ENTITIES
//EQUIPMENT PROPERTIES
Equipment;Block-1;25;-0.5;0.75;0
Equipment;Block-0;50;-0.5;0.75;1
//END OF SHIPLYS DATA EXPORT
```

Figure 8: Example of SHIPLYS file created with CAFE Application

2.6 ShipLCA

2.6.1 Description of software

The ShipLCA Application is an evaluation software that can be used to estimate the 'life cycle cost, environmental and risk impacts' in order to determine the optimal solution amongst different design alternatives.

At present there is no life cycle software specific for the marine/ship building industry, and it becomes very time consuming and difficult to carry out the life cycle assessment. The ShipLCA software fills the gap in existing LCA software with the consideration of ship life stages and various activities. Within ShipLCA the three most significant impacts are included: cost, environment and risk. The software can be used to help shipyards, ship owners and operators, and policy makers to estimate the life cycle impacts during the early design stage. The software will help to determine optimal alternatives while selecting engines, configuring systems or applying different sources of electricity.

2.6.2 Scope and limitation of functionality

The initial focus of the software was on the machinery systems on-board hybrid ships but this has been extended so that it can also be used for new build ships and retrofitting cases.

2.6.3 Data exchange with SHIPLYS platform

The integration of ShipLCA and the SHIPLYS Platform is used to exchange data (input and output). This will allow ShipLCA to read specific case ship data from the SHIPLYS data service and provide life cycle costs, environmental data and risk back to the Platform which will be used in the decision making tool (Figure 9).

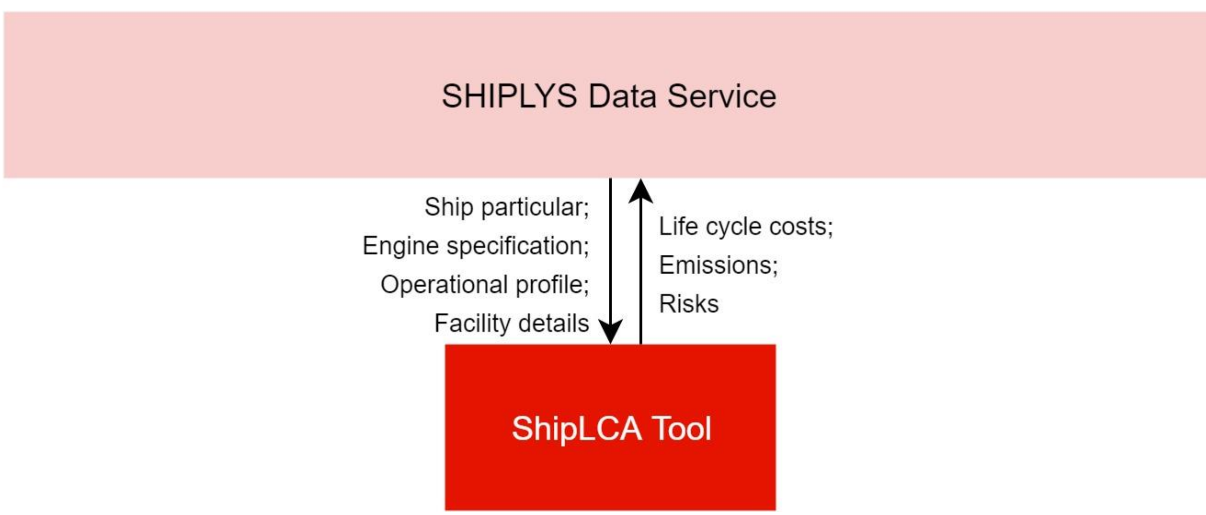


Figure 9: Integration and data exchange between SHIPLYS platform and ShipLCA

2.6.3.1 Input formats

- General information as text or numbers
  - Life span, ship total price, sensitivity level etc.
  - Project name
- Activity specific databases: facilities, machinery, fuel, electricity, to name a few,
  - Cutting, welding, blasting, bending and coating facilities;
  - Main engines, diesel generators and battery packs;
  - Heavy fuel oil, marine diesel oil, marine gasoline oil etc.;
  - Electricity from wind, hydro, nuclear etc.
- Results: costs, emission quantities, risk priority number and converted costs.
  - Life cycle costs including different life stages: construction, operation, maintenance and scrapping;
  - Emissions:
    a) Global warming potential (GWP): CO_2, CH_4, CO, N_2O, etc.
    b) Acidification potential (AP): SO_x, NO_x, HCL, NH_3, etc.
    c) Eutrophication potential (EP): PO_4^{3-},NO_x, NH_3, COD, etc.
    d) Photochemical ozone creation potential (POCP): C_2H_4, C_2H_6, C_7H_8, CO, etc.
  - Risk priority number

2.6.3.2 Output formats

- Excel reports: the results are saved as an Excel file which could be used for further analysis and comparisons afterwards.

2.6.4 Setup of ShipLCA with SHIPLYS platform

ShipLCA can be installed without license as a standalone software. The software was developed for Windows operation system with JAVA 8 environment. The integration between ShipLCA and the SHIPLYS Platform will require a license in order to connect and allow exchange of data/databases. The software can be executed from job service in batch mode called with command line parameters: 1) "–i" is used to define the platform service url; 2) "-p" is used to define the project name. The overall results are marked with different activity numbers and ShipLCA provides results for two activities: A124 Calculate cost of ship and A127 Estimation of environmental impact.

2.7 MCDA

2.7.1 Description of software

The SHIPLYS MCDA (Multi Criteria Decision Support Analysis) application provides a mathematical approach for end-users to assess and evaluate different options based on a variety of criteria corresponding to life cycle costs, risk and environmental impact.

Figure 10 shows the MCDA Application as applied to Scenario 1, in which assessment results from ShipLCA for each alternative in terms of economics, environmental impact and risks, are inputted into the MCDA Application for a comprehensive comparison to be carried out. As a result, the optimised design alternative is suggested. The software was written in C# using the .NET framework and runs on MS Windows 7 or later. The software requires the .NET framework and a computer capable of running the operating system. The software is delivered as a standard Microsoft installer package.

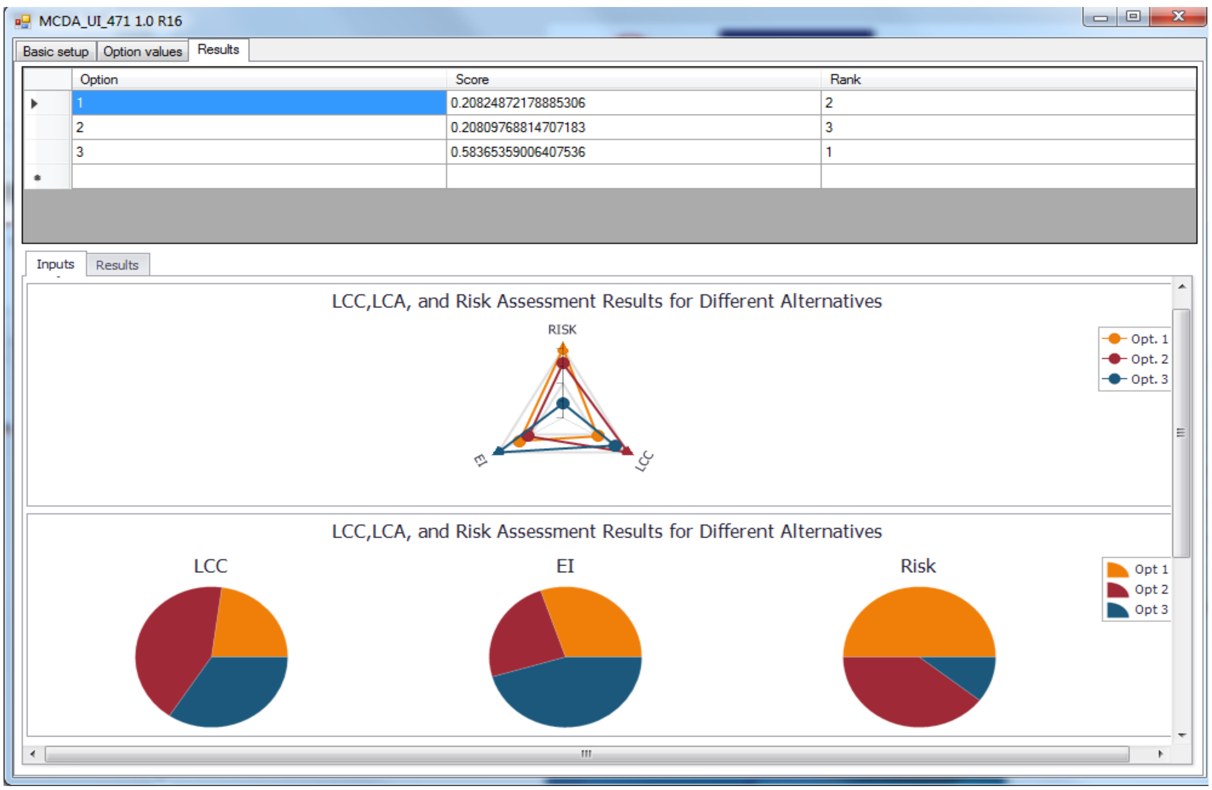


Figure 10: MCDA applied to SHIPLYS Scenario 1

The MCDA methodology has also been applied to Scenario 3. Figure 11 shows how the production performance at a shipyard for retrofitting activity can be measured and improved using optimisation (not shown in the figure). The same approach can be used in shipyards involved in new building ship construction.

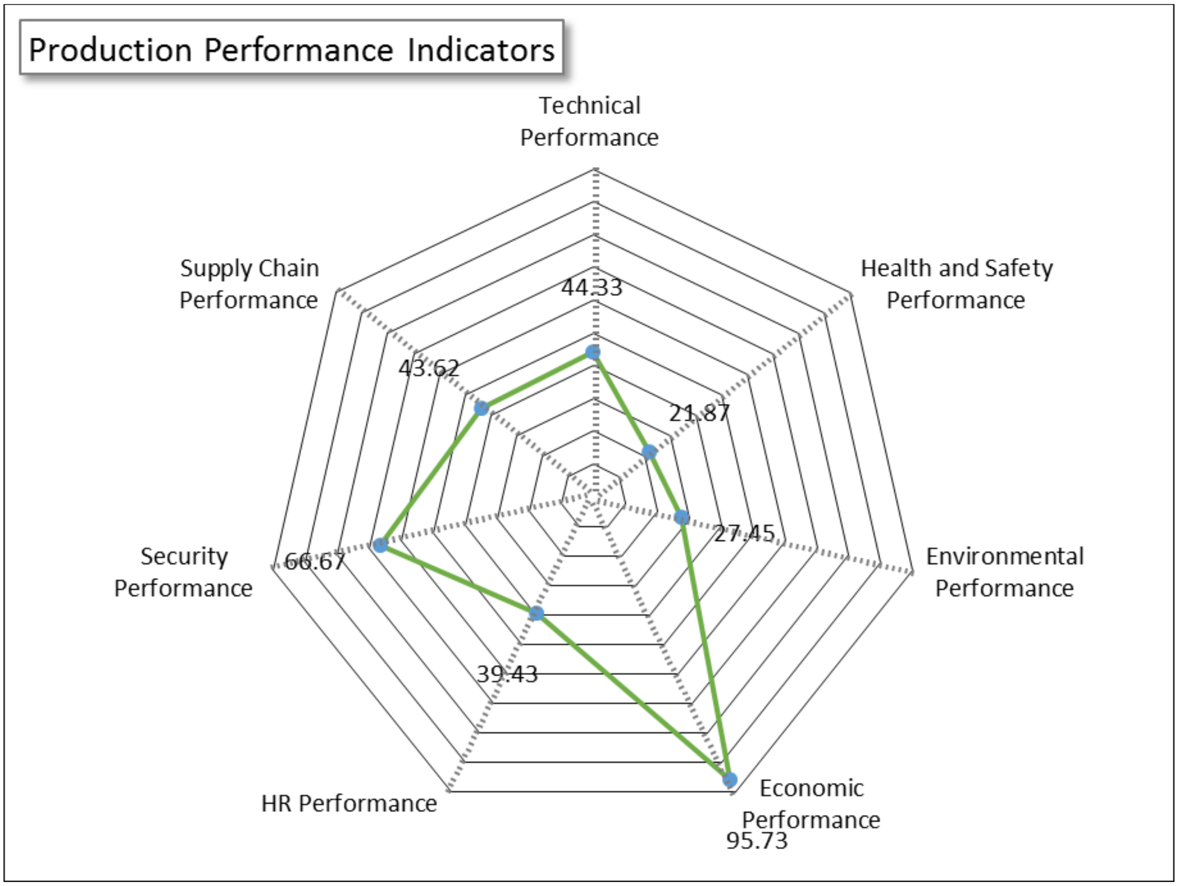


Figure 11: Measuring performance at shipyards

2.7.2 Scope and limitation of functionality

With intention of being flexible to satisfy requirements from different stakeholders, various MCDA mathematical models have been implemented in SHIPLYS MCDA Application, 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)

It should be noted that in the SHIPLYS MCDA Application, all measurement criteria (i.e. LCCA, EI, risk) are assumed to be independent. The mathematical models implemented did not consider the inner links among the criteria. The User's preferences are incorporated as weighting factors. The User is recommended to have reasonable level of knowledge about the decision making process and refer to the user manual for model selection.

2.7.3 Data exchange with SHIPLYS platform

2.7.3.1 Input formats

The Application will connect to the platform and read all available analysis cases for a specified project that have been generated with the SHIPLYS LCT Application.

2.7.3.2 Output formats

The software does not write anything back to the SHIPLYS platform; however, it will produce the following output to use elsewhere.

- Assessment report in PDF format
- Assessment report in Image format

2.7.4 Setup of software with SHIPLYS platform

When used in conjunction with the platform there are two ways it can be achieved:

i) Registered and started from the DMT, this will pass in the relevant data server and project
ii) The user can specify the server and choose from available databases/projects on that server before continuing with analysis.

2.8 SEASAFE

2.8.1 Description & Scope of software

SEASAFE Professional creates precise 3D vessel models, derives calculations and produces reports. It ensures designs comply with IMO and national regulations. It can generate manuals and T&S booklets within hours. It can also build 3D wind models, produce KG/GM limit curves and calculate damage stability, both deterministic and probabilistic.

2.8.2 Scope and limitation of functionality

For the purposes of SHIPLYS, SEASAFE will be used for A12221-Define compartments and A12224-Calculate stability and trim.

2.8.3 Data exchange with SHIPLYS platform

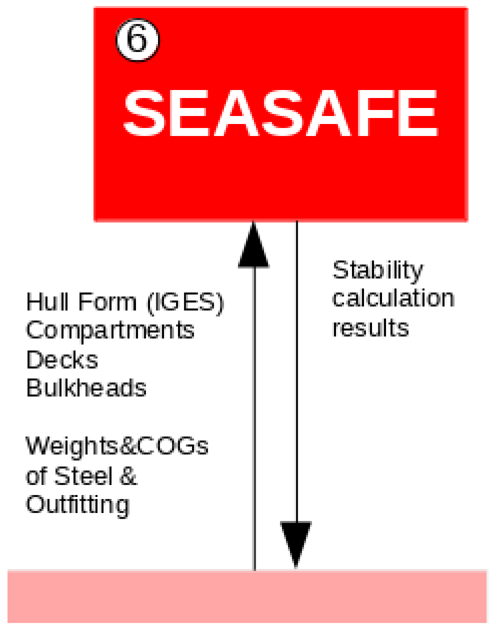


Figure 12: SeaSafe - Data exchange with SHIPLYS platform

2.8.3.1 Input formats

- Hull as IGES or offset table
- Compartments via constraints, using decks, transverse/longitudinal bulkheads and hull
- Weights and COGs

2.8.3.2 Output formats

- pdf report

2.8.4 Setup of software with SHIPLYS platform

Install SEASAFE with license. Integration with job service. Software execution from job service in batch mode called with command line parameters to be defined.

2.9 RulesCalc

2.9.1 Description of software

RulesCalc is a design and Rule compliance Application that can integrate the assessment within the design phase. 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

RulesCalc can be used as a standalone system or in conjunction with other design software packages, including Napa, Tribon and Lloyd's Register ShipRight SDA.

2.9.2 Scope and limitation of functionality

For the purposes of SHIPLYS, RulesCalc will be used to assess for A1224-Create preliminary structure design and in more detail for: A12241-Calculate longitudinal strength, A12242-Define midship section scantlings, A12243-Define other transverse sections scantlings, A12244-Carry out preliminary superstructures structural design. Based on non-compliance with the minimum or maximum values established in the LR Rules and Regulations, warning errors that appear in the calculations indicate the limitation of functionality.

2.9.3 Data exchange with SHIPLYS platform

Figure 13: LR RulesCalc Data Exchange with SHIPLYS platform

2.9.3.1 Input formats

- Frame Ruler via SpacingTable entity (relevant are the positions)
- Ship entity (main dimensions)

2.9.3.2 Output formats

- Plate/Profile entities defining midship section

2.9.4 Setup of software with SHIPLYS platform

Install LR RulesCalc with license. Install integration code and execute it with parameters specifying parameters such as input file, service connection.

2.10 PPT

2.10.1 Description of software

Production assessment is important for LCA/LCCA which is shown in the following Figure 14 representing the annual costs on the x-axis and the stations of vessel's life beginning with "Planning and Design" on the y-axis. Most of the funding provided by the owner is required in a short period of time during production and retrofit, whereas risks (e.g. late delivery, wrong sequence of production processes) may even increase the amount of funding. In order to enable the production assessment during the early bidding stage so as to predict more precisely the overall costs over the lifetime of a ship, a custom software solution, called Production Planning Tool (PPT) has been developed.

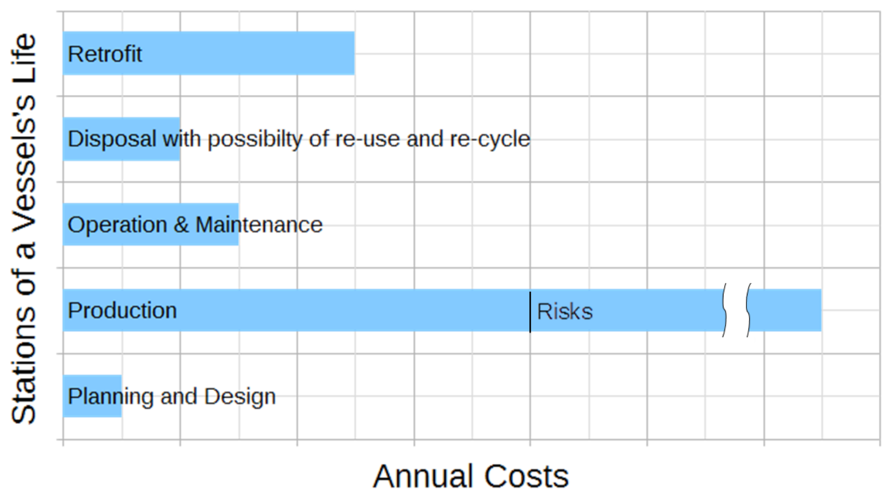


Figure 14: Life Cycle analysis – annual costs associated with stages in a vessels life

Once the structural data has been generated by rapid prototyping Applications for design it can be used by PPT to generate the production relevant data, starting with the derivation of interim product structure in the case of new building projects. In the case of retrofitting projects where the interim product structure plays a minor role, the first input can also be just a specification document provided by the owner, which in the same way as described for the RIT can be imported and linked with specific retrofitting tasks. Independent of project type, PPT enables rapid definition of tasks, schedule, material and equipment and related costs. Amongst others, the rapid definition is made possible by the integrated catalogue management system providing general data such as task templates to be used for various projects. Another important feature of PPT is the schedule optimization allowing, for instance, minimisation of the overall project duration and costs. Once all the required data has been defined, appropriate reports can be automatically generated such as a cost report that is structured according to SFI grouping codes and represents a bid to be provided to the owner.

2.10.2 Scope and limitation of functionality

The main scope of PPT is to support "Activity 129 – Perform preliminary planning of production" and in doing so making a reliable estimation for production schedule with:

- little information
- little effort and
- in a short time.

Amongst others using PPT, the work breakdown structure, material and equipment, schedule, capacity requirements and resulting costs can be determined.

A future version of PPT could include an advanced method for estimating raw material using, for instance, an optimization component trying to nest as much as possible parts into a given raw plate by considering further constraints such as distances between parts and to the edge of plate.

2.10.3 Data exchange with SHIPLYS platform

Depending on the project type, whether it is a new building or a retrofitting project, the required input data and resulting output might be different since in retrofitting projects the interim product structure often plays a minor role, which is shown in the following figures.

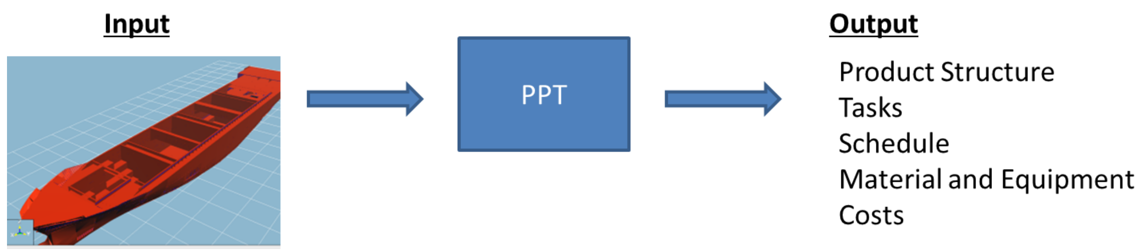


Figure 15: New Building - Input and Output

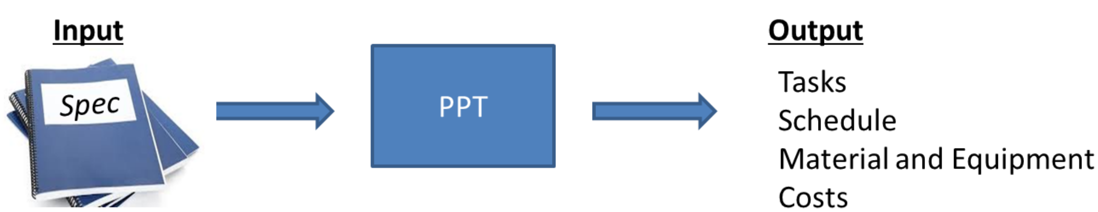


Figure 16: Retrofitting - Input and Output

2.10.3.1 Input Data

Figure 15 shows the required input for a new building case that is the early ship design. Since retrofitting projects are more task driven, the main input is a specification to be provided by the owner and containing description of retrofitting activities to be carried out. The specification can be directly imported and analysed using PPT (see Figure 16: Retrofitting - Input and Output).

2.10.3.2 Output Data

For a new building project, the output data in the first place is the interim product structure derived from the early ship design (see Figure 15: New Building - Input and Output). Afterwards, the related tasks, schedule, material and equipment and related costs are determined, which in case of retrofitting projects can be directly derived from the provided specification (see Figure 16: Retrofitting - Input and Output). Besides the already mentioned output data, in case of retrofitting project, also the specification document and related links pointing to the task descriptions in it can be stored.

2.10.4 Setup of software with SHIPLYS platform

PPT is fully integrated into the SHIPLYS platform using Java based client for the REST-based communication with the services. Once PPT is installed, it can be used standalone or automatically launched from the Design Management Tool (DMT) for a specific project and store its output data into the Data Service.

3 Application of SHIPLYS Platform

3.1 Perspectives from different stakeholders in the use of SHIPLYS services

3.1.1 Introduction

The SHIPLYS Consortium has representation from a variety of stakeholders in the early ship design process. SHIPLYS partners include three shipyards, a classification body, and service providers such as software developers, consultants and researchers in ship design, life cycle assessment and planning. Apart from these in-house stakeholders, SHIPLYS has interacted with SHIPLYS Stakeholders Advisory Committee (SAC) members listed here http://www..com/advisory-committee/ and has held annual meetings with them (the first and the last being physical meetings and the second an online meeting). Additionally, SHIPLYS has gained from the perspectives of representatives from other H2020 projects such as LINCOLN, HOLISHIP and RAMSSES. This section of the report brings together the perspectives offered by different stakeholders in different forums. It revisits users' requirements, as solicited and documented in the initial stage of the project, in light of outcomes from the project, in order to assess how the project has addressed such requirements.

3.1.2 SHIPLYS users' requirements as captured in Quality Function Deployment (QFD) approach at the beginning of the project

SHIPLYS followed a formal approach using QFD to identify and prioritise users' requirements and develop software functionality corresponding to such requirements. This was reported as part of the SHIPLYS Deliverable D2.2: A report on business case and return on investment. Different stakeholders were involved and their opinions lead to a better understanding of end-users' needs and developing a product that fulfils their requirements.

The below planning matrix, referred to as the House of Quality, was developed as part of the approach (in D2.2) and is shown again in

Figure 17. In the matrix, on the vertical axis are different user defined requirements with their relative importance, and on the horizontal axis are software functionalities/ characteristics. The colour coding indicates the strength of the relationship between a specific software functionality and the corresponding user requirements. Red, yellow and green colour shown strong, medium and weak relationship respectively.

As a result, this matrix gives the rating of functional characteristics by considering the strength relationship with users' needs and their relative importance rating.

Table 2 shows the order of importance (first column) corresponding to the characteristic mentioned (second column) of the first twelve characteristics. The order of importance is the 'rating' as mentioned in the last row of the matrix in Figure 17.

Whats - User-client values / needs				Hows - Software characteritics																					
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Main need / requirement category	Category definition	Need/requirements sub-categories	Importance rating	Extensive database	Life cycle cost assessment tool	LC environmental assessment tool	Life cycle risk assessment tool	Multi-criteria decision support tool	Ship operation profile tool	Ship configuration tool	Rapid prototyping tools	Production analysis and planning tools	Integration of developed tools	Ship Design Workflow controller	Information on software data reliability	Use of and compatibility with existing early design tools	Data history, variety and traceability	Interactive usage of component database	Theoretical and user manual and after-sale support	Concise and clear automated reports	Well defined structure & simple user input procedure	Easy installation procedure	Purchase and maintenance price of software	Software verification by 3rd party / registry	Hardware requirements
Reliability	Being free of doubts and uncertainties	Being confident in calculations and data	9	M	M	M	M	M	M	M	M	M		M	M	M	W	W	S	W				S	
		Being confident in the software technical performance	8		M	M	M	M	M	M	M	M		M		M			S		M	W		S	S
		Supporting ship design in accordance with rules and regulations	8	M		S	S		M		W				W	M									
		Documenting and reporting the design process	7	M			M				M			S			S	M		S	W				
Convenience	Doing work with little or no effort, stress or limits	Having an intuitive and clear user interface	8		M	M	M	M	M	M	M	M				M		M			S				
		Requiring no special IT skills	6	M	M	M	M	M	M	M	M	M	S	S		M		M	W	W	S	S			M
		Having simple installation process	6		M	M	M	M	M	M	M	M				M			W			S			M
Competence	Making informed design decisions, performing the work well, maintaining high level of task / work quality	Estimating energy consumptions, environmental impacts and risk	7	M	S	S	S	M	S		S	W	S			M	W	M			M				M
		Making ship behavior predictions	7	M			M	S	M	M	M		S			M		W							M
		Being able to compare different ship designs and identify optimal solutions	8	S	M	M	M	M	M	M	M	M	S	M		M	M			W	S				M
		Estimating design work activities and volumes	7	M	M					M	M	M	S	S		M					S				M
		Providing input for production process	7	S	S	M	M	M	S	S	M	S	M			M		S		M					W
Efficiency	Doing the work fast, reducing time	Having flexibility in ship design modification	8	M							M	M	S	S		M		S			M				M
		Making quick estimations	8	M	S	S	S	S	S	S	S	S	S	M		M		M			M				S
		Automating of design processes	6	M						M			S			M		M			M				M
		Enabling a variety of information handling and processing options	7	M	S	S	S	S	S	S	S	S	M	S		M	M	S			M				M
Profit	Increasing income	Gaining value for money	7		S											M			W		M		S		W
		Software resulting in monetary savings	7		S			M		W		S	W			M					M		S		W
			Score	315	371	306	348	308	325	312	361	332	334	274	35	372	96	252	104	79	326	68	70	85	287
			Rating	9	2	12	4	11	8	10	3	6	5	14	22	1	17	15	16	19	7	21	20	18	13

Figure 17: Quality Function Deployment process

(strong relationship = red; medium = yellow; weak = green)

Rank	Functional characteristic	Feedback from stakeholders (close to project completion) during workshops and other interactions
1	Use of and compatibility with existing early design Applications	Generally, stakeholders are convinced that SHIPLYS Applications are compatible with certain existing early design Applications; for example, they have seen how output from existing software such as RulesCalc can be used. However, as indicated in a number of queries, the misunderstanding is that only those Applications shown in various demonstrations are capable of being used in an integrated manner via the SHIPLYS platform; this is not the case: any Application with the appropriate 'glue code' can exchange data with other Applications (that also have the appropriate glue code) via the SHIPLYS platform. More training/ demonstrations to end-users can help in making this aspect clearer.
2	Life cycle cost assessment Application (cost of production, operation, maintenance, repair and refurbishment)	There are a few SHIPLYS software Applications that can support this functionality - modules in ConceptShip, the University of Strathclyde's LCAT (Life cycle assessment (LCA) tool)
3	Rapid prototyping Applications	A key question here is; what level of detail is expected of the prototyping Applications at the early design stages? SHIPLYS consortium believe that the prototyping Applications developed are sufficient for the early design stages. Another question pertaining to this matter is; are these Applications useful such that their outcomes are relevant and can be taken forward *beyond* the early design stages. SHIPLYS consortium believes that end users will find that the use of SHIPLYS Applications will provide support to them beyond the early design stages.

Table 2: Preliminary list of prioritised functional characteristics*

Table 2 (continued): Preliminary list of prioritised functional characteristics*

4	Life cycle risk assessment Application (performance time profiles, degradation profiles)	The Application developed by IST - ShipRisk enables risk assessments to be carried out in terms of structural reliability. In another context, risk/ hazard assessments within ship production systems can be supported by the PPIT (Production Performance Indicator Tool) developed by TWI. The PPT (Production Planning Tool) developed by AES enables the identification of risk/ hot-spots in project scheduling and resources allocation.
5	Integration of developed Applications (data synchronisation and module communication)	It seems that the message that SHIPLYS platform is essentially a platform to exchange data (assuming it exists in an appropriate format) from and to different Applications has not been properly understood. More training/ demonstrations to end-users can help in making this clearer. In addition, the fact is that 'complete' integration without any human intervention was never the aim of the project (and is, perhaps, unachievable).
6	Production analysis and planning Applications	Stakeholders appreciate that the SHIPLYS Application PPT is useful in production planning and analysis. TWI's PPI (Production Performance Indicator) approach needs user-friendly explanation so that the end users are not discouraged by the theory behind it.
7	Well defined structure & simple user input procedure	Overall, the SHIPLYS Applications do not require complicated inputs.
8	Ship operation profile Application (transport capacity, service speed, operating cost, type of propulsion)	ConceptShip developed by IST supports this functionality.
9	Extensive database with information on ship main particulars, ship construction and operational characteristics	Most SHIPLYS Applications have relevant databases; for example, USTRATH's LCA tool has data relating to emissions, IST's ConceptShip has cost data.

Table 2 (continued): Preliminary list of prioritised functional characteristics*

10	Ship configuration Application	ConceptShip, RSET, Cafe are all Applications that can be used to establish ship configuration during early design stages. The notion that even at early design stages, the configuration can be checked for compliance has been demonstrated by the use of Lloyd's Register's RulesCalc.
11	Multi-criteria decision support Application	This functionality has been demonstrated in the SHIPLYS scenario on hybrid propulsion system optimisation and in the performance management of production systems at shipyards.
12	Life cycle environmental assessment Application	Stakeholders appreciate that the Application has been demonstrated in the SHIPLYS Application of optimising a hybrid propulsion system in short route ferry but that it can be applied in other situations as well.

Table 2: Preliminary list of prioritised functional characteristics*

* Calculated based on the importance of a requirement and the level of impact of the respective technical characteristic on the requirement.

3.1.3 A project-end assessment of how SHIPLYS users' requirements were met by the project

The third column in Table 2 summarises how SHIPLYS has addressed the user requirements as identified in the initial stage of the project. SHIPLYS Consortium members acknowledge that with additional time, as requested unsuccessfully, better integration, more elaborate testing and more training workshops could have been carried out.

Additional feedback received from SHIPLYS stakeholders covering multiple strands including and beyond those stated in Table 2.

This section includes specific feedback from SHIPLYS Stakeholder Advisory Committee members particularly from M Borja Cardama[3] from Cardama Shipyard, Vigo, Spain. The issues raised are mentioned in the bullet points below, followed by a response from SHIPLYS Consortium

- *There are different stakeholders at different stages of ship; key ones include ship owner, ship designer, operator, classification body and regulators (particularly those who want better end-of-life management). The stakeholder that pays extra is not necessarily the stakeholder that gets the benefit. So what is the incentive for an optimum technical solution such that a) overall costs are minimized, and b) multiple stakeholders can assess such solutions from their own perspective?*

[3] Email sent by M.Borja Cardama, dated 11 July 2019, to Ujjwal Bharadwaj, cc Nicholas Tsouvalis.

Moreover, there may be a requirement for a less expensive solution with reasonably good technology rather than the best technical solution that may be too expensive to be affordable in certain markets. How will SHIPLYS help in such situations?

SHIPLYS Consortium response:

SHIPLYS supports early stage design from a life cycle perspective so that decisions can be made not on short-term gains but long-term benefits. When ship owners (customers of shipyards) know the long-term benefits of extra initial capital costs, they will be encouraged to seek better solutions, not necessarily the cheapest options. On the other hand, a better solution may not necessarily be substantially more expensive.

Apart from supporting end users to benefit from a life cycle perspective, SHIPLYS (through the MCDA functionality developed in the project) allows multiple stakeholders to assess implications from different perspectives that they may have. A ship manufacturer using the SHIPLYS platform could offer different solutions based on the initial requirements of the client, in order for him to select the alternative that fits his operational and business targets. By changing a certain parameter of the initial ship design (e.g. engine type, fuel type etc.) we could derive to a different offered solution from a lifecycle perspective, more attractive to the ship owner.

The versatility of the SHIPLYS Applications allows meeting special demands of the ship-owner or the yard. The user of the Application can select, at various stages of the design procedure, not the latest most effective technology, but simply, less costly systems, to meet the special requirements of a specific client. Such requirements are dictated by the markets in which the ship owner/ operator is operating. For example, apart from Capital Cost (CAPEX) required, the Operation Cost (OPEX) of a high technology system may be deemed unviable in some cases, requiring the optimum solution for such clients to be a reasonably robust technology that is cost-effective and affordable. Such solutions can be arrived at by the application of SHIPLYS approach and Applications.

- *Have you tested SHIPLYS Applications in more scenarios than stated?*

SHIPLYS Consortium response:
We would have preferred more comprehensive testing of SHIPLYS Applications; we have attempted to do as much as possible in the time available.

- *It would be good to have more dissemination and training sessions so that end-users can see for themselves the results of the project and its applicability.*

SHIPLYS Consortium response:
This is a fair point. We have had time for a limited number of workshops only. Due to constraints, even the timing of the workshops in Varna and Vigo was not ideal, with stakeholders winding down operations for the summer break. If we had more time, we would have more workshops.

3.1.4 Guidelines for application of different software

Guidelines for the application of different software developed within the SHIPLYS project are described here.

RIT: As described in chapter 2.2 it is recommended to use RIT and make the requirements specified and provided by the owner within a tender document machine-readable at the beginning of the whole ship design process. Once it is done, it is easier to keep the overview in case requirements have been changed or new have been provided or to find the related document and specific text positions in case further details are needed. Furthermore, other Applications can afterwards automatically import the requirements. In doing so, errors can be avoided, and time saved.

PPT: The rapid definition of data using PPT is first of all based on the integrated catalogue management system providing general data to be used for various projects. This kind of data described in chapter 2.10 can represent general task templates, material and equipment items or standards like SFI grouping codes. It is recommended to populate the catalogues with the appropriate data, since the more data is available and predefined the more often it can be used for specific projects and revised in case it is required. In doing so the project specific data can be defined faster resulting in time savings and finally money.

ConceptSHIP: The Project Settings include a number of constant values to be used in each project, such as unit costs of fuel and labour that need to be updated regularly. The hull form generation process used is based on a library of offset tables stored in a spreadsheet so that each user can add new numeric descriptions of more hulls, with different shapes and dimensions, improving the quality of the output. None of the graphic outputs produced by the system is updated automatically when the associated data changes, to increase the speed of optimization procedures. It is therefore recommended to produce the graphical outputs only when the final solution is found.

SHIPLCA and SHIPLYSMCDA:
Environmental impact and life cycle cost analyses have been, until relatively recently, considered two separate aspects. However, there is now an increasing industry requirement to combine these two aspects.
Within SHIPLYS, SHIPLCA and SHIPLYSMCDA can be used in combination to determine both the environmental impact and life cycle cost assessments respectively. There is ongoing work on how to best measure environmental impact and life cycle costs using a common metric. There are approaches that use money as the common measure; however there are benefits (increased transparency of the underlying data) to keep the measures separate. Likewise in life cycle costs there are benefits to clearly see which phase of an asset's lifecycle has what corresponding cost, not least because of multiple stakeholders who have more interest in the costs associated during a particular phase. SHIPLYS has adopted a hybrid approach providing the end user the option to determine if they would like to see a common measure for life cycle costs and environmental impact or separate measures. The MCDA tool supports analyses based on where the focus of the multiple stakeholders involved lies within the ship's lifecycle and also in terms measures of environmental impact, costs and risk.

3.1.5 Benefits for different stakeholders

This sub-section needs to be read in conjunction with feedback from stakeholders mentioned in the previous sub-sections; much of the feedback reported earlier relates to certain end-user benefits identified earlier on in the project. To avoid repetition, the focus here is on aspects not mentioned before.

Designers

One of the SHIPLYS Platform benefits is reducing the time involved in the ship design which leads to improving competitiveness of ship design offices. In addition, the designers can use different modules within the platform and therefore they can be involved in different ship design processes and combine them.
Although SHIPLYS is targeted towards the very early design stages of ship when designers and shipyards are responding to tenders, one of the benefits of the application of SHIPLYS is that such early work can be more readily used in the later stages of design when the bid is successful and the newbuilding or retrofitting project is launched.

Shipyard operators

SHIPLYS will support shipyard operators in optimising the use of their resources (time, personnel and costs) in the production of new building or retrofitting/ repair projects. Project risks/ hotspots can be identified and managed by the PPT (Production Planning Tool) Application. Production planning tool supports a shipyard to make reliable estimations regarding the duration of new building or retrofitting projects and related costs. Amongst others, it contains a scheduling component and a functionality to generate work breakdown structure to support the early production planning and e costs. The overall shipyard production process can be assessed on criteria including Health, Safety, Environment, Costs and Reliability using the Production Performance Indication Tool (PPIT).

Typically, shipbuilding tenders, new building or retrofitting/ repair projects, need quick response in the limited time and data available. It is to provide support in this challenging situation that SHIPLYS will enable SMEs shipyard to make more reliable estimates based on the owner tender requirements, in the early stage of inquiry, and the shipyard`s existing production capacity. The shipbuilding sector is a ship owner market, this means that the shipyards needs to have enough flexibility to adapt to the requirements of the ship owners in their response to the offer request, the versatility of the SHIPLYS tools support this important requirement

At the same time, the possibility of analysing during the pre-contractual period, the implementation of alternative technological and production solutions, the evaluation of their effectiveness taking into account the Risk-based Life Cycle Assessment, the environmental impact, the cost and the planning, gives a competitive advantage to the SME shipyards.

Ship owners

The benefits to ship owners are explained at length in Section 3.1.3. In addition, by providing a life cycle perspective, it encourages long-term thinking that is often required to justify high initial costs. By including environmental impact in assessments in the SHIPLYS approach (in the ShipLCA Application), ship owners can be conscious of the environmental footprint of different options.

Operation and maintenance professionals

SHIPLYS includes the concept of risk-based inputs during the early design stage. Such inputs are meant to reduce operation and maintenance costs and also provide some indication as to which parts of the structure are more susceptible to damage though the life of the ship.

Classification bodies

The use of SHIPLYS streamlines the approval process by collating all the data in a central place in well-defined data formats. This potentially allows classification bodies to perform validation assisted by automation.

Researchers

The SHIPLYS project has already supported several PhD researchers and gives further opportunities to continue the research in advanced shipbuilding technologies.

Software developers

The SHIPLYS project offers the ability to integrate other software applications into the SHIPLYS platform and software developers will be able to promote their applications and expand their customer base and market infiltration.

3.2 Guidance on use of SHIPLYS approach to support circular economy

3.2.1 Background

Since last decade, society has started paying particular attention to the Circular Economy. A Circular Economy entails the re-use of resources and the minimisation of waste to the extent possible. It is much more than just recycling material from the product at its end of life. More precisely, according to the Ellen MacArthur Foundation [1], "*A circular economy is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, and aims for the elimination of waste through the superior design of materials, products and production systems".* Accordingly, the Ellen MacArthur Foundation has made their famous "butterfly diagram" to explain this concept. In the diagram, the left part shows the use of renewables and the right part shows the use of finite materials. The latter is of interest for SHIPLYS. Figure 18 below demonstrates the application of circular economy in SHIPLYS adapted from the Ellen MacArthur Foundation's "butterfly diagram".

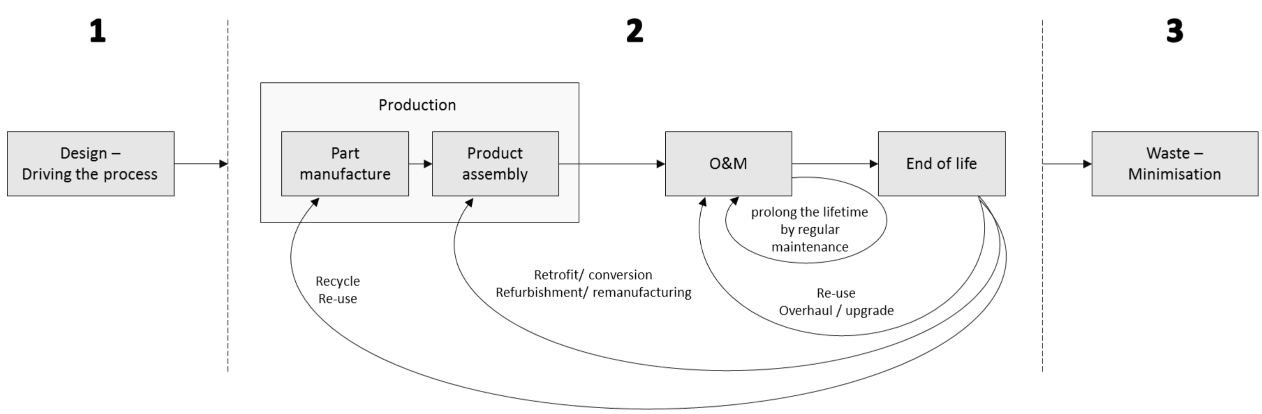


Figure 18: Circular economy applied in SHIPLYS

3.2.1.1 SHIPLYS Circular Economy

SHIPLYS aims to support the identification of optimum ship design at the early stages of design through the assessment and the evaluation of the life cycle performance of various design options. This forms the starting point of the circular economy. The design stage is driving the whole process that determines the feasibility of applying such concept. For example, the maintenance plan is interrelated to the ship design process. In particular, the initial hull thickness may significantly affect how often the hull steel needs to be inspected and renewed if necessary; the thicker hull requires the lesser maintenance. A ship-owner who prefers to carry out minimum hull maintenance may need to specify that maximum steel thickness is used in the hull design, thereby the initial cost of ship construction will be higher. In addition, different maintenance intervals may also affect the quantity of the steel to be recycled at scrapping stage.

The second part of Figure 18 explains how the circular economy is applied. During the operation and maintenance (O&M) stage, regular maintenance will be applied by either operator or a maritime service provider to prolong the lifespan of the ship. This is indicated as innermost circle in the diagram. When the cycles are no longer sufficient or there is a major damage, the ship will need repair or upgrade; old parts can be re-used or recycled in other ships or for other purposes. At some point, the ship will need retrofit/ conversion to satisfy the regulatory requirements, perform better environmentally and economically or for a lifetime extension. Such major production activities will generate large amount of used products that triggers the remanufacturing process. The remanufactured products can be then used in other ships or other business domains. For instance, in SHIPLYS Scenario 3, the remanufacturing process is shown in Figure 19, developed according to [2]. When the new scrubber is installed, the used products and components (such as old scrubber, pipes and fittings) are removed and sent for remanufacturing by internal or external companies. This is called reverse supply chain. The parts that are not feasible for remanufacturing, i.e. waste, can be considered for the alternative usage. The remanufactured products are ready for use in other ships or the same ship for other usage, which is called forward supply chain.

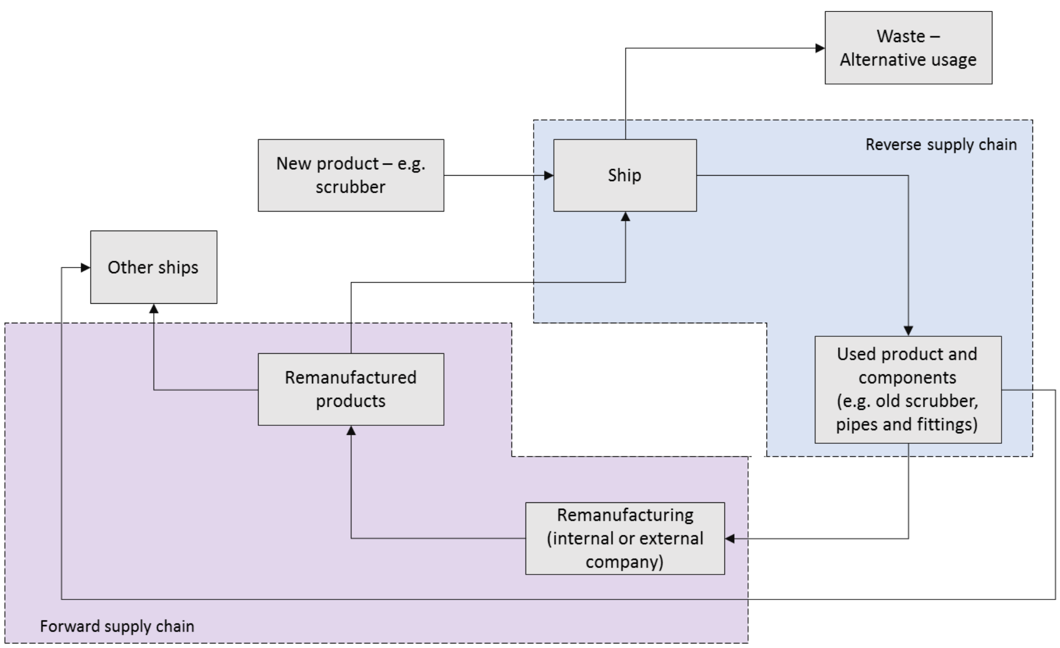


Figure 19: The remanufacturing process in SHIPLYS Scenario 3 on retrofitting

At the very end stage, the ship may be decommissioned and recycled. The clear majority of its materials are re-used. This closes the last loop of the process [3].

This process supports circular economy in its three dimensions: economic, environmental, and social [4]. In relation to economics, it saves cost for customers and increases profit margins for business. For example, the remanufactured product can provide the same performance and reliability as original at costs typically only 50%-80% lower [4]. For society, it creates a large number of job positions, which will require skills training on special equipment. From an environment perspective, circular economy minimises the waste and the raw material required for producing new product. Through this process, the non-renewable resources are kept in circulation, energy usage and greenhouse gas emissions are reduced.

For instance, Table 3 presents the general ratios of material contents for marine engines; steel and cast iron account for substantial parts of the engines while small portions of aluminium, copper, zinc, lead and nickel are also listed in engine compositions [5]. Through a series of processes, components of materials can be recycled for reproducing steel and cast iron, whereas the rest are to be disposed by landfilling or incineration. The required energy and produced emissions for certain recycling processes have been determined by a number of researchers as shown in Table 4 [6].

3.2.1.2 SHIPLYS Circular Economy: Concluding remarks

This section shows how the SHIPLYS approach and Applications can support the Circular Economy. This early design approach encourages a long-term view at the design stage itself, which is usually the most cost-effective stage of intervention.

Engine material	Weight ratio (%)
Steel	40.0
Cast iron	46.0
Aluminium [Al]	8.0
Copper [Cu] and Zinc [Zn]	0.2
Lead [Pb]	0.1
Plastic	0.9
Rubber	0.9
Paints	0.9
Oils and Grease	3.0
Total	**100.0**

Table 3: Material content of typical marine engine [5]

Item			Steel and cast iron	Stainless steel	Al	Cu	Zn	Pb	Ni
Key references			**[7]**	**[8]**	**[9]**	**[10]**	**[11]**	**[12]**	**[13]**
Energy	MJ	Electricity	1.71	7.18	0.10	–	0.73	–	1.92
		Natural gas	0.62	2.60	10.22	–	0.34	–	2.30
		Coal	–	–	–	–	1.46	–	1.71
		Blast furnace gas	–	–	–	4.95	–	7.00	–
		Heavy fuel	–	–	–	–	–	–	0.22
Material	kg	Pig iron	0.02	0.06	–	–	–	–	–
		Oxygen (l)	0.04	0.17	–	–	–	–	–
Emission	Kg	SO_2	1.02E-04	4.28E-04	4.41E-03	2.00E-05	3.67E-03	2.00E-05	–
		NO_x	2.40E-04	5.27E-06	2.65E-03	7.00E-05	1.57E-03	7.00E-05	–
		CO_2	1.05E-01	4.41E-01	5.45E-01	2.00E-01	–	2.00E-01	1.19E-02
		CO	2.40E-03	1.01E-02	8.83E-04	1.50E-05	–	1.50E-04	–
		PM2.5	1.59E-02	6.71E-02	8.83E-04	1.90E-04	3.94E-05	7.90E-03	2.95E-04
		PM10	2.01E-04	8.46E-04	–	2.60E-04	7.56E-06	1.06E-02	4.29E-05

Table 4: Energy and material required, and emission released for material recycling [6]

3.3 Potential for reduction in Ship Lifecycle and Energy costs through SHIPLYS approach

SHIPLYS software has the potential to reduce lifecycle and energy costs relating to not only the direct economic cost but also equivalent cost of environmental and risk impacts.

In the early design stage, the stakeholders will prefer to invest in an optimized design provided by the shipyards or design offices. At the beginning of the design stage, there will be many available designs and they can be selected, and decisions made quickly from the perspective of direct economic investment, but it is not so straight forward when considering environmental and risk impacts. For example, when considering the application of a hybrid propulsion system (use of both engines and battery packs as a propulsion system), there will be a huge investment increase in the construction stage. However, due to less time of operation of engines, the fuel consumption and maintenance costs are significantly reduced, and the investment will be paid back during the ship operation stage, with further savings as the ship's age increases. The same applies to other/new technologies, whenever they are planed or considered to be adopted, there will be an initial investment, and as the purpose of these technologies is to reduce certain impacts and increase the performance, there will be a cost reduction during the ship's lifetime operation. In this way, the investment will be repaid, and stakeholders will be able to reduce the lifecycle cost.

The energy costs usually involve electricity and fuel consumption; electricity in shipyards as well as on-board ships and the fuel consumption during the vessel operation. Adopting new technologies or new designs will change the energy consumption. For example, in Scenario 1 of SHIPLYS, while applying the hybrid propulsion system, there will be a reduction in the fuel consumption, as the generators will work less, but increased electricity as the battery (that can be charged using wind energy) will provide part of the energy demands during manoeuvring. This will lead to less fossil fuel oil consumption on-board and hence the emissions released will be reduced. After considering the carbon credits (and other emission credits as well), the cost due to emissions release can be quantified and easily used in the decision-making process.

The Applications developed provide means to estimate the ship fuel consumptions, for both propulsion and electric power generation, taking into consideration the details of a given voyage. This allows the determination of the EEDI (Energy Efficiency Design Index), for verification of compliance with IMO/MARPOL mandatory requirements on CO2 emissions and of the EEOI (Energy Efficiency Operational Index) which quantifies the level of CO2 emissions in a realistic operational scenario. The type of fuels used and the measures eventually adopted to reduce emissions of the main engine (scrubber, Selective Catalytic Reduction - SCR) are also taken into consideration in respect to their initial costs, operational costs (for example the consumption of urea in SCR), influence in the engine fuel consumption and in the volume of emissions.

The availability of the above functionalities allows the assessment of different design scenarios, namely different configurations of the propulsion system and ship service speed. The assessment is made in terms of costs (CAPEX and OPEX) and in terms of environmental impact, measured by the amount of emissions of CO_2, CO, HC, NO_x, SO_x and PM produced in operation. The possibility of carrying out this type of evaluation at an early stage of the ship design is a helpful tool for the decision-making process and leads to more energy efficient design solutions.

For risk assessment, a qualitative method is applied:

1) identify risks,
2) quantify frequency, consequence and mitigation levels;
3) determine RPN numbers;
4) conversion of RPN to cost.

With this method, the risk impact is included in the software as a part of life cycle total cost.

After considering the environmental and risk impacts, the results will help identify the benefits that the new technologies/designs could bring to stakeholders and provide a suggestion on an optimal alternative.

Similarly to the on-board/ship analysis, the Applications developed can also be used to improve the utilisation of facilities in the shipyards. During the construction/retrofitting processes involved in ship-building a large amount of energy is spent with activities such as cutting, welding, blasting and coating to name a few. The use of project management optimisation tools combined with available facilities and operational requirements will help the evaluation of energy costs and environmental impact within the shipyard. Not only can these be used for day-to-day planning of projects but have the potential of being used to investigate different infrastructure/equipment solutions for shipyard development.

4 Concluding Remarks

Within this Deliverable 8.2, the partners of the SHIPLYS project have presented a set of good practice guidelines for each of the software developed under the project or integrated into the SHIPLYS platform.

The current deliverable aims at offering a guide to end-users of the SHIPLYS platform regarding different aspects of the SHIPLYS software, from the scope and limitations of each functionality provided by the different software Applications to the required set of data (type, format etc.) for each software Application to perform the task it was developed for.

Initially, an overview of the role of each software Application within the ship design cycle has been presented as a typical workflow of design activities at an early stage of the ship design process.

Next, for each of the software Applications (RIT, ConceptShip, RSET, CAFÉ, ShipLCA, MCDA, LR SEASAFE, LR RulesCalc and PPT) the subjects of the scope, limitations, data exchange and setup of software with SHIPLYS platform have been analysed.

Finally, the potential and the benefits of the SHIPLYS platform have been presented through the perspectives of different stakeholders, who provided their feedback throughout the implementation of the project. Their recommendations have been taken into consideration in the development of the SHIPLYS platform giving special attention to the subjects of the Circular Economy and how it can be improved with the use of the SHIPLYS software. Additionally, the reduction of Lifecycle and energy costs that can be achieved with the use of the different software integrated to the SHIPLYS platform were considered.

It is evident that the SHIPLYS platform offers a number of significant advantages to the ship design process form a lifecycle perspective, while it covers key issues of the modern shipping industry, making it an important tool for every end-user involved in the ship design activities.

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