European Technology Platform of the Waterborne Industries

Maritime Europe Strategy Action

SEVENTH FRAMEWORK PROGRAMME

SEVENTH FRAMEWORK PROGRAMME
THEME 7: Transport (including Aeronautics)

D3.1 TTG Production: Clustered research projects

Maritime Europe Strategy Action

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Description of the Task:
A comprehensive catalogue on the State of Technology

Task 3.1 View of the clustered research projects, state of art, achievements, opportunities for implementation. The deliverable D.3.1 will be structured along the following lines:

• Identification of relevant European (from FP6 onwards), national, regional and other RDI projects in the area of production as well as their main actors – Network of Projects;

• Analysis of the content and results of those projects as well as of the general state of the art in Europe and globally, including other sectors where relevant and possible – State of the Art;

• Proposals for cooperation and information exchange in the network - Cooperation Potentials.

The work will be shared between the WP partners along technical sub-areas as described before. Partners will use own expertise, their networks and the support of the WATERBORNE TP and the Mirror Group. The Task Leader (CMT) will sure that the work in the sub-areas will be harmonised, that gaps are covered in the analysis and that potential synergies within the TTG and with other technology areas will be identified. The work will be documented in Deliverable D.3.1 which will be updated according to the dates. Results will also be represented and discussed during the workshops and conferences described in Task 3.3.

NOTE FOR THE PUBLIC:

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Table of contents

1. Executive Summary

Content

This Deliverable describes the **State-of-the-Art (SotA) on Production Technologies** and the use of **Innovative Materials** in European shipbuilding and identifies first **technology gaps** which need to be filled with research and development in the coming years. In addition, the document looks at the status of **cooperation between research projects and researchers** and derives recommendations for improvements.

Contractual Basis

The work on this document is corresponding to Task 3.1 in the contractual Description of Work (DoW) of MESA, which is quoted at the front page of this report. The structure of the document has been harmonised with the other Technical Groups (TTG) as far as possible. This document has been updated according to comments received by the Project Officer.

Why production

European industry is facing tough international competition, in particular in shipbuilding and maritime technologies. Despite of market distortions by state aid and restrictive trade laws in some regions of the world, the European maritime sector has successfully established itself in high-value added niche markets for complex custom-made ships and has started to explore new opportunities in the emerging "Blue Growth" markets. This success has been achieved by advanced production methods, excellent networks and supply chains (production management) and secured **employment and wealth** in many maritime regions as well as in the hinterland. Europe is leading the development of green technologies contributing to **de-carbonization**, **energy efficiency** and decreased **life cycle cost**. However, only competitive production will enable Europe to **drive the development and implementation** of those technologies in line with the policy goals. Shipyards play a key role in this process - their productivity, ability to integrate stake holders and technologies and quality largely defines the competitiveness of the entire production chain, as well as **safety of ships, resource and energy efficiency** of the products and the life cycle processes.

Scope of the SotA Analysis and Interfaces to other MESA TTGs

The SotA presented in this report covers the most important **processes in the life cycle** of modern ships with emphasis on the **production phase**. A detailed bottom-up analysis has been conducted in seven Technology Sub-Areas (TSA) which are presented in Chapter 3 of this report:

- Design tools and their integration (TSA 3-A);
- Production preparation and management tools (TSA 3-B);
- Metals and their processing (TSA 3-C);
- None-metallic structural materials and their processing (TSA 3-D);
- Materials and processes for corrosion and fouling protection (TSA 3-E);
- Assembly and outfitting techniques (TSA 3-F);
- Maintenance, repair, retrofitting and end-of-life (TSA 3-G).

During the progress of work the scope has been précised within the contractual frame and upon agreement with the Project Officer. In particular, production techniques for none-transport related maritime structures (e.g. offshore platforms) have been included where synergies with typical shipbuilding processes can be found. In the field of design methods and tools, emphasis was put on aspects related to life cycle processes, whereas specific design tools for energy efficiency (e.g. hydrodynamics) have been covered in D1.1 (TTG1-Energy Efficiency) and design for safety in D2.1 (TTG2-Safety). The analysis covers primarily developments from 2002 to date with focus on the period from 2007 (start of FP7). Previous developments have also been considered for the current State-of-the-Art if relevant.

Approach

The State-of-the-Art, described in detail in Chapter 3, is based on a **bottom up analysis** of research outcomes, but also the current status of commercial application in industry and current rules and regulations.

In a first step, about 250 EU and national (Europe and beyond) have been identified as relevant for TTG-03, then the **results of about 183 projects** have then been included in the SotA analysis. Results ("foregrounds"), publications and implementations have been systematically recorded in unified templates which were also made available to the other MESA TTGs.

To support the analysis some 150 organizations from within the MESA consortium and outside the project have been contacted and **32 experts agreed** to provide input to TTG-03. These experts have been continuously consulted to receive input and feedback to results of the analysis. Focused technical workshops jointly with multipliers (i.e. existing European and national associations and expert groups) were organized as combined events with other projects or conferences. Those, and direct consultations with external experts have proven to be most efficient during the analysis.

Main technical developments as well as recommended showcases (success stories) and technology gaps have been **summarized in detail on TSA level** in Chapter 3.

The detailed analysis has then be complemented by a **strategic analysis** in Chapter 2. This summary chapter aims to give an overview on main technology trends in strategic fields, stretching across the TSA's, without trying to be complete in detail. Technology trends in Chapter 2 were selected as being of prime importance for the competitiveness of the sector, relevant for products made in Europe and representing significant technical progress during the last years.

Further details of the approach are given in Chapter 2.1 and 3.1.

Main conclusions from the SotA Analysis

- While in many cases it has been difficult to find relevant information about project outcomes and their implementation in industry (see Chapters 2.1 and 2.3) and the analysis may therefore be incomplete in detail, the TTG-03 team is confident that available information and expert judgement was sufficient to represent the **main lines of technical development and gaps in sufficient accuracy**;
- A large gap can be observed between the state of **production technologies in leading yards and smaller companies**. While the description of the state-of-technology is primarily referring to leading yards, the situation in smaller yards is described where appropriate. Technology Readiness Levels achieved are usually given as ranges representing the different state of application across the industry. The analysis has underlined the need of **technology transfer** and technology adaptation to smaller companies to maximize the impact of research. This should be reflected in a Research and Innovation Agenda (D 3.2);
- **Continuous research and development** along strategic lines, rather than isolated projects, is important to achieve a sustainable improvement in competitiveness. RDI on production technologies on European, national and private level have contributed significantly to achieve and maintain the leading position of EU shipyards in high value-added niche markets. Success Stories (D 3.4) will demonstrate this in more detail.
- In an international comparison **Europe the leading research and application of maritime production technologies** relevant to its products. The efficient cooperation of research entities and industry in projects and implementation makes the European maritime research area (EMRA) unique. However, competing players in the global market tend to invest more in research infrastructure, "basic" maritime research to take up key enabling technologies and international rule development. Details on the European position in the world will be given in Chapter 2.2.5 while recommendations on international cooperation will be presented in Chapter 2.3.

Main technology trends in strategic fields

The following technology areas related to TTG-03 have been found of key importance for the competitiveness of the maritime industry and represent focus areas of research and development:

- **Design for life cycle** methodologies and tools have been developed and applied. This includes tools and processes for improved retrofitting as well as dedicated decision support and assessment tools. A more consistent use of operational data using the potentials of big data management and industry 4.0 as well as more sophisticated and integrated life cycle simulation tools are technology gaps to be overcome in the next decade (see Ch. 2.2, topics 2.2.1 and 2.2.2).
- **Simulation tools and numerical modelling** for investment and resource planning, robot programming and process modelling have been developed and are used by leading actors along the value chain. Those tools need to be further improved for new manufacturing processes and materials and to be integrated. Logistics and supply chain management are one of the major advantages of leading European yards versus their competitors (see Ch. 2.2, topic 2.2.2).
- **Automation of pre-assembly processes** primarily of metallic structures has reached an impressive level in leading shipyards with a clear European lead in the use of low distortion welding processes. The level of mechanization and automation in block and final assembly, in outfitting, repair and retrofitting, in smaller shipyards and in the production of offshore structures bears a significant potential (see Ch. 2.2, topic 2.2.3).
- **The use of innovative materials and material combinations** has made significant progress during the last years, but due to lacking long-term experience, lacking standardization and high cost and insufficient work sharing along the supply chain is not common practice yet. Nonetheless, the use of advanced material combinations, lightweight and adaptive structures, innovative coatings is a major contribution for greener shipping and competitiveness of shipyards and ship operators (Ch. 2.2, topic 2.2.4).

Outlook to other MESA Deliverables

This document forms the basis for **Deliverables D 3.4 (Innovation Show Cases)** in which successful outcomes of research projects and their implementation in industry will be presented and for **D 3.2 (Proposal for an R&D Roadmap)** in which a sequence of future research topics will be derived to fill the gaps identified in this document. Finally, the document will provide input to D 6.2 (Updated Strategic Research and Innovation Agenda) across all Technical Groups (TTGs) represented in MESA.

2. Strategic Analysis

2.1 Steps performed and outlook to future deliverables

Contractual basis and scope

The work reported in this document is related to Task 3.1 of MESA and according to the contractual DoW comprises the following main steps:

(1) a **systematic analysis** of technological developments (SotA) in the area of PRODUCTION including Design, Manufacturing, Assembly, Life Cycle Processes and related construction MATERIALS for ships;
(2) drawing **conclusions on main technology gaps** which will be further elaborated in a road map in D 3.2 and
(3) **recommendations on improved networking, cooperation and information exchange** between projects and researchers based on the lessons learned from the work in MESA TTG-03

The work for steps 1 and 2 above has been organized seven **Technology Sub-Areas** (TSA) in accordance with the DoW of WP3 of MESA:

- Design tools and their integration (TSA 3-A) – led by partner FSG;
- Production preparation and management tools (TSA 3-B) – led by partner CMT;
- Metals and their processing (TSA 3-C) – led by partner RWTH, later replaced by CMT;
- None-metallic structural materials and their processing (TSA 3-D) – led by CMT;
- Materials and processes for corrosion and fouling protection (TSA 3-E) – led by SAF;
- Assembly and outfitting techniques (TSA 3-F) – led by FSG;
- Maintenance, repair, retrofitting and end-of-life (TSA 3-G) – led by NMTF.

During the progress of work the scope has been further précised within the contractual frame and upon agreement with the Project Officer.

- In addition to the production of ships, production techniques for none-transport related maritime structures (e.g. offshore platforms) have been included in areas were potential synergies with typical shipbuilding processes have been found;
- Focus was given to design methods and tools related to life cycle processes, whereas specific design tools for energy efficiency (e.g. hydrodynamic tools) have been covered in D 1.1 (TTG1 - Energy Efficiency) and design methods and tools related to Safety in D 2.1 (TTG2 – Safety);
- In addition to European projects a large number of national projects (Europe and worldwide) have been included in the detailed analysis as well as the state of industrial use and rules and regulations;
- In preparation of Task 3.4 – Show Case Description – the TSAs were asked to pre-identify technological developments and project results which led to a successful implementation in industry and led to significant competitiveness improvements of the sector;
- Within the TSAs emphasis was put on technologies with prime importance for the overall shipyard competitiveness with significant technical progress during the last years.

The analysis covers primarily developments from 2002 (corresponding to the start of FP6) to date, although focus was given to projects from 2007 (FP7) and previous developments have been considered if relevant for the current State-of-the-Art.

Methodology

Figure 1 shows the approach used in the work of Task 3.1 and the links to subsequent tasks in WP 3. The basic principles of this approach was presented at the Kick-Off meeting of the project and agreed by all TTGs of MESA.

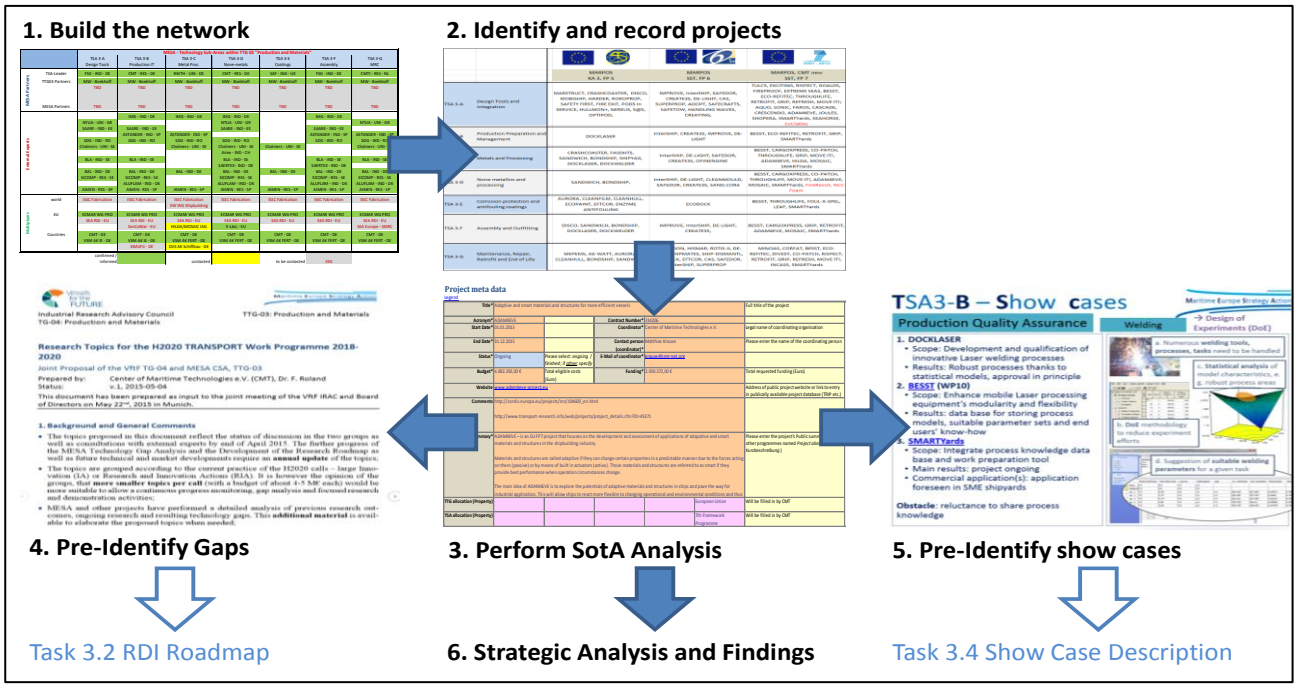


Figure 1: Steps performed to define the SotA & technology gaps and connection to follow-up tasks

The Expert Network (Step 1)

With the aim to achieve a critical mass of information on projects and their outcome, industrial practice as well as rules and regulations CMT together with the TSA leaders contacted 153 organizations with relevant expertise in production and materials. **32 experts** – most of them from outside the MESA consortium – responded to the call by filling an Expression of Interest form (Annex 1) and providing basic information on relevant projects they were involved.

The full list of experts for TTG-03 is given in Chapter 3 of this report.

This network was complemented by the **partners in MESA TTG-03** and **direct contacts** between the TSA leaders and specific projects.

Figure 2 gives a summary overview of the expert network used in TTG-03.

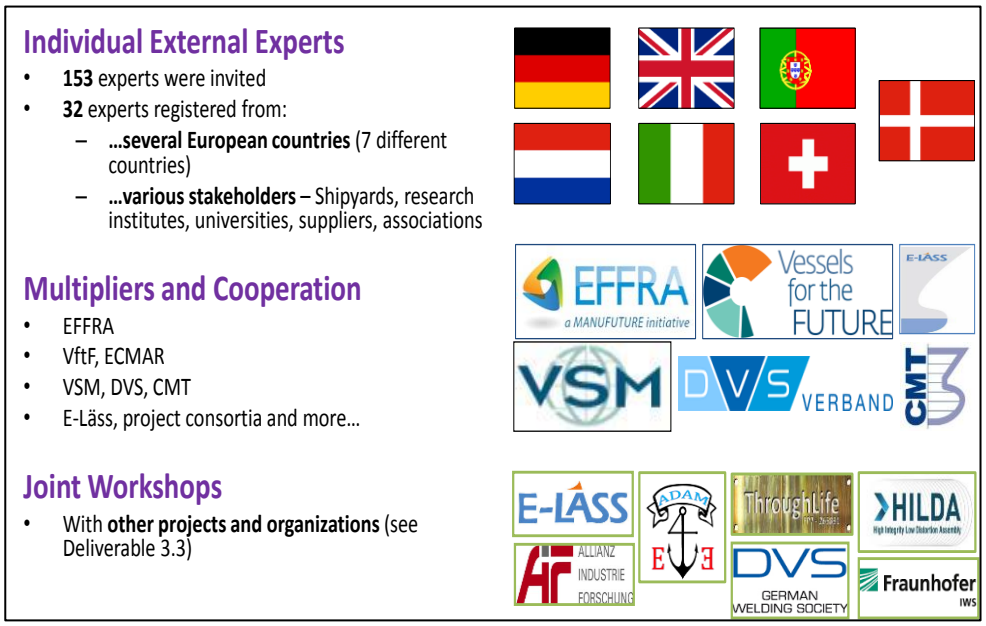


Figure 2: Key features of the expert network used by MESA TTG-03

Unfortunately, the feedback received by the expert network by electronic communication and during the MESA project was limited due to reasons further explained in Chapter 2.3. The TTG-03 team of MESA therefore increasingly cooperated with **multipliers** (existing European and national associations and expert networks) which provided feedback from their members and consulted them in joint workshops and conferences with MESA TTG-03. Moreover, the work in MESA TTG-03 was aligned as much as possible with **similar Working Groups** (without public funding) e.g. in ECMAR and Vessels for the Future, using common pools of experts and joint events. This approach has been found more successful than the individual contacts with experts. The full list of workshops conducted / participated in connection with Task 3.1 is given in Chapter 3.

Identification of relevant projects and research outcomes (Step 2)

Starting from an initial list of 491 projects potentially interesting for TTG-03 Materials and Production (including all relevant projects funded under FP6 to H2020 – Transport, other European and national projects) 246 were found relevant after preliminary studies and **183 projects were analysed in detail** within the seven Technology Sub-Areas (TSA) – see Chapter 3. The analysis included

- **European projects** from FP5, 6, 7 and H2020 (Transport, Oceans/Blue Growth, NMBP, SME);
- **National projects** from Denmark, Finland, Germany, Greece, Netherlands, Norway, Spain, Sweden, United Kingdom and USA;
- **Transnational projects** (MARTEC ERA-NET).

In addition information from international actors (Japan, Korea, China, USA, and Brazil) received from the "Materials and Fabrication" Committee of the **International Ship and Offshore Structures Congress** (www.issc2015.org) and the corresponding reports were included in the analysis.

Using desktop (internet) studies, relevant data bases, expert interviews, workshops and own expertise of the TSA leaders, project meta-data (funding instrument, title, acronym etc.), partner information, **foregrounds, publications** (including websites) and information regarding the **exploitation of foregrounds** were collected in a structured format and put into an own data base at CMT, then serving as a central information repository for the group. In total, **562 publications** and **324 foregrounds** were identified, with an increasing amount over time. Chapter 3 describes this process in more detail.

It must be noted, that very **limited information**, in particular on research results and the exploitation of foregrounds has been found in the public domain. Existing data bases (TRIP, EurOceans, CORDIS, MARPOS et al) are mostly incomplete and rarely include information on national projects and post-project information. The mandatory public parts of the final reports of projects are not usually accessible and COM services have not been able to provide this information. Direct contacts with project partners yielded different results, with some projects and partners being reluctant to share information.

Table 1 below gives an overview on the share of projects relevant for TTG-03 for which outcome-related information could be found as well as a statistics on the average number of foregrounds and publications per project, for which information could be found. The statistics for FP7 may be too low, as many projects are still ongoing. HORIZON 2020 is not included in the statistics, as no projects were concluded by the time the analysis was conducted. For some large projects covering a wide range of topics, only information relevant for TTG-03 was considered. Details and further explanation on Table 1 could be seen in Chapter 3.

It can be concluded that:

- The **visibility of R&D project outcomes is still limited** – reasons and recommendations are given in Chapter 2.3;

- The amount of **visible project outcomes is increasing**. Maritime projects on "Materials and Production" for which relevant information could be found produce quantitative outcomes much above average as given in the FP7 evaluation reports. More information on this statistics can be found in Chapter 3;
- Public information on R&D projects alone does not provide a sufficient basis to reliably assess outcome and implementation of research;
- However, **combining public domain information with expert interviews and "inside knowledge" allows to assess the State-of-the-Art in research and industry with sufficient accuracy**.

Table 1: Share of projects for which outcome related information could be found and average number of outcomes per projects.

Share of projects for which outcome related information could be found			*Average number of outcomes per project based on share on the left*	
Funding Scheme	on Publications	on Foregrounds	Publications	Foregrounds
EU FP7	63%	43%	7,9	8,1
EU FP6	54%	48%	10,7	7,7
EU FP5	17%	22%	8,5	2,0
Other	50%	11%	2,8	3,8
Average	46%	31%	7,5	5,4

State of the Art Analysis (Step 3)

The state-of-the-art analysis was conducted with a bottom-up approach for seven Technology Sub-Areas (TSA) that are defined for TTG-03 "Materials and Production". The detailed analysis is included in Chapter 3 of this report per TSA. The analysis was conducted under the lead of the task leaders and involved the input received from external experts and at dedicated workshops. Intermediate results were presented, discussed and endorsed by those experts and at the workshops.

For each of the TSAs the **detailed analysis includes**

- a list of projects analysed and a brief report on interaction with external and internal experts;
- a brief summary on the status of industrial use and rules and regulations for major technology areas found relevant for the TSA;
- a detailed analysis of the results of R&D projects and their contribution to the SotA in major technical developments. This is complemented by an overview list of analysed projects in Annex 2 and their contribution to TSAs and technological sub-topics;
- A visualization of logical chains of projects interacting and building on each other towards strategic goals;
- A first proposal on possible "Innovation Show Cases" (Step 5), either successful individual projects or sequences of projects with a common outcome ("Game changer"). This list serves as a basis for a further selection and description of "Innovation Show Cases" in Deliverable 3.4.

While the detailed analysis provides a good foundation for an assessment of the State-of-the-Art in production technologies in shipbuilding, it is too fragmented to draw strategic conclusions and identify the "big picture". To overcome this, the **main conclusions on the State-of-the-Art** in technology fields found most relevant for the competitiveness of European shipbuilders are summarized in Chapter 2.2, whereas a first list of **identified technology gaps** (Step 4 in Figure 1) is given in Chapter 2.3.

Outlook to follow-up Deliverables

This Deliverable D 3.1 is the first deliverable of TTG-03 (WP-03) forming the baseline for

- **Deliverable D 3.2** – Proposal of an RTD Roadmap on Production and Materials, following up step 4 as in Fig.1;
- **Deliverable D 3**.4 – Innovation Show Cases for Production and Materials, following up Step 5 as in Fig. 1

The outcome of workshops conducted throughout the work in WP3 will be reported in **D 3.3 –** Workshops. Finally, the outcome of the work in TTG-03 will be consolidated on project level in **Deliverable D 6.2** – Updated Strategic Research and Innovation Agenda.

2.2 Summary on the state-of-the-art and related technology gaps

The following chapter summarizes the state-of-the-art and main technology gaps identified for **technology areas** of **strategic importance** for the European maritime industry and its products. A more detailed analysis per Technology Sub-Area is presented in Chapter 3.

The SotA as described in this chapter is mainly related to **leading edge research and development** and **current practice of leading industry players**, i.e. it describes what is technologically possible and not necessarily what is implemented in the majority of shipyards. The need for increased technology transfer to broaden the use of leading edge technology and to achieve a critical mass as well as a larger impact on European scale is addressed separately, where relevant.

To allow for a quick **executive overview** main technology areas and sub-technologies relevant for TTG-03, the technology levels reached and a preliminary list of important technology gaps is presented in Table 2 on the following pages. Each of the technology areas is then explained in more detail in this chapter with their importance, state of the art and gaps.

Table 2: Executive Overview of technology levels reached and important technology gaps

Main Technology Areas	*TRL* reached*	*Gaps identified*
2.2.1 Design for Life Cycle Processes (Production, Maintenance, Repair, Retrofit, Dismantling) Related to TSA-3A and G		
Life Cycle Performance Assessment (LCPA) • for equipment and systems • holistic LCPA for complex products (ships)	TRL 7-9 TRL 5-6	Integration into design process of complex products, reliable operational data feedback into design, prediction of future scenarios and cost drivers
Design for Life Cycle Processes • design for "conventional" production • design for new materials and processes • design for retrofit, repair, maintenance, dismantling • decision support tools for retrofitting	TRL 7-9 TRL 2-4 TRL 3-5 TRL 6-7	Knowledge and design methods for new materials and processes, Business models, IPR for life cycle data and asset management, advanced condition monitoring and condition based maintenance
Approval procedures integrated in Design • for conventional processes and materials • for new materials and processes	TRL 8-9 TRL 3-6	"fast track to approval" based on equivalent safety, calibration of real-life data, accelerated lab tests and numerical assessment tools; quality assurance, work safety and environmental protection procedures for new processes and materials
2.2.2 Numerical Modelling and Integrated Simulation of Life Cycle Processes (Production, Maintenance, Repair, Retrofit, Dismantling) Related to TSA-3B, 3C, 3D, 3E, 3G		
Discrete event simulation • resource and layout planning, scheduling • cost, energy, environmental assessment of production • simulation for offshore, retrofit, repair	TRL 5-9 TRL 3-5 TRL 4-6	Simplified simulation tools, models and tools for repair, retrofit, offshore installation, dismantling, integration of real life data, integration of several functionalities
Kinematics, ergonomics and process simulation • verified tools for (conventional) maritime applications • integration of tools with other numerical models • numerical modelling of new production techniques	TRL 4-5 TRL 3-4 TRL 2-4	Validation of numerical tools versus experiments, development of numerical simulation for new production processes and materials, solutions for big data and distributed simulation, optimization of complex systems, real life data feedback

Virtual Reality and Reverse Engineering • VR in design • VR in production, repair, retrofit • Reverse engineering (measurements to CAD) • Decision support for retrofitting	 TRL 7-9 TRL 4-7 TRL 5-6 TRL 5-6	Extended simple and robust solutions for repair and retrofit in complex environments, handling of big data
ICT Environment for Integrated Simulation • Simulation at stand-alone IT systems	 TRL 4-8	Distributed simulation and "virtual demonstrators" on high-power computer systems, management and security of "big data"
2.2.3 Welding and Automation of Production and Life Cycle Processes, Innovative Production Processes related to TSA-3C, 3E, 3F		
Welding of metallic structures • Conventional welding • Laser and hybrid welding (stationary, mobile) • Friction stir welding	 TRL 5-9 TRL 4-8 TRL 3-9	 Welding of advanced steels, parameter optimization, automation Welding of thick structures and advanced steels, mobile welding FSW tools for steel, qualification of welding and post-treatment in maritime
Cutting and edge preparation • Plasma cutting, laser cutting for thin sheets • Mechanical or thermal edge preparation	 TRL 7-9 TRL 5-8	 More efficient laser cutting, economy of scale Automated edge preparation, thermal edge preparation for advanced steels
Automation of production processes • Part manufacturing and pre-assembly • Assembly, repair and retrofit, dismantling, offshore	 TRL 7-9 TRL 3-5	Simplified automation, advanced manufacturing equipment (autonomous, intelligent), process re-engineering, design for production, human-machine interaction
Additive Manufacturing (AM) in maritime	TRL 2-3	Processes and equipment for large parts, integration with other manufacturing processes, functional properties of AM parts, approval and quality assurance, IPR issues
2.2.4 Advanced Materials and multi-material structures including design and production techniques related to TSA-3A, 3D, 3E, 3F		
Take-Up and Qualification of Advanced Materials for maritime use • Structural lightweight with conventional materials • Adaptive structures • Advanced material in none-critical applications	 TRL 7-9 TRL 3-5 TRL 4-7	 New structural concepts including outfitting, use of ultra-high tensile steel Prove of concept, materials and production at larger scale More industrialized manufacturing and process integration

• Composite and advanced materials in load bearing • Coatings with reduced drag resistance (see also TTG-1)	TRL 5-8 TRL 4-5	Long term real life experience, cost efficient processes, design integration Long term experience on the behavior, application technologies
Multi-material joining • Adhesive bonding • Mechanical joining • Pre-fabricated multi-material components	 TRL 4-8 TRL 4-8 TRL 3-6	 Standards and pre-approved solutions, automation and industrialization of processes, efficient process chains, inspection, repair and recycling

* ***TRL levels (H2020, Work Programme 2014-2015, General Annex G):*** *TRL1 – basic principles observed, TRL2 – technology concept formulated, TRL3 – experimental proof of concept, TRL4 – technology validated in lab, TRL5 – technology validated in relevant environment, TRL6 – technology demonstrated in relevant environment, TRL7 – system prototype demonstration in operational environment, TRL8 – system complete and qualified, TRL9 – actual system proven in operational environment. For the purpose of this document "operational environment" is a real production process in a shipyard or similar.*

2.2.1 Design for Life Cycle Processes (related to TSA 3A, 3G)

Life Cycle Performance Assessment

Importance	During the recent years, ship operators, shipyards and equipment suppliers have become increasingly aware on the impact of design on life cycle cost and environmental footprint of their products. The demonstration of better life cycle performance (LCP) to customers are key to compensate higher labor and building cost of European producers.
SotA	LCP Assessment (LCPA) for individual components are largely available and in use by equipment suppliers (TRL 8-9). **Methods and tools for holistic LCPA** of ships have been recently developed, and partly validated and demonstrated in relevant environment (TRL 6). Company specific solutions and methods developed in other industries are being tested in desktop studies (TRL 4-5). LCPA is however not yet fully integrated in the design process.
Gaps	**Integration in the design process** and optimization strategies to balance different requirements are needed. Availability of **reliable operational data** and their integration in design is a challenge due to IPR issues and for new operational scenarios (ships under extreme conditions, new Blue Growth markets). Reliable **prediction of future cost drivers** (e.g. fuel cost) as well as upcoming legislation are challenges for trustworthy LCPA.

Design for Life Cycle Processes

Importance	Decisions in design largely determine cost in production, repair, retrofit and dismantling. New production techniques on hand open opportunities for better products, which requires Innovative concept and detail designs to fully use the potentials. On the other hand new production processes require modifications in design to be efficient and reliable.
SotA	Different aspects of **design for production** have been studied in research since many years, but need to be continuously updated reflecting new processes and materials. Specialized yards with in-house design use rules or simulation for design for production (TRL 8-9), primarily for conventional processes. Solutions and principles for **design for retrofit, easy maintenance and repair or dismantling** have been developed and tested (TRL 3-4), but are mainly used for ship equipment and much less for decisions influencing the overall ship concept. **Decision support tools for retrofitting** are available and partly demonstrated in relevant environment (TRL 5-6) – see also MESA TTG-01 and TSA 3G.
Gaps	N**ew production processes and materials** require new design and simulation tools (see item 2.2.3 below). While ICT solutions for life cycle data management are largely available, new **business models**, measures for **IPR protection and ICT security** as well as new approaches for **life cycle asset management** are required to implement design for life cycle processes to its full potential. Approaches in other industries (such as aeronautics) could serve as blue print for maritime life cycle chains. A better knowledge on **product behavior under real life conditions** (long term, combined loads) are essential in new markets and applications.

Approval Procedures

Importance	For innovative technical solutions (new materials, production processes) and new applications beyond existing rules and standards risk based design has to be applied. The framework for this available and requires a proof of equivalent safety as well as approved quality assurance procedures. This is a time consuming process which requires specific knowledge for each new case which often hinders the application of innovations in practice.

SotA	For the design of **conventional processes and materials** tools are available and largely integrated in the design process which are based on existing rules and standards (TRL 8-9). The adaptation of existing rules and experiences for **close-to-conventional solutions** (e.g. new welding procedures or metallic materials) is relatively easy, but requires sufficient time for the design and approval process (TRL 5-8). However, for **radically new materials** with a large variety of design and processing options (composites, AM) new approaches and tools are required (see also TSA 3D under chapter 3 and topic # 2.2.3 below).
Gaps	New ways for a "**fast track to approval**" of new materials and processes are needed. Based on **real-life data** (long term, combined loads in maritime environments) **accelerated lab tests** and **numerical assessment** methods and tools need to be developed and turned into new standards and guidelines. Consistent standards for **quality assurance** during all life cycle processes, including measures for work safety and environmental protection need to be developed.

2.2.2 Numerical Modelling and Integrated Simulation of Production and Life Cycle Processes (related to TSA-3B, 3C, 3D, 3E, 3G)

Importance	Increasing complexity of products, new operational scenarios, the trend to one-off products, reduced design lead times as well as complex distributed process chains lead to increasing economic risks for the stake holders in the maritime value chain. Process planning merely by experience or "try and error" in real life is less and less an option. Numerical modelling and virtual simulation of life cycle processes is a means to better understand and plan processes and to find an optimum balance between functional requirements of the product and life cycle processes. New technologies to handle "big data", high performance computing as well as virtual reality technologies are key enablers which support more complex and integrated simulation of life cycle processes. Advanced simulation capabilities are a precondition for mechanization and automation beyond part manufacturing and pre-assembly (see topic # 2.2.3 below).

Layout and resource planning and scheduling

Importance	See above
SotA	Advanced planning tools, simulation models and optimization approaches are available and used for layout (investment) planning, logistics, **resource planning and scheduling** by leading shipyards (TRL 7-9), partly including the supply chain (TRL 5-7). Feedback of real-life data into planning is established in leading yards, supporting shop floor management. In smaller yards advanced planning tools are rarely used. First models for offshore assembly, repair, retrofit and dismantling have been developed and tested in relevant environment (TRL 4-6). Stand-alone solutions are available for **cost assessment, energy monitoring** in production or assessment of the **environmental footprint**, but those tools are not integrated and find limited everyday use in the maritime industry to date (TRL3-5).
Gaps	**Simplified simulation** and planning tools for smaller yards, development of more reliable numerical models for **offshore, repair, retrofit and dismantling**, **integration of real life data** into planning along the process chain; extension of discrete event simulation with **additional functionalities** like quality assurance, cost monitoring, energy and environmental footprint

Kinematics, ergonomics and process simulation

Importance	See above; Complex manufacturing and assembly processes of large parts require advanced simulation methods to design equipment and work sequences as well as to understand complex processes and to foresee problems.
SotA	Tools for **ergonomics** (human work), simulation of **machine kinematics**, the **simulation of physical phenomena** in production processes including forecast on properties (e.g. welding) are available and tested in other industries (TRL 3-5 for maritime), but need to be validated and integrated for specific conditions in maritime, in particular for new production techniques.
Gaps	**Validation** in maritime industries and offshore (large parts, extreme conditions, complex structures, one-off), models and verification (physical testing) for **new production techniques**, **integration** and interaction of various aspects of production simulation (discrete event, geometry and kinematics, finite element, process and product properties, statistical factors) and along the life cycle process chain; human-machine interaction, technologies to handle **big data** and high power computing (ICT), distributed simulation of complex processes (ICT); **statistical** process models, **optimization** techniques for complex systems, real life **data feedback**

Virtual Reality and Reverse Engineering

Importance	See above, VR technologies allow a better visualization of technical solutions towards customers as well as integrated into processes, reducing paper and providing a higher level of up-to-date information directly integrated into design. Reverse engineering is needed where PLM is not available to create numerical product models from measurements in reality (e.g. in retrofitting of ships).
SotA	Various VR techniques are available and are used **in design** by leading shipyards (TRL7-9). Prototype applications of **VR integrated in production, repair and retrofit** are available (TRL 4-8), but not widely used. Integration of simulation and VR is currently limited to prototype studies (TRL 4-5). **Reverse engineering** has been validated under relevant environment (TRL5-6), necessary measurement technologies are fully available (TRL 7-9)
Gaps	Further process integration and validation in maritime life cycle processes.

ICT Environment for Integrated Simulation

Importance	See above; More complex and integrated simulation of complex production environments will require high computing power to get acceptable response times. Moreover, the amount of data to be managed and processed in short time will dramatically increase. ICT security is essential for distributed simulation, real-life feedback and distributed data storage. ICT infrastructure can be a limiting factor for more integrated simulation.
SotA	Simulation in the maritime industry is currently run mostly on **stand-alone computer systems** within a company (TRL 7-9). Interfaces to other systems are in principle available, but adaptations are mostly needed for specific cases (TRL 4-6). In the first maritime case studies, distributed simulation in computer grids has been successfully demonstrated (TRL 5-6).
Gaps	**High performance computer** and data management networks, solutions for **ICT security**, data mining and technologies for the management of **big data** (ICT)

2.2.3 Joining and Automation of Production and LC Processes (related to TSA-3C, 3F)

Welding of metallic structures (conventional, laser, friction stir)

Importance	Due to good properties, available long term experience and easy processing; metallic structures will remain the back bone of ships and maritime structures in the coming decade. Welding processes are significantly influencing cost and lead time as well as quality and thus safety. Low heat input and high energy efficiency processes reduce rework in assembly and outfitting, energy demand, and improve working conditions.
SotA	**Laser and especially laser hybrid welding** is fully feasible and partly commercially exploited in the pre-fabrication of maritime components (TRL 5-8). Laser welding also allows the production of innovative components, such as steel sandwich panels and tailored blanks. Mobile laser welding of larger parts and assembly joints has been proven to be feasible in principle (TRL 4-6). A variety of **conventional welding processes** are established and widely used in industry (TRL 5-9). Based on available knowledge and technology, best practice to select and adapt optimal welding processes need to be spread to a wider community especially of small shipyards. **Friction Stir Welding** (FSW) for butt and partially fillet welds on lightweight alloys (e.g. aluminum) is an established process and standard as well as customer-specific components are being produced by specialized companies under market conditions (TRL 7-9). FSW of steel is possible in principle (TRL 3-4) and bears a high potential especially for multi-metal joints, high fatigue loads and difficult to fusion-weld alloys.
Gaps	**Laser welding**: Decreasing cost of the laser equipment and available practical experiences will allow to **extend the application** to smaller companies (technology transfer), to advanced metallic materials (aluminum, high tensile steel and other) and to the assembly of more complex structures. The technologies and knowledge for this extension is widely available. Mobile laser welding of larger parts and assembly joints needs further developments in view of process integration, work safety and quality assurance. **Conventional welding**: New **variations of process parameters** and welding techniques will be continuously developed for practical use in particular in connection with an increased automation of the production of large and complex structures in workshops, on land and offshore. Welding of very high tensile steels needs to be qualified for maritime use. **FSW**: The availability of low cost reliable **tools for FSW of steel** is currently a show stopper for economic use in the maritime sector. Applications where improved joint quality and the ability to join different (metallic) materials need to be found, validated and qualified as well as applications to improve conventional weld quality by FS post treatment.

Metal cutting and edge preparation for welding

Importance	Cutting is the first process in part manufacturing. Its quality has impact on accuracy, weld quality and assembly, however this impact is less than for joining processes.
SotA	Wide variety of **cutting processes** are available. Processes are sufficiently known and are widely used. Plasma cutting still appears to be the most efficient solution for maritime application (TRL7-9), whereas laser cutting is ready for use for specific requirements like advanced materials or high edge quality and accuracy (TRL 6-7). Some shipyards use specialized subcontractors for cutting and forming for increased economies of scale. **Edge preparation** for welding and is done mechanically (milling, grinding) either manually or in automated processes (TRL 6-8).

Gaps	Business models for cooperation and economy of scale, more efficient edge preparation for coating, including thermal processes; correlation between edge preparation and coating life time

Automation and mechanization of production and life cycle processes

Importance	Demographic developments (lack of qualified personal) as well as high labor cost are main drivers for mechanization and automation. However, work safety aspects (laser assisted processes, offshore assembly), quality aspects are additional reasons to increase the degree of automation which also allows reducing energy demand and emissions.
SotA	In **part manufacturing and pre-assembly** (flat components) the degree of automation has reached a significant level in leading yards (TRL 7-9), whereas manual processes still dominate smaller yards. Mechanization and automation of subsequent **assembly and outfitting processes, offshore assembly** as well as **repair, retrofit and dismantling processes** is limited to a few robot applications in leading yards and is largely dominated by manual processes in workshops (pre-assembly in leading yards) or on board. Means for simplified and more advanced automation are in principle available, but need to be further adopted and implemented in practice (TRL 3-5).
Gaps	Simplified automation for smaller yards, process re-engineering to improve pre-conditions for automation, design for production, intelligent manufacturing systems (no offline programming), specific kinematic and sensor solutions for maritime applications – both stationary and mobile systems, advanced simulation to prepare automation, human-machine-interaction, advanced manufacturing processes for new materials

Additive Manufacturing (AM) ("3D Printing")

Importance	AM (sometimes referred to as 3D printing) is a key enabling technology with a high potential also for the maritime sector. It allows the production of optimized and complex components with improved functionalities, which cannot be produced so far, due to limitations in the production processes. AM also bears the potential to reduce the number of processing steps and thus reduce cost and production lead time.
SotA	While the concept has been proven (TRL 4) and AM is commercially used in other industries for extremely complex parts or the need for extreme lightweight, the current **cost and performance** of known processes are not sufficient for economic use in the maritime sector. Limitations in the size of parts which can be produced, low fatigue performance of AM parts and lacking integration in the shipbuilding process chain are other challenges ahead for maritime use (TRL 2-3).
Gaps	**Functional properties** of components manufactured with AM need to be improved. More efficient **processes and equipment for larger parts** are missing. **Quality assurance / approval strategies** as well as IPR issues in a modified global supply chain need to be clarified.

2.2.4 Design, Processing and Use of None-Metallic Materials and Hybrid Structures (related to TSA-3A, 3D, 3F)

Importance	New materials, the more intelligent use of conventional materials and hybrid structures with the right material at the right place are main mechanisms to **improve product performance** (payload-to-weight ratio, durability, functionality, safety) and thus to reduce life cycle cost and improve the environmental impact (e.g. fuel and emission reduction). New materials are also needed to develop innovative products for new operational scenarios (e.g. arctic) and markets (offshore). The efficient and reliable use of new materials requires new process chains and technologies from design through production to repair, retrofit and dismantling.

Take-up and qualification of advanced materials and structures for maritime use

Importance	Material sciences have yielded significant progress during the last years by developing advanced materials with nanoparticles, adaptive properties or integrated condition monitoring and intelligence. However, extreme environmental conditions and safety hazards in maritime operations require profound knowledge and qualification of the material behaviour under combined stressors (loads, chemical exposure, radiation etc.) and in long term. In addition, cost efficiency of advanced materials for maritime products require modular design approaches and standard solutions to increase economy of scale.
SotA	New first principle design methods (Finite-element analysis) and advanced joining methods allowed to use **tailored blanks and beams** from conventional materials (metals) also in leading shipyards (TRL 7-9). More advanced structures (sandwich panels) have been demonstrated in operational environment (TRL 6-8), but full commercialization has not yet been achieved. **Adaptive structures with conventional materials** have been proven technically and economically feasible at lab scale (TRL 3-5), but production processes need to be further developed and qualification at larger scale is pending. For **less critical components** (interior walls, windows, pool areas composite materials and adaptive surface layers have been applied in pilot applications (TRL 4-7), but industrialization at larger scale is missing. **Very advanced materials** for maritime applications currently work in lab scale, but are too costly and properties are not sufficiently proven for real-life applications in the sector (TRL 3-5). **Composite structures for critical components** are under development and partly applied, in particular for fast ferries and naval ships (TRL 6-8). Various **coating systems** for reduced resistance, improved anti-fouling and corrosion protection have been developed (TRL 4-6), but commercial products are rarely available and limited experience is available for combined properties and long term behaviour under realistic conditions.
Gaps	Advanced structures with integrated outfitting, light weight and advanced functional properties (including adaptability to changing operational conditions) and their integration in ship concepts; cost efficient use of very advanced materials for maritime; efficient design and approval processes for advanced materials and composites; economy of scale and standards for composites; long term experience on material behavior under realistic marine environments, systematic take-up of solutions from material sciences and other industries

Multi-material joining, adhesive bonding and other joining techniques

Importance	New materials and material combinations require new design and manufacturing techniques. In complex structures like ships, joining of various materials is a major cost factor, but also largely determines product quality and safety.
SotA	Knowledge and technologies for **adhesive bonding** in the maritime sector are proven to be feasible and find first commercial applications (e.g. aluminium to steel joints, windows in cruise vessels) - (TRL 4-8). However, the process is still complicated, requires specific environmental conditions, specific conditions and mostly case-by-case approval. Standard materials, processes and approval procedures need to be developed and available data and experiences need to be made more readily available and useable for a range of similar applications. **Pre-fabricated multi-material components** are being developed in a variety of industries and are in principle suitable for mass production, bearing a substantial cost saving potential. They have the potential to produce ships and marine structures more efficiently, improve product quality (strength, ageing, damping etc.), more flexibly (customer needs) and with improved life cycle performances (TRL 3-6).
Gaps	Standards and approval of adhesive bonding, wider use and qualification of mechanical joining for multi-material components in maritime applications, standard solutions and industrialization of manufacturing, assembly and outfitting of multi-material components; integration in ship concepts, design and production processes; inspection, repair, recycling technologies and processes

2.2.5 European shipbuilding in the world

Production **technologies are means to produce products**, like ships and marine structures, and hence need to be developed and applied in order to meet the specific requirements of the product. Any comparison on the state-of-the-art in production technologies would be misleading if it is not related to the products produced in a specific region or by a specific shipyard.

Main maritime products per region...

Type of ships	China	Korea	Japan	Europe	Brasil	USA
Crude oil tanker	••	••	•		•	
Bulk carriers	••	•	••			
Product & chemical tanke	•	••				•
LNG and LPG carriers	•	••	•			
Container vessels	••	••	•			
RoRo and other cargo	••	••	•	•		•
Cruise, Pax and ferries			•	••		
Mega Yachts				••		
Offshore vessels	••	••		•	••	•
Naval vessels	•			••		••

... and (selected) resulting research focus areas

Steel and metals dev.	+	++	++			++
None metallic materials		+	+	++		++
Thick sheet welding	++	++	++		++	
Thin sheet welding			+	++		++
Production automation		+	++	++		
Simulation		++	++	++	+	

Figure 3: Main products & priorities in production R&D (ISSC2015 Congress, Lisbon, 09/2015)

Figure 3 has been elaborated in cooperation with the International Ship and Offshore Structures (ISSC - www.issc2015.org), Committee V.3 – Materials and Fabrication Technology and shows main products and production-related research priorities in different regions of the world. A more detailed analysis on the SotA of production technologies in Europe and Japan has been presented in the report "Analysis of Technology Trends outside Europe – Japan" in the frame of the European VISIONS (Visionary Concepts of Ships and Floating Structures) in 2009.

Another aspect to be considered when assessing the status of production technologies is the way **companies are organized**: while European shipbuilding is dominated by a large number of smaller yards, their competitors in Asia are normally significantly larger and focusing on series of more or less standard products. Moreover, they are usually embedded in multi-sectorial companies, allowing them to use synergies with steel makers, IT developers and other sectors. Both concepts have advantages and disadvantages which cannot be discussed in detail at this stage nor will those organizational concepts change in near future. However, they are important to understand different ways to produce ships.

Despite those differences, a number of conclusions can be drawn with regard to the **European position in production technologies and related research** at global scale (details of projects outside Europe are given in the relevant TSA's in Chapter 3):

Research Funding Schemes and cooperation in projects:

- Europe and its member states provide excellent funding opportunities for applied research. **Cooperation between competing industry players and between research and industry** is unique in Europe.
- Other countries, in particular in Asia, however put partly significant more efforts in **building research infrastructure** (e.g. Center for Additive Manufacturing in Korea, larger national maritime research institutes), in more **basic research on key enabling technologies** for the maritime sector and on **systematic rule development** (Japan, trans-Asian cooperation). Cooperation across national borders in Asia is increasing, but has not reached European level. All this puts a potential thread to the European lead in production technologies.

Status of Production Technologies:

- Europe is largely leading research, development and implementation of technologies relevant for technology areas needed for the **efficient production of specialized high-value added vessels in small series or as single productions**, i.e. in design methods and tools, production planning and logistics along the supply chain, use of innovative materials, thin sheet welding and distortion management, automation in pre-assembly, pre-outfitting;
- The **main competitors** in this field of products are **Japan, Korea and potentially China**. Those countries put immense efforts into building know-how and expertise, which is partly supported by EU and national European development aid, research cooperation, training and other funds;
- Asian shipyards are usually part of trans-sectorial companies, which allows for synergies in research and development.
- Japan and Korea are leading in the development of **new materials** (including steel materials) as well as in certain areas of digitalization. The Japanese way and culture to approach **automation and mechanization** is unique and leads to a much higher level of (low tech) automation as compared to Europe (continuous small improvements, re-engineering of processes to allow for simple, robust and efficient solutions), even though the products are not comparable in many aspects (sheet thicknesses, complexity of products and outfitting).

Recommendations for international R&D cooperation are given in Chapter 2.3 below.

2. 3 Recommendations for cooperation and implementation

Based on experiences made during the SotA analysis in MESA as well as in the everyday work of CMT within other European projects and associations, this chapter will list some observations on the documentation and dissemination of project outcomes, as well as on the exploitation of results and cooperation of projects within and beyond the maritime community. Recommendations will be made to further improve the situation. This analysis and the recommendations are valid **beyond the scope of the TTG on Production and Materials**. More ideas, which are not covered below, are also available and ready for further discussion.

Documentation and Dissemination of Project Outcomes

Hypothesis: **Project Outcomes are often NOT consistently and clearly DOCUMENTED and are POORLY VISIBLE**

Observations:

- The reporting guidelines and templates for the "Plan for Using and Disseminating Foregrounds (PUDF) respectively the Final Report are useful and provide a good overview on project outcomes as seen **at the end of the project**;
  However, these reports are not consistently filled by all projects and they are often not available for analysis and for the general public beyond Commission services.
- A large variety of **data bases** (e.g. TRIP, MARPOS, EurOceans and CORDIS) and **surveys** financed by EC provide fragmented and incomplete information, overload the projects and lead to a reluctant response. Many data bases are not maintained after the end of the funding for them. CORDIS appears to be still the most complete and reliable source of information.
- Limited information about **national research activities** is available in European data bases. National data bases contain different levels of information and their use requires inside knowledge. Analysing and comparing outcomes of national and EU projects is therefore difficult and time consuming.
- **Post-project information** on the use of results and their impact is largely missing. No instrument is in place to follow-up implementation after the end of the projects systematically and continuously.
- Recent opportunities to support **projects** in **dissemination after their end** can have positive effects.

Recommendations:

- Projects (like MESA) or consultants which are contracted by EC to analyse research outcomes shall be given **access to the information** in the Final Reports, at least to their public part;
- The **public part of the Final Report** shall by default contain at least a list of foregrounds, a brief description, a contact person and the list of publications (all this information is currently required for the Final Report, but not necessarily in the public part);
- The public part of the Final Report containing the above information shall be made readily available at a **central IT-platform** under supervision of EC e.g. CORDIS (all other data bases and platforms have found to be less complete and are normally only maintained while funded through a project);
- The **number of surveys and questionnaires** supported and financed by COM shall be better coordinated and reduced;
- Standard information formats about research projects shall be agreed and maintained between **EC and the member states**. National research data bases shall be connected and basic information about the projects shall be made accessible in CORDIS or another central IT platform;
- Mechanisms and incentives shall be established to monitor the implementation of project outcomes **after the end of the projects**, e.g. after one and after three years. This should be implemented in a central platform to avoid a large number of parallel questionnaires and surveys.
- Professional help to projects to support **post-project dissemination** shall be maintained and extended.

Cooperation between Projects and Researchers

Hypothesis: **Direct information exchange between projects working on similar fields and cooperation between them is mainly driven by individual initiative and CAN BE IMPROVED**

Observations:

- Projects running in the same part of the research programs usually **know each other** (e.g. in maritime Transport of Blue Growth), while similar projects running on national level or in other parts of the European program (e.g. KET) are usually not known;
- **Direct cooperation** between similar projects is limited to exceptional cases. Giving follow-up projects access to the Deliverables of previous projects is the main way to implement this. Mechanisms to implement such a cooperation (joint workshops, joint research and access to results, and joint follow-up activities) as well as the legal requirements are not widely known;
- **Thematic Networks** and **User Groups** (with member fees financing additional research or follow-up activities) have proven to be efficient instruments in the past, but are not being used lately.
- Larger projects (focus on cooperation within the own consortium) as well as the move "closer to market" (Demonstrators and corresponding IPR issues) decrease cooperation beyond the limits of the own project;

Recommendations:

- Identify **clusters of projects** working on similar fields, ideally across funding programs (e.g. Transport, Blue Growth, KET) with the help of the corresponding Technology Platforms and associations;
- Encourage and support **joint technical workshops** and other dissemination events across projects. This as well as connected technical visits will increase the interests of experts to actively participate in those events;
- "**Thematic Networks**" on technical fields can support information exchange, cooperation and may initiate follow-up activities complementing research (e.g. standardization activities, technology transfer). Those networks can be funded by CSA's which have more technical than policy supporting character. Those Thematic Networks require a critical mass of projects to participate and (with the limited number of maritime projects funded in each call) shall thus include national projects and other sectors;
- Provide **guidelines and templates for cooperation**, e.g. sample contracts to give mutual access to deliverables etc. Make best practice experience more widely available;
- Develop **incentives for trans-sectorial cooperation** between projects. Specific calls for existing projects to implement trans-sectorial cooperation could be one of them.
- **Joint calls** e.g. between Transport and KET could foster cooperation and interaction between sectors.

Take-Up and implementation of project results

Hypothesis: **While the uptake of research results by partners of the projects analysed appears to be ABOVE AVERAGE, the uptake of results by partners outside the project consortia is VERY LIMITED and bears potential for improvement.**

Observations:

- For the projects which gave information to the MESA TTG-03 analysis, the uptake of results by partners in the form of commercial application or follow-up research seems to be satisfactory, especially for the partners who developed the results and in "Transport" projects. Information about the uptake of results in other parts of the Framework Programs is less encouraging. The use of results by entities outside the consortium is largely limited to direct contact of projects with companies (e.g. in User Groups) and to the transfer of knowledge to follow-up projects through partners;
- There is no systematic mechanism for know-how and technology transfer in place in and beyond the maritime sector, although projects like SMARTYards have made a first step;

- The implementation of research results often requires "follow-up" activities, like standardization, input to rule making, the elaboration of training material (especially for post graduate training) or technology transfer to smaller companies. This need is neither reflected in the corresponding research strategies of the sector nor there is a systematic approach to support those follow-up initiatives, e.g. by means of other instruments from the research framework programs or by regional funds;
- The same applies for a systematic knowledge transfer from Key Enabling Technologies (KET) into the maritime sector.
- Networks in the projects – especially the large projects – are often "static" and do poorly involve partners from less developed regions.

Recommendations:

- Specific calls and measures to support ongoing projects in follow-up activities like standardization, international rule making or training measures;
- Include follow-up activities like rule making, standardization, training and technology transfer to SME in the Strategic Research and Innovation Agendas;
- Encourage the establishment of industrial User Groups and develop incentives for projects
- Better link basic research, applied research as well as SME instruments and European infrastructure funds in the maritime sector
- Support technology transfer and the Europe-wide cooperation between regional maritime clusters;
- Support the implementation of partners from less developed regions in Europe into ongoing research (e.g. joint calls with other programs)

International Cooperation (outside Europe)

Hypothesis: **There is a LIMITED overview on technical developments in the maritime sector on European level and NO STRATEGIC APPROACH towards international cooperation.**

Observations:

- There is no systematic survey of research activities and technical developments in the maritime sector **outside Europe**. Through the participation in conferences and through market participation companies and research centers have a good overview about specific fields of expertise, but the overall picture remains fuzzy.
- There is no clear strategy for international cooperation in the maritime sector, identifying thematic and geographic areas for cooperation considering also the protection of the European maritime manufacturing sector and IPR protection. More international cooperation in rule making, the development of international legislation, material sciences and to explore new market potentials would bring benefits for Europe, whereas knowledge transfer on production processes at high TRL shall be seen critical.

Recommendations:

- A monitoring mechanism on **international technical developments** shall be established jointly by the Technology Platform and EC;
- Specific funding instruments to support European researchers in particular from SME to attend international conferences and participate in international rule making activities;
- Consider specific calls for rule making and basic science for cooperation with international partners;
- Better harmonise research cooperation and technology transfer on national level on production processes and technologies in the maritime sector with industrial policy (protect European know-how and market leadership)
- Support exploratory measures on research cooperation e.g. with Russia and South America

3 Detailed Analysis of clustered projects

3.1 Introduction

As stated in the DoW, TTG 3's first and second overall goal is 'to systematically analyse technological developments in the area of PRODUCTION, including Design, Manufacturing, Assembly, Life cycle Processes and the related Materials and derive strategic development goals and research needs in the Technology Area.'
The first step to achieve this target is a State of the art Analysis (SotA) that considers corresponding research activities, but also their results and the extent of the results' commercial exploitation and/or successful subsequent further research.
The third strategic aim of TTG 3 is described as follows: 'In addition, the TTG aims to improve networking, cooperation and information exchange between actors working on the field of PRODUCTION research, primarily on European, but as much as possible also on national, regional and company level. This will help to improve the efficiency of research, the application of results and to increase the visibility of successes in maritime production oriented RDI.'
On the one hand, the effect mentioned above is dedicated to encouraging research stakeholders to define and pursue future research agendas in a cooperative manner. Apart from that, such cooperation is also a prerequisite for the proper achievement of the first goal in such a way that as many sources of information as possible should be exploited for the SotA in order to achieve a comprehensive overview on the activities in the research fields of materials and production.

Methodology

In the first phase of the project, the focus was on establishing a network, identifying relevant research projects, and collecting information related to these. This chapter describes how that work was organised.

Technology Sub Groups and internal experts

TTG 3's mission is to cover research on production and materials in the maritime industry. Because of the broadness of this field, the scope has been subdivided into seven Technology Sub Groups (TSAs), each of them led by one of the beneficiaries engaged in TTG 3. Table 3 shows the TSA's names and responsible beneficiaries.

Table 3: TSAs and responsible beneficiaries

TSA ID	Name	Leader
TSA 3-A	Design tools and their integration	FSG
TSA 3-B	Production Preparation and Management Tools	CMT
TSA 3-C	Metals and their processing - cutting, shaping, welding	CMT[1]
TSA 3-D	Non-metallic structural materials and their processing – joining, outfitting	CMT
TSA 3-E	Materials and processes for corrosion and fouling protection	SAF
TSA 3-F	Assembly and outfitting techniques	FSG
TSA 3-G	Maintenance, Repair, Retrofitting and End-of-Life	NMTF

Internal and external Experts

Together with the TSA leaders, CMT identified a set of experts who are supposed to be able to have a complementary overview on TTG 3 related research and its impact. Invitations to join the TTG 3 external

[1] Originally, the leadership to TSA 3-C was assigned to RWTH. Since RWTH asked for termination on their participation in the MESA project by February 28th, 2015, CMT has assumed that responsibility.

expert group, along with questionnaires in which the addressees were invited to identify the TSAs which are most appropriate to them were sent to 153 addresses. In total 34 of the invited contacts notified about their interest by **filling and signing the declaration of interest forms**. An empty sample of subject form is given in Annex 1 and an overview on confirmed external experts can be seen in Table 4.

Table 4: Confirmed external experts and their allocation to TSAs

Name of Organisation, country	Type of Organisation	A	B	C	D	E	F	G
Saare Paat, EE	Shipyard	y	y		y		y	
IMG Ingenieurtechnik und Maschinenbau GmbH, DE	Equipment Supplier		y	y	y		y	
National Technical University of Athens, NTUA,GR	University	y			y			y
Astander Astilleros de Santander, S.A., SP	Shipyard		y	y			y	y
Blatraden AB, SE	Equipment Supplier	y	y		y		y	y
Airex AG, CH	Equipment Supplier				y			
Chalmers Technical University, SE	University	y		y	y	y		y
SHIP DESIGN GROUP Galati, RO	Design Office	y	y	y	y		y	y
SAERTEX GmbH & Co. KG, DE	Equipment Supplier				y		y	
BALance Technology Consulting, DE	Consultant	y	y	y	y	y	y	y
Aluflam A/S, DK	Equipment Supplier		y		y		y	y
Swerea SICOMP AB, SE	Research Organisation	y	y		y		y	y
Asociación de Investigación Metalúrgica del Noroeste (AIMEN), SP	Research Organisation	y	y	y	y	y	y	y
University of Southampton, UK	University					y		
Aalto University, FI	University			y	y			
CETENA Centro per gli Studi di Tecnica Navale, IT	Research Organisation	y	y	y	y	y	y	y
Delft University of Technology (2 experts), NL	University	y	y					y
TNO, NL	Equipment Supplier			y	y	y		
Precitec GmbH & Co. KG, DE	Equipment Supplier	y		y			y	y
Fraunhofer IFAM, DE	Research Organisation					y	y	y
University of Liege, BE	University	y	y				y	y
Instituto Superior Técnico, University of Lisbon, PT	University	y				y		y
UniGe - DITEN, University of Genoa, IT	University			y	y		y	y
Fincantieri SpA, IT	Shipyard	y	y	y	y	y	y	y
Technische Universität Hamburg – Harburg TUHH (2 experts), Hamburg, DE	University	y	y				y	y
Ruhr-Universität Bochum RUB, Bochum, DE	University	y	y					
MME-Group, NL	Equipment Supplier							y
DBI, DK	Equipment Supplier				y			
CESI, IT	Equipment Supplier			y				
Listemann AG, LI	Equipment Supplier			y			y	y
GICAN - Groupement des Industries de Construction et Activités Navales, FR	Research Organisation							
University College London - Department of mechanical Engineering, UK	University	y	y			y	y	y

Identification of relevant projects

CMT identified an overview of ongoing and completed research projects. From about 500 identified projects CMT pre-selected about 250 relevant projects in the area of production and materials. The TTG3 beneficiaries and the external experts were invited to provide information on those relevant projects as well as additional ones. By doing this, projects from other European countries and overseas came to the TTG's attention as well. Information was collected for the subject relevant projects in this document in order to proceed with the detailed analysis. The data collection process will be further explained.

TTG 3 avoided analysing projects that took place in a time before the EU FP6. Likewise, also national projects older than that were disregarded. However, some projects from EU FP5 were also analysed and stated in the report in order to show the continuity and relevance of the studies in the same research field.

Collecting the project data

CMT provided project data entry forms that were generated in MS Excel format. For each of the class of information which is detailed below in Table 5, a spreadsheet was foreseen. The data entry forms were stored on an SVN server which was accessible to all the TTG 3 beneficiaries, so collaborative working on the data sets was possible.

Table 5: Classification of project data

Class of information	Description	Examples
1. Project meta data	Basic information about the project. This kind of information can normally be found in the public domain.	Title, Acronym, Funding authority and Programme, Contract number, Coordinator (organisation and person), budget and funding, Public project website, Public project summary
2. Project partners	Information about parties (coordinator, beneficiaries, members of advisory board etc.) involved in the project	Full name and short name of involved party, country, type of organisation, role in the project (Coordinator etc.)
3. Publications	Information on any kind of publication related to the project. The project data base also allows for uploading corresponding files or web links.	Type of publication, Author(s), Title, Time, Medium, Publishing company, Additional information, Link
4. Foregrounds	Information on expected or existing exploitable project foregrounds.	Title, Description, Type
5. Exploitation of Foregrounds	Information describing the expected or existing impact of the project, i. e. description of the planned or actual exploitation of foregrounds. The project data base also allows for uploading corresponding files or web links.	(Title of) Foreground, Beneficiary, Nature (of exploitation), Exploitation plans, Status (exploitation planned, started, completed), (description of) actual exploitation, Source/status of information, Success stories and "Lessons learned / gaps"

In order to collect the above information, CMT and other TSA leaders provided an extensive amount of effort. CMT checked several databases for the identification of relevant projects; EU funded projects from CORDIS Database including Transport and NMF programmes, the transnational projects from the MARTEC / ERA-NET database, Factories of the Future projects, national projects, databases of several research institutes, etc. Further, the publicly available information on the web was collected. The recent funding programme of EU, H2020 was also investigated. However, no completed and/or ongoing projects were found relevant for this report.

In most cases the public information was not sufficient for the detailed analysis of the projects. Therefore, all partners put additional effort to get further insight by contacting the relevant project coordinators and/or project partners. These contacts were performed via e-mail / telephone correspondences as well as through face to face contacts during several workshops and events. The details of the relevant workshops will be given in the following section.

Organisation of workshops

Basic information like Project meta data, Project partners and Publications can often be retrieved rather easily, e. g. by means of exchanging e-mails with the Coordinator. Contrarily, it is usually much more delicate to obtain information on Foregrounds and their Exploitation. Telephone interviews or, even better, face to face meetings are a much better choice to encourage open discussion, to avoid misunderstandings, but also to jointly identify open gaps in research and thus to lay the cornerstone for the development of a future research strategy. To this end, TTG 3 decided to organise several workshops and to invite the external experts. Where possible, workshops of several TSAs were combined, or synergies with other events (conferences, project meetings) were sought, to raise the attractiveness for potential attendees.

Below Table 6 is a brief list of the workshops organised and/or attended by TTG3 in order seek for further chances to exchange information.

Table 6: Workshops organised or attended by TTG 3

Event Name	Place	Date	WP3 Participants
E-LASS Kick-off + E-LASS & MESA work shop	Borås (SE)	2013-10-08.09	CMT
MESA Project Workshop	Brussels (BE)	2014-03-04...06	CMT, MW, DAMEN, FSG, NMTF
Lightweight structures (Joint E-Lass – MESA Workshop)	Papenburg (DE)	2014-03-26	CMT
Coatings (Joint MESA Workshop)	Papenburg (DE)	2014-03-26	CMT, SAF
E-LÄSS Meeting	Papenburg (DE)	2014-03-27	CMT
TTG 3 Workshop	Hamburg (DE)	cancelled	-
Innovative applications of glass structures in the maritime industry (joint workshop MESA-ADAM4EVE)	Hamburg (DE)	2014-10-02	CMT
German Welding Society (DVS) meeting of working group 'Welding in ship building and marine technology' (joint workshop)	Hamburg (DE)	2014-11-06	CMT, (RWTH)
Friction Stir Welding Workshop (joint workshop MESA-HILDA)	Geesthacht (DE)	2014-11-20	CMT
Adhesive bonding Workshop (workshop jointly organized by MESA and the maritime section of the German National Funding AiF	Hamburg (DE)	2015-01-21	CMT, DAMEN
Additive Manufacturing Seminar IWS	Dresden (DE)	2015-02-25	CMT
Innovative Design Solutions (Joint workshop ADAM4EVE – MESA)	Espoo (FI)	2015-06-04	CMT, DAMEN, FSG, MW

Statistical analyses of projects considered

CMT has identified 491 projects in the areas of maritime and production. After the preliminary studies, 246 of those projects were found relevant and found worthwhile for further information collection. Each TSA Leader evaluated the collected information and further contacted the project coordinators to get more insight on the projects. Some of the projects were found relevant, but not worthwhile to mention in the State

of the Technology Report. Therefore, CMT as well as other TSA Leaders further selected 183 projects for detailed analysis. Some of the projects were analysed by more than one TSA. For example, the outcome of EU 7th Framework project "BESST" is found to be relevant to all TSAs in the area of production. The list of projects that are covered in the analysis are given in Annex 2. For reference only, the list of all relevant projects (whether they were analysed on the report or not) are also given in Annex 3.

More than half of the analysed projects were/are funded by EU within the 5th, 6th and 7th Framework programmes. The rest of the projects were/are funded by national authorities. Within the analysed projects (3) of them were transnational projects that were funded by more than one country. The majority of the national projects were from Germany with a total number of 50 projects. National projects from Denmark (3), Finland (2), Greece (1), Netherlands (3), Norway (1), Spain (1), Sweden (3), UK (2), USA (11) were also analysed within this report. An overview of the funding of analysed projects is given in Table 7.

Limited information was found on project related publications and foregrounds. Table 8 shows the availability of information for the publications and foregrounds. The values in the table are based on a ratio between the total number of analysed projects and the number of projects where information was found about publications and foregrounds. For example, in the FP7 programme 55 projects were analysed and project related publications were found for 35 projects which is shown as 64% availability of information on the project related publications. Based on the availability of information, 562 publications and 324 foregrounds were identified for the analysed projects. The number of publications and foregrounds are given Table 9.

Table 7: Funding of projects

Funding Scheme	Number of Analysed Projects
EU FP7	56
EU FP6	23
EU FP5	23
Other	81
TOTAL	183

Table 8: Availability of information for Publications and foregrounds

Funding Scheme	Publications (Availability of Information)	Foregrounds (Availability of Information)
EU FP7	63%	43%
EU FP6	54%	48%
EU FP5	17%	22%
Other	50%	11%
Average	46%	31%

Table 9: Number of publications and foregrounds

Funding Scheme	Number of Publications (where information was available)		Number of Foregrounds (where information was available)	
	Total	Per Project	Total	Per Project
EU FP7	276	7,9	194	8,1
EU FP6	139	10,7	85	7,7
EU FP5	34	8,5	10	2,0
Other	112	2,8	34	3,8
Total / Average	561	7,5	323	5,4

Some of the general findings, observations and notes from the study of collecting project data are listed as follows:

- It should be considered that, most of the analysed projects from FP7 are still ongoing. With this consideration in hand, it could be said that the availability of information, number of publications and foregrounds are increasing for the EU funded projects from FP5 to FP7.
- More than half of the analysed projects are the ones funded by EU. It is relatively harder to access the information, publications and foregrounds for the national and co-funded projects. The information collected for these projects are mostly based on the individual efforts and knowledge of the TTG3 partners.
- Production related research is highly influenced from the commercial status of the industry. Relatively longer projects which took place over the recent 3-5 years are highly affected and interrupted from the economic crisis which results in the lack of application of the project outcome.

SotA Analysis per Technology Sub-Areas

The following sub sections have been prepared by the corresponding TSA leaders. CMT edited and complemented the material. Each TSA leader has provided details about the communication they have developed with the "External Experts" in their TSA. The TSAs have also provided information on the workshops to collect information on the different technologies available in the TSAs field of work.

To understand the State of the Art in a field of work, TTG 3 followed the approach to differentiate the existing State of the Art in the Industry and the State of the Art in the research and development phase of the field of work. By doing so, the existing technological gaps in the industry and the required areas of developments can be possibly identified. With this idea in hand, all the TSAs provided the existing technologies in the industry under the "Industrial Practice" section, while the technologies/concepts that have been developed and/or in development in the different funded research projects have been documented under "Research and Development" section. An overview on the list of research projects analysed has been provided at the start of each of the SotA analysis of a TSA. Additionally, a detailed description on the concepts researched and developed in the listed research projects have been provided in the "Research and Development" section of the TSA.

For development of any new ideas, it is important for the idea to adhere to the rules and regulations existing in its field of work. These rules and regulations have been explained in the "Rules and Regulations" section of the TSAs SotA analysis. These regulations were on one hand obstacles, but also drivers for developing new technologies and concepts to overcome those obstacles.

Each TSA have pre-selected potential show cases and mentioned them at the end of their report. The subject show cases will further be elaborated in the Deliverable D3.4.
In order to systematically analyse the projects, research domains and sub topics were identified for each technology sub-area. The overview of the technical topics covered in the SotA analysis per TSA is given in below Table 10.

In the detailed analyses, the state of the technology in maritime production is documented. The study is based on the completed and ongoing projects from Europe and other countries. The focus was not on only identifying the projects, but also their outcome as applications. Collected information is based on publicly available information which was limited and not providing enough insight for the purpose. Therefore, extensive amount of effort was spent by TTG3 in order to collect information on the foregrounds and application cases by contacting the project coordinators as well as the end users of the project. It should be noted that, the detailed analyses in this report are open for further improvement considering the ongoing / upcoming projects as well as the completed ones which could not be analysed in detail due to lack of information and/or contact points.

Table 10: Research Domains and Sub-topics per TSA

TSA 3-A Design Tools and their integration
• Design Integration • Life Cycle Thinking • Energy Efficiency, reduction of emissions • Damage stability • Seakeeping , dynamic intact stability • Safety issues • Human Element • Risk Based Design • Hydrodynamics • Generation of surfaces or grids • Structures • Underwater noise • Ship Operation • Simulation of production, production in general
TSA 3-B Production Preparation and Management Tools

• Simulation
  ○ Simulation in Logistics
  ○ Simulation in Retrofit and Repair
  ○ Simulation in Outfitting
  ○ Simulation as a service
  ○ Supporting tools and integration
  ○ (Simulation)
• Virtual Reality / Augmented Reality
  ○ VR/AR for Training and Method Planning
  ○ VR/AR for Digital Engineering data
• Production Quality Assurance
  ○ Production Quality Assurance (PQA)
  ○ for Welding
  ○ PQA for geometric accuracy
  ○ PQA for Weight Management
  ○ TQM (Total Quality Management)
• Other conceptual studies and product preparation involving tools
  ○ Prototype planning
  ○ Concept studies

TSA 3-C Metals and their processing - cutting, shaping, welding

• Materials and design
  ○ High tensile steel
  ○ Lightweight structures
  ○ Construction and design
• Metal processing
  ○ Joining technology; Laser technology, Adhesive bonding & others

TSA 3-C Metals and their processing - cutting, shaping, welding(continued)
○ Edge preparation ○ Automation / mechanisation ○ Quality Management ○ Maintenance, repair, retrofit • Life Cycle oriented approaches ○ Life cycle performance assessment ○ Life cycle oriented processes / services • Product specific R&D ○ Offshore Energy platforms
TSA 3-D Non-metallic structural materials and their processing – joining, outfitting
• Weight and application optimisation • Strength and Fatigue • Production processes / joining • Overcoming of the SOLAS requirements and other regulations • Safety issues / fire • Environment • Economic benefits / LCPA • Offshore Platforms
TSA 3-E Materials and processes for corrosion and fouling protection
• Coatings Processes and Inspection, ○ Coating Process ○ Coating Inspection ○ Surface Preparation and coating removal ○ Coating Application ○ Best coating Practice process • Anticorrosive Coating Material, ○ Test methods investigation ○ Alternative Materials to Steel • Antifouling Coating Material, ○ Test methods and benchmark of advanced paint solution ○ Evaluation of in-field performance of foul release coating ○ Evaluation of friction resistance of current fouling prevention coatings ○ Ways to reduce frictional resistance • Fouling Prevention (not coating related), • Design for Coatings, • Worker Exposure, Environmental releases
TSA 3-F Assembly and outfitting techniques
• Joining ○ Conventional Welding ○ Laser Welding ○ Electro gas Welding ○ Friction stir welding

TSA 3-F Assembly and outfitting techniques (continued)
○ Welding of lightweight or composite materials ○ Adhesive bonding of ship structures ○ Mechanical joining ○ Pipe outfitting ○ Knowledge transfer • Attachments ○ Pipe outfitting ○ Dimensioning of components and support structures for cargo securing ○ Semi-automated stud welding/marking • Planning and organisation ○ Simulation aided process planning ○ Retrofitting of vessels • Materials ○ Structural lightweight using metallic materials ○ Non-metallic or composite materials and their benefits • Design ○ Weight optimisation using conventional materials and designs ○ Modular ship design ○ Advanced design studies
TSA 3-G Maintenance, Repair, Retrofitting and End-of-Life
• Energy saving technologies and devices • Decision support for & inspection planning • Inspection and monitoring of ship's hull structure • Inspection and monitoring of ship's machinery • Repair and retrofitting • Life cycle simulation • Business model for through life asset management

3.2 TSA 3-A Design Tools and their Integration

Introduction

This part of the document outlines the State of The Art on Design Tools and their Integration in shipbuilding as per current practice in European shipyards and suppliers of equipment and services. A first principle overview has been created and presented during the MESA-workshop in Brussels on March 5th, 2014.

- MESA partners who contributed to TSA 3-A are FSG, CMT and also with comments from others.
- A total of 17 external experts from industry, research and academia have submitted Expressions of Interest and partly provided information on projects.
- Relevant project information was collected in Excel as input for internal data base of EU and German National R&D Projects. A total of 37 EU projects from FP5 to FP7 partly finished and ongoing as well as 7 German and 1 Norwegian national R&D projects were analysed.

The starting point is the following list of research projects (Table 11), which have been analysed in depth.

Table 11: TSA3-A Design Tools and their Integration –analysed projects

ADOPT	EXTREME SEAS	MARSTRUCT	SEAHORSE
AQUO	ETOPS	MOBISHIP	SESIS D
BESST	FAROS	NEREUS	ShipMesh
CASCADE	FIRE EXIT (SAFEGUARD)	OPTIPOD	SHOPERA
CRASHCOASTER	GOALDS	PODSinSERVICE	SMARTYards
CRESCENDO	HANDLING WAVE	ROROPROB	SONIC
CyClaDes	HARDER	S@S	TARGETS
DCOPT	HULLMON+	SAFECRAFTS	TULCS
DISCO	IMPROVE	SAFETY FIRST	3D-MARITIM
EMSA 1 – EMSA 3	InterSHIP	SAFEDOR	
EXCITING	JOULES	Advanced environmental design optimalisation & control	
GENESIM	Life Cycle Costing in Schiffbau und Schifffahrt	Schiffsfenster	

The analysis cover several topics for above projects which will be briefly explained in the following "Research and Development" part. Detailed analysis and project outcomes are given in Table 12 for the below **main focus topics**:

- **Design Tool Integration** including link to production preparation
- Life cycle thinking with methods & tools for **Life Cycle Impact Assessment** (cost and environment)
- **Risk based design**
- **Simulation of production** with connections to design data

Industrial practice

Review

Design Tool Integration

It has been shown that leading shipyards carry out their own designs with a huge variety of design tools. The integration of such design tools in the design process (including planning and production) is not an easy task and different handicaps must be tackled today.

Two main philosophies can be observed: an "all in one provider" for a number of tools integrated in to one big package (e. g. AVEVA, CATIA, SENER Marine) or the use of specialized tools (Best in Class) with higher integration efforts to be covered by shipyard IT-experts. Both philosophies have pro and cons and each shipyard has to decide on their optimum approach. In contrast smaller shipyards often outsource the design and/or work with specific design offices.

The scope of integration is a bigger challenge and not realized in many cases because many independent challenges from hydrodynamic optimization, stability (intact and damage), FEM (strength and vibration), hull fairing etc. in early design stage and requirements for subsequent detailed design and planning purposes as supported by ERP-systems do not actually always allow for a fully integrated design process and data handling. However, first steps have been taken by the industry to tackle these challenges.

Production Planning and the simulation of production processes are well under way in the European maritime industry. However, a serious gap can be identified between those data needed for simulation and those provided by the various design tools. The industry is currently not able to provide a proper flow of information without such gaps in the processes.

Life Cycle Thinking

Life cycle thinking can be approached from three different perspectives:

- Financial
- Environmental
- Customer Care incl. data handling during operation

For decision making purposes CAPEX (capital expenditure) as well as OPEX (operational expenditure) must be considered during the design phase of a new vessel. Increasing attention on operating costs has led the builders of complex ship types to assess the operating costs in early design stage (beside typical challenge of offering best price in just designing and building the vessel).

From an environmental point of view, reduction of energy and related GHG-emissions is on the top of the agenda. Other emissions like SOx, NOx are under discussion since many years through the introduction of Emission Controlled Areas. The release of particular matter is getting in focus in ports and with respect to reduced albedo in ice /snow covered areas thus increasing the radiative forcing. For an assessment of the environmental impact, existing methodologies need to be adapted for needs of the maritime industry.

Simulation tools for life cycle performance are partly used in large yards and with a focus on structural performance. Systematic life cycle performance assessment is carried out only by leading yards for individual components.

Design for Life Cycle

Life Cycle PDM in cooperation with other stake holders is technically feasible, but still not used due to insufficient business models. On the other hand the complexity as already addressed in the integration for design tools will even increase if the whole design for life cycle is considered.

Conclusion

Projects like InterSHIP, BESST and others have led to significant improvements in larger industry, however smaller companies are lagging behind. There has been encouragement in the industry to integrate the "Life Cylce Analysis in 7 days" along with the "Design in 7 days", so that a complete analytical overview of the ship would be obtained even during the design phase of the ship. However, integration of design tools based on a life cycle thinking approach is not available yet. Challenges arising from the introduction of new maritime products and small series (complex prototypes) are to be overcome by the industry.

Rules and regulations

Review

Regulatory demand is an increasing challenge for the maritime industry. Although safety issues and in particular damage stability for passenger ships and Ro-Ro passenger ships has been in focus for many years, a further update of the SOLAS convention is planned in order to embed latest knowledge as gained from several research projects in the new safety regime. This task is supported by several research studies funded by EMSA and actually ongoing with the EMSA 3 study. Dynamic intact stability is currently not addressed in IMO instruments however incidents with container ships and passenger ships prone to severe high roll angles show that a compelling need for such instruments exists.

An evacuation analysis will be also mandatory for passenger vessel in the near future.

The last years were characterized by ongoing discussion and decisions within IMO regarding the environmental impact of ships like GHG-emissions affecting climate change, other emissions like SOx, NOx and PM damaging the environment, ballast water requirements with its positive impact on biodiversity or underwater noise as examples. It is expected that the legislative pressure will sustain or even increase with many environmental problems not yet solved. One particular aspect is the possible trade-off between the requirements of the Energy Efficiency Design Index to reduce the installed engine power against safety related maneuvering requirements in harsh weather condition. This is a good example that a more integrated view on design aspects is necessary in the future rather than to tackle one by one issue by a new regulation at a time.

Conclusion

Regulatory development will have an increasing impact on the design and construction of ships and a more holistic approach should be considered in the future. Goal based design standards supported by risk analysis rather than prescriptive rules are certainly an option in this respect.

Research and development

Review

The research projects, which have been reviewed (Table 11) cover a huge diversity in topics. These topics are relevant for the design of ships with gradual impact on life cycle stages like ship´s basic design, detailed design, production and operation. Brief overview for each topic will be given in the following paragraphs. Detailed analysis on the special focus topics mentioned in the introduction will be given in Table 12 with the achievements / results of the analysed projects. Projects and their relevance have been clustered as given in Figure 5 in order to identify the relevant technology areas which have been addressed.

A particular number of projects already have the integration of the whole design development including production chain in focus. Even e.g. Project Data Management (PDM), Enterprise Resource Management (ERP) systems, “CAD to production” and other relevant topics for design integration have been partly addressed. However, the specific requirements from each shipyard are quite different and thus, only principle methodologies have been investigated so far. As mentioned before, the business case for such integrated solutions does not exist today but is expected to become more probable in the future.

Some of the projects proposed ideas for integration of different design study tools, so that a continuous flow of information is available with the designers even when there are design changes implemented due to the requirements from different design departments within the design stage (e.g.: Steel Weight Calculation, Work Breakdown calculation, FEM testing of the design, etc.).

Projects like BESST and JOULES have fostered life cycle thinking in large industry and developed assessment methods and tools. In the currently running EU-funded project SMARTYards, there is a list of proposed ideas in research for the integration of design phase in the early planning stage after an order has been placed.

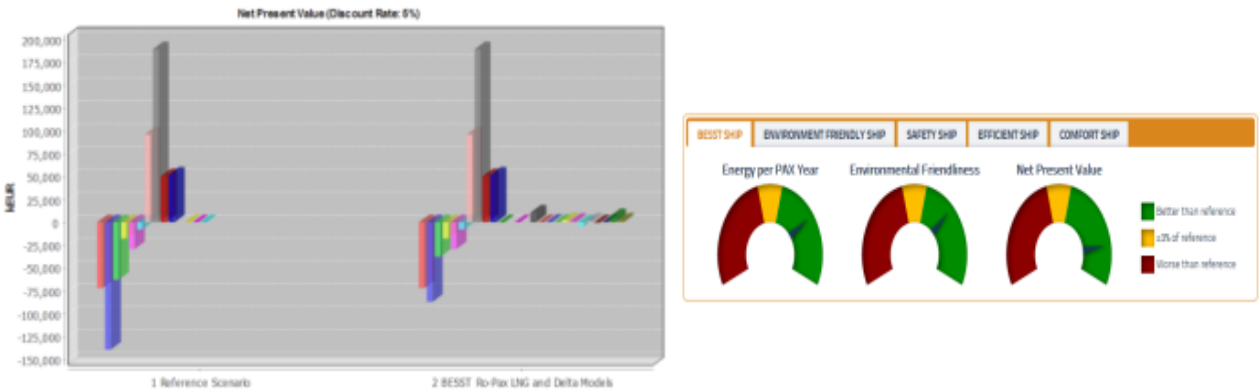


Figure 4: Life Cycle Analysis Tool (Top: NPV results; Bottom: Ship Comparison results) [BESST]

TARGETS and JOULES develop integrated energy models and in order to reduce the environmental impact of ships with respect to the energy demand, climate change and other harmful emissions. Ongoing life cycle impact assessment is good practice in ongoing EU projects. THROUGHLIFE has identified problems and business models to improve cooperation of life cycle stake holders.

Scope and Boundaries of the Review/Analysis

Detailed analysis on the main focus topics mentioned in the introduction, namely "Life Cycle Thinking", Design Integration", Risk Based Design" and "Simulation of Production" will be given in **Table 12** with the outcome of the analysed projects. Detailed analyses and further topics related to design tools for energy efficiency (e.g. hydrodynamics) have been covered in other MESA Deliverables; D1.1 (**TTG1-Energy Efficiency**) and design for safety in D2.1 (**TTG2-Safety**).

In the following paragraphs, the brief analyses are given on the sub-topics which **are not in the main focus** of TTG3 – Production TSA 3-A Design Tools and their Integration:

- Energy Efficiency, reduction of emissions
- Damage stability
- Seakeeping, dynamic intact stability,
- Safety issues
- Human element
- Hydrodynamics
- Generation of surfaces or grids
- Structures
- Underwater noise

Energy Efficiency, reduction of emissions

Reduction of emission of greenhouse gases (GHG) and other emissions damaging the environment are in focus. Possible strategies are hydrodynamic optimisation, increased energy efficiency or installation of abatement technologies. Several studies were carried out in projects like BESST, TARGET, JOULES, Advanced environmental design optimalisation & control.

Damage stability

Damage stability for Passenger Ships incl. Ro-Pax has been on the agenda for many years due to issues requiring further action in regulatory framework. Since 2007, an ongoing sequence of EMSA research studies regarding the required safety level on Passenger Ships (Incl. Ro-Pax) is striving to promote a new safety level

for IMO damage stability instruments. Analysed projects in this topic are GOALDS, CRASHCOASTER, ROROPROB, NEREUS, HARDER, SAFEDOR, EMSA 1 – EMSA 3.

Seakeeping , dynamic intact stability

This set of projects is addressing the behaviour of ships in seaways incl. development of simulation tools. The objectives are primarily in the enhancement of safety. ADOPT, Handling Wave, EXTREME SEAS, NEREUS are some of the projects analysed in this field.

Safety issues

A number of different safety issues have been addressed in the analysed research projects. The range is from evacuation analysis incl. safe abandoning from ships, safe maneuvering in adverse weather conditions, and safe operation of PODs as well as resilient design of safety relevant systems. This also includes the human element, which is closely related to the safe operation of ships. Another research in this respect is the risk based design, which takes into account an integrated approach to include various safety aspects. In Shopera project a proposal for improved rules for save manoeuvring in bad weather conditions was developed. In the area of evacuation of Passenger Ships; software tools to tackle challenges of high passenger density on board cruise ships or Ro-Pax Ferries were developed in projects like FIRE EXIT, SAFECRAFT, SAFETY FIRST. After the HULLMON+ project, it was possible to monitor the integrity of the hull at any time. Reliable operation of PODs in all weather conditions were investigated in PODSinService project. SEAHORSE project focused on designing resilient systems with transfer of results from aeronautics.

Human Element

In the CyClaDes, CASCADE, FAROS, SEAHORSE projects investigated the improvement and optimisation of bridge design.

Hydrodynamics

Guidelines for the design of pod-driven ships were created and developed in OPTIPOD and ShipMesh projects.

Generation of surfaces or grids

Generation of grids in early design stage for hydrodynamic purposes or CAD (Computer Aided Design) to FEM (Finite Element Method) tools were developed in ShipMesh and EXCITING.

Structures

MARSTRUCT Network was established in EU wide to improve comfort, effectiveness, safety, reliability and environmental performance of ship structures. Innovative structures for passenger ships were developed in DISCO project.

Underwater noise

Several projects were identified dealing with underwater noise as a research topic to address the increased noise impact on mammals from shipping. Aquo and SONIC projects evaluated better alternatives that would meet the IMO requirements in underwater noise measurement and control.

Table 12: TSA3-A Projects per research domain and (sub) topic

Research topics	Analysis	Projects
Life Cycle Thinking	Life Cycle Performance Assessment (LCPA) tool was developed with key performance indicators representing the economic, environmental and safety impact as well as the effects towards passenger welfare.	BESST
	The concept for the Life Cycle Performance Assessment was extended to include the production phase, namely the production of fuels but also taking into account materials and yard production when required. This was necessary to cover the foreseeable future demand for alternative fuels, which are expected to be inherently clean but have a significantly higher energy demand for production. A screening LCA methodology in early ship design has been developed	JOULES
	Approach and methodologies of life cycle assessment were further developed and integrated into the through-life asset management of vessels. Business cases for life cycle thinking have been investigated and shown the potential for further application in the maritime industry.	THROUGHLIFE
	LCPA tool named Voyage Controller was developed for identifying worthy retrofitting candidates and to establish appropriate green technologies that can be suitably fitted at minimum cost and lead time, while considering the condition of the particular ship, her service profile, her remaining life cycle and the governing and expected regulations.	RETROFIT
	Basic concept and methodology development of LCPA as well as relevant software tool integrations were carried out in the earlier projects.	Life Cycle Costing (LCC), 3D-Maritim
Design Integration	An optimisation methodology for ship structural design using CAD (Computer Aided Design) / FEM (Finite Element Analysis) integration was developed	BESST
	Tools for simulation of energy grids to assess energy consumption and emissions for certain ship design is being developed	JOULES
	A structured, modular and flexible software platform for the early design of ships was developed in a German national project. Various simulation and design tools were integrated into a user friendly GUI (graphical user interface).	SESIS
	3D-Maritim created a networking platform for the relevant and concurrent activities of 3D ship model	3D-Maritim
	Multi criteria (including production) design optimisation method was developed in order to select the optimum design within the evaluated alternatives.	IMPROVE
	Integrated project with various sub projects, all of them aiming at improving shipyard processes.	InterSHIP

Research topics	Analysis	Projects
Risk Based Design	A new methodology was developed integrating probabilistic / risk-based approaches in the design and approval processes for ships and ship systems. Safety is included as an additional quantified design objective – along traditional performance requirements like speed, capacity, endurance etc. And risk is used as measure to evaluate the effectiveness of design changes with respect to safety. Risk-based design approach was applied in evaluation and optimisation of wide range of material and structure mixes. Human error, causing 90% of maritime accidents, were integrated into risk-based ship design.	SAFEDOR DE-LIGHT Transport FAROS
Simulation of production, production in general	Relevant to modelling and simulating the production systems, a common data structure was developed including the product related parameters that needs to be taken from the design. Early design stage product data generation methodology is developed together with geometry related production constraints.	GeneSim SMARTYards

Timeline of projects, grouped in the analysed topics is given in below Figure 5.

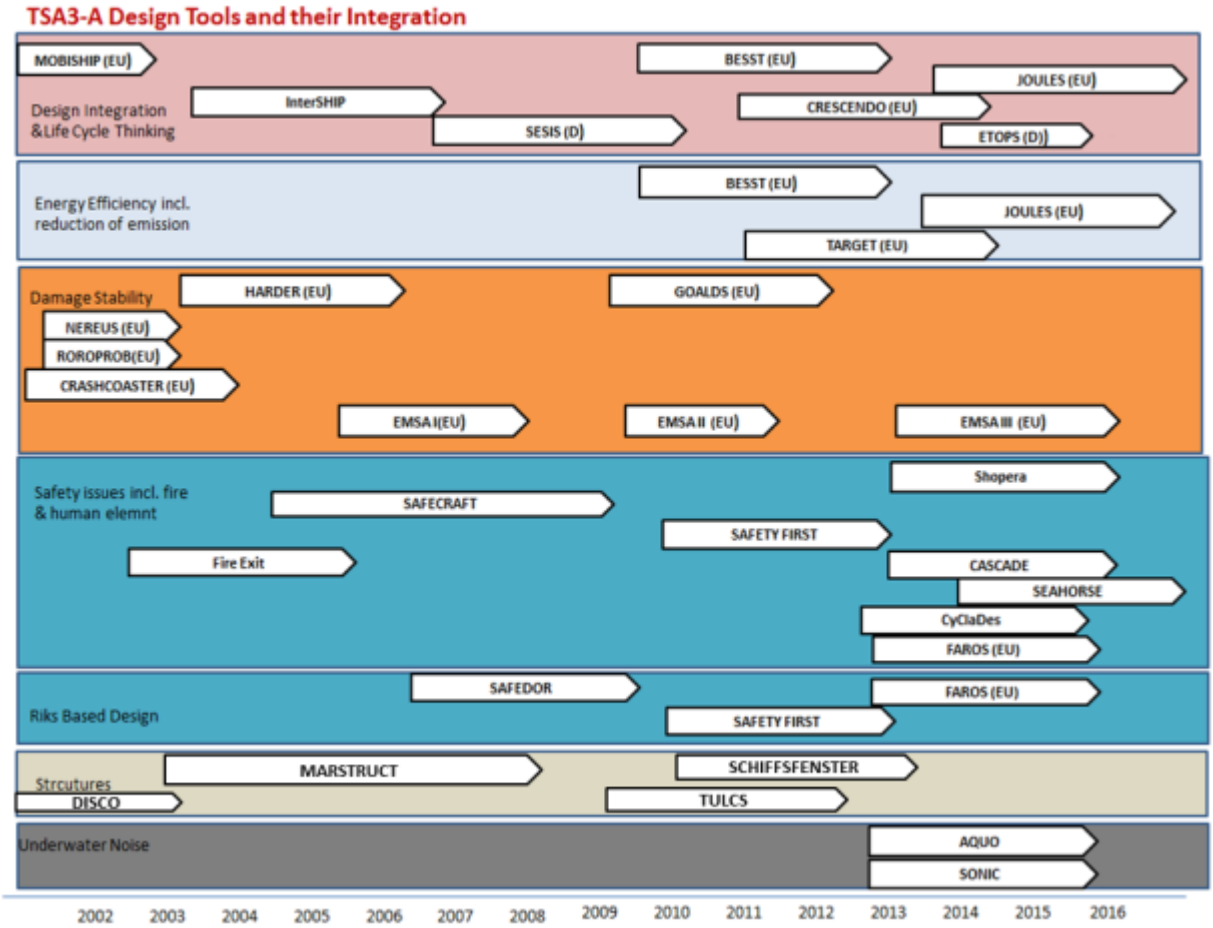


Figure 5: TSA 3A Design Tools and Their Integration - Project timeline

Conclusions

The review of the state of the art of industry practice, the development of rules and regulation and R&D-projects specifically related to the Integration of Design Tools has identified various technology gaps which will be further discussed in the R&D Road Map. The analysis also brings to light that adaptation of design, system & safety methodologies from other industries (e.g. aeronautics) should be further investigated. In this respect, a potential for further collaboration should be explored.

Some of the major technology gaps that are identified are listed below:

- Life Cycle Performance Assessment

  Integration in the design process and optimization strategies to balance different requirements are needed. Availability of reliable operational data and their integration in design is a challenge due to IPR issues and for new operational scenarios (ships under extreme conditions, new Blue Growth markets). Reliable prediction of future cost drivers (e.g. fuel cost) as well as upcoming legislation are challenges for trustworthy LCPA.

- Design for Life Cycle Processes

  New production processes and materials require new design and simulation tools. While ICT solutions for life cycle data management are largely available, new business models, measures for IPR protection and ICT security as well as new approaches for life cycle asset management are required to implement design for life cycle processes to its full potential. Approaches in other industries (such as aeronautics) could serve as blue print for maritime life cycle chains. A better knowledge on product behavior under real life conditions (long term, combined loads) are essential in new markets and applications.

Suggested show case

Life Cycle Thinking

Life Cycle Thinking becomes an increasingly important issue in industry due to various reasons. In first place, operating costs determine a big part in the financing of a ship and thus need to be minimised as far as practicable. On the other hand, from an environmental point of view, the use of resources during production of the ship and of the production for the fuels needed during operation is becoming key interest as soon as alternative fuels (other than conventional liquid fossil fuels) are used. In third place, data integration from early design to dismantling of the ship is expected to save time and costs in the future.

Life Cycle Performance Assessment:

Combining economic and ecologic issues in one assessment tool

In the BESS project, an innovative Life Cycle Approach and Assessment Tool was developed, wherein specific Key Performance Indicators (KPIs) were incorporated to represent the performance level of a ship over its life cycle. The technologies developed in sub-projects were analysed on its level of influence in cost, environment, safety and customer satisfaction, on being built in a ship. Figure 6 shows the analysis result of the influence of a technology on the NPV of a Ship.

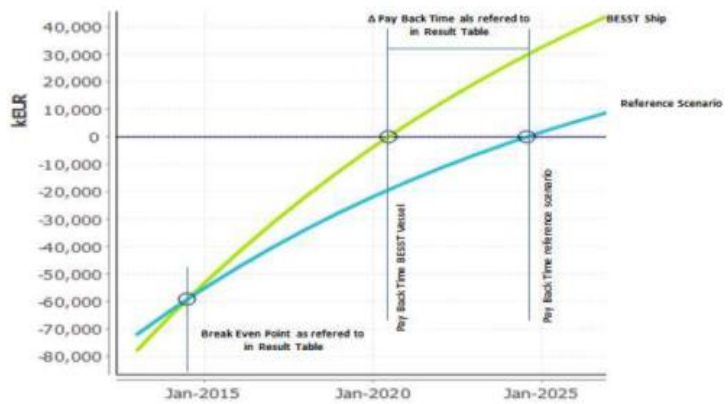


Figure 6: NPV graphs from the LCPA tool (ships with and w/o the technology) [BESST]

The impact of the technologies developed in the project were analysed with respect to three types of reference ships (Large Cruise Ship, Medium Cruise Ship and Ferry Ship). Figure 7 shows the impact on energy consumption, environment influence and NPV of a Medium Cruise Ship on implementation of the technologies developed in the project. These basic results are available in the public project website.

Figure 7: Representation of the results in reference ship [BESST]

Following the BESST project, the JOULES project has extended the concept for the Life Cycle Performance Assessment including the production phase, namely the production of fuels but also taking into account materials and yard production when required. This was necessary to cover the foreseeable future demand for alternative fuels, which are expected to be inherently clean but have a significantly higher energy demand for production. A screening LCA methodology in early ship design has been developed and is currently under scrutinising in the JOULES project.

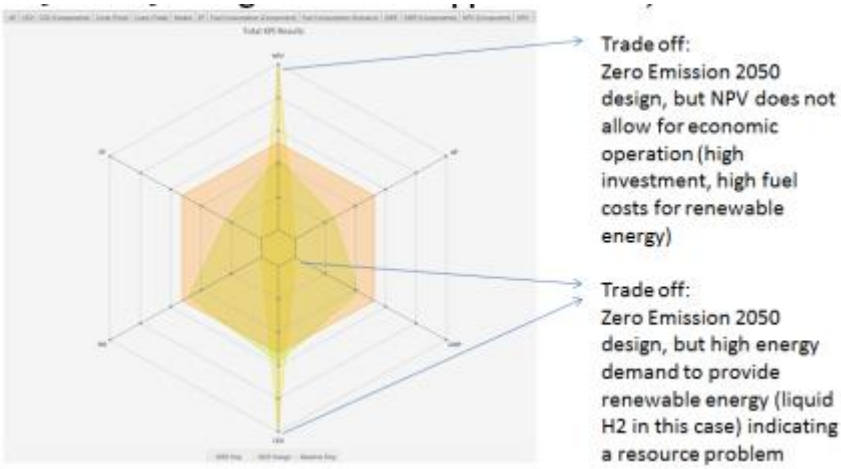


Figure 8: KPI-results comparison - Ro-Pax reference vessel and innovative zero emission designs

Within the THROUGH-LIFE project, business cases for life cycle thinking have been investigated and shown the potential for further application in the maritime industry.

Data Integration

A second big issue in Life Cycle Thinking is the data integration from early design to dismantling. However, the progress which has been made starting with the MOBISHIP project followed by InterShip will be presented. As a result, data integration became more and more a yard specific issue and examples will be given, how the integration proceeded.

3.3 TSA 3-B Production Preparation and Management Tools

Introduction

- MESA TTG partners who contributed to TSA 3-B are FSG, CMT and MW, with comments from others.
- A total of 16 external experts from industry, research and academia have submitted Expressions of Interest and partly provided information on projects.
- Relevant project information was collected in Excel as input for internal data base of EU and German National R&D Projects.

Table 13: TSA3-B Production Preparation and Management Tools - analysed projects

3-D-Schwerlast-aufnehmer	Elasta	INTERSHIP	SIMGO
BESST	GENESIM	POWER-VR	Simulation Toolset
CREATE3S	Gewichtsmanagement	RETROFIT	SMARTYards
Curved Panel II	GRIP	RROSPER	Use-VR
DOCKLASER	HEPP	SESIS	
ECO-REFITEC	IMPROVE	SIMBA	

Industrial practice

Review

Production organization contributes as one of the significant factors influencing the competitiveness of the production processes by having an effect on production cost and lead time. With nearly 60-80% of the ships value (including material cost) are contributed by subcontractors and suppliers, it is imperative in a highly integrated and work sharing process chain of European shipbuilding to study about the possible integration strategies for the process chains. Shipyards play a very important role as integrators and organizers of the individual actors in this chain. Although there are various areas of research still possible in the integration of European Shipbuilding, there have been some significant developments achieved within the European shipyards. The developments achieved in the area of Production Preparation and Management can be categorised basically into four areas of interest. They are,

1. Simulation
2. Virtual Reality / Augmented Reality
3. Production Quality Assurance
4. Other conceptual studies involving tools

Simulation

Production planning and control within industries across various sectors have become of significant importance. The decision making process is a combination of various complex situations existing at any moment in an industry. The dynamic characteristics contributing to the culmination of complex situations can be better handled with the development of technologies, which allow simulation studies to be executed in order to arrive at effective solutions in an easier process. With these advantages in mind, Center of Maritime Technologies (CMT), Flensburger Schiffbau GmbH & Co. KG (FSG) and other partners founded the Simulation Cooperation in the Maritime Industries (SimCoMar) which is dedicated to continuously developing the simulation toolset STS (Simulation Toolkit for Shipbuilders). STS helps planners in the shipyards to analyse different process sequences and resource allocations and to analyse their impact on lead time before a planning decision is made. Simulation is also used to control and re-schedule the work in the event of unforeseen delays. In effect, the shipyards and ship owners' risk of extra costs due to bad planning is reduced. [FSG]

The toolsets available within the STS were used to perform Production line simulation studies with the application of optimisation algorithms. These simulation studies were utilised to analyse the possible layouts of the production line with considerations given to lead time of each machinery in the production line, the area available within the production line and reducing the effect of bottlenecks in the production line. With the aid of different simulation model representing the different production line configuration the optimal production line layout was designed and later utilised. The simulation models were also used to analyse the lead time of the part fabrication unit. [FSG]

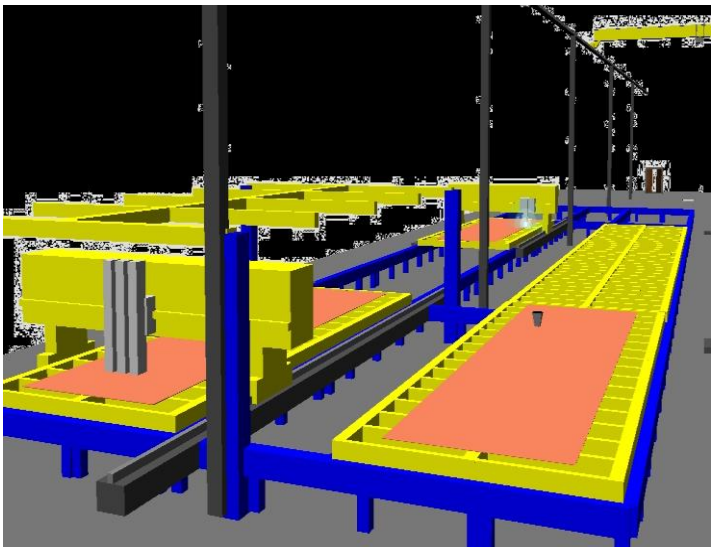


Figure 9: Part Fabrication production analysis in a simulation model [FSG]

Virtual Reality /Augmented Reality

Equipment suppliers, like MAN, have now started to develop "animated 3D pdf" to aid their customers in the handling and maintenance of their productions. The animated 3D pdf (Figure 10) provides guidance to the customers by giving step-by-step instructions for assembly / disassembly / repair of components, while highlighting and providing the manoeuvrability of the object in concern in the product [MAN].

Figure 10: Animated 3D pdf [MAN]

Another application is providing a digital working document for the worker, which is recently developed in a German national project PROSPER. Unlike in an overloaded conventional workshop drawing, the worker is lead step by step through the task and supported with only the necessary information. The worker remains largely free to choose the order of assembly. Position and orientation of the selected work piece are displayed via augmented reality on a tablet.

Figure 11: Digital Information for the Worker

Production Quality Assurance

Design of Experiments is one of the methodologies that have been significantly followed by the shipyards in the European Shipbuilding society to design, plan, operate, execute and maintain the required quality levels for its products. Statistical Quality control has been widely utilised to obtain an overview on the level of quality competence of their products. With the emergence of new and highly sophisticated technologies, such as laser scanners, the on floor deductions of quality levels have been able to be obtained at a faster rate.

Other conceptual studies and product preparation involving tools

Apart from the above mentioned classifications wherein the production processes were analysed and optimised, there are also other tools and concepts that are also significant in developing a best possible production technology. One such tool could be mentioned as the Prototype planning tool, wherein nowadays large shipyards apply customized in-house software solutions for **planning of outfitting components** and their installation. DigiMaus is a tool that is utilised to plan the assembly of outfitting for a complete ship. By doing so, an overview on the assembly planning for the outfitting tools could be obtained. These plans would then be utilised in the overall production plan of the ship. [FSG]

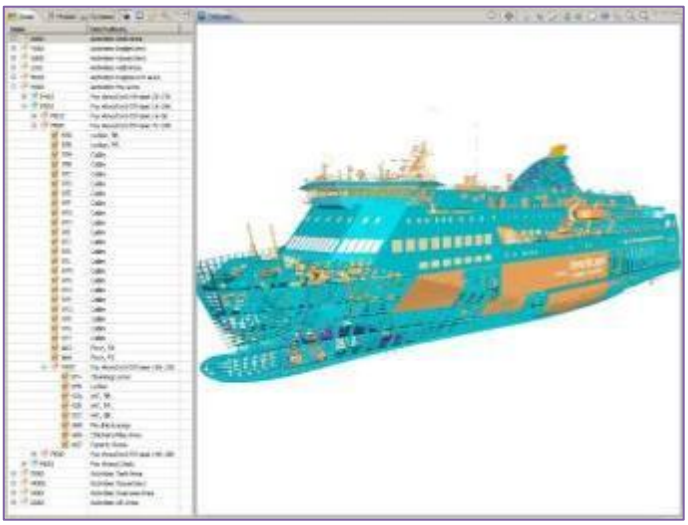


Figure 12: DigiMaus Tool [FSG]

Rules and regulations

Review

Shipyards or shipyard equipment suppliers who intend to apply or to offer novel production equipment are usually asked by classification societies to give evidence that stable processes can be ensured and critical quality characteristics can constantly be achieved, otherwise no approval would be given for the equipment. This fact has of course been one of the drivers for the development and application of statistical process models.

Research and development

Review

Similar to the categorisation of the State of the Art existing in the industry explained above, the State of the art of the Research Development achieved till date in the field of Production preparation and Management tools can be categorised in the same way. They are Simulation, Virtual Reality / Augmented Reality, Production Quality Assurance and other conceptual studies and product preparation involving tools.

Table 14 provides an overview on the various research development obtained under the categories. The research have been at times developed and further utilised for improvements in more than one research project. The table is followed by Figure 13 which provides an overview of the timeline of the analysed projects.

Table 14: TSA3-B–Projects per research domain and (sub) topic

Research topics	Analysis	Projects
Simulation		
Simulation in Logistics	In the BESST project, Simulation model and studies were carried out with the Simulation Toolkit for Shipbuilding (STS) to develop a tool for **optimising ship logistics**. Simulation tools were developed to represent the rooms and areas around the ships as volumes). To obtain the best possible routes between two volumes generated using the above mentioned concept, another transport route estimation simulation tool was developed. In projects RETROFIT and GRIP, the logistics of goods involved in a retrofitting process of equipment in a shipyard has been analysed to study the various retrofitting scenarios. In SMARTYards (running project) a concept for the complete logistics planning and material tracing inside a Small and Medium Sized shipyard is under development.	BESST, SIMGO ECO-REFITEC RETROFIT, GRIP, ECO-REFITEC, IMPROVE, InterSHIP SMARTYards
Simulation in Retrofit and Repair	In projects like RETROFIT and GRIP, simulation models representing shipyard facilities were developed for analysing the best **retrofitting solution** in the shipyard and to achieve more reliable planning results at lower planning efforts. The aim is to analyse the various lead time possibility based on different scenario studies. The various processes, resources, schedule and constraints were taken into consideration during the analysis of the retrofitting simulation study. Simulation studies are in progress.	GRIP, RETROFIT, ECO-REFITEC, PROSPER
Simulation in Outfitting	The production simulation proved itself as a good evaluation tool in production planning. For the support of the production planning the simulation was used only within the area of the steel production. No standardised simulation tools were available to simulate the activities performed during outfitting assembly. In the project, simulation toolset for the ship outfitting was developed, which exhibits the advantages of modularity and shipbuilding-specific standardisation by unifying the concepts of resource planning, transportation planning, process planning etc. The simulation models provided the capabilities in production planning of shipyards ensuring the expenditure minimization in the modelling phase as well as the high adaptation ability of the simulation models to the shipyard-specific production environments.	SIMBA
Simulation as a service	In SMARTYards (running project) the concept of providing the shipyards the simulation service without the necessity of having in-house simulation expert is in development.	SMARTYards , SESIS

Research topics	Analysis	Projects
	This concept would facilitate the shipyards to simulate the shipyard processes in a specific simulation model available in a server, representing their shipyard and utilise the benefits of better precise results of simulation even without the availability of appropriate qualified personnel.	
Supporting tools and integration (Simulation)	In RETROFIT and GRIP (running projects), in order to aid the shipyard planners in handling of information a java based supporting tool called AnteSIM is in development. Using this supporting tool, the shipyard planners can perform basic simulation studies within the tool just by providing the required data input. The Tool also provides a possibility of accessing a remote simulation model for a more detailed simulation analysis of their shipyard processes. A database schema to maintain the templates of the shipyard processes and its related resources were developed in projects SESIS and GENESIM. They are in further development in running projects SMARTYards and HEPP. This database schema will aid the shipyards in their planning – simulation activities of regular orders. Apart from that, the information saved in the database schema can be used as an input for the simulation studies in Plant Simulation software.	GRIP, RETROFIT, ECO-REFITEC SESIS, GENESIM, SMARTYards, HEPP,INTERSHIP IMPROVE, POWER-VR SIMGO
Virtual Reality / Augmented Reality		
VR/AR for Training and Method Planning	Equipment suppliers apply animated 3D pdf technique to provide guidance to step-by-step assembly/disassembly/repair of components POWER-VR aimed at process integration of VR/Augmented Reality, e. g. by means of apps for hand held devices, onsite worker support with task details, etc.	Use-VR POWER-VR PROSPER
VR/AR for Digital Engineering data	In SMARTYards (running project), the concept of providing the work breakdown information of an assembly process in a 3-D pdf, which could be accessed in real time by workers in their Smartphone or tablets, is in development.	SMARTYards , PROSPER
Production Quality Assurance		
Production Quality Assurance (PQA) for Welding	In BESST and DOCKLASER, the concept of utilising statistical process modelling to analyse and select the optimal and appropriate welding parameters for a particular section of a ship was developed. The results of the Statistical process modelling and welding parameters are available in a process knowledge data base, from wherein the shipyard planners can plan the production process chain of the welding and assembly processes. Thus providing a Production Quality Assurance for welding processes during the planning stage. The methodology is planned to be further utilised in SMARTYards.	BESST, DOCKLASER, SMARTYards

Research topics	Analysis	Projects
PQA for geometric accuracy	Accuracy Management: In SMARTYards (running project), the idea of utilizing 3-D laser scanners for Image acquisition of micro panel is in development. The 3-D output obtained from the laser scanners installing in the bending machines will be used to compare with the designed bending parameters of the product. This quick and on hand feedback on the required amount of bending will aid in fastening as well as assuring in attaining the required quality in the geometric accuracy of process.	BESST, Elasta, Curved Panel II, InterSHIP, SMARTYards
PQA for Weight Management	Weight management: Measuring devices were developed to obtain updated information on structures' **mass and center of gravity**.	Gewichtsmanagement, SMARTYards, 3-D-Schwerlast-aufnehmer
TQM (Total Quality Management)	In SMARTYards (running project), it is planned to develop a complete Accuracy Management System which is adaptable in a Small and Medium sized shipyards by using the in-house practise in large shipyards as well as incorporating the infusion of new technologies such as reverse engineering, so as to obtain accurate product information.	SMARTYards
Other conceptual studies and product preparation involving tools		
Prototype planning	Software solutions to meet the challenges connected with **prototype planning** are developed in projects like RETROFIT, GRIP and HEPP. It is planned that the tool AnteSIM would be further developed in order to accommodate the complete planning of a prototype production in a shipyard.	BESST, ECO-REFITEC, HEPP, RETROFIT, GRIP, PROSPER
Concept studies	In BESST, **conceptual studies** dealing with novel ship operations were analysed in order to develop new concept ideas like containerized storage systems and side load arrangement.	CREATE3S, BESST

TSA 3-B Production Preparation and Management Tools

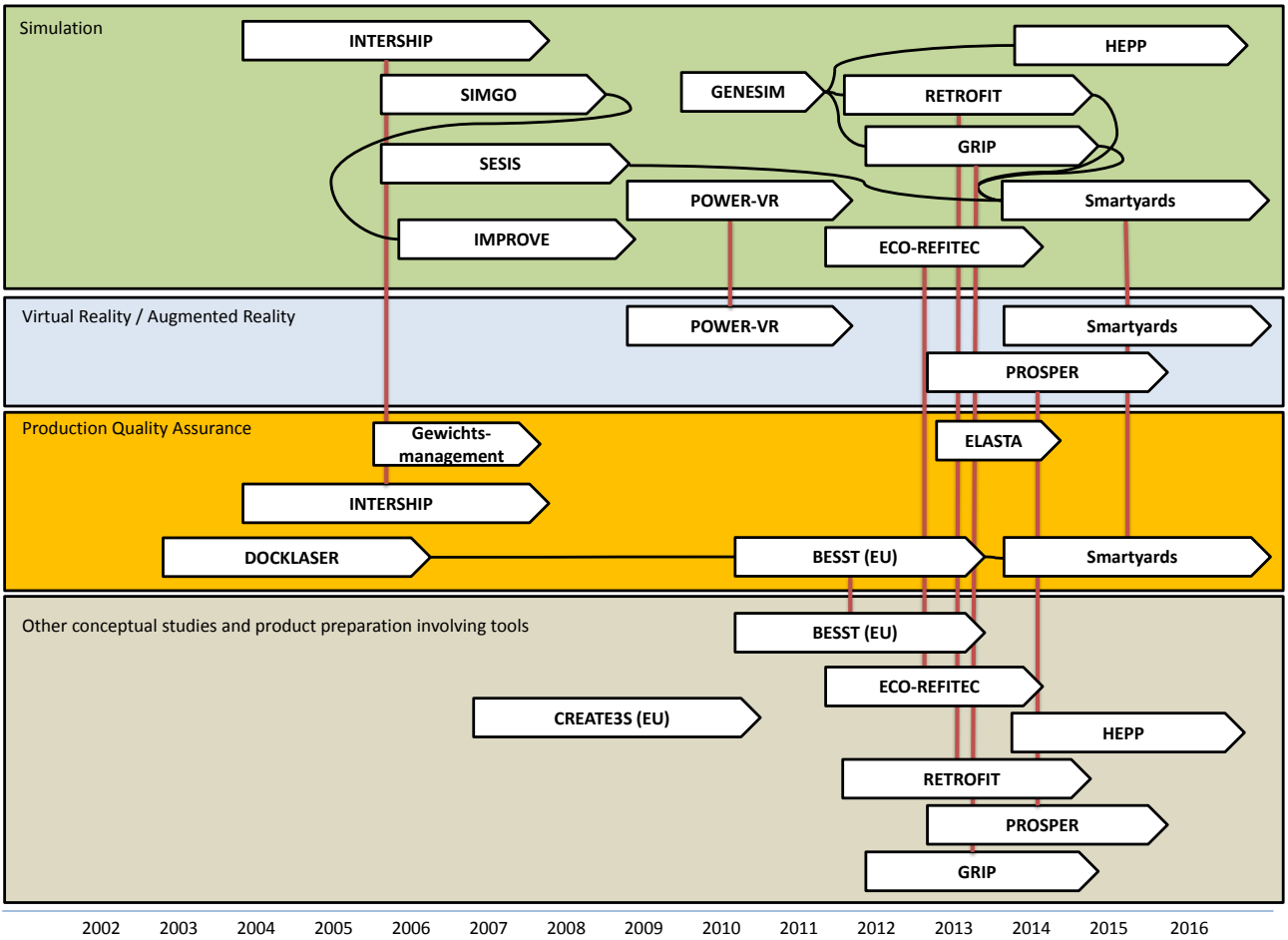


Figure 13: TSA 3-B Production Preparation and Management Tools – Project timeline

Conclusions

The developments achieved in the research area of Production Preparation and Management were detailed above. The obstacles (especially for smaller shipyards) in the adaptation of simulation technology for planning of production processes would be the involvement of high investment cost (software license), time needed to develop simulation models and requirement of personnel with simulation expertise. There is also the general obstacle of reluctance to share process knowledge within the shipbuilding industry. These obstacles could be overcome by following some of the research needs explained below. As it could be seen, though there have been new research conducted on the production process technologies, there exist opportunities for further research for fill in the technology gaps. The Technology Gaps and Research Needs grouped further discussed in the R&D Road Map.

Suggested show cases

Simulation

One of the best show case for discrete event simulation could be given as the planning methods for manufacturing one-of-a-kind-ships which was documented by CMT. This showcase gives an insight on how European shipbuilders improved their capabilities in producing highly specialised and complex vessels by implementing innovative planning techniques. Particularly, the document explains why the application of discrete event simulation is a key factor for this achievement while providing information on the evolution

of the simulation processes and their applications in several shipyards. Below figures provide some of the referred applications.

Figure 14: 3D animation of a space allocation model for long term simulation (source: MW)

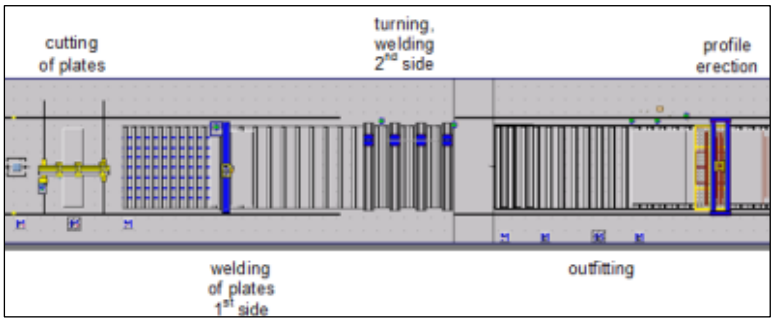


Figure 15: 2D animation of panel line simulation model for short term production planning (source: FSG)

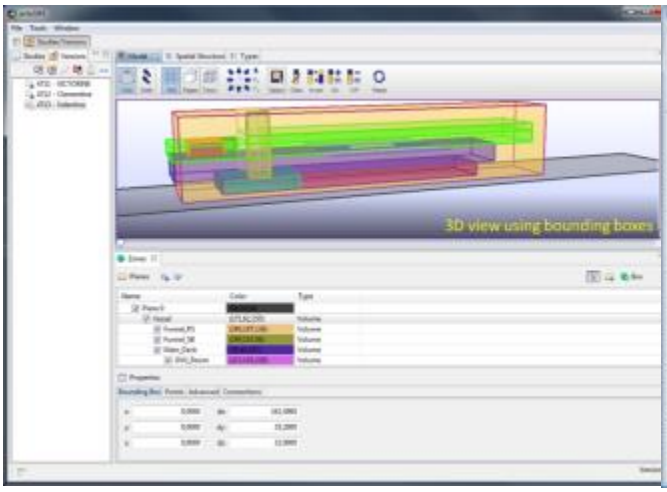


Figure 16: Management of simulation input information using the anteSim tool. (Source: CMT)

Figure 17: Simulated occupation of dry dock and area for block assembly (Source: MW)

Virtual Reality /Augmented Reality

The projects USE-VR and POWER-VR had the scope of developing a technology to represent a product in virtual reality and consequently adapt the production/operation/maintenance part of the product via virtual reality. They then identified the solutions such as Adaptation of 3D-Technology like 3D-PDF that have been already in use in other industry. These solutions enhanced the usability and proof of economic efficiency of the product. Commercially it provided an important factor in executing maintenance procedure using 3D-PDF. Applications were developed to integrate the processes connected to a product to be visualised in Virtual reality. Further developments that could be envisaged are the object recognition for use of Augmented Reality in maintenance. Figure 18 shows the flow of development that is and can be achieved in the field of virtual reality.

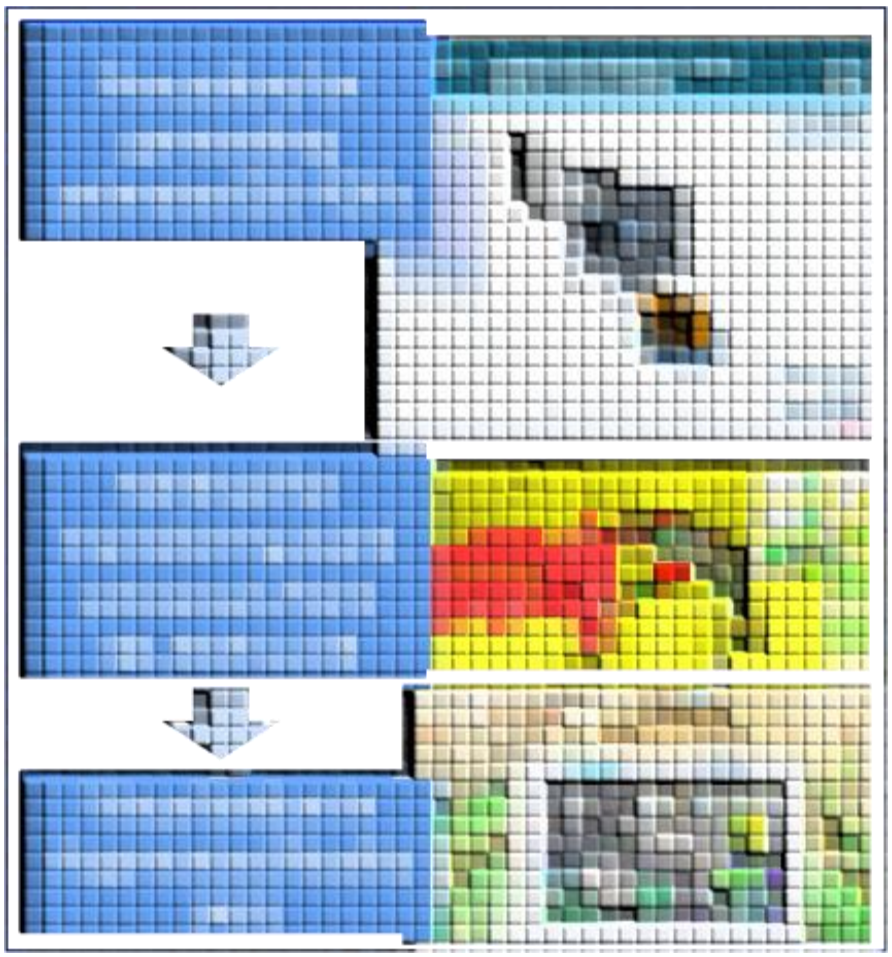


Figure 18: Virtual and Augmented Reality solutions in Production Technologies [MAN & TUHH]

Production Quality Assurance

Since long, statistical methods have been used to support quality assurance in shipbuilding. The three examples below indicate how the application of DoE (Design of experiments) has consequently been enhanced over the past years.

1. **DOCKLASER**
   Use of Statistical methods in earlier projects like DOCKLASER was case specific and dedicated to achieving the approval for one or a few new pieces of manufacturing equipment and/or processes. DoE also helped reducing the amount of specimens to be tested while at the same time yielding a maximum of quantifiable and reproducible process knowledge. (a and b in Figure 19)
2. **BESST**
   In BESST, DoE was again used to ensure proper process quality and to deliver optimised process parameter sets, but in addition a process parameter knowledge data base was developed in order to share welding process knowledge. The various methodologies, Welding procedures and its results that were performed during the project was integrated in a “Welding Knowledge Database”, which could be used by end users to select the optimum welding processes and parameters suitable for their needs. All the welding parameters are defined after its test results were analysed using statistical model. These statistical models provided the area of optimum performance for the welding technologies. (c and d in Figure 19)

3. SMARTYards

SMARTYards is aiming on further integration of solutions by combining the process knowledge data base with an existing tool for work preparation, thus allowing for making the work preparation more efficient and less prone to errors.

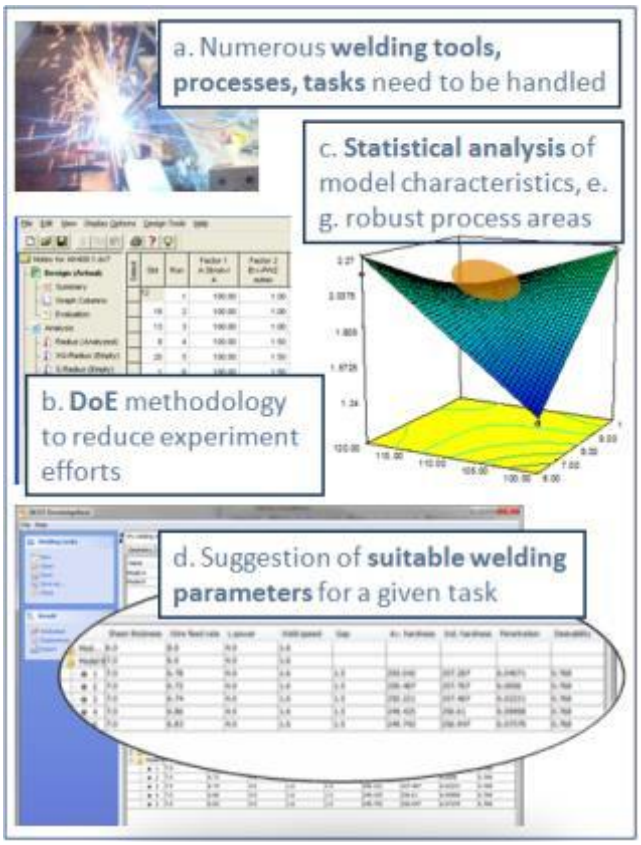


Figure 19: Welding Knowledge database with Statistical Models

3.4 TSA 3-C Metals and their processing – welding, joining, outfitting

Introduction

- MESA partners which contributed to TSA3-C are RWTH Aachen University (RWTH), Center of Maritime Technologies (CMT) and Meyer Werft (MW).
- The involved external experts are:
  - Technology Centre Aimen, (AIMEN)
  - Astilleros de Santander, S.A. (SANTANDER)
  - BALance Technologie Consulting, Bremen (BAL)
  - Chalmers University of Technology, Gothenburg
  - European Council for Maritime Applied R&D (ECMAR)
  - Ingenieurtechnik & Maschinenbau GmbH, Rostock (IMG)
  - Ship Design Group Stl, Galati (SDG)
  - Verband des deutschen Schiffbaus e. V., Hamburg (VSM)
  - Aalto University, Espoo (Aalto)
  - CETENA Centro per gli Studi di Tecnica Navale (CETENA)
  - Delft University of Technology (TUD)
  - Toegepast Natuurwetenschappelijk Onderzoek (TNO)
  - Precitec GmbH & Co. KG (Precitec)
  - Fincantieri SpA (FC)
- The information gathered in this report consists of public available information and personal statements of experts. The analyses comprised 55 projects, 27 of these being European funded ones, and the others being national funded (23 German, 3 Finnish, 1 Spanish, 1 COFUND within MARTEC programme by Germany & Turkey). The analysed projects can be seen in Table 15.
- Three workshops were held to collect additional information and feedback. Comments received from the attendees have also been considered when compiling this report.
  1. A TSA3-C workshop took place in Brussels (March 05th, 2014).
  2. A joint workshop was organised with German Welding Society's (DVS) working group 'Welding in ship building and marine technology' (November 06th, 2014), focusing on metal processing technologies and their application in shipbuilding.
  3. A public workshop was offered by TSA3C and the project ADAM4EVE (June 04th, 2015). The event dealt with innovative design solutions, most of them using steel.

Table 15: TSA3-C metals and their processing - analysed projects

ADAM4EVE	DOCKWELDER	IBESS	Rohrleitungskleben
BeKas	Einseitiges Elektrogas	Intership	SAFEDOR
BESST	Elektrogas	LASHARE	Sandwich
Bolzenschweissen	FASA	LeiSe	Schiffsfenster
Bondship	FASDHT	MANU	SHIPYAG
BRIDLE	FASEK	Mekapro	SMARTYards
CO-PATCH	Fensterband	MESCHLAS	Standardtkleben
CREATE3S	FSW_Steel	MIG Löten	Teilangesclossene T-Stösse
CROCELLS	FSW-Ship	MOSAIC	THROUGHLIFE
D0	HILDA	MOVE IT!	T-joints
DE-LIGHT TRANSPORT	Hochfeste Stähle	PaLas	UPQuer
DOCKLASER	HybriLas	QuInLas	

After a first brief analysis, eight projects were excluded from further analysis, for several reasons:

- OFFIENGINE deals with thermal spraying on marine engine parts, using Oxy-fuel-injection (OFI). This topic fits more to *TSA3-E-Corrosion protection and antifouling coatings*.
- CARGOXPRESS created a new holistic approach to freight ship construction design. Used material and joining methods are not obvious at the moment. The same applies to the project CRASHCOASTER, which is exploiting the crashworthiness of ships side's structures.
- GRIP surveys energy-saving-devices (EDS) in dependency to hull lines and creates an analysing tool. Therefore it is not of interest for TSA3-C.
- CREVCORR and its successor CORASS deal with corrosion phenomena; therefore, they were passed to TSA3-E.
- FUTURIA is related to composites; the project was taken care of by TSA3-D.
- CARLOS is oriented towards outfitting of ships using robots. Therefore, this project was handed over to TSA3-F.
- HALO is rather basic research on Laser beam sources and exploring opportunities to make them more adaptive. The topic can become relevant for shipbuilding later.

Industrial practice

Review

The European shipbuilding industry is responsive to competitive pressure by a specialisation in lucrative niche markets where higher cost of labour can be compensated by efficient technical solution. Special types of Ships, as passenger ships, RoPax, naval ships or ships for special application require varying qualities of steel and a variation of material thickness, which are adapted to required strength characteristics. This trend is enhanced by the claim for more energy saving vessels using lightweight designs. The use of efficient welding and joining technologies is required for the realization of innovative ship constructions. On the other hand the cost pressure enforces the use of highly productive automated manufacturing technologies.

Blockbuilding construction

For the purpose of minimisation of welding tasks and handling times in the ship erection process, a ship is separated into different blocks, which consist of several sections. E.g. a small cruise ship consists of approx. 60 blocks that comprises of six to eight sections each.

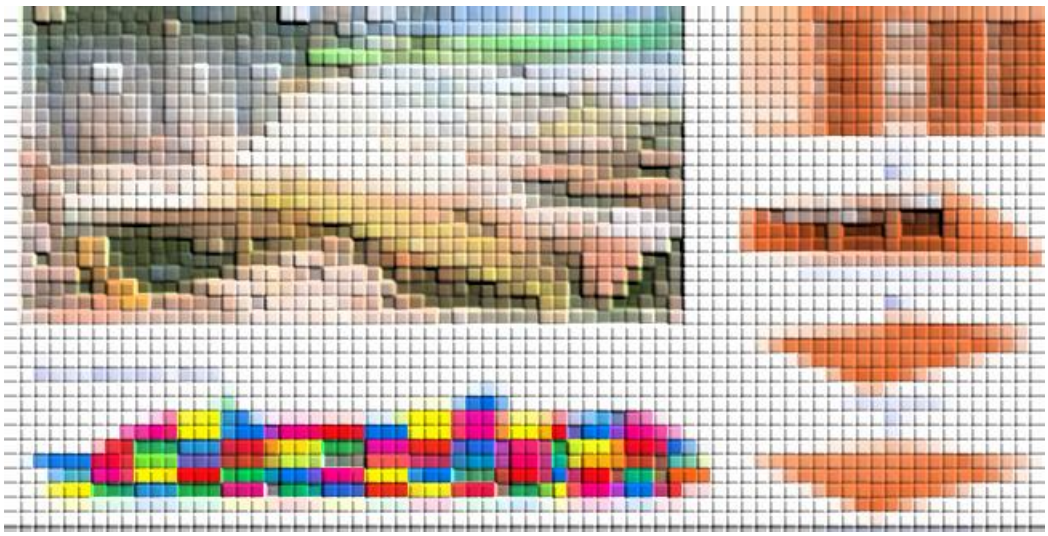


Figure 20: Hierarchy in the Production of Blocks

In the first step, steel plates are coated for corrosion protection and cut to size by plasma torch system. These steel plates are welded up to form panels. The cut to size steel plates are mounted with profiles, struts and

side walls to form sections and are then equipped and pre-installed with electrical wiring and pipes. The single sections are joined to form a block. The individual blocks, the heaviest of which may weigh 800 metric tons, are welded together and wired to become the entire ship, the hull comes into being. Due to the modularisation panels, sections and blocks must form a perfect unit. Therefore high quality within the production is required. [Meyer Werft]

Used Materials

Large transport ships, cruise ships and luxury yachts as well as increasing diversity in specialized vessels and in offshore industry are changing the needs of the European shipbuilding industry. Digital welding processes have improved the economic processing of metals and the technical quality of its joints. The possible applications of metal inert gas (MIG) welding systems range from steel alloys to aluminium. The underwater structures of ships are mainly built of steel grade A. Depending on the conditions, such as less aggressive environments, also steels of grades B, D and E are used. A 32, E36 or E40 are also utilised where high tensile is required. For steam and pressure boilers heat-resistant tempered fine-grained structural steel is used which fulfil the requirements of high ductility at low temperatures. Also austenitic or nickel alloyed steels are used in this field of application. The tubes are usually made of high-strength steel. The environmental conditions also influence the choice of material for the pipes, e.g. high strength steels alloyed with manganese, molybdenum or chromium. If high toughness at low temperatures is required, nickel alloyed or austenitic steels are used. Pipes made of high-alloy steels are required for cargo tanks and pressure vessels. As a non-ferrous metal, aluminium and its alloys are used. Application examples could be given as, hulls of yachts and speedboats as well as funnels, ship superstructures or piping. Other non-ferrous materials are copper, and copper alloys and nickel alloys. Especially in the construction of liquefied natural gas carriers (LNG/LPG) or pressure pipes for condensers and heat exchangers also require these materials.

Welding technologies in shipbuilding

Steel as by far the predominant material in the ship building, crane building as well as water and offshore industry requires technical and economic aspects as well as situation-specific or application-specific solutions. Although production of ship panels has characteristics of series production, the assembly requires so far purely manual work, especially within a ship's hull. Environmental conditions affect the production differently, especially in the erection of offshore wind turbines. Unlike to enclosed hangars, wind, rain and temperatures vary greatly outdoors. In interaction with aggressive salt water, as typical in the offshore area, arises a maritime structure of conditions that have to be considered by the choice of suitable welding technologies.

The number of welded joints per ship that are approximate 120 to 140 km illustrates the importance of welding technology to ship erection. Several welding technologies are state of the art in different fields of application. [FSG]

The used technologies are:

- GMAW
- SAW
- SAW multi wire
- Laser hybrid welding

Most of the steel joints in shipbuilding are realized by manual welders. Universal and powerful systems are needed, whose components are perfectly harmonising.

Laser hybrid welding is used for both joining of steel and aluminium. A laser beam is combined with a GMAW process. It is predestined for long seams with a large weld depth and a maximum required strength. The advantage of the combination is the edge bridging possibility (GMAW) and large weld depth (Laser). The outcome is both, quality and productivity benefits and investment advantages. Both methods focus their

energy on the same process zone and thus increase weld depth and speed compared to the single process. The hybrid method minimizes part distortion due to the lower energy input and produces significantly less weld spatter.

Automation

Increased productivity and improved efficiency can be realized in the vehicle production and in general engineering through systematic automation with robots. This is due to small number of lots in the shipbuilding industry hardly transferable. Here intelligent mechanization solutions for repeatable routes and welding paths open favourable opportunities. Two typical areas of application are panel manufacturing and installation of the tubing. For mechanized use of the GMA process on longitudinal fillet welds in horizontal and vertical position and integrated torch weave welding tractors are helpful.

Rules and regulations

Review

When it comes to effects of international rules and regulations on steel processing in European shipbuilding, one issue often observed is that new established rules act as a trigger for innovation. When such rules ask for a higher product quality level, one result might be shipyards' efforts to reorganise their production processes in order to cope with these new demands. In such situations, European shipyards tend to strive for developing automated solutions in order to avoid putting too many additional costly person hours into the production of a ship. For instance, the Performance standard for protective coatings (PSPC) issued by IMO led to a series of projects (e. g. BeKaS) in Germany which aimed to fulfil the PSPC condition to provide free edges of certain steel structures with a 'radius of 2 mm or equivalent'. Several technologies (thermal and mechanical) and equipment for treatment of such edges were developed.

A second important issue consists in challenges connected with proper interpretation and application of existing rules when actors (i. e. shipyards and their customers) enter into a new market by manufacturing products other than those they are accustomed to. Based on the increasing offshore industry, particularly influenced by the market segment of the offshore wind industry, the production and manufacturing of offshore structures is a significant factor of German shipyards. The requirements of offshore structures are completely different compared with those of vessels. Consequently, rules and regulations of vessels cannot be applied, mainly due to the reason that repairs of offshore platforms are significantly more complicated and expensive than those of vessels, so the formers should be avoided whenever possible. Therefore more strict rules and regulations have to be applied in the production and manufacturing line of offshore structures. Production representatives of German shipyards[2] pointed out that it was evident in the daily work that a lot of these new rules and regulations for offshore structures are overlapping in their statements. Furthermore it is said that inexperience of the parties result in a strict way of interpretation for the sake of being on the safe side, and therefore production costs are rising, due to a much more time consuming workload. Currently, the working group is in a process of analysing this issue deeper, potentially resulting in a formulation of new standardization and regulation proposals, dedicated to the offshore industry.

Research and development

Review

Projects have been distinguished by research domains, topics, and – if appropriate – sub topics. Within the projects allocated to TSA3-C, a set of research domains has been identified, each of them containing several research topics. The result of the grouping is displayed in Table 16 below.

[2] Arbeitskreis Fertigung im VSM (Verband des deutschen Schiffbaus) – Working Group Manufacturing in the German Shipbuilders' Association

Table 16:TSA3-C metals and their processing –Research domains and (sub) topics

Research domain	Research topic	Research sub topic
Materials and design	High tensile steel	
	Lightweight structures	
	Construction and design	
Metal processing	Joining technology	Laser technology
		Adhesive bonding
		Others
	Edge preparation	
	Automation / mechanisation	
	Quality Management	
	Maintenance, repair, retrofit	
Life Cycle oriented approaches	Life cycle performance assessment	
	Life cycle oriented processes / services	
Product specific R&D	Offshore Energy platforms	

It has to be noted that many projects address several of the named domains and topics. Therefore, some projects are mentioned several times. Furthermore, there are overlaps with other MESA TTGs.

Table 17:TSA3-C – Projects per research domain and (sub) topic

Research topic	Analysis	Projects
Domain Materials and design		
High tensile steel	HOCHFESTE STÄHLE focused on possible application of high tensile steel in thick walled structural members, e. g. in mid-size container ships. Experimental investigations on the fatigue strength under consideration of notch effects and others led to the conclusion that almost 5 % of the total steel weight compared to higher-tensile steel may be saved compared with the normal and higher-tensile steels.	Hochfeste Stähle
	The FASDHTS project surveyed the realization of high-tensile steel in fast mono-hull ships. Therefore new structural concepts were developed. Further to corresponding design concepts, the project also addressed manufacturing techniques (laser welding, bonding), and the introduction of new maintenance, inspection and corrosion protection systems, thus making the ship's entire life cycle more efficient.	FASDHTS
	MOSAIC involves two groups of structural materials, namely high strength low alloyed steels (HSLA) in specific structural details and second the replacement of specific structural parts of the ship with composite materials. Design guidelines on best practise application of these materials are being developed. The expected results are to improve the structural response of the ship, to reduce the lightship weight of the structure, to reduce corrosion and to reduce the maintenance and overall operation cost of the vessel.	Mosaic

Research topic	Analysis	Projects
Lightweight structures	Various R&D projects focused on reducing structural weight of ships by applying metal materials using innovative designs like I-Core panels. Cooperation with other transport sectors was widely involved. SANDWICH aimed to develop novel metal-composite lightweight sandwich panels for primary load-carrying and/or crashworthy structures in ships and land transport by combining a laser welded metal structure with different non-metallic core materials.	Sandwich
	Follow-up projects like SAND.CORE and DE-LIGHT TRANSPORT developed best practise procedures and designs for materials such as those developed in SANDWICH, see Research topic *Construction and Design* below.	SAND.CORe, DE-LIGHT-Transport
	The use of metal foams is another approach towards lightweight structures. MESCHLAS developed designs for several applications of sandwich constructions consisting of steel plates and aluminium foam (rudders, engine foundations).	MeschLas
	Projects that deal with repair processes for metallic structures, like CO-PATCH can be found in 3.8 TSA 3-G Maintenance, Repair, Retrofit, End of Life.	Co-Patch
Construction and design	There are several studies dealing with the <u>material properties and manufacturing characteristics</u>, and their impact on design options. Strength and fatigue assessment and the prediction of crack propagation is in the focus of the IBESS project, while BESST concentrated on comparing fatigue properties of structures welded conventionally and by means of Laser, aiming at approval for designs using Laser welded thin sheet constructions. Similarly, the ongoing project "T-JOINTS" investigates strength behaviour and other properties of Laser welded T joints, aiming to develop design methods and criteria for such constructions and/or semi-finished products. The FASA project is looking into fatigue strength modelling of laser-welded steel sandwich plates having comparatively thin plate thicknesses (from 1 mm up to 5 mm).	IBESS , BESST T-Joints FASA
	Also, <u>standardisation and modularisation</u> are key aspects of R&D activities. CREATE3S for instance targeted on separating the ship's buoyancy and cargo carrying functions, thus to be able to realise various specific designs based on a limited set of design modules which can be produced at larger quantities. The latter fact allows for introducing more efficient production organisation forms.	Create3S SAND.CORe
	<u>Lightweight design</u> has constantly been playing an important role in European R&D activities. SAND.CORE was a CSA dedicated to identifying best practise in lightweight construction (metals and composites) of several vehicle manufacturing sectors. The project was followed by DE-LIGHT TRANSPORT which developed prototype lightweight designs for ships and for rail and road vehicles. Next to the design of the mere lightweight structures, questions dealing with their integration with the surrounding conventional ship structure were solved.	DE-LIGHT Transport SAND.CORe, DE-LIGHT Transport, SMARTYards

Research topic	Analysis	Projects
	Technology transfer between different transport sectors was done, as described above, in SAND.CORe and DE-LIGHT Transport. The recently started project SMARTYARDS is striving for 'smart' solutions that help making technologies available/affordable for small and medium shipyards which are already established at bigger ones. Solutions supporting the design and work preparation process are among the technology candidates to be investigated. Intership project provided strategies for joining, assembly, outfitting, testing and validation procedures to provide accurate and reliable methods for multi-material sandwich design tools. While the conventional way to design a ship is to strive for optimal performance levels at a defined operational point only, ADAM4EVE has investigated adaptive materials and structures similar to morphing wings which are known from airplanes, in order to obtain best performance levels even with varying operational conditions. Trim flaps for RoPax vessels and variable bulbous bows for inland water way ships are among the developed solutions. There are further projects which are following similar approaches. In the EU Funded project CRASHCOASTER, the probable improvement in the damage survivability of coasters and medium sized RORO cargo ships were analysed by exploiting the crashworthiness of the side structures. In the project, ideas were developed in order to overcome the conventional design measures for the survivability, which normally substantially restricts the operational capacity of the ships.	Intership ADAM4EVE Crashcoaster
Domain Metal processing		
Joining technologies		
Laser technology	The development of Laser driven joining process and equipment was the aim of SHIPYAG. YAG laser based systems with fibre optical cable transmission were introduced to realise low cost, versatile, safe laser welding technology. PALAS dealt with the development of a multidimensional Laser-hybrid welding to raise efficiency and quality for panel-line-production in ship erection. In another German national project, TEILANGESCHLOSSENE T-STÖSSE, partially penetrated MSG-laser-hybrid welded T joints were qualified to acquire the class approval. A project called HYBRILAS covered Laser-MAG Hybrid welding of thick material (steel, thickness > 20 mm), the application area being pipelines and wind mills. Joining processes further down the ship assembly line were addressed in FASEK, the objective being to provide a fully mechanized, sensor based vertical down welding system for the section fabrication to the industry. Similarly, QUINLAS was into the development of equipment, processes and QA measures for	ShipYag PaLas Teilangeschlossene T-Stöße HybriLas FASEK QuInLas

Research topic	Analysis	Projects
	welding of 3D ship structures using Laser only (applying wobbling welding) and Laser hybrid technology. Although not applied in the production yet, the developed sensor system was found promising by the end users. DOCKLASER was the first project to develop mobile equipment for Laser welding and cutting of ship structures and outfitting, including the development and approval of corresponding processes. Subsequently, BESST provided further improved solutions, including a modularised, lightweight and fully automated welding tractor, and statistical models of the developed welding processes. Within the ongoing Factories of the Future Integrated project I4MS, the sub project LASHARE provides the opportunity to demonstrate Laser technologies for manufacturing SMEs. The MOBILLAS experiment demonstrates the suitability of a semi-automatic mobile welding device similar to that dealt with in Docklaser. Laser manufacturing technology was also involved in a couple of projects that investigated novel design solutions. SANDWICH developed novel metal-composite lightweight sandwich panels for primary load-carrying structures in ships and land transport by combining a laser welded metal structure with different core materials. The collaborative German project BEKAS demonstrated the suitability of reconfigured Laser (and Plasma) welding equipment for preparation of steel edges prior to coating (see below *edge preparation*, and *TSA 3-E Materials and Processes for Corrosion and Fouling Protection*). Furthermore, the applicability of Laser welding technology for sandwiches consisting of steel and aluminium foam was proven in the MESCHLAS (see above *construction and design*) project.	Docklaser (EU) BESST (EU) LASHARE (EU-FP7) Sandwich (EU) BeKaS (D-BMWi) (Meschlas)
Adhesive bonding	BONDSHIP aimed to pave the way for the introduction of adhesive bonding in shipbuilding by a number of measures: Guidelines for design, modelling, testing, production, fire protection, inspection and repair of bonded joints were developed as well as acceptance tests and criteria. Test and inspection methods for bonded joints, including material data documented application cases and joint designs were further outcomes. The practical application case studies also provided documented production and assembly procedures and practical experience and skills from using adhesives in a shipyard. SAND.CORe and DE-LIGHT Transport contributed to further enhancing and harmonising the know-how on adhesive bonding in shipbuilding, while the German project KLEBEN aims to fill the gap of missing standard designs for typical bonding joints in shipbuilding structures. The ongoing project ROHRLEITUNGSKLEBEN has a similar approach, but it is rather aiming on pipe systems in ship outfitting. An adhesive can fulfil more tasks than the primary function to keep parts or structural members connected. Damping and the	Bondship SAND.CORe, DE-LIGHT Transport Kleben Rohrleitungskleben LEISE

Research topic	Analysis	Projects
	transmission of forces are issues that are handled in several projects. LeiSe's aim was to assess the noise damping properties of the glue used to join composite cabins with the steel structure, and a series of projects addresses the design that foresee big ship windows bonded to a steel ship's structure. The aim in this case is to make the window glass a part of the load bearing structure, so weight reduction is the ultimate goal.	SCHIFFSFENSTER , Fensterband
Others	Electrogas welding is addressed in two German projects: ELEKTROGAS aims at increasing the productivity and reducing the energy input of the final assembly of vertical joint design for the shipbuilding exterior body shells designed with HSLA steels in thicknesses from 15 to 30 mm with the use of electrogas arc welding.The objective of EINSEITIGES EGS is the creation of an automated single-sided electro-gas process on irregular butt welding. Emphasis is put on achieving a process that is robust with respect to shipbuilding typical variation of parameters, like gaps. Closed loop control and statistical process models are the keys to solve this challenge. Friction stir welding (FSW) of aluminium structures is an established technology. The FSW SHIP project provided design solutions for Al superstructures of ships, and the corresponding joining processes. FSW for steel structures and for dissimilar materials is the next step. FSW STEEL took care about the development of corresponding tool machines, and HILDA works on the scientific foundation for a reliable FSW process applicable to DH36 steel with a particular focus on the European shipbuilding sector. This will be accomplished using a combination of process property optimization, micro structural evaluation, mechanical testing, global and micro structural modelling and, finally, the development of smart software to predict the post weld conditions. BOLZENSCHWEISSEN investigated the question whether stud welding can be applied to cyclic loaded primary structures of ships, especially to the relatively thick bulbs of Holland profiles. The focus was on drawn stud-arc-welding of M8- and M12-studs with ferrules. Holland profiles of the series HP100 and HP200 made of higher tensile steel (A 36) were chosen from the ship structure. MIG-LÖTEN was dedicated to increasing the connection quality of galvanized outfitting through the use of MIG brazing. As a concrete application, the joining of galvanized ballast water pipes was pursued. The development of technological joining parameters, and tests to proof strength, corrosion protection and tightness of joints were undertaken.	Elektrogas Einseitiges EGS FSW Ship FSW Steel HILDA Bolzenschweißen MIG-Löten
Edge preparation	A set of projects on edge preparation has been found, the scope of those being the treatment of exposed edges prior to coating (i.e.., not edges prior to welding). MEKAPRO's objective was to provide an inexpensive, automated machine for mechanically treating the	MekaPro

Research topic	Analysis	Projects
	exposed edges, which can easily be integrated into the shipbuilding process. BEKAS's mission was similar, but the intended solution foresaw equipment and processes for thermal treatment of exposed edges, leading to rounded edges, thus fulfilling rules stated in the Performance standard for protective coatings (PSPC). The performance of anti-corrosive coatings applied to such edges was also studied and compared with sharp end bevelled edges. As a follow-up project of BeKaS, HANDPLASMA investigated the possibility for realising manually guided Plasma tool for treating exposed edges.	BeKas Handplasma
Automation / mechanisation	Currently, SMARTYARDS is aiming at making automated welding equipment achievable for smaller shipyards thanks to using smart robot technology. CROCELLS developed a set of climbing robots which can be used for inspection and maintenance (see also TSA 3-G), but also for welding tasks. DOCKWELDER, BESST (both see *Joining technologies /Laser technology* above), BEKAS and MEKAPRO (see edge preparation) are among the relevant projects on automation and mechanisation of metal processing. In addition to these funded projects, shipyards have conducted private projects modernising their production facilities by introducing automation and mechanisation. Examples will be given in the show cases.	SMARTYards CROCELLS Dockwelder, BESST, BeKaS, MeKaPro
Quality Management	In the EU funded projects DOCKLASER, BESST and SMARTYards, the <u>Quality and reliability</u> of new joining processes were analysed and tested by developing and applying statistical process models. More about this methodology is detailed under TSA 3.B. <u>Accuracy</u> is a particular quality issue in the production of large ship structures. InterShip and BESST included sub projects dealing with calculation of deformations, optimisation of weld sequencing and other approaches to predict and prevent distortions. Other projects were dedicated to measuring and removing existing distortions. D0 addressed procedures for prediction of distortion, but also for calculating appropriate parameters for applying straightening measures (induction heat, Laser) to remove existing deformations, and the accompanying measuring technology. The results of the D0 project were not applied due to the financial crisis.	Docklaser, BESST, Smartyards InterShip, BESST D0
Maintenance, repair, retrofit	<u>Technical solutions</u> for Maintenance, repair and retrofitting were dealt with in a couple of projects. Several of the mobile pieces of equipment for Laser welding and cutting developed in DOCKLASER are suitable for use inside ships to foresee attachments for outfitting, or to remove and replace structural parts. The idea of reinforcing stress hotspots or cracks of steel parts by over laminating a piece of composite material was studies in DE-LIGHT TRANSPORT. The ongoing project CO-PATCH investigates this and further ideas, and solutions both for the maritime industry and for civil engineering are being developed. Next to extending the	DockLaser DE-LIGHT Transport, CO-Patch

Research topic	Analysis	Projects
	structures' lifetime by supporting their strength, impacts are also expected with respect to corrosion prevention. The MOVEIT! project suggested strategic opportunities for modernisation of inland fleets for freight transport. Besides engine and propulsion issues, processes for retrofitting the hull forms are addressed as well.	MoVe IT!
Domain Life Cycle oriented approaches		
LC performance assessment	Among the projects analysed in the report at hand, DE-LIGHT TRANSPORT was the first to study systematically the economic impact of novel solutions (in this case metal and composite lightweight structures) on a product's life cycle performance. BESST then made a step forward by developing a dedicated tool allowing for doing analyses of ships' life cycle performance in terms of its economic, ecologic, social, and safety dimensions. These were applied to assess the solutions derived from the various BESST sub projects, among them a study on fatigue properties of laser welded structures (see *Construction and Design* above) and mobile and modular laser welding equipment (see above Joining technologies Laser technology). AdaM4EVe makes use of the same LCA tool.	DE-Light Transport BESST AdaM4EVe
LC oriented processes / services	Within THROUGHLIFE, new approaches for through-life asset management for selected technologies and application scenarios were developed, considering the technologies' cost efficiency, environmental performance and safety, but also the roles and interests of the typical actors (new building yards, repair yards, ship operators) in the life cycle. Some of the technologies covered in the project are related to metallic structures, namely sensor based condition monitoring systems, and innovative steel.	Throughlife
Domain Product specific R&D		
Offshore Energy platforms	The projects scope is the installation of offshore wind turbines. The objective of the project is to develop an economic technology for the one-sided Under-Powder (UP) welding in transverse position for plate thicknesses from 13 mm to 80 mm. In this regard, known economic advantages of utilising the benefits of flat-position welding will be analysed. Developments are in analysis in the UP welding technology so as to obtain repeatability and economic efficiency in small batch productions.	UP-Quer

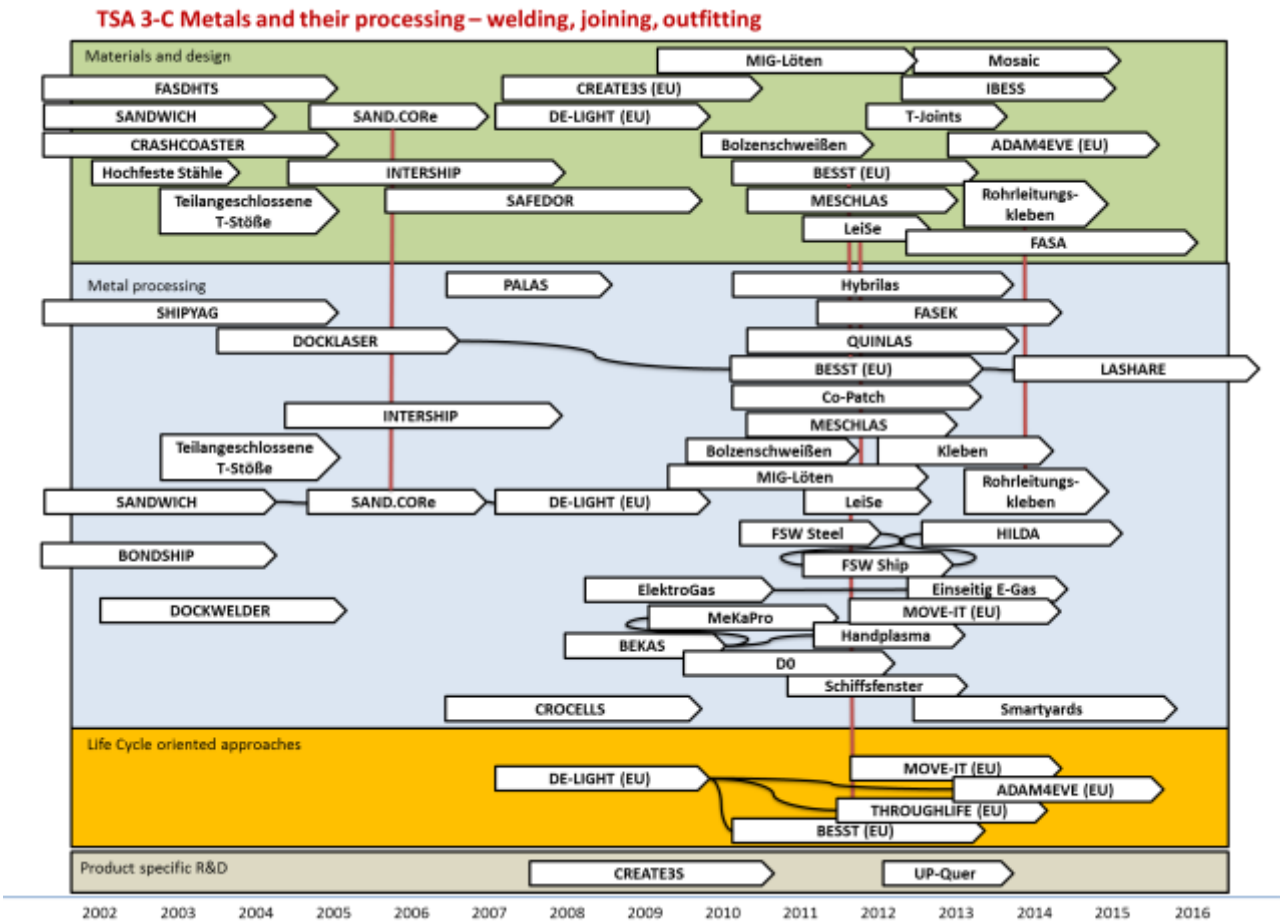


Figure 21: TSA 3-C Metals and their processing – Project timeline

Conclusion

New-building shipyards

Regaining competitiveness is an ambitious challenge for European shipyards. Especially manufacturers from Far East make use of their locational advantage, particularly lower production costs and labour expense. The research projects reviewed indicate several approaches to cope with Europe's disadvantage in this respect by focusing on advanced production technology. Material and labour cost intensive manual operations are replaced by mechanized or automated devices. These are used for work intensive tasks like edge preparation as well as for welding, using efficient or innovative techniques for ship erection. Modern welding technologies such as Laser hybrid, Electro gas (EGW) or Friction stir welding (FSW) become more and more common, as well as adhesive bonding.

Though aiming at reducing production costs, European shipyards have to maintain their reputation of delivering highest quality and customer oriented products. It is therefore imperative that the use of advanced materials, for example high-tensile steel, composite and smart materials, is considered in combination with new joining technologies and innovative design approaches.
Shipyards which follow this innovation strategy are literally in uncharted waters. Both the implementation of innovative joining technologies and the promising advantages of advanced materials often cannot be class certified by applying conventional rules. As already described in the section on TSA 3-A, this again calls for a more holistic rule making approach.

Maintenance and Repair

Only a few of the projects reviewed deal with maintenance and repair. These projects cover advanced materials, for example composites patches to prevent crack growth or to reinforce crack risky parts. Others deal with development of manual laser cutting and welding devices. Obviously Laser safety is a main obstacle in the application of manual laser devices in shipyard environment.

The project MoVe IT! uses a holistic approach to modernize inland freight ships and prevent them from over ageing. Therefore several technologies are implemented. The ships drive and power systems are renewed and the hole ship is retrofitted to marked requirements.

Offshore Energy

Only little information (two projects) could be found on R&D activity explicitly related to offshore wind turbines and at the same time falling under the domain of TSA 3-C. Considering the environmental change and the shortage of fossil fuels, this field of action has to be a future focus. The Strategic Research Agenda issued by the European Wind Energy Technology Platform illustrates the importance of this field. (http://www.windplatform.eu/)

Suggested show cases

In an early phase of the project, experts were asked to suggest show cases which give evidence that R&D projects on metal materials and their processing successfully leveraged innovation in the maritime industry. Most of the topics proposed for TSA 3-C dealt with Laser technology – either processing of metals using Laser, or Laser based manufacturing equipment, or new ship design approaches that became possible thanks to Laser technology. There was one more proposal related to improved work safety and health. It was decided within TTG3 to combine those proposals covering Laser to a single show case called 'Ships made of Light – Lighter Ships', since it illustrates the manifold of Laser application and the benefits that can be utilised by shipyards.

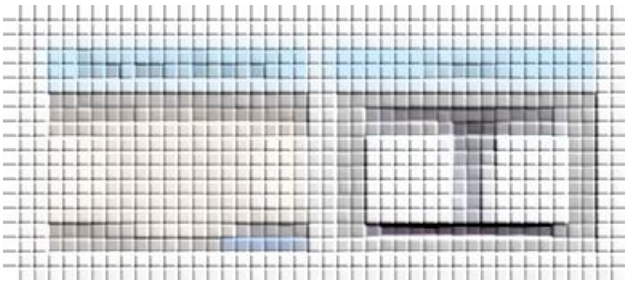


Figure 22: Comparison of typical submerged arc and laser weld

Comparison of a typical submerged arc and laser weld is given in Figure 22.

The darker zone shows the area of molten material for joining identical plates and roughly corresponds to the energy input

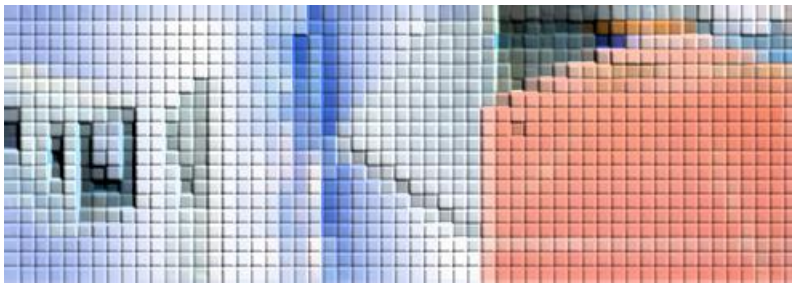


Figure 23: Typical inveesment shares in developing laser welding technology

Laser welded sandwich panels and a typical application in a ship deck is given in Figure 23. Those panels were used in many applications outside shipbuilding as well.

3.5 TSA 3-D Non-metallic structural materials and their processing – joining, outfitting

Introduction

The following sub chapter summarises the state of the art analysis on the basis of several workshops, technical events and expert talks and takes up the findings from the MARPOS Gap analysis in 2011.

The most important events are the co-managed E-Lass / Mesa events with its kick-off on the 8th and 9th of October 2013 at SP Sveriges Tekniska Forskningsinstitut, Borås, Sweden. The workshops are held once or twice a year in different locations. **E-LASS**, the European Network for Lightweight Applications at Sea, aims to promote the use of lightweight materials and lightweight design in the maritime industry as well as reveal the gap between research and industrial use. Within this network about 80 members of different stakeholders like yards, operators, suppliers, academia and class, met and discuss the actual topics in terms of lightweight in the maritime industry. The network as well as the events is supported by CMT on behalf of the **MESA** FP7 research project. Furthermore, information from other workshops, e.g. Evonik workshop on materials for future ship application with 25 external experts, or national workshops on specific technologies, e.g. bonding in shipbuilding, are included in the analyses.

All off these events are aiming for gathering the current state of the art of lightweight materials, provided by the different stakeholders. Lightweight materials are herewith defined as all types of structural material that is neither steel nor aluminium but containing benefits in terms of better weight/structural strength ratio or other benefits. The reason for this definition is related to the SOLAS rules, describing e.g. the use of materials for ships at sea. Chapter II Regulation 17 in SOLAS states that any other material than steel or aluminium has to prove equivalency in terms of safety in case of fire. This sub-chapter documents that this issue is partly dominating the obstacles for industrial use of lightweight material in marine structures.

The following sections describe the state of the art technology from the different stakeholder's point of view as well as technological approaches, research results and best practice examples since the MARPOS Gap analysis in 2011. The conclusions sums up and harmonises the research gaps in terms of lightweight materials for marine structures. The following projects are considered, partly already mentioned in MARPOS.

Table 18: TSA3-D Non-metallic structural materials and their processing - analysed projects

Adam4Eve	BESST	Compas	CONVINCE
Co-Patch	De-Light Transport	ECO-Island Ferry	E-Lass
Lass	Fire-Resist	FLOT	Throughlife
Kompas	Mosaic	LightTankModule	NCC Foam
Bondship	Deep-Co-Hus	DISCO	SMARTYARDS
Sand.Core	Safejoint	Kleben (German)	

Industrial practice

Review

In the range of codes, rules and regulations several vessels and maritime structures are made either partly or full of lightweight materials. Especially high speed ferries using the HSC code, navy vessels or smaller boats and ferries with restricted service are using composite materials. However, there are also intentions to use lightweight materials even for SOLAS vessels. SOLAS rules ensure the safety of seagoing merchant ships. The conversion of the STENA Hollandia and STENA Britannica – two RoPax vessels – were intended to include a full composite superstructure. A consortium from a composite manufacturer, design offices and a conversion yard developed solutions and designs for meeting the same safety as steel structures with respect to SOLAS

and regulation 17. The use of 50 tons respectively 90 tons of composite material saves more than 50% of weight in comparison to the conventional steel design. The solution for joining the steel structure and the composite structure were tested in terms of strength and behaviour under fire. Figure 24 demonstrates a typical steel-composite design.

Figure 24: Exemplarily A60 Composite-Steel design

The risk based design and the technical solutions were discussed with Lloyds Register and the members of the flag states from the Netherlands and UK. A major weakness was the lack of knowledge from the authorities and class with respect to lightweight materials and risk based design approaches. Although all parties were involved in research or other projects in terms of lightweight materials and risk based designs, the knowledge could not be accessed by the personal involved. Due to the tight time period planned for conversion and the expanding time for the risk based approach discussion as well as recommended tests, the superstructures were made in ordinary steel design. Contrary to this afore-mentioned example, two superstructures made of carbon fibre reinforced plastic (CFRP)-sandwich panels were produced and assembled to steel corvettes for the Indian navy. Due to a special composite-steel joint, the panels could be welded to the steel structure. This limits the risk for the ship yard assembling the parts and ensured a high quality within the critical adhesive part, see Figure 25. In terms of Mega-Yacht projects, non-load carrying parts are built in FRP and fixed to the either aluminium or steel structure. However, first full FRP superstructure designs are promoted on the market but not yet successfully applied towards larger ships (above 50m of length).

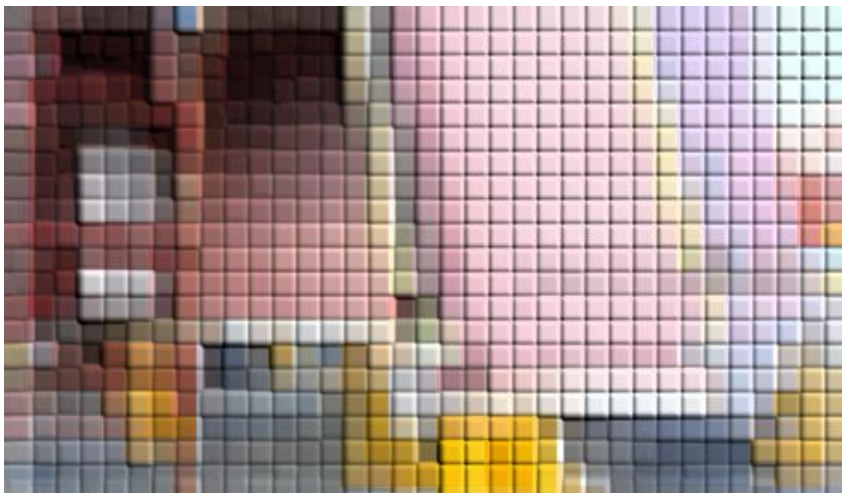


Figure 25: Example for composite panel with joint

The supplier's point of view is focused more on the processes with respect to lightweight materials. Developing innovation processes for the fabrication or assembly of lightweight materials decrease the costs that are still not competitive to steel or even aluminium in terms of material and production. However, innovation leads to new kinds of materials e.g. fire retardant or bio degradable composites, see Figure 26 . Especially the fire retardant composites are in the focus of industry as the fire behaviour of composites is a major obstacle for the use in maritime structures. Here, the project Fire-Resist developed several promising technologies that are at the moment in further development towards market implementation. Furthermore, the large scale fire testing in the best project demonstrated the good performance of already available fire protection systems, e.g. LEO-System from Saertex.

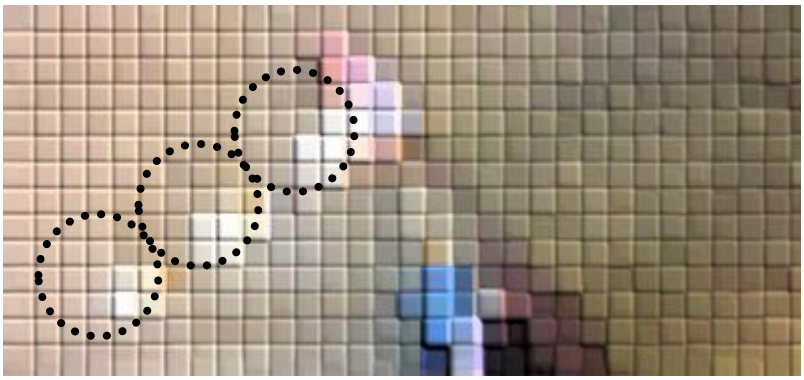


Figure 26: Fire retardant composite specimens

Also bio-composites become more important due to their potential independence from base-materials like oil and their environmental impact. However, the produced structures indicate that production quality is a major issue to receive adequate products. Natural fibres have to be processed to receive fibres of unique quality and bio-resins show not comparable characteristics in comparison to e.g. epoxy resins. NCC Foam and other projects are looking into new kinds of bio resins and composites. Especially lignin as a waste product of the paper industry is suitable to be the raw material for carbon-fibre, while Hemicellulose, another waste material of paper making, is feasible to be the basis for a bio resin.

Beside vessels, offshore structures have great potentials for using lightweight materials. However, the barriers to the use of composites are equivalent to the ones for maritime vessels. In terms of an offshore structure, Figure 27 demonstrates the amount of rules and regulations that have to be considered.

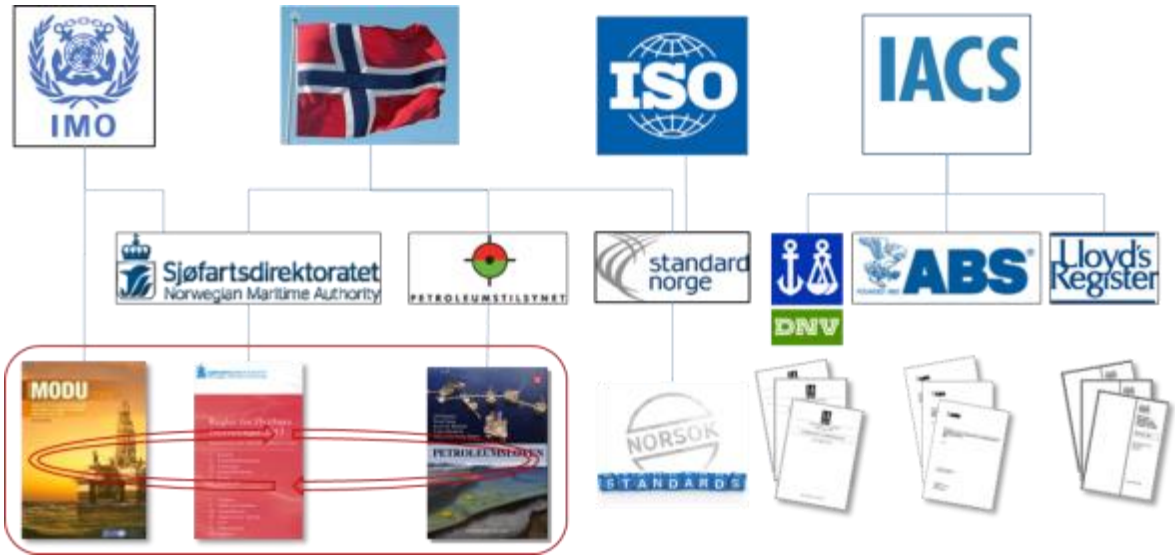


Figure 27: Regulatory framework for an offshore structure (exemplary)

Nevertheless, using lightweight structures offers great potential for operational saving. Small high speed ferries for example are consuming less fuel at same speed in comparison with steel or aluminium vessels. Furthermore, the CFRP Hull needs only low maintenance and is free of corrosion.

One of the most critical issues in using FRP is the need for joining techniques in terms of dissimilar materials: most of the structures will consist of a material mixture with steel or aluminium as main part. Today's joining techniques in terms of FRP to metallic structures are very limited: bonding or bolting is the most common ones. However, bonding is a not class approved technology and needs case by case an approval on a not standardised procedure.

Conclusion

- Lightweight materials are successfully used for construction of high speed vessels, yachts, navy vessels, small boats and ferries with restricted service use
- The high value lightweight materials are often too expensive if either the time for amortisation is limited to few years or a short payback time is recommended
- Only a holistic approach in the use of lightweight materials ensures the highest performance of the material. This is often not implemented. Mostly, a steel design is assumed to be built in composites.
- The risk based approach is time consuming due to the not harmonised interpretation between the stakeholders
- Involved steel yards give a higher price for composite structures due to unknown risks and lose of work (composite parts will be produces externally)

- Using the results and experiences from former research projects (BESST, SAFEDOR, etc.) composites could be successfully applied in combination with steel on navy vessels. However, a classification society has not approved but surveyed the construction.
- For the assembly of superstructures to steel corvettes for the Indian navy innovative composite-steel joints were used, which ensured the high quality of the assembly.
- Regulatory requirements are not updated with the latest developments on composite materials and are not harmonised
- The economic benefits are often not clear or still not compensating the user's concerns

Rules and regulations

Review

The range of codes, rules and regulations is wide spread in the maritime field. According to the specific type of ship, operational area, cargo, structure, purpose, flag state etc., different codes must be or can be applied. A general differentiation might be the operational area in terms of e.g. seagoing vessels, inland waterway vessels or even offshore structures. But within these main groups as well as in between them are several other diverse groups of vessels or structures with own rules and regulations. The overall rules for seagoing vessels are established by the International Maritime Organisation (IMO) and in most cases referred to special ship types. Examples for rule frameworks from IMO are SOLAS[3] or HSC[4]. SOLAS rules are applied to about 99% of merchant ships in terms of gross tonnage and cover 159 signatory flag states[5]. These rules ensure a minimum level of safety standards in several areas. Furthermore, according to the flag state and the classification societies, other national rules have to be applied. While most of the regulation and rules from the classification societies are harmonised among each other, e.g. by the International Association of Classification Societies (IACS), the national rules are diverse. The same applies looking at naval and civil ships. For navy vessels it is common not to use SOLAS or civil national rules as this is not prescribed by authorities. However, the navy codes are partly based on SOLAS or HSC with the main difference that the safety of ship and crew may be secondary to the safety of those under the protection of the navy ship. The Naval Ship Code (NATO document) is an example for a goal based standard that determines a minimum level of safety for naval vessels. Goal based standards and prescriptive standards are the two major distinctions of rules. In this context the goal based standards describe the required result contrary to the prescriptive standards specifying the way and the means towards a defined result.

[3] Safety of Life at Sea (SOLAS) by IMO

[4] International Code of Safety for High-Speed Craft by IMO

[5] Implications of the United Nations Convention on the Law of the Sea for the International Maritime Organization, Study by the Secretariat of the International Maritime Organization (IMO) (LEG/MISC.7), International Maritime Organization, 2012

Goal based standards	Prescriptive standards
• Result-oriented • Defines goals • Risk-informed • Compliance judged by performance measurement	• "What to do and how to do" prescribed • Defined means • Not risk oriented • Compliance determined by "check-list"

The most important issue with respect to lightweight materials in maritime structures is to meet the safety requirements. Non-metallic materials, especially fibre reinforced plastics (FRP) and structures made out of them are in nearly all cases combustible and meet therefore not the SOLAS safety requirements when built as load-carrying structures. Fire on board of seagoing vessels is one major risk for the loss of life at sea. Beside temperature and smoke, the loss of structural integrity is determined as a serious harm. Metallic structures are not combustible and retain generally speaking "a structural integrity reserve" due to the temperature/strength behaviour of the metals within the time mark of one hour after ignition. Structures made of combustible materials do not have the above-mentioned structural reserve. Furthermore, they are secondary fuel to the fire. Therefore, prescriptive standards do not allow the use of such materials. However, goal based standards only determine the same level of safety, e.g. SOLAS Chapter II-2 Regulation 17[6]. This regulation gives the opportunity of using lightweight materials by proving equivalency to steel structures. One of the major concerns in this matter is the process and methodology of proving this equivalency. This topic is discussed within the several IMO committees as well as between the regulatory bodies and class societies. It is expected to work on this topic within the IMO-SOLAS Sub-Committee on Ship Design and Construction starting from January 2014.
However, alternative designs containing lightweight materials could already be applied under SOLAS rules. Using a risk-based-design approach and validating the safety equivalency (structural test, fire test, etc.) enables a class approval and flag state approval but only case-by-case, e. g. for each structure or vessel, see Figure 28. Though, no SOLAS ship structure contains structural lightweight materials yet.

Figure 28: Risk based design methodology - Source: Lloyds Register

This methodology is nowadays common but there are no harmonised guidelines or rules neither for the procedure itself nor for required tests and results. Therefore, the needed amount of effort and costs is only vague predictable. An IMO correspondence group is established under the lead of the Swedish transport agency to bring in proposals for Reg.17 guidelines. The first draft on proposed guidelines for carrying out the

[6] SOLAS: CONSTRUCTION – FIRE PROTECTION, FIRE DETECTION AND FIRE EXTINCTION
Alternative design and arrangements - The purpose of this regulation (Reg.17) is to provide a methodology for approving alternative design and arrangements for fire safety

in Reg. 17 mentioned "engineering analysis" was neglected by IMO in spring 2015. The correspondence group will now update the guidelines and talk to the flag state authorities. In this group, more political then technical issues were raised. Moreover, the member states of the European Union were not unique in their vote in this manner.

However, there are rules allowing the use of lightweight materials. The HSC code or the Large Commercial Yacht Code (LY3) is allowing lightweight materials but have restrictions with respect to the fire safety, see Figure 29.

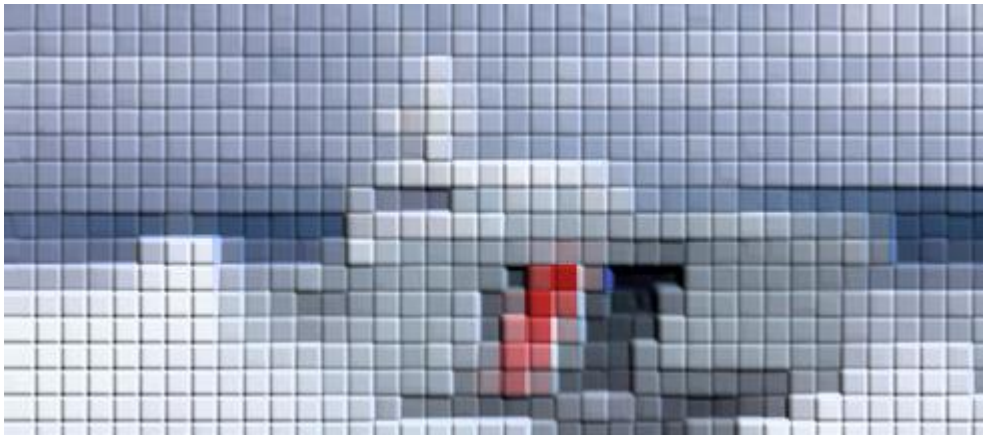


Figure 29: Patrol Boat made of Carbon Fiber Composite - Source: Lloyds Register

Conclusion

- There are no overall rules for all type of ships with respect to structures and materials
- Depended on the operational area or vessel type, some rules allow already the use of lightweight materials
- The use of lightweight materials is committed to the equivalency of safety compared to metallic structures
- The methodology of demonstrating equivalency is not harmonised between the regulatory bodies
- There is a strong demand for reliable data on lightweight materials to facilitate confidence
- National rules, especially for inland navigation or short sea shipping, are often contrary to EU and IMO rules. Furthermore, other rules and guidelines have to be applied for, e.g. offshore structures.
- The amount of regulatory bodies, classes, authorities, etc. for approving vessels or structures is obstructive, due to their different rules (goal based / prescriptive) and whether a risk based design approach has already be applied
- Effort should be spent to bring the knowledge of FRP on a national basis to harmonise IMO efforts

Research and development

Review

Table 19 TSA3-D–Projects per research domain and (sub) topic

Research topics	Analysis	Projects
Weight and application optimisation	The use of lightweight materials such as FRP sandwich structures in SOLAS vessels lead to new lighter design offering the possibility to extend the number of decks. Moreover, the integration of local lightweight solutions due to their mechanical or other beneficial properties were applied. Furthermore, integrated solution for outfitting within the structural lightweight members are investigated and tested.	BESST, MOSAIC, ADAM4EVE, activities of KTN, ThroughLife
Strength and Fatigue	Determination of the material properties of the particular materials and examining of the fatigue life and crack behaviour of conventional and new bio-composites. The knowledge is used to strengthen structures suffering high fatigue relevant loading or even cracked structures by covering with FRP patches.	BESST, DE-Light Transport, Groot composite Throughlife. Co-Patch
Production processes / joining	Development of reliable assembling techniques for lightweight structures and outfitting – multi material joints. Steel-composite connections are already successfully applied on naval ship. New welding techniques for low distortion structures in steel are investigated	ADAM4EVE, BESST, Kleben + Rohrkleben HILDA
Overcoming of the SOLAS requirements and other regulations	Determination of the possible use of particular lightweight materials (e.g. FRP composite) in the light of SOLAS by demonstration or developing of Reg.17 guidelines.	FLOT, Kompas, E-LASS
Safety issues / fire	Development of lightweight materials with fire retardant properties or of non-combustible material with equivalent strength and performance properties in comparison to state of the art composites.	FIRE-Resist, innovations made by BLATRADEN company, Compas, CONVINCE
Environment	Examining of the environmental impact of lightweight materials	ECO-Island Ferry Project, ADAM4EVE
Economic benefits / LCPA	Defining of potential sources of cost reduction resulting from application of lightweight materials: lower maintenance costs due to the low corrosion, influence on stability and payload due to light weight (Comment: Both lead to more a more efficient operation with respect not only to economic figures but also with respect to ecological aspects. However, the nowadays production costs are still leading to ROI (return on investment) times that are out of the ship operators scope.)	ECO-Island Ferry Project, ThroughLife, ADAM4EVE, TankLightModule, Activities of KTN
Offshore Platforms	Application of the lightweight designs for the Offshore platforms	FLOT (Offshore and Lightweight), Activities of KTN, Co-Patch

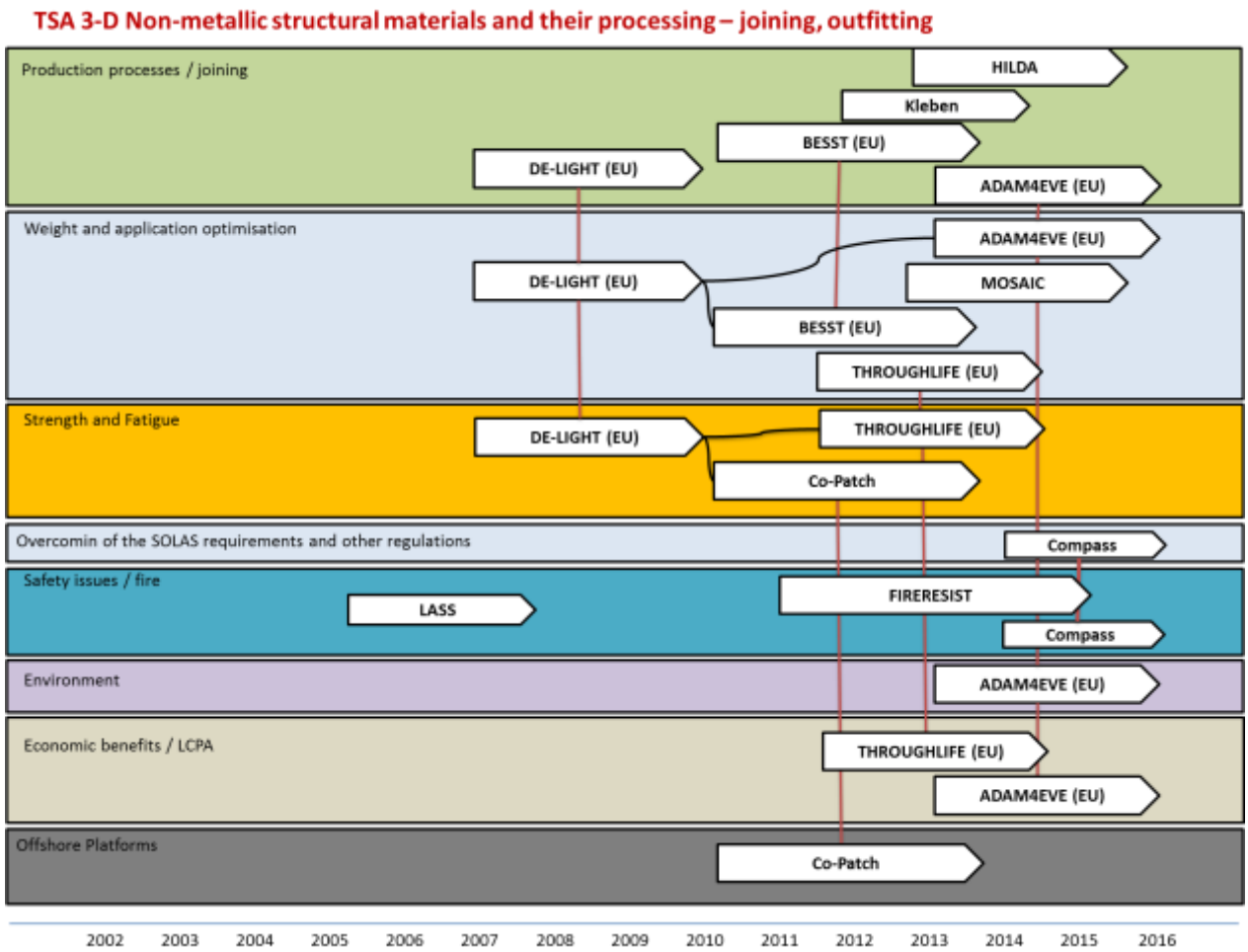


Figure 30: TSA 3-D Non-metallic structural materials and their processing – Project timeline

Conclusion

- Lightweight materials demonstrate great potential in their use as structural or strengthening material in small-scale or laboratory testing. Larger applications and longer testing durations are needed.
- There is no harmonised material and test database. Most of the results from the different research projects stay in the consortium and are not evaluated towards previous research.
- In most projects no authorities or classification societies are involved. If they are involved, the knowledge is not converted into a knowledge base used for industrial applications or rules / guidelines.
- One of the key-parameter for using composite on SOLAS vessels is the behaviour under fire loading. Here, the major point is to find fire-retardant composites as well as testing standards.
- The economic benefits are highly dependent on the initial costs that are still high in terms of lightweight materials. New cost effective production methods for composites are needed with focus on the requirements from end-users (shipyards).
- Regulatory requirements have to be standardised and harmonised for a successful use of lightweight materials. Especially the transport authorities of Denmark and Sweden are involved in such efforts. However, a wider scope of stakeholders is needed.

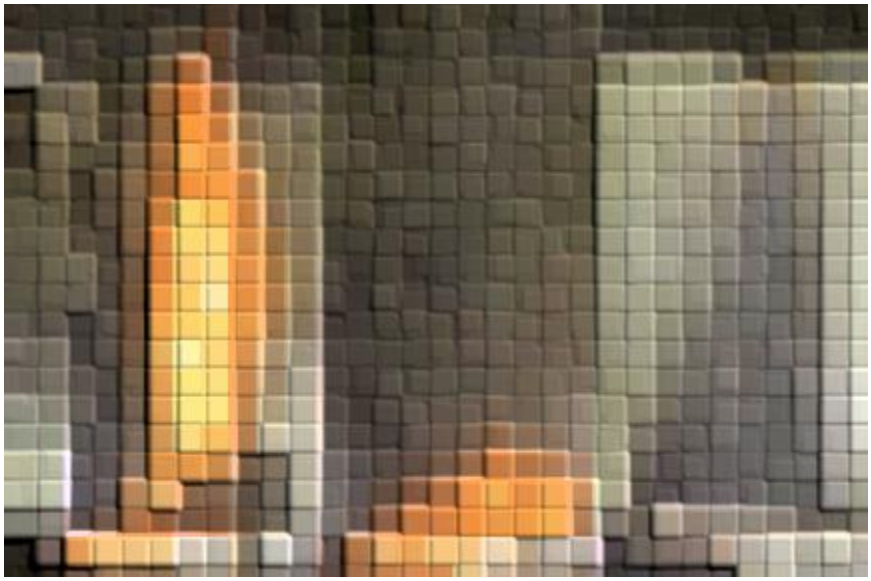
Suggested show cases

1. BESST: composite-steel joint

Tested and applied CRFP sandwich to steel joint via adhesive bonding including mechanical fixtures. The joint was tested under static, dynamic and thermal loading and passes the costumer's requirements.

The production methodology of pre-fabricated panels including the bond ensures an optimum process time on the shipyard. Here, only welding of the steel part and minor work on the composite is required for assembly. (Figure 31)

Figure 31: CRFP Sandwich



Composite sandwich structure in fire This showcase demonstrates the risk-based design option on composite structures. In case of a fire, drencher systems will activate and extinguish the fire as well as protecting the composite.

The structure contains nearly full structural strength after the test. Also other options, e.g. a coating system "LEO", were applied and successfully tested. (Figure 32)

Figure 32: Fire Test of Composite Steel Join [BESST]

3. Composite Patches successfully applied on naval ships, offshore platforms and civil constructions

Composite patches can strengthen structures in terms of fatigue loading. This prolongs the life-time of structures even when repaired due to cracks. The improved fatigue behaviour of these hybrid constructions can also be used to prevent damage from important structural parts.

Long-time studies from the Australian Navy demonstrate that the benefits and use of these patches are significant in terms of cost reduction in maintenance.

Figure 33: Composite Patches

3.6 TSA 3-E Materials and Processes for Corrosion and Fouling Protection

Introduction

The information within this report has been gathered from a number of sources including: Safinah's extensive in-house records of conference and journal papers that have been published on matters surrounding marine and industrial coatings; involvement in previous and current EU research projects; UK government funded research projects; end user surveys; books, for example, "Advance in Marine Antifouling Coating and Technologies"(see annexe), and conversations with well-established and respected members of the marine and heavy duty coatings industry who are involved with all aspects of this sector. In order to increase the cooperation potential, two workshops were also carried out. One of them looked at the potential use and benefit of self-healing coatings for water ballast tanks.

The following list of projects (Table 20), has been analysed in this report. The use of an acronym (in order to shorten the project name) has been used. The project title name can be found in the annexe "Abbreviation".

Table 20: TSA3E: Material and processes for corrosion and fouling prevention–Analysed projects

AMBIO	CERTOL	FOULPROTECT	SEACOAT	AOMAS
A2M	CHANGE	FOUL-X-SPEL	SEAFRONT	FOREIGNYARD CBS
BACT2ALGA	CLEANMOULD	GREENSHIP	SHIPINSPECTOR	FRA4SHIPCOAT
BEEST	CLEANSHIP	HAI-TECH	SMARTYards	LL4NBC
BEKAS	CO-PATCH	HISMAR	STEELCOAT	RFPPAINT
BIOCORIN	CORFAT	IATS	TARGETS	RPCP
BIOFOUL CONTROL	DISPRO	LEAF	TBTIMPACT	SALTMIT
BYEFOULING	ECODOCK	MOSAIC	THROUGHLIFE	SASBLASTING
CARBONCOMB	ECO-REFITEC	NANOMAR	WELDAPRIME	SPQAQCIMPROVE
CAS	EFTCOR	PAINT FILM CRACKING		SPITYARDLASERABLATION
CCNS	FLIPPER	RISPECT		50RHDTP

Industrial practice

Review

Shipyards use mature technology (i.e. since the early 1970's there have been few radical developments). As seen in Diagram 1, in terms of the coating process, modifications appeared in the 1960's with the introduction of abrasive blast and airless spray equipment as well as epoxy paint.

For the shipyard, the need is to improve productivity in ship building. This may be obtained by:

- Paint application: using coatings with shorter drying time, with less number of coats, with more surface tolerant properties;
- Better integration of the coating process at the design stage;
- Paint inspection: use of electronic inspection tools.

The ship-owner, on the other hand, is more interested in paint performance and reducing the potential amount of paint maintenance and repair.
Research in the field of coatings engineering has lagged behind that of the other elements of shipbuilding, in much the same way the development of the coating process has lagged behind the steelwork and outfitting processes. It is possible to identify four areas where improvements could be made:

1. Process improvements;
2. Product improvements;
3. Use of alternative materials;
4. Improved integration of the coating process.

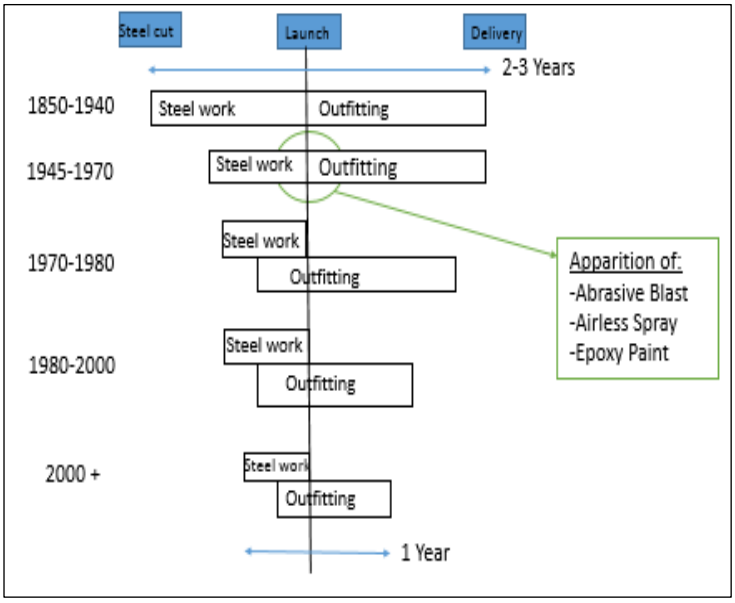


Figure 34: Timeline of Shipbuilding History

Process improvement

There are no technologies on the horizon that will provide major improvements to the coating process. The automotive and domestic industries constitute the majority of the market for manufacturers of spray equipment. Heavy industry makes up a small proportion with the shipbuilding industry not mentioned at all by many companies. From this it is possible to conclude that the shipbuilding industry represents a very small percentage of the market for spray equipment manufacturers. The effect of this is a situation where there is little chance of any manufacturers entering into a research and development programme that will address the needs of the shipbuilding industry more directly, as it is unlikely that they will re-coup their investment.
Research continues into the use of lasers, this has principally been to reduce the amount of repair or rework of damaged coatings. The problem of adopting this approach is that it will further compound the current situation where coatings and their application are not seen as a value adding process.

It is possible that the application of alternative surface preparation methods may lead to improvements in productivity within a yard and improvement of the in-service performance of the applied coatings. CO_2 hydro blasting and water jetting had been used successfully for surface cleaning activities as they cannot create a surface profile.

Hydroblasting has been used in conjunction with specifically designed Euronavy ES301 coating. It has been reported that an improvement in the overall productivity of the process has been achieved. It may be a happy coincidence but the first water ballast tank that the system was used upon appeared to be of a much simplified design. This may have been to accommodate the blasting hose needed which as a result led to a reduction in the complexity, thus improving the working conditions for the applicators, which will no doubt have had a positive effect on the performance of the coating.

Surface preparation methods such as hydroblasting and slurry blasting drastically reduce, if not totally remove, the levels of dust that workers are exposed to. As a result of this, these types of systems are becoming more widely accepted in the protective coatings market. It is also fair to expect the allowable worker exposure limits to be reduced over time, thus any other solutions must seek at least to match current exposure levels if not reduce them.

Product Improvement

A range of functional requirements for any new coating product was developed in the BESST programme and confirmed during the joint Throughlife/MESA workshop in Papenburg. The conclusions that can be drawn from this are that the product investigation can be divided into two sections; primers and finish coats. The common improvements sought are:

- Reduction in curing/drying time;
- Wider environmental and temperature application window;
- Open over coating interval;
- Cleanable, smooth surface;
- Increase in resistance to chemical and oil degradation;
- Reduction of the number of scheme and coating layers;
- More surface tolerant coatings (i.e. with lesser surface preparation);
- Reduction of the VOC;
- Ease of repair / touch up;
- Resistance to damage.

A universal primer specifically must possess the above plus be:

- Compatible with typical shipyard welding and cutting processes;
- Compatible with coating schemes applied to it.

Whilst there is a requirement for finish coats to exhibit:

- Better impact and abrasion resistance;
- A smoother surface finish, particularly for external steelwork.

Areas that are continually highlighted by shipbuilders for focus are the reduction of curing time and improving impact and abrasion resistance of the coating. Reducing the cure/drying time will decrease the dwell times associated with the coating process thus improving the productivity of paint cells, and reducing the occurrence of handling damage during transit due to insufficiently cured paint. Improved impact and abrasion resistance will reduce the amount of touch up required to coatings applied early in the build cycle. By addressing these areas it may be possible to gain more control over the coating process through the reduction of rework.

The Throughlife project has developed a self-healing coating, by incorporating beads containing a self-healing liquid into the applied paint film. When the film is damaged the beads break and release their contents allowing the film to 'heal' thus preventing further breakdown and subsequent corrosion. Testing was undertaken for UV exposure, in an IMO water ballast tank test rig and in a WBT on board a vessel in service. The test results have proved that in principle the concept works, however further research is needed before the concept could be commercialised.

The development of new exotic paint chemistries is a delicate balance of the actions of the chemical components and the application process in the field. There will always be a degree of compromise such as trying to reduce the curing time whilst reducing the VOC emissions. This achieves a shorter drying time using a high volume solid paint, but at the expense of a reduction in pot life.

The development of new molecules is generally outside the capabilities of a paint company; it is more the domain of the raw material suppliers. A raw material supplier must see the demand for a new product before they are likely to engage in any costly development work. To this end it is the responsibility of a paint company to identify this need and approach a raw material supplier with a proposal; whereby they are granted exclusivity for a period of say five years. Unless this occurs it is unlikely that there will be any development of new molecules in the near future.

It should also be noted that there is a long lead-time associated with the development of new coatings. This is as result of the cycle of formulating and testing the product. Then there is the process of gaining approval for the coating itself, and any new materials contained within it. Once all of this has been achieved it is possible to introduce the product to the market. For example the testing period for a new product would typically last 2 years. This results in a cycle for development of a typical organic paint being approximately 5-10 years. Also the use of additives to enhance the properties of products currently on the market has yet to be properly investigated.

Materials

There is the possibility of using alternative materials with improved corrosion performance, such as stainless or corrosion resistant steel, aluminium, FRP, or composite, however it is unlikely that the majority of shipbuilding will move away from mild steel in the foreseeable future. These could be used in areas where the structure is not supporting large local or global loads of the vessel, such as the superstructure. However it is not possible simply to replace mild steel with a material that provides better corrosion resistance or will not corrode. This would require detailed structural analysis to ensure that the design is capable of coping with the loads likely to be applied to it. Also the use of these more exotic products is not without an associated increase in material, handling and redesign costs.

There is merit in conducting further research into alternative materials which possess similar properties to that of mild steel in terms of:

- Structural properties;
- Material handling;
- Joining;
- Weight;
- Cost.

A material which exhibits many of these characteristics, may provide a potential solution. It may be possible to demonstrate that the increased cost of that material in terms of one of the factors above, may be balanced by removing the need to apply a protective coating to it and maintain it during the service life.

Improved Integration

The IMO Performance Standard for Protective Coatings (IMO PSPC) was introduced in an attempt to improve the in-service performance of applied coatings in ship water ballast tanks (WBTs). The regulation has set out application standards which are expected to ensure the coatings last for 15 years. Since its introduction many shipbuilding yards have highlighted the increased burden it places upon them in terms of inspection work, which is a direct cost to the builder and does not add value to the finished product.

This has re-opened a wider debate on the integration of the coatings process into the overall production planning process in shipbuilding. One study undertaken in the UK has assessed the impact of the PSPC on shipbuilding, the responses indicate the increase in workload as a result of the introduction of the PSPC. Another study (Dispro) has just been completed which quantified the benefit to overall production cost by considering the coating process at the design stage.

It has been reported that between 12-25% of the total labour costs of building a ship are associated with the coating process and of this as much as 30% is used for rework. Thus significant savings/ improvements could be realised using the technology and products currently available if better integration were achieved.

Conclusion

Overall the coating process lags behind other shipbuilding processes such as production and outfitting in terms of both research and development. Paint companies will continue to lead product development, which is likely to focus on formula optimisation. The use of additives is also likely to increase however the industry will remain dependent on epoxy-based chemistry until raw material suppliers can develop new molecules which are capable of matching the cost and performance of these products.

Research indicates that it is unlikely that any completely 'new' process equipment will be introduced. For the foreseeable future substrates will be prepared by propelling a hard media at the surface to create a suitable anchor profile, and forcing the liquid paint through a nozzle to apply it. Alternative technologies have been used in the cleaning process most notably CO_2 blasting and hydro-jetting however these processes can only be used for secondary surface preparation as they are unable to create a surface profile.

Areas for further research which are likely to provide cost savings are: improving the integration of the coatings process, for example though improved design or production planning; the use of alternative materials for secondary structures where appropriate; inspection of applied coatings focuses on Quality Control, a move towards Quality Assurance would help to build quality into the process rather than inspect it out.

Rules and regulations

Review

The most recent regulatory change in the coatings area of the industry has come in the form of the IMO Performance Standard for Protective Coatings (IMO PSPC) ultimately this standard seeks to improve the safety of ships by reducing corrosion and the subsequent loss of structural steel from the main hull girder in ship water ballast tanks (WBTs).

A recent study which canvassed opinion across the industry highlighted a number of problems with the regulation as its stands, as such a large number of revisions of the unified interpretation related to the PSPC. The lack of clarity of the regulations can lead to variance in their interpretation.

From a health, safety and environmental perspective there is continuing pressure to 'clean up' the shipbuilding process, such as the introduction of limits on the release of Volatile Organic Compounds (VOC's) from coatings. This has driven paint manufacturers to develop high solids (lower VOC) coatings and shipyards to introduce methods to capture and dispose of released VOC's.

Conclusion

It will be a number of years before the success of the IMO PSPC can be judged in terms of reducing the number of ship losses from structural failure in the WBTs. As the first vessels delivered in accordance with these regulations are only five years old, and the typical age of those lost due to corrosion-related structural failure was over 15 years old. The issue is further clouded by the introduction of revised rules (Common Structural Rules, CSR) which also aim to improve the structural performance and reliability of ships.

From an environmental standpoint it is highly unlikely that worker exposure limits or allowable discharge rates will be increased, the opposite is almost inevitable. Increasingly stringent health and safety legislation is expected to be the major driving force behind the adoption of either new process technologies or coating products, as cleaner and greener alternatives are sought in shipbuilding.

Research and development

Review

A description of the research topics evaluated in this report are mentioned in Table 21. These are classed under the following headings:

- Coatings Processes and Inspection,
- Anticorrosive Coating Material,
- Antifouling Coating Material,
- Fouling Prevention (not coating related),
- Design for Coatings,
- Worker Exposure, Environmental releases.

An analysis of findings is given at the end of Table 21.

Table 21: TSA3-E–Projects per research domain and (sub) topic

Research topics	Analysis	Projects
Coating Processes and Inspection	**Coating Processes** ->BESST looked at identifying the coating needs of shipbuilders and examined the coating process to identify causes of damage and delays. The significant lack of development of the processes used to clean and prepare substrates and apply protective coatings, when compared to other shipyard production processes was identified.	BESST
	->Edge preparation prior to coating was heavily researched in the German BEKAS project, and the connected investigation of corrosion protection quality for coated edges also considered edges that had been coated in different ways.	BEKAS
	Coating Inspection ->The objective of the HISMAR project is to design, develop and build a working self-navigating robotic prototype for the purpose of autonomous hull cleaning and inspection of ocean going commercial and military vessels.	HISMAR
	->The objective of RISPECT is to develop an inspection planning tool that is intended to be used by the shipping industry. The tool will use standard descriptions of structural components and defects and standardised calculation methods along with experience-based calibration factors and will be based on reliability analysis. Shipping companies will either obtain a complete system or apply the standard within their own systems to allow communications with the central statistical database (CSD).	RISPECT
	->CLEANSHIP is a project designed to prevent and detect fouling on ships, which frequently have to be taken out of service to be cleaned due to the formation of hull fouling from the marine environment. -> The project CORFAT looked at a maintenance process based on monitoring the status of the structural integrity in terms of developing fatigue cracks and active corrosion using the permanent Acoustic Emission (AE) technology. The conventional maintenance and inspection can be replaced by a cost effective and condition-based detection of defects.	CLEANSHIP

Research topics	Analysis	Projects
	->Similarly to CORFAT, the project SHIPINSPECTOR looked at an automatic corrosion inspection system. Technology used in this case is based on long range ultra-sonic testing. As part of the QA and QC process, the RFP Paint and CAS projects evaluate the use of paperless systems. ->The CAS project looked at the hull condition monitoring process with the use of supporting software (rather than by excel spreadsheet as is currently being carried out for thickness measurement). As a result it will become possible to handle hull condition data acquisition electronically as well as its preparation, analysis and assessment. **Surface Preparation and coating removal** SPITYard LaserAblation, SAS Blasting, SPQAQCImprove and EFTCOR projects looked at surface preparation techniques. Current surface preparation processes employing chemical stripping, blast media and high-pressure water techniques which generate large waste streams and are difficult to perform inside a tank, the SPITYard LaserAblation project looked at closed-loop Laser Ablation as a potential alternative technique. The project EFTCOR looked at environmentally friendly and cost-effective technology for coating removal other than the grit blasting technology used at present. **Coating Application** The projects looked at improving efficiency and reducing costs in the shipyard without downgrading the coating performance. Projects looked at the minimum requirement in terms of humidity level (50RHDTP), pre-construction primer retention (RPCP), flash rust (FRA4ShipCoat) and salt level (SaltMit). **Best coating Practice processes** Foreignyard CBS and LL4NBC projects looked at best practice in terms of the coating process. For example, the Foreignyard CBS project looked at comparing current coating related processes in Europe, Japan and USA and established best practice processes.	CORFAT SHIPINSPECTOR RFP Paint (USA) CAS SPITYardLaserAblation SASBlasting SPQAQCImprove EFTCOR SaltMit, 50RHDTP, RPCP, FRA4ShipCoat Foreignyard CBS LL4NBC
Anticorrosive Coating Materials	BESST looked at alternative coating materials (sol gel coatings, foil film) and the incorporation of additives (carbon nano tube, zeolithes, nanoclays) into coatings to improve the performance of anticorrosive paints principally in the cruise ship market. THROUGHLIFE investigated the use of micro-capsules to provide self-healing properties to anticorrosive protection paints. A UK grant project (Paint Film Cracking) investigated primer embrittlement in ballast tank coatings. The understanding of this issue will enable the coating life cycle to be prolonged.	BESST Throughlife Paint Film Cracking

Research topics	Analysis	Projects
	WELDAPRIME looked at providing a protection primer with an optimum thickness and affordable cost, offering durable corrosion protection, resistant to mechanical damage and weldable without zinc fumes.	WELDAPRIME
	The objective of the STEELCOAT project is to reduce the use of toxic and hazardous compounds and extend the service life of anticorrosion coatings for steel. The project aims to develop novel green, environmentally friendly, anticorrosion coatings with extended durability for steel protection. The coating will be based on green nanoparticle, conductive polymer, in both high solids (HS) solvent-borne and water-borne anticorrosion maintenance coatings.	STEEL COAT
	The main objective of BIOCORIN is to develop an innovative biomimetic and eco-efficient environmental technology for inhibiting microbial induced corrosion (MIC) produced by biofouling through the integration of microorganisms in a sol-gel coating for metal surfaces of civil engineering structures in marine and terrestrial environments such as highway bridges, gas and liquid transmission pipelines, waterways and ports, airports and railroads.	BIOCORIN
	The NANOMAR project aimed to develop a new generation of “smart” bifunctional coatings that combine self-healing anticorrosion ability with antifouling properties for offshore applications such as oil-mining platforms and windfarms. The main scientific approach on which this project was based was the controlled release of the active species (corrosion inhibitor and biocide agent, respectively) from nanostructured receptacles (nanocontainers) in damaged zones of the coating.	NANOMAR
	Test Methods Investigation CCNS and ECODOCK looked at test method evaluation for corrosion resistance. ->CCNS looked at faster testing for atmospheric and immersion exposure condition that still have relevance to real life in-service degradation of coatings and corrosion of the underlying structure. ->The objective of ECODOCK was to develop a test method for primer coatings. As an example it was to evaluate: - coating degradation at steel edges as a result of exposure testing in sea water / marine atmosphere. - suitable test methods for the evaluation of coating flexibility and internal stress.	CCNS ECODOCK
	Alternative Materials to Steel -> MOSAIC, CLEANMOULD and CO-PATCH projects, looked at alternative materials to steel. ->The project MOSAIC looked into the replacement of specific structural parts of the ship (superstructures, transverse bulkheads, partial decks, etc) with composite materials (such as GRP) to reduce weight and corrosion. As a result, this will reduce the maintenance and overall cost of operation of the vessel and reduce fuel consumption. ->The objective of CO-PATCH is to demonstrate that composite patch repairs or reinforcements can be environmentally stable and therefore that they can be used as permanent repair measures on steel marine structures and steel civil engineering infrastructure applications.	MOSAIC CLEANMOULD CO-PATCH

Research topics	Analysis	Projects
	Shipbuilding and other industries will continue to use products based on epoxy chemistry, until another product is introduced or developed that gives better performance in terms of comparable price, productivity and performance. A lot of research is being carried out into conductive raw material, powder (graphene, nanocomposite), polymer (based on PANI), sol gel and super hydrophobic coatings. Also these materials have shown encouraging results in terms of anticorrosive performance in the laboratory environment. They currently do not have any track record in the field.	
Antifouling Coating Materials	**The following projects looked at fouling prevention formulation with the view of making them more environmentally friendly:** ->The AMBIO project examined in the laboratory a wide range of nano-structured coatings, 15 of which were field tested and showed promising results. ->The results of the AMBIO project have led to several other projects like for example: A2M, CARBONCOMB, SEAFRONT, SEACOAT. ->The A2M project looked at enzyme-based active principle as a means of avoiding toxic chemicals in antifouling paint. ->SEACOAT seeks to improve understanding of bio-interfacial processes involved in the colonisation of surfaces by marine fouling organisms. The goal was to discover which nano- and micro-scale physico-chemical properties of surfaces influence the adhesion of fouling organisms ->The SEAFRONT project was aimed at integrating multiple technology concepts such as surface structure, surface chemistry and bio-active/bio-based fouling control methodologies and drag-reducing solution for mobile and stationary maritime applications. -> CARBON COMB looked at the synthesis of environmentally friendly nanoscale polymers of nanostructured carbon (carbon nanotubes ie CNT, graphene) by employing cost effective methods. CNTs were found to have a positive impact on fouling performance in the AMBIO project. ->The LEAF project is looking to optimize the copper biocide coating matrix in order to eliminate completely the release of biocides. ->The German HAI-TECH project successfully developed a coating structure that mimics the surface of sharks (Hai is German for shark). It is intended to investigate the fouling properties of such surface geometries in an upcoming successor project.(Foulprotect). ->The CERTOL project aimed to create antifouling coatings where substances poisonous to fauna can be substituted with environmentally safe but efficient components. The research focused on looking at surface microtopology, unfriendly to fouling. ->The BACT2ALGA project aim was to understand the following: - Reproductive stage of biofouling organism; - Factors that influence the surface selection before the fouling organisms settle permanently onto the surface. ->The FOUL-X-SPEL project looked at non release biocide. BYEFOULING is an ongoing project which addresses high volume production of low toxic and environmentally friendly antifouling coatings for mobile and stationary maritime application. The technology will look at the incorporation of novel antifouling agents and a new set of binders into the formulation.	AMBIO A2M SEACOAT SEAFRONT CARBON COMB LEAF Hai-Tech FoulProtect CERTOL BACT2ALGA FOUL-X-SPEL BYEFOULING

Research topics	Analysis	Projects
	Test methods and benchmark of advanced paint solution. **->**This was the focus of the ECODOCK and IATS projects. **Evaluation of in-field performance of foul release coating** The greenship project looked at monitoring all new applications of HEMPASIL X3 (silicone paint) using the SeaTrend performance monitoring software. As a result, the effect of the newest generation of silicone paints will be documented. **Evaluation of friction resistance of current fouling prevention coatings:** The Target project researched the problem of biofouling and reviewed the main fouling prevention technologies used today. This project also evaluated the impact of the fouling prevention technologies in terms of friction resistance. **Ways to reduce frictional resistance:** This project focused on coatings (made from rubber) used to delay laminar turbulent transition on the ship's hull. As stated, the issue of fouling is not addressed by this project and this technology is only intended for the bow of the ship. We are unlikely to see the introduction of any new biocide-based antifouling products due to the REACH regulations. As a result, the research currently carried out in biocide technologies is to investigate the reduction of their release level into the environment. Another similar strategy to the biocide, involves the use of environmentally friendly enzymes. The development of low surface energy, amphiphilic or hydrophilic polymeric systems also have to overcome the entry into market requirements of shipowners such as demonstrating a suitable track record or a reliable cost benefit.	IATS ECODOCK GREENSHIP TARGET FLIPPER (MARTEC)
Fouling prevention (Not coatings)	Alternative fouling prevention was looked at in projects CLEANSHIP and BIOFOULCONTROL: ->The CLEANSHIP project looked at ultrasonic fouling prevention. ->The BIOFOULCONTROL project developed a new method for control of marine biofouling in the cooling system of vessels with application of ozone. The intelligent process control of the ozone dosage to attain optimum system operation.	CLEAN SHIP BIOFOULCONTROL
Design for Coatings	The DISPRO project sought to re-evaluate the design process in order to consider the needs of the coating process as part of overall production. Seeking a minimum total cost solution, whereby the production and coating costs were considered, demonstrated that it is possible to reduce overall production costs. The additional benefit of this approach is that the coating work content is reduced which will have additional benefits for the overall throughput of a yard and potential in-service benefits due to reduced maintenance. In reaction to the IMO PSPC regulation, a design study was undertaken in BEKAS, aimed at avoiding too many free edges in void spaces and ballast tanks which would need to be rounded according to PSPC.	DISPRO BEKAS SMARTYards

Research topics	Analysis	Projects
	In the EU Funded project SMARTYards (currently running), optimisation of Design for Coatings is analysed by developing a proposed Coating Decision Support System, which gives a score for the coating system by determining the practices and processes involved in the shipyard. The aim is to streamline the coating processes so that time, money and raw materials are saved.	
Worker Exposure, environmental releases.	The ECODock project sought to improve the performance of marine coatings during the lifetime of a ship and to reduce the environmental impact of marine coatings.	ECODock
	The TBT Impact project, looked at the implications of TBT pollution and its ban. It also developed tools, such as indicators, quality control programmes and policies, for monitoring and managing the environmental impacts of organotin compounds.	TBT Impact
	The project CHANGE, looked at the amount of cuprous oxide required in antifouling paint in order to control fouling in the Baltic Sea, as different agreements are approved depending on the country (i.e. Finland: 35% cuprous oxide - Sweden: inferior at 10% of cuprous oxide).	CHANGE
	The project ECO-REFITEC looked at the application of foul release coatings in maintenance and repair and the potential reduction of environmental impact in terms of blasting and painting.	ECO-REFITEC
	The AOMAS project looked at the potential use of a mechanical arm in situations that require a worker to operate heavy tools, use tools overhead or in any other poor ergonomic positions, for periods of an hour or more.	AOMAS (USA)
	The SmartYards project looked at process improvement, reduction of waste, and environmental exposure in small European shipyards.	SMARTYards
	In the future it is highly likely that based on environmental and health and safety legislation that the limits for release of pollutants and contaminants from shipbuilding as well as VOC's from coatings as a whole are likely to be reduced.	

The European projects are shown in the project and relation history timeline below. A time line and a link between all the projects evaluated is also given in Figure 35.

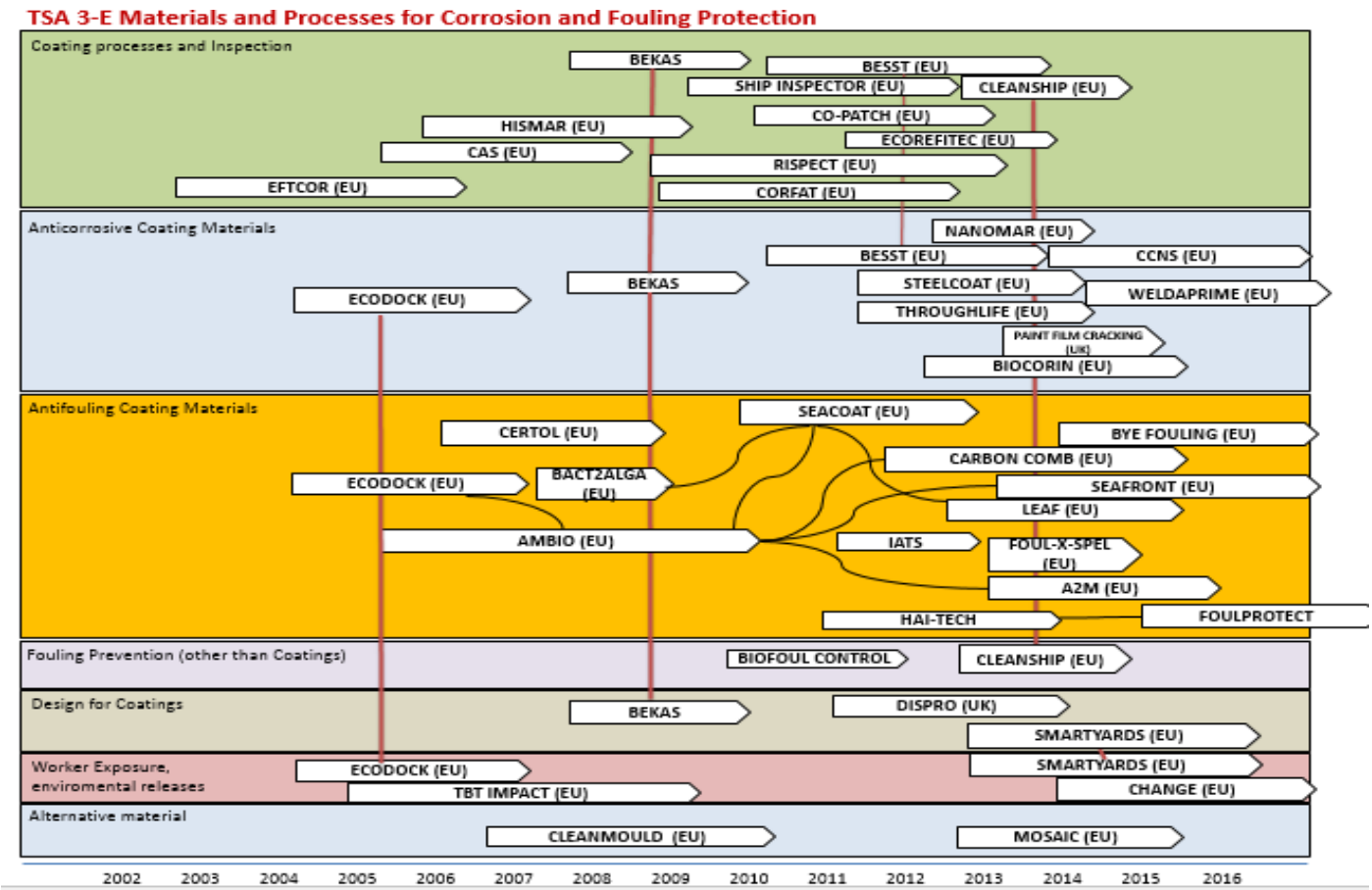


Figure 35: TSA 3-E Materials and Proc. for Corrosion and Fouling Prot. – Project timeline

From this project history, the following statements could be made:

- <u>General comment:</u>
  There was a dramatic increase in the number of EU research projects between 2007 – 2009 in all of the areas evaluated.

- <u>Fouling prevention:</u>
  In terms of fouling prevention, there are currently two types of coatings available on the market. There are based on biocide antifouling (using cuprous oxide) or Foul Release technology (hydrophobic surface made of silicone polymer combined with a silicone oil).

  - The project increase is more significant for this area (antifouling coating material area). Other research projects run by the French government were found to be very similar to the European projects listed in Table 21. These projects mainly focused on the use of alternative technology considered friendlier than cuprous oxide in antifouling coatings. There are called: AF Electrocoatings, Biopaintrop, Coppertree and Ecopaintpaca.

  - There is a need to reduce the impact of a coating on the environment as well as to improve product performance. This can be seen by the numerous projects looking at removing partially or totally the amount of copper in the coating's formulation or adding environmentally friendly

biocides such as enzymes (degrading adhesive type) or other materials (ie: Econea®, Selektope®, aXiphen®).

- Another strategy is to look at alternative surfaces.
  They can be based on amphiphilic or hydrophilic polymer (using PEG or Zwitterion) as opposed to what is currently on the market which is mainly based on hydrophobic polymer (i.e foul release coatings). These materials are still at the research phase but boths material may provide resistance against slime. Zwitterion materials may present more potential than PEG materials as they are more capable of "bonding" with water.
  As mentioned before, Hydrophobic surfaces, (foul release coating), suffer from the fact that they do foul in a static environment. In most of the current foul release coatings, slime also adheres to the coating when the ship is in transit increasing frictional resistance and fuel consumption.
  Combining foul release with biocide raw material was also evaluated in order to add benefit from both technologies. This technology is currently being sold by the paint manufacturer Hempel under the product name Hempaguard X7.
  Smart Polymer where the polymer undergo change depending upon the exterior environment was also considered.

- Currently, there are only a few commercialized fouling prevention products which are environmentally friendly (ie which contain no copper compounds) and which work in static conditions. (i.e foul release coatings do not work in a static environment and some cleaning of the hull will be required).
  These technologies are in their infancy and have a limited track record. These technology uses raw materials which are pushed through the various countries' raw material registration processes. The raw materials used are Econea® (chemistry: Tralopyril), Selektope® (chemistry: Medetomidine), or aXiphen® (chemistry: Phenylcapsaicin) which intend to replace cuprous oxide (predominant hard shell fouling biocide in antifouling paint) in the paint formulation. The Selektope® raw material being launched by I-Tech was developed as part of an EU project called Selektope. The latest addition in this area is based on a raw material called Inhibio®.
  Another potential alternative (also using a different concept) is available using fibres as a raw material in order to prevent fouling in the coating (material developed by Micanti, Thorn D).

- Fouling prevention coatings are used to stop fouling from attaching to the ship's hull which will increase the frictional resistance of the ship and, as a result, increase fuel consumption. One project (Target) has focused only on the evaluation of the frictional resistance of current fouling prevention coatings.

- Other projects have focused only on frictional resistance (not on fouling prevention) and how this can be reduced in a number of ways such as by using an air lubrication system or a boundary layer stabilization system.
  -Air lubrication systems (ie air film, air cavity, micro bubble evaluated in European projects such as Targets, Smooth or industrial projects like Silverstream) intend to reduce the drag of a ship thereby reducing the friction forces acting between the ship's hull and sea water. Although these systems are not directly related to coatings they may present some advantages.
  -Boundary layer stabilization system:

Project Flipper by Martec is currently researching the use of coatings (made from rubber) to delay laminar turbulent transition on a ship's hull. The issue of fouling is not being addressed by this project and the technology is intended only for the bow of a ship.

- Research into fouling prevention based on technologies other than coatings is also being carried out, involving the use of ozone or UV lights (from Phillips). UV light is harmful for most (micro) organisms even in small doses. The effects include DNA damage (hampering reproduction) and/or cell damage. The effectiveness depends upon, wavelength, total dose, what part reaches the micro organism, which micro organisms are targeted. Other areas (not researched as part of an EU project) investigated the following topics: ultrasonic antifouling systems, radioactive materials, pulse power and magnetic technologies.

- Anticorrosive materials:
  - Research into anticorrosive material is currently more driven by improving the product lifetime performance in the marine and protective coating industry rather than restricting the use of raw materials. Improving upon the correlation between laboratory tests and in-field testing is now becoming critical.

  - Coatings are mostly based on epoxy technologies, however research has also been carried out into other polymer technologies like conductive polymer (or pigment), sol gel. These technologies may include a self-repair system that may increase the coating lifespan and reduce necessary repair work. Reducing the film thickness of the coating may increase its crack resistance, an issue that is critical in water ballast tanks. As a result this would reduce the amount of inspection work needed and therefore increase the profitability of a ship.

- Other areas of research:
  - Other areas of research include improving productivity in the yard (for example by looking at the impact of the paint process at a design stage), reducing the amount of paint inspection (using TRUQC Paperless software) work and hull cleaning using new software and robots.

Conclusion

Overall the coating process lags behind other shipbuilding processes such as production and outfitting in terms of both development and research. Paint companies will continue to lead product development, which is likely to focus on formula optimisation. The use of additives is also likely to increase however the industry will remain dependent on epoxy based chemistry until the raw material suppliers can develop new molecules which are capable of matching the cost and performance of these products.

Research indicates that it is unlikely that any completely 'new' process equipment will be introduced. For the foreseeable future substrates will be prepared by propelling a hard media at the surface to create a suitable anchor profile, and forcing the liquid paint through a nozzle to apply it. Alternative technologies have been used in the cleaning process, most notably CO_2 blasting and hydro-jetting, however, these processes can only be used for secondary surface preparation as they are unable to create a surface profile.

Areas for further research which are likely to provide cost savings are seen as improving the integration of the coatings process, for example though improved design or production planning. In addition the use of alternative materials for secondary structures where appropriate. Finally inspection of applied coatings focuses on QC, a move towards QA would help to build quality into the process rather than inspect it out.

One fundamental issue remains the use of sub-contractors for the coating process, as in the short term it is them who will benefit from cost saving initiatives rather than the shipyard. Another issue is how to sell the promise of improved throughlife performance of coatings to owners though inproved designs, products or working practices, as ultimately these factors will result in reduced maintenance costs. The hurdle remains that of demonstrating the throughlife benefit of investing in additional funds at new build (CapEX) to reduce the operational running costs (Opex), to deliver a minimium life cycle cost for the vessel.

Suggested show cases

The Through life project looked at self-healing and absrasion resistance of coatings

Self-Healing

The Through Life project looked at anticorrosive paint and, more specifically, at self-healing coatings for use in water ballast tanks. The project incorporated micro capsules containing a commercial corrosion inhibitor to provide self-healing properties to a heavy duty marine protective coating (Figure 36). Coatings containing varying amounts of self-healing material were tested both in the laboratory using the IMO PSPC testing programme and also in the field in a ship's ballast tank (Figure 37) and compared against a commercial coating (Hempadure Quattro 1760). The results (Figure 38) at this stage are promising although further wider ranging testing is required before the technology could be commercialised.

The potential benefits of self-healing coatings are:

- Application of only one coat of paint, which as result reduces cost.
- Reduction of re-work and decrease in maintenance costs.

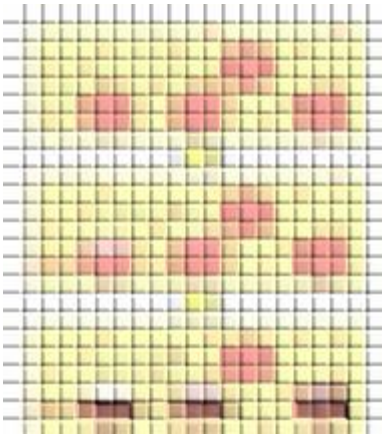


Figure 36: Mechanism of self-healing

Figure 37: Installation of frame in the WB

At the start of the experiment and their performance in the ballast water tank field at the end of the experiment (Figure 34). Damage induced by Erichsen cupping (1.3mm).

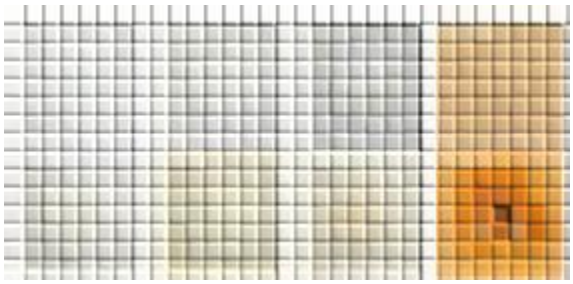


Figure 38: photos of the tested sample

Abrasion resistance:

The Throughlife project also developed a test apparatus (Figure 39) for abrasion resistance of coatings and steel substrates. Final testing is still ongoing, however due to the collaboration with an owner the test has been calibrated in order to establish a link between the number of cycles in the test apparatus and time in service (Figure 40). There is the opportunity to develop the test into an industry if not international standard test programme for abrasion resistance.

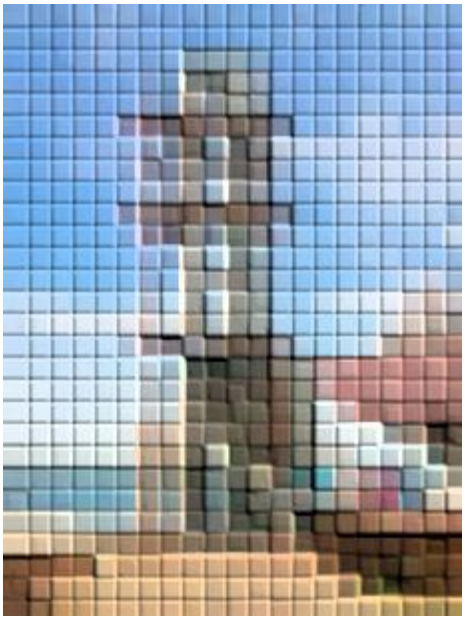


Figure 39:Test aparatus

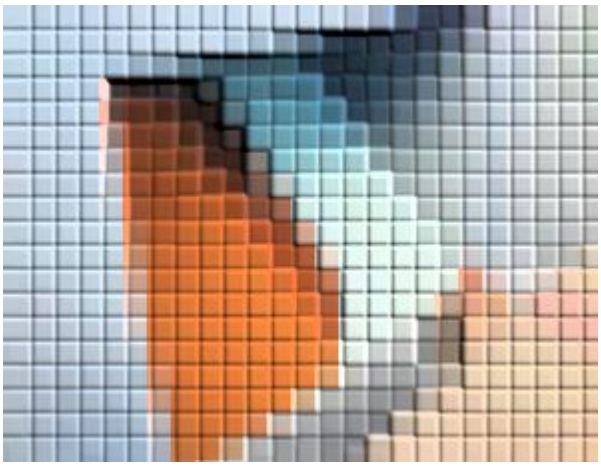


Figure 40: Calibration of test aparatus

3.7 TSA 3-F Assembly and outfitting techniques

Introduction

This part of the document outlines the State Of The Art on assembly and outfitting in shipbuilding as per current practice in European shipyards and suppliers of equipment and services.
The research has been conducted by the MESA consortium consisting of Center of Maritime Technologies (CMT), Meyer Werft (MW), Flensburger-Schiffbau-Gesellschaft mbH& Co KG (FSG) and RWTH Aachen University (RWTH).
Multipliers could be found in the cooperation SimCoMar (Simulation Cooperation in the Maritime industries) and the interbranch cooperation SIMoFIT (Simulation of Outfitting Processes in Shipbuilding and Civil Engineering) which involves experts both from the shipbuilding industry and civil engineering.
The information in this report consists on public information for preselecting the projects and information from the project consortium and the end users to clarify open questions. In cooperation with the MESA partners and external experts the projects have been arranged according their research topic(s) in the research landscape for outfitting and assembly techniques in the maritime industries.
Up to now the analysis for TSA3-F assembly and outfitting techniques includes 21 European funded projects from FP5 to FP7 as well as 20 national German projects. A list of the projects can be seen in Table 22. Since the project BESST consists of several different research topics that are considered relevant for this study it is listed more than once.

Table 22: TSA3-F assembly and outfitting techniques – analysed projects

ADAM4EVE	Adhesive Bonding	BESST	Bolzenschweißen
BONDSHIP	CARGOXPRESS	CARLoS	CREATE3S
DE-LIGHT-Transport	DISCO	DOCKLASER	DOCKWELDER
EIMEFÜ	Einseitig EGas	Elektrogas	FASEK
FSW-Steel	GeneSim	GRIP	HILDA
IMPROVE	InterSHIP	LeiSe	MIG-Löten
MOSAIC	MoveIt!	PALAS	QuInLas
Retrofit	Rohrleitungskleben	SANDWICH	Schiffsfenster
SHIPYAG	SimBA	SimGO	SmartYARDS
Standardrohrhalter	Teilangeschl. T-Stöße	Unterbauten	UP-Quer
Zurr-und Laschkräfte			

Industrial practice

Review

The production process in shipbuilding is defined by the complexity of the product ship. A ship can be considered as a one-of-a-kind product even in small series due to constant changes of design and building methods. Therefore, production development as well as production planning and control feature specific requirements in shipbuilding in regard to the complexity of the processes and the availability of data. Shipbuilders which are focussing on series of ships or boats have slightly differing restrictions during their assembly and outfitting processes which can be compared in part to the automotive industry.

The need to remain competitive to other shipyards with lower cost of labour forced the European shipbuilding industry to adapt to niche markets where efficient technical solutions can compensate the higher worker wages. The building of special types of ships like cruise ferries, RoRo and RoPax vessels, naval ships, Offshore vessels or ships for special applications require new building concepts, integration of new materials and a profound understanding of the balance between performance parameters, functionality, impact on the environment and comfort. During the last years the rising demand of offshore structures has become another important market segment.
The shipbuilding industries of Non-European countries are about to conquer these niche markets as well, which requires a continuous progress in research to remain one step ahead and thus remain competitive.
In steel ship production the ship's hull is assembled using a modularisation strategy. This offers the possibility to work on the joints in a favourable weld position since the assembly can be manufactured in an orientation that is most suited to the work that has to be done. Additionally this allows the utilisation of different work strategies like line production or parallelized work on different work sites.

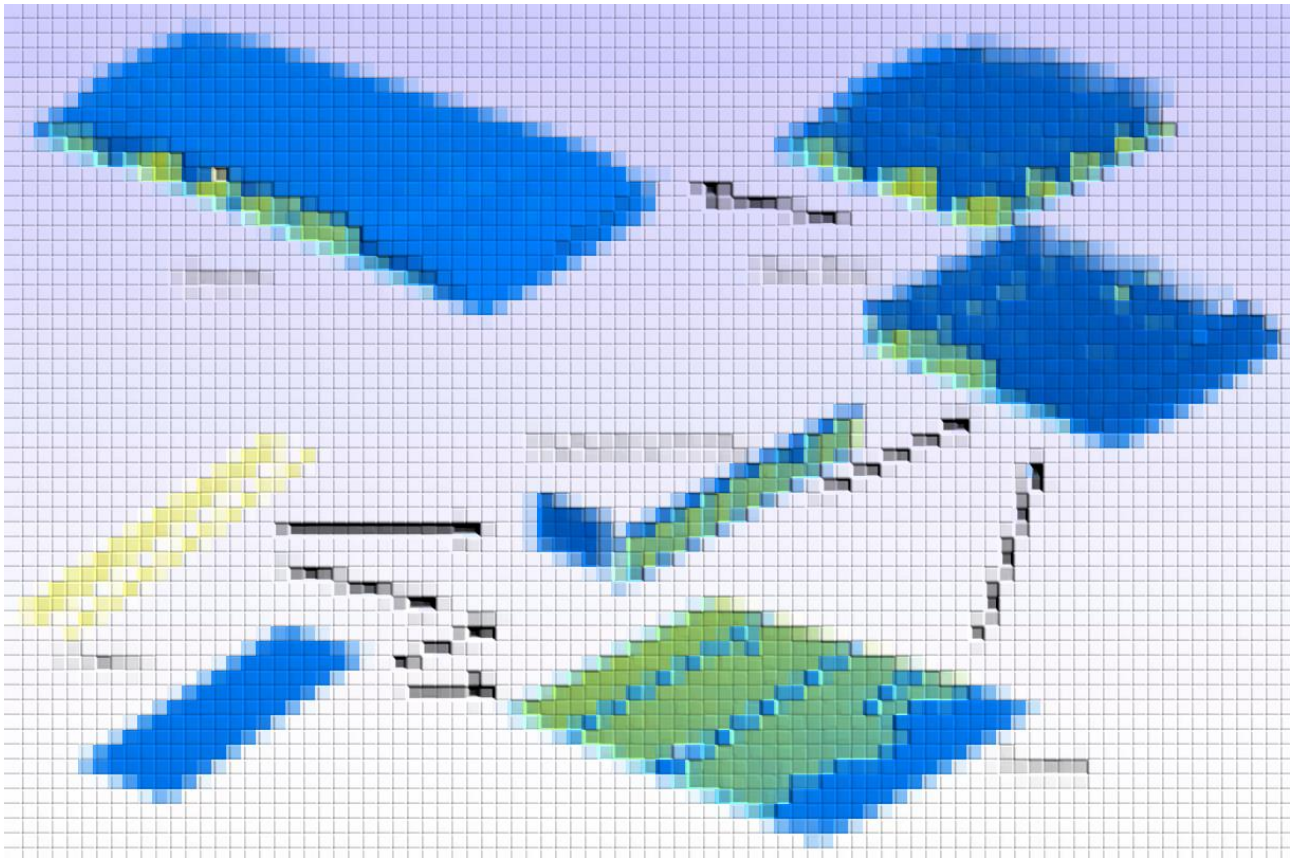


Figure 41: Schematic visualisation of a modularized building strategy of steel hull production

The outfitting processes are interwoven with the steel assembly and start at an early building phase. This results in an improved accessibility during the outfitting processes. The combination of outfitting and assembly processes result in the decrease of production costs. The more of the ship structure is completed the more costly it gets to finish the outfitting processes. This can increase the cost of an outfitting process by factor 10 if it has to be done in the final hull erection phase. Apart from the diminishing accessibility the extra costs are generated because the heat generated from joining methods of the outfitting harms the final coating of the structure or isolation materials which have to be repaired.
A detailed planning is essential to manage the right work order sequence and place of work for each assembly and outfitting process to maximize accessibility and minimize rework. Since shipbuilding can be considered

one-of-a-kind production the development and implementation of tools to evaluate different building strategies has a huge impact on the building costs. Event discrete simulation of material flow is a tool that sees increasing use in shipbuilding during the planning and the production phases.

Conclusion

Advancements of outfitting and assembly techniques to improve the product or lower the production costs of a vessel have to comply with existing rules and regulations. It is deemed necessary to integrate the results of European research as fast as possible into the technical regulations to allow the impact of the improvements on the competitiveness of the European shipbuilding industries.

Since the huge variety of different ship designs results in a lot of challenges which have to be solved, many of the research studies focus on individual solutions. This causes a risk in the transferability of the results or in the creation of isolated applications.

The Increase of the complexity of the products and the decrease of batch size create a growing demand for tools to help with validation of planned schedule and management of production steering to minimize bottlenecks and improve resource management.

Rules and regulations

Review

New materials and new assembly or outfitting techniques have to comply with the corresponding rules and regulations for shipbuilding. The inclusion of new materials and new techniques to these rules is critical for the application of research results.

The main rule sets for new building of ships are depending on the classification society which is commissioned to supervise the building of a vessel. Twelve of the main classification societies compose the “International Association of Classification Societies” (IACS) which has been founded in 1968. More than 90% of the world’s cargo carrying ships’ tonnage is covered by the classification standards set by the twelve member societies of IACS. (Source: IACS Website). The rules and regulations of these classification standards cover the complete shipbuilding and repair sector. One of the most important rule sets in regards to outfitting and assembly is IACS No.47 – Shipbuilding and Repair Quality Standard which is revised continuously to adapt the rules to state-of-the-art technologies and materials.

In regards to offshore constructions the classification societies contain sets of “Offshore Rules”, which are comparable to the mentioned rules but have enhanced requirements regarding the documentation of the work processes and the materials used. Offshore Health, Safety and Environment (HSE) regulations are even stricter than standard shipbuilding rules, because of the severity of possible disasters. Directive 2013/30/EU on safety of offshore oil and gas operations and amending Directive 2004/35/EC is the norm of the requirements in this case.

Many shipyards have other standards they admit themselves to, e.g. the “Deutscher Schiffbaustandard” (German shipbuilding standard) which might be overruled by the rules of the classification societies but are more detailed in respect to certain applications like the preparation of surfaces during assembly and outfitting. In addition to that, many shipyards use their own standards like “General Technical Specifications” (GTS) when choosing and ordering parts for outfitting.

A rule set, which influences the outfitting and assembly processes indirectly, is the IMO Performance Standard for Protective Coatings (IMO PSPC) which has been included in TSA3-E. This new coating standard requires the preparation of the surfaces in ships water ballast tanks (WBTs) in the form of circular form bending of the edges of steel parts through e.g. a grinding process and the improvement of welded surfaces through removal of excess weld metal and smoothing of the joint surface. This production processes have to be included in the assembly procedures at a point of time where the surfaces to be grinded are easy accessible and in a favourable position. This represents a challenge to both planning and production alike.

Conclusion

The diversity of processes and materials used in the building of ships implicate a huge variety of involved rules. To improve the speed of implementation of new researched technologies into the shipbuilding process many research projects focus on testing and evaluation of new concepts and/or technologies to reduce the effort to adapt the corresponding rules to the state-of-the-art technologies.

Research and development

Review

Table 23: TSA3-F Assembly and Outfitting techniques –Projects per research domain and (sub) topic

Research topics	Analysis	Projects
Joining	**Conventional welding:** • Due to the predominant use of metallic materials in shipbuilding, welding can still be considered as the most important joining technique here. The improvement of conventional welding techniques by reducing the heat input or allowing the welding of thick plates in one pass has been mainly conducted by national and private founded projects, but some EU projects have contributed to this task too.	DOCKWELDER
	• Traditional welding techniques have been in the focus of research activities for a longer period of time. To improve the benefit of this proven and tested joining method in assembly and outfitting where manual labour is the normal case, research for automatic welding systems like an adaptable robot arm or automatic systems for vertical-down welding were the next step of the implementation of new systems to save costs.	DOCKWELDER, FASEK
	• Under –powder welding is an important welding method in shipbuilding due to its greater repeatability and economic efficiency in comparison with other welding methods. The trend to focus on the use of renewable energies for the sake of climate protection has increased the demand for utilisation of proven assembly processes for the installation of offshore wind turbines.	UP-Quer
	Laser welding: • The high amount of heat input during the conventional welding process and the deformation of the steel involved has been the reason to search for other methods to join steel components in the different assembly and outfitting processes during the shipbuilding process. Both the development of reliable and affordable laser welding processes and the adaption of rules and regulation for the different utilisations of this process were the starting point for the implementation of laser welding technology here.	SHIPYAG Teilangeschlossene T-Stöße DOCKLASER
	• While laser and laser-hybrid welding is used widely in stationary systems which can be found in preproduction, its benefits have still be harvested for assembly and outfitting. The research on movable laser sources which can be utilized in the narrow environment of steel modules or laser sources that could be equipped to multiple axes robots will allow laser application in assembly and outfitting. While technically deployable there are still safety aspects that have to be solved, when using laser technology in the confined workspaces typically found in this area of application.	DOCKLASER, BESST
	• Stationary laser welding systems have to comply with the batch size of one which is the norm in one-of-a-kind shipbuilding. The laser	PALAS

	welding with laser-hybrid or laser remote processes has to meet the demands on three-dimensional welding constructions or in the changing business of panel lines. The designing of interfaces between the CAD-data, the part positions and the welding tool has been the focus of several research projects.	QuInLas
	Electro gas welding: • Electro-gas high performance arc welding is a powerful welding technique but its application for HSLA steels was very limited because of the loss of strength and toughness in the heat affected zone. The high energy input per unit length and the grain growth were responsible for this loss. There have been several national founded research projects which aimed at the increase in efficiency when utilizing electro-gas arc welding for higher strength shipbuilding steel.	Elektrogas Einseitig EGas
	Friction stir welding: • Friction stir welding is a young welding technique which proposes benefits in regards to quality and lower heat input. Since the adaption of this technique has just begun the corresponding research projects are doing basic work at the moment: Collecting of stable process parameters for normal and high tensile steel, designing of reliable and robust tools for the welding process and creation of FEM-simulations of the joining method for different materials. Further research will likely establish friction stir welding as an important joining method especially for joining of steel and aluminium plates as needed when designing ships with lightweight deck structures.	FSW-Steel HILDA
	Welding of lightweight or composite materials: • Modern ship designs have a growing percentage of parts (e.g. parts of the superstructure) which are constructed from lightweight materials. Mostly applied are composite materials or aluminium. These materials require special joining techniques. The rules and regulations often do not cover the aspects needed to apply these methods. Research conducted in this area therefore focuses on the preparation to add the new joining methods to the rules as well.	SANDWICH DE-LIGHT-Transport BESST
	Adhesive bonding of ship structures: • Due to the difficulty of welding some of the materials that are used to improve ship performance and to decrease damage to the structure by heat input, new joining methods had to be considered. The EU-project BONDSHIP has been a trailblazer in regards to adhesive bonding in shipbuilding. During the project a guideline for adhesive bonding has been developed which was published by DNV. New adhesives for bonding of different materials were developed and had to be tested in regard of durability and resilience.	BONDSHIP Adhesive Bonding
	• The use of adhesives can have other benefits as well. The adhesively bonded structure of Cabins joined to the surrounding ship structure can provide better noise damping properties than a conventional one. To utilize these benefits the interdependencies between the adhesive (thickness, type, etc.) and the noise damping qualities had to be determined. Though a concept to totally substitute steel parts in the housing area could not be proven, valuable data for the application of adhesives to avoid noise disturbance in passenger cabin areas could be obtained.	LeiSe

	Mechanical joining:
	• Modern mechanical joining techniques form another alternative joining method which results in a reduced heat input. These technologies have primarily been developed out of EU- or national projects, but some projects used the developments in this field to improve the knowledge and application base.
	Pipe outfitting
	• Pipes are one of the mayor outfitting components of modern ships making research in this area worthwhile for cost reduction. Several national German projects focus on different aspects of improving the pipe outfitting process. Since the heat input during the welding process of the pipes damages the coating of the material different methods to reduce the heat have been researched.
	  ○ The application of modern mechanical joining techniques helps to avoid damage to the coating.
	  ○ MIG welding of zinc-coated pipes was another research area
	  ○ Adhesive bonding of pipes was the next step of research. The benefits of this method were reduced costs of the process by reducing the rework on the joint and the application with respect to cramped circumstances/constraint positions.
	• The assembly of the pipe fittings is another process that has been identified to contain room for improvement.
	Knowledge transfer:
	• Since small and medium enterprises in the shipbuilding industries often lack the research potential of large enterprises research has started on implementation and adaption of advanced technologies by knowledge transfer from large to small and medium enterprises in a way that both partners can benefit from.
		DE-LIGHT-Transport
		EIMEFÜ
		MIG-Löten
		Rohrleitungskleben
		Bolzenschweißen
		SMARTYards

Attachments	**Pipe outfitting:** • Several national German research studies have concentrated on improving the fittings of pipes. One approach was a study on the implementation of a standardized pipe bracket system to minimize flawed constructions and harmonise existing rules and regulations which were insufficient. • Improvements of the process to fasten the pipes brackets to the ship structure were another research topic. **Dimensioning of components and support structures for cargo securing:** • The dimensioning of ship components is an agreement between resilience and investments. To avoid the over sizing of sockets on container vessels or lashing equipment on Ro-Ro vessels tools have been developed to calculate the stress on individual components. Simplifying assembly processes can help to reduce costs. Calculation tools can help to decide if it is possible to safely secure the cargo on deck plates with an increased thickness or if is necessary to include intercostal stiffeners in the design which result in a more complex and thus costly assembly process.	Standardrohrhalter Bolzenschweißen Zurr- und Lasch-kräfte Unterbauten

	Semi-automated stud welding / marking: • Highly skilled workers are a valuable asset of European shipyards. During the outfitting of ship superstructures many arduous repetitive tasks have to be handled. First research for mobile robot co-workers which can be assigned to tasks like stud welding or marking based on information from a CAD model has been started. To adapt mobile robots to the complex environment of shipbuilding allowing them to determine their position in the superstructure will allow the automation of many menial tasks freeing the workers for more complex work.	CARLoS
Planning and organisation	**Simulation aided process planning:** • The complexity of different processes and their time and space constraints causes many fluctuations of resource utilisation. The interdependencies between different assemblies require an accurate planning to avoid costly delays. Event discrete Process simulation can be a valuable asset during the planning and assembly phase of a ship. Standard simulation tools offer a limited number of tools for modelling these assembly phases of a ship which resulted in the need to create a simulation toolset for assembly and outfitting processes. • The work order sequence can have a huge amount of influence on the throughput of production facilities. In one-of-a-kind-production it is necessary to determine an efficient work order sequence in a short amount of time without the benefit to do different production runs. By combining simulation models of production areas with mathematic optimisation methods it is possible to test different production programs in advance thus finding an eligible order sequence. • The provision of product data is a requirement for the utilisation of process simulation. The required data exists in several different applications of a company. A generic database was developed which allows the import of different data formats, stores and translates data in a collocation that can be used to conduct simulation experiments and can store and evaluate simulation results. **Retrofitting of vessels:** • The adaption of existing vessels to specific changes of their application area and to new regulations results in assembly and outfitting processes which have to be conducted often in a confined and cramped space. New techniques for assembly and outfitting help keeping the costs down. • The greening of ships has become an important factor in ship operation and for retrofit processes. The implementation of new technologies for improved overall environmental footprint is a mayor research theme of several projects. • The reduction of operation costs can increase the life span of a vessel. One mayor research area is the reduction of the fuel consumption by replacement of propulsion system components or usage of energy-saving-devices.	SimBa SimGo GeneSim Retrofit Retrofit GRIP MoveIt! GRIP MoveIt!
Materials	**Structural lightweight using metallic materials:** • Aluminium alloys and high tensile steels are commonly used in modern ships because they confer weight saving potentials. Detailed case by case assessments are needed to apply them though because	SANDWICH

	of the problems that come along with the use of thin structures (e.g. corrosion, fire, buckling). • The fatigue properties of welding joints are often a limitation for metallic structures which make use of stiffened plates. It has been determined that laser hybrid welding can provide improved fatigue properties. This topic has been systematically researched on by BESST with the aim to approve this innovative welding method and create application guidelines. • Metallic sandwich panels do not share the problems of this structures while they have a reduced weight compared to conventional structures and share other beneficial characteristics like fire resistance, improved crash worthiness and space saving. Prefabricated metallic sandwich structures are available on the European market as a proven material alternative after a series of research projects tested those structures and provided application cases and guidelines along. In the course of the research projects production and assembly techniques along with design tools were developed. • The combination of HSLA (high strength low alloyed) steels with their anticorrosive and structural benefits and composite materials with their weight reduction potential a research topic too. This combination aims at combining these advantages to improve the ship structure. **Nonmetallic or composite materials and their benefits:** • Ships that carry passengers (e.g. cruise liner, RoPax ferries) have a high portion of large windows integrated in their superstructure. Apart from the need to withstand typical design loads like water pressure from waves or immersion of windows in emergency cases modern materials can increase the sheer stiffness of the steel structure up to factor 10 depending on layout and properties of glass and bonding or rubber gasket. • Since ship hull design is always a compromise between optimized hull forms for each of the expected areas of operations of the ship the inclusion of adaptable hull-form features would allow a modification of the geometry to increase the efficiency under different boundary conditions. • Adaptive and smart outfitting materials could increase the ship's efficiency in regard to vibration damping, heat take up, thermal energy storage or fire resistance.	BESST SANDWICH InterSHIP DE-LIGHT-Trans-port MOSAIC Schiffsfenster ADAM4EVE
Design	**Weight optimisation using conventional materials and designs:** • First principle design tools (Finite Element Calculations) help to improve construction design capabilities by allowing a more efficient use of conventional materials at the right place and thereby reduce the structural weight of vessels. Standard tools for this job are already available. • During the course of several projects, the integration of these tools into the ship design phases was improved. Focus of these activities was mainly to improve the early design phases. • Research has been conducted about overall structural optimization considering weight as well as production and repair costs.	IMPROVE InterSHIP BESST IMPROVE InterSHIP

	Modular ship design: • Tailor-made solutions for specialized logistic challenges result in innovative designs. Designs like a modularized dock-ship/feeder-barge concept require new concepts for assembly and outfitting if they are to be produced in a competitive way. **Advanced design studies:** • The project CARGOXPRESS combines many advanced concepts regarding materials, ship design, sustainability, greening, propulsion systems into a design study for a 200 TEU twin hull self-unloading container vessel for small ports with a combined LNG-electric-sail-propulsion system and a composite material hull.	DISCO CREATE3S CARGOXPRESS

TSA 3-F Assembly and outfitting techniques

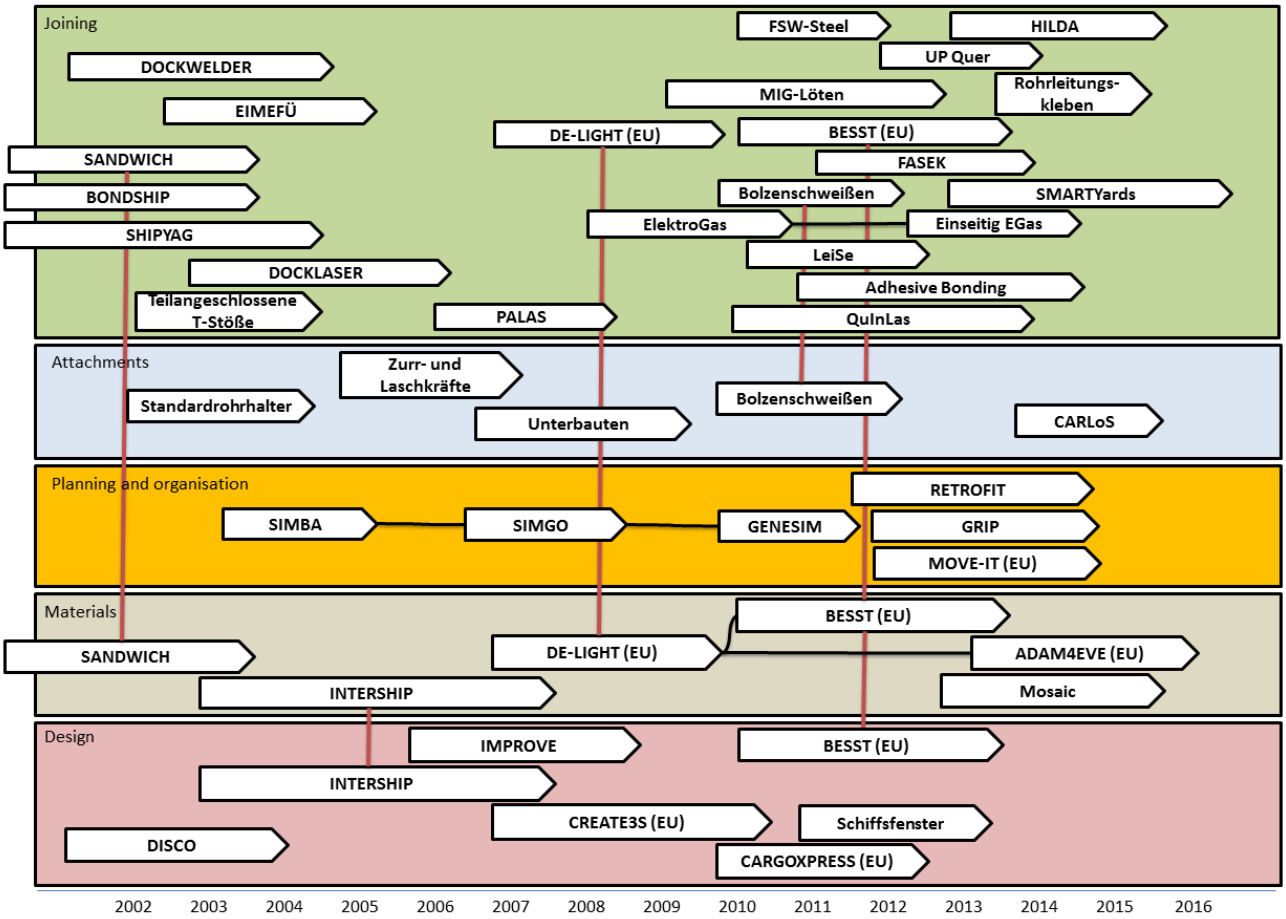


Figure 42: TSA 3-F Assembly and outfitting techniques – Project history and relations

Conclusion

Shipbuilding production is a multifaceted industry branch which requires advances of technology in many aspects due to several challenges. In order to regain the competitiveness against hard pressing competitors from Far East, European shipbuilders had and will have to concentrate on special ships which are one-of-a-kind or small batch products. Below is a list of challenges together with the available technology to overcome and the gaps to be filled for further improvement:

- New Assembly and Outfitting Techniques: Continuous improvement of both product and production increases the complexity and variety of processes during shipbuilding. The management of those complex processes will be the major challenge of the future to keep both budget and schedule. Material flow analyses using discrete event simulation based tools are efficiently used to create a virtual production by modelling the fabrication processes and their dependencies on the product.
    - Further research is needed on the integration of production simulation in way of data acquisition and handling from/to other information systems such as product design software, enterprise resource planning systems, scheduling etc.
- New Materials and Processes: Weight reduction, improved resistance to extreme weather and corrosion and increase of structural performance are the main reasons for the implementation of new materials in shipbuilding to allow the production of sophisticated high quality vessels.
    - In order to improve both throughput and quality, new / improved joining methods are needed to combine parts of the structure that include new materials.
    - Wider application of laser welding, friction stir welding or adhesive bonding can help to satisfy the needs to join lightweight materials and the steel structure of a ship with the necessary quality. At the moment the process parameters have only been determined for a small field of application which need to be improved.
    - It is expected that the offshore market segment with its high requirements in regards to durability and safety will lead to a rising demand of research on offshore topics in the time coming. Examples of this include but are not limited to new and innovative assembly strategies, adaption of new and weather resistant materials with long service life and improvement or implementation of new joining techniques which are applicable on offshore sites. Several research projects which focus on offshore building especially on the installation of offshore wind farms have been started already. At the moment this research has led to some national research projects with often connatural goals.
    - Faster adaption of rules and regulations are required in order to apply and benefit from the improvements in design, involved materials and used assembly and outfitting techniques.

It has been also found that there have been research topics for specialized fields of application, the majority of the research projects focus on shared research topics. Therefore, it is recommended that the research focus should aim for consolidated topics and for wider applications.

Suggested show cases

The following show cases were selected:

1. **InterSHIP**, "Modular Ship Concept", www.Intership-ip.com

- Scope of project: Definition of a strategy to realize a modularization in ship construction process
- Main results:
    - Definition of generic modular process and impact criteria for handling modularity in the design phases
    - Ideal concept solutions
    - Descriptions for design and information management systems
- Commercial application(s):
  The production process of the ship hull was reorganized according to the results of the project

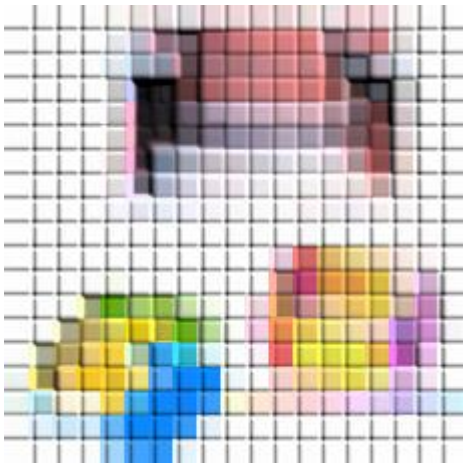


Figure 43:Modular Ship Concept

2. BESST, "Cost efficient building and refurbishing processes" www.besst.it

- Scope of project: Development of new outfitting strategies for public areas, Life cycle assessment
- Main results:
  - Simulation tools for refurbishing processes allow the evaluation of different building methods.
  - New modular passenger cabin concept for easy refurbishing processes.
- Commercial application(s):
  - Lifecycle cost tool
  - Simulation tools for refurbishment of passenger areas

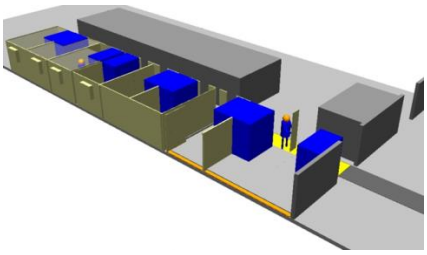


Figure 44:Refurbishment SImulatin Model

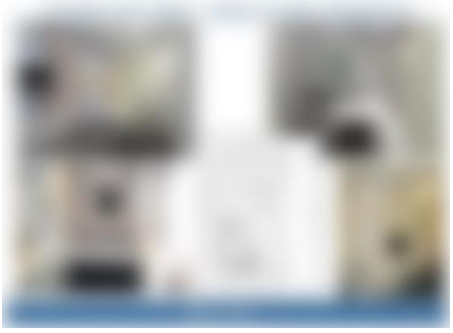


Figure 45: Modular Cabin Concept

3. SIMBA

- Scope of project: Development of a simulation toolset for outfitting.
- Main results:
  - Simulation tools for assembly, outfitting and space allocation that allow a detailed evaluation of different assembly concepts.
  - Tools can be used for other branches like civil engineering as well, because of versatility.
- Commercial application(s):
  - STS (Simulation Toolkit Shipbuilding)

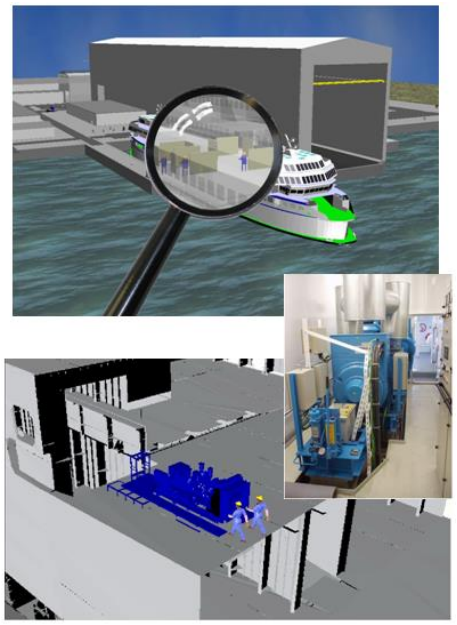


Figure 46: Outfitting Simulation

4. BESST, "Flexible and Modular Laser Equipment" www.besst.it

Scope of the project:

Development of modular and flexible laser equipment enhancing smaller and medium sized shipyards to use laser technology in their production, in different production environments;

Main results:

- Design and system integration of modular equipment incl. welding torches for different applications
- Statistical process models of welding parameters for easy start-up and use
- Laser Safety concept for achieving a Safety level in accordance with the standards

Commercial applications:

- Commercial offer of welding torches
- Implementation of new laser welding applications

Figure 47: Prototype of welding tractor

Figure 48: Developed welding head

3.8 TSA 3-G Maintenance, Repair, Retrofit, End of Life

Introduction

This chapter outlines the state of the art on ship Maintenance, Repair, Retrofitting, Conversion and End of Life. These functions are necessary to ensure that a ship can meet its operational and safety requirements and contribute substantially to the ship's lifecycle-costs. In order to reduce these costs, much effort is needed to optimise processes, activities and tasks within these functions.

This optimisation must cover a mix of organisational, financial, technological, and regulatory aspects. In addition it will be shown that the human factor is a dominant factor, needing an increasing amount of attention to ensure that stakeholders understand the consequences of rapidly developing technical advancements, responsibilities towards the environment, and social and demographical trends. This is preparing them to take timely decisions and actions, in order to remain competitive against upcoming markets.

In this chapter these aspects are covered, based on the analysis of selected projects and other information. In the project information gathering process open source information from the internet was used to identify project documentation and project deliverables. In addition (former) project leaders were approached by email in order to find out whether project deliverables were transformed to commercial products or services. The response varied from "no response at all" to "very informative". Available information has been submitted to the MESA TTG 3 project database. Analysed Projects are summarized in Table 24.

Table 24: TSA3-G Maintenance, Repair, Retrofit, End of Life –analysed projects

AE WATT	BESST	Broadband@Sea	CAS
CO PATCH	CORFAT	DIVEST	Eco-REFITIC
GRIP	HISMAR	INCASS	IShare@Sea
JOULES	MAINBOT	MEPENS	MINOAS
POSSEIDON	REFRESH	RETROFIT	RISPECT
ROBOSHIP	ROT	ROTIS II	ShipDismantl
SUPERPROP	SHIPMATES	Shore Support	SMARTYards
THROUGHLIFE			

In the following Industrial practice, Rules and regulations, Research and development, and suggested showcases are discussed.

Industrial practice

In the following the Ship's life cycle is used to discuss the industrial practice in the shipping industry. Firstly the term life-cycle is explained and relevant definitions are given. Then the different roles in the maritime chain are identified and explained. The purpose is to ensure a common understanding of this sector.

Then the state of the art in the field of maintenance, repair, retrofit and end of life is explained, followed by an analysis of trends and developments. The purpose is to create a common understanding of the various needs of stakeholders, the present solutions for their needs, or the available RDI results which could provide a solution for these needs.

Review

Ship Life-cycle

The lifetime of a ship is generally defined as "Ship Life-cycle". This cycle starts with the specification of a need in functionalities, e.g. a ship capable of transporting a certain number of containers at a defined operational speed. Based on these functionalities the ship is designed, engineered and built.

The next phase is the exploitation phase, in which the ship is operated. In order to ensure that it can meet its operational and safety requirements, the ship is periodically inspected and on a daily base maintenance is carried out. In the event of a malfunction repairs are done either by the crew, a shipyard, suppliers or a combination of strategic partners. Finally ships are periodically put in a dry-dock for underwater hull maintenance and inspection.

Since ships are operated for many years, equipment can become obsolete or no longer maintainable. Further regulations can form an incentive (e.g. policies for reducing energy use and greenhouse gasses) for creating the need for modification or replacement of certain equipment. Finally from an economical point of view a need for new or modified equipment can arise. This process is generally addressed as "retrofitting".

During the lifetime of a ship a decision can be made to use a ship for a different function as for which it was originally designed. E. g. a tanker can have a second life as floating mooring system. This process is generally addressed as "conversion". The last phase is the "end of life ". The ship is put out of commission and sold to a scrapyard to be dismantled.

Definitions

The following definitions are used:

- *Ship maintenance*: Activities undertaken to preserve as nearly, and as long as possible the original operational condition of the ship functions and systems while compensating for normal wear and tear. Ship maintenance is governed by (international) authorities such as class societies but is also subject to national rules and regulations. Common ship maintenance approaches are corrective maintenance and preventive maintenance (planned or condition-based). Activities may include disassembly, parts/components replacement, assembly and trails, surface preparation.
- *Ship repair*: Activities undertaken to restore ship functions and systems to acceptable or usable condition of state after sustaining damage, in accordance with the governing rules and regulations. Activities may involve removal of damaged equipment or structures, engineering, manufacturing, assembly, surface preparation and outfitting.
- *Ship retrofitting*: Activities undertaken to modify or replace existing ship systems, equipment and structures with additional or new/updated components, using parts developed or made available after the time of original manufacture. The retrofitted ship is subject to governing regulations. Activities may involve re-design, removal of equipment and structures, engineering, manufacturing, assembly, surface preparation and outfitting.

Ship conversion: Activities undertaken to adapt a ship to new use, by modifying existing functions and equipment or by adding new functions and equipment. Ship conversion may include re-design, engineering, parts manufacturing, assembly, installation and outfitting, surface preparation and extensive trials, and result in a totally new use or service.

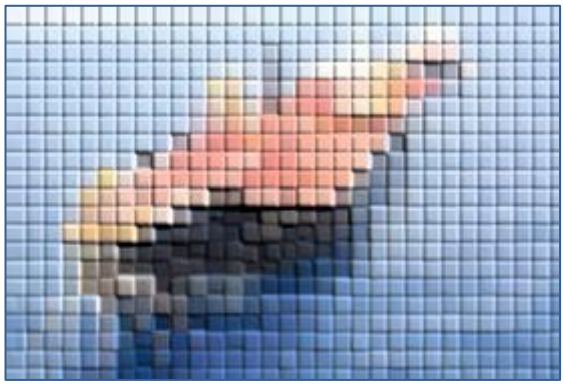


Figure 49: Converted ship

Organisational Roles in Ship's Life-cycle.
In the ship's life-cycle different stakeholders are involved, acting from various backgrounds, interests and motives. In the following the various roles and their primary interest and/or responsibilities are addressed:

- *Investor.* The investor provides the needed funding and his interest is a maximum Return on Investment.
- *Owner.* The owner is responsible for the design specifications and decisions made during the design/built phase. During the exploitation phase he is responsible for keeping of the ship in good order, ensuring that the ship is safe to operate, and that it complies with (new) regulations. He is further responsible for informing the Class Society of any events or circumstances that may affect the continued conformance of the ship with the Society's Rules. Finally the owner will decide on matters for the need of modifying, retrofitting, selling, or scrapping the ship.
- *Ship designer.* The ship designer is responsible for the design of a ship that meets the operational requirements and the requirements from the Classification Society. As a professional he will inform the owner on solutions which might need a larger initial investment, however that pays back during the exploitation phase. By doing this a basis is created for implementing a maintenance philosophy, based on lifecycle costing.
- *Ship builder.* The ship builder is responsible for the delivery of the ship as product.
- *Inspector Class Society.* Ships are subject to a through-life survey regime if they are to be retained in class. These surveys include the class renewal (also called "special survey"), intermediate survey, annual survey, bottom/docking surveys of the hull, tail shaft survey, boiler survey, machinery and ballast tanks surveys and, where applicable, surveys of items associated with the maintenance of additional class notations. The surveys are to be carried out in accordance with the relevant class requirements to confirm that the condition of the hull, machinery, equipment and appliances is in compliance with the applicable Rules.
- *Operator.* The operator is responsible for the operational deployment of the ship. His primary worry is meeting the operational requirements and from that point of view, the ship's availability (= minimum downtime) is his primary interest.
- *Crew.* The crew is responsible for the safe operation of the ship and performing the day to day maintenance and "simple" repair. They must inform the owner of situations that influence the operation or the safety of the ship or crew.

To support the ship-owners and crew in maintaining the ship in good and safe order, different industrial roles can be identified:

- *Suppliers of equipment and services.* Suppliers offer basically two services: (1) the supply of required equipment or systems including related information for operation; (2) the supply of services e.g. performing certain maintenance and/or repair tasks or giving advice on maintenance to be performed, based on an analysis of the condition of ship's equipment or structure (condition based maintenance). In the service area there are developments to offer ship-owners "total service packages". Such a service package would include a total responsibility for guaranteeing of a certain functionality on-board of a ship, for example a functioning propulsion system. The ultimate service is the total responsibility for the maintenance of a ship, the "on stop shop concept". Such a concept is already in operation for the Royal Netherlands Navy where the Naval Dockyards in Den Helder has this role. Some shipyards promote such a concept for the ships that they have built.
- *Shipyards primarily active in ship maintenance and repair.* The yards possess the necessary infrastructures for dry-docking, vertical and horizontal transport and workshops for steel works and pipe-

fitting. Maintenance and repair to ship hull structures is usually done by the yard but also by sub-contractors. Maintenance and repair work to ship systems and equipment is usually done by sub-contractors.

- *Shipyards primarily active in retrofitting and conversion.* The yards have the capability to carry out complex work that includes engineering and production activities much similar to new building shipyards. The yards may or may not possess own engineering and parts fabrication facilities or employ sub-contractors. Competitiveness is much determined by the shipyards' capability to manage such complex projects.

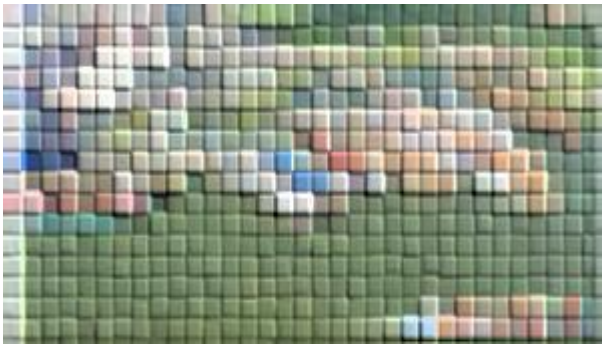


Figure 50: Damen Ship repair yard Pernis - The Netherlands

In the following it will be shown that many (EU) projects have explored various tools, technologies and business processes to support the above mentioned roles in their function.

State of the art in industrial practice

The state of the art in maintenance, repair, retrofit, end of life will be evaluated per stakeholder. This will be done for ship-owners, crew, suppliers and different type of shipyards. In the following an overview is given in their needs and present solutions and/or available RDI results which could provide a solution for these needs.

Owner.

For ship-owners it is of great importance to reduce out of -service time of the ship as a result of maintenance, repair and/or inspection activities. These activities must further be fitted in the service profile, in order to meet the operational and commercial requirements. Examples of identified solutions to support this need are:

- For decision support and inspection planning of ship structures, concepts are available in the form of expert systems using standard descriptions of structural components and defects and standardized calculation methods (RISPECT, CAS).
- For inspection of chains that moor offshore floating platforms and FPSO's the Moorinspect project aims to develop a prototype inspection robot that uses guided ultrasonic waves to detect fatigue cracks and wall loss in the anchor chains..
- For monitoring purposes, technology is available. E.g. monitoring technology based on acoustic emission testing (AT) combined with follow up Non Destructive Testing for monitoring the status of structural integrity in terms of developing and proceeding fatigue cracking and active corrosion (CORFAT). Another development is proposed by the CleanShip project for fouling prevention without the need for taking a ship out of service. The solution is to deploy long range ultrasonic plate waves travelling throughout an entire ship hull below the water line in order to be able to (i) prevent or slow down the accumulation of fouling and (ii) achieve a continuous monitoring to allow earlier and cheaper removal. This type of monitoring can support inspection and maintenance activities based on the principles of condition based maintenance. Such measurements allow the prediction of required maintenance tasks, the execution of which can be planned during a port visit of the vessel.

- For engine replacement, systems are available for replacing gas turbines at the quayside during a port visit.
- For Maintenance and Classification inspection of the ships inner and outer structure (autonomous) robotic inspection systems have been designed and proven with prototypes. In addition to inspection tasks, it was shown that robots can be used for cleaning the ship's underwater hull, thus reducing drag and required propulsion energy (fuel, emission reduction). The systems are designed to be used during a harbour visit and come with intelligent analysis software[7]. Finally Robotic systems have been designed for cleaning ballast tanks. (MINOAS, HISMAR, ROTISII, INCASS, RoboShip, ROT, MAINBOT).

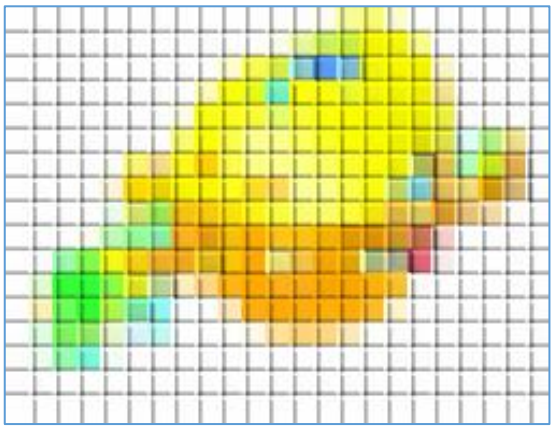


Figure 51: ROTIS II Remotely Operated Vehicle

Ship-owners are forced by legislation to reduce energy use and Greenhouse Gas emissions of their ships. In addition there is legislation on ballast water. This legislation is for example enforced by Emission Control Areas. For these reasons ship-owners are faced with major decisions that involve the investment of capital. In the present economic situation [2015] those decisions are hard to make due to low freight prices and fluctuating fuel costs.

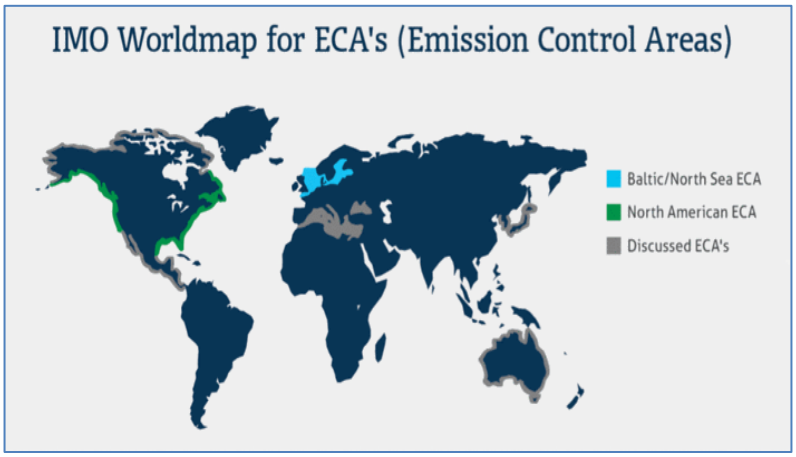


Figure 52: Emission Control Areas

This accounts especially for decisions on the retrofitting of existing vessels. For new ships new technologies are easier to implement. In order to make the right decision, there is a need for owners to evaluate the various technical options in relation to return on investment. Examples of identified solutions to support this need are:

- To evaluate fuel saving and emission reduction a methodology is developed (RETROFIT).
- To optimise the interaction of ship's propeller and ship's hull, tools for ship-owners for quick decision making are being developed. Further energy saving devices are developed (GRIP). An example is shown in Figure 53 where as part of the project a Pre Swril stator was installed on MV Valvoline, realising a reduction on power of 7 %.
- In order to fulfil emission requirements on SOx, NOx, and clean ballast water proven technology is available such as Scrubber technology (Figure 54) , LNG retrofit, Selective Catalytic Reduction (SCR) technology and ballast water systems.

[7] Note. 2015 - An Underwater Hull Cleansing Robot is operated by a company in the UAE.

- In order to support retrofitting investment by technical feasibility and cost benefit analysis, a life cycle energy management system has been proposed. This system intends to provide sufficient insight into the energy performance of the ship (REFRESH).
- In order to make decision concerning energy saving technologies, advanced simulation models for the energy grid of the ship have been designed. This simulation tool is intended to be used in the early design stage (JOULES).

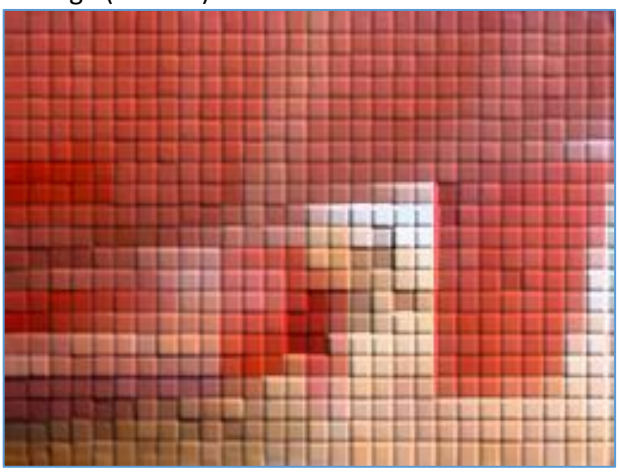


Figure 53: Pre-Swril stator installed on MV ValovineIn

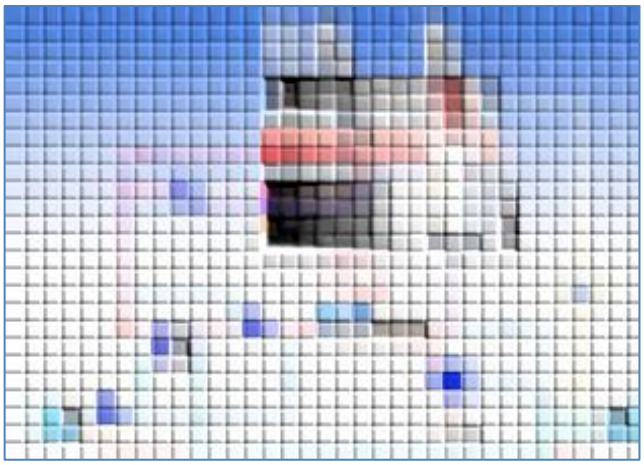


Figure 54: Scrubber technology (Green Ship of the future – ECA emission study)

Crew.

For ship owners it is hard to find a sufficient amount of experienced technical personnel to maintain the ships in good order. For that reason there is a need for organisational and technological solutions to support the crew. Examples of identified solutions to support this need are:

- To support the ship operator and crew a business model for through-life asset management has been developed and tested in business cases (THROUGHLIFE).
- New manning concepts have been designed, tested and put into operation by the use of officers who are both qualified to maintain and to navigate the ship (MAROF). This in combination with the operational support of shore based experienced chief engineers, proves a successful concept, enabling the operator to operate with less experienced engineers aboard their ships (Wagenborg Shipping). (NL project Shore support).
- For lubrication systems a sensor based processing unit has been designed that continuously monitor ships lubricated systems in order to provide an effective scrutiny over its serviceable life, enabling non-skilled operating crews to predict degradation, anticipated problems and take remedial actions before damage and failure occurs (POSSEIDON).
- Suppliers of equipment's and services move towards a role of being totally responsible for the maintenance of a system on board of a ship or for the ship as total system, thus reducing the workload for the crew of a ship (NL project Shore Support).

Suppliers of equipment's and services.

As discussed above suppliers move to a role of being partly or totally responsible for the delivery and through life maintenance of equipment or systems. This development is a prelude to the trend of more and more autonomous ships, as will be discussed in the paragraph 'analysis of trends and developments'. In order to able to provide such a service, information (data) on the status of ship's systems, equipment and structure

must be measured and transmitted from the ship to the shore. Examples of identified solutions to support this need are:

- In aircraft industry system Aircraft Condition Monitoring Systems are in use. Such systems record and monitor flight data and information from aircraft equipment and systems. This data is analysed by ground based experts, thus enabling them to improve the performance of aircraft and to optimize their lifetimes. Concepts like this are already in to operation. E.g. Wagenborg Shipping has installed a remote monitoring system on the turbo compressor and shaft generator, enabling the shore support to monitor the degrading of these systems, and to predict failures using condition based maintenance techniques. Based on this information maintenance tasks are identified [Schuttevaer, September 7Th 2013 page 24].
- In order to diagnose small marine generator sets, tools have been designed (MEPEMS).
- In order to monitor cylinders a two sensor array (per cylinder) of acoustic emission transducers has been developed. It monitors wear and degradation of critical machine parts used (AE-WATT).
- In order to standardise data formats for the exchange of readings of ship's parameters, a data standard is developed. Further the ICT/TELECOM possibilities for transfer of this data are investigated (Ishare@sea, Broadband@sea).

Ship maintenance and repair yards

Periodically ships must be dry docked for maintenance and inspection of the underwater ship, in order to keep the ship up to standard. In addition maintenance and repair activities are needed, that cannot be done when the ship is in operation. This type of activities are usually done by dedicated maintenance and repair yards.

Such type of yards usually provide the necessary infrastructures, procurement, basic floor technologies capability and overall project management. The specialised activities are subcontracted to equipment and service suppliers, for which the yard has an external network and a supportive logistic supply chain.

The yard planning process often is "frustrated", due to the fact that maintenance- and repair lists in practice are not complete upon arrival of the ship at the yard. In addition this type of work in practice always leads to surprises (= unforeseen work). Ship repair and maintenance activities are labour intensive in particular when addressing on-board systems and equipment. Steel work (parts manufacturing, assembly, joining, surface preparation), pipe fitting etc. are usually low mechanised as the investments in mechanisation are not justified by the customary (low) throughput. In order to provide the optimum service for customers, the shipyard has a need for optimised business processes, tooling to support this and machinery.
Examples of identified solutions to support this need are:

- To support the ship owner, shipbuilder, repair yard, operator and crew a business model for through-life asset management has been developed and tested in business cases (THROUGHLIFE).
- A blueprint for a technologically advanced and environmentally friendly ship repair/conversion yard has been delivered (SHIPMATES).
- An analysis of the most recent and applicable European requirements concerning ship repair processes is available. It covers specified emission standards, prohibitions, responsibilities, and obligations for the ship repair shipyards (Eco-Refitic).
- In daily practice the forming of alliances with key suppliers and service providers by making available permanent workshop facilities at the shipyard location has proven to be a successful business model, allowing for reliability, fast response and efficient processes.
- A floating workshop in support of small repairs at a shipyard is under development (SMARTYards).
- To increase productivity, flexibility, quality and working conditions laser processing techniques and equipment for the final assembly area in ship new building and repair have been developed (DockLaser).

- Robotised welding machines are available for larger shipyards and under development for smaller yards (SMARTYards).
- Cleaning, blasting and painting processes are nowadays subjected to severe environmental limitations. Commonly hull cleaning, blasting and painting is done in dry dock, though there are also underwater cleaning and painting techniques. The use of cleaning, blasting and painting robots either or not in dry dock offers a solution for a higher performance level and lower costs (MINOAS, HISMAR, ROTIS II, INCASS).
- In order to repair and/or reinforce large steel structures with defects a composite patch repair method is available (CO-PATCH).
- Methods are developed to connect dissimilar materials (e.g. composites, steel) (SMARTYards).
- A useful technology is "reverse engineering", the possibility to acquire real product information by sophisticated measuring and calculus technology. The technology is needed when product information of ships needing repair, retrofitting or conversion is not available in virtual and/or hard print. Laser technology based measuring equipment (laser scanner and tracker) are already available, enabling a shipyard to create a 3 dimensional picture of e.g. an boiler room including position and size of machinery, piping, etc. (Figure 55)

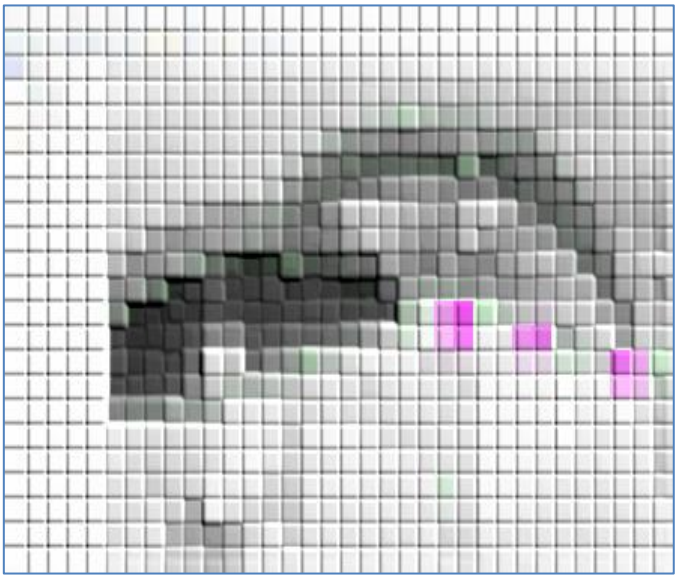


Figure 55: 3 D scan in support of reverse engineering (www.faro.com)

Ship retrofitting and conversion yards

As discussed ship-owners are faced with decisions on the retrofit of conversion of ships in operation. This type of activities can be far reaching, thus requiring a shipyard who can perform this.

This type of yards are in terms of magnitude, technical complexity, lead-time and finances, close to ship building. For this reason they require technical skills and managerial skills comparable to those of new building shipyards. Ship conversion is already a well-established practice with strong focus on offshore activities (oil/gas). These yards must compete on quality, price and lead-time. For this reason they must minimize associated risks by investigating and validating technical alternatives and production strategies to obtain market-conform competitive solutions. The activities are more labour intensive than ship new building, due to the disassembly and assembly work that needs to be done. Project management, planning, and supply chain management are comparable with new building contracts. The degree of mechanisation for steel work (parts manufacturing, assembly, joining, and surface preparation), pipe fitting etc. is less than on new-building shipyards.

Examples of identified solutions to support this need are discussed above and shown in the following:

- A tool has been developed to assist shipyards to plan retrofitting activities while meeting environmental standards, and additionally allowing for the estimation of the associated cost of the ship retrofit. The tool shall enable stakeholders of retrofitting projects to take an informed decision among implementation alternatives and strategies. It also provides another perspective to judge the feasibility of greening technologies, particularly from an environmental point of view (Eco-Refitic).

Scrap yards

When the ship reaches its end of live, it needs to be scrapped. Many ships are scrapped in Asia (India, Bangladesh and Pakistan), where workers (including children) do their job under dangerous, unhealthy and environment unfriendly conditions. It is also known that designing and enforcing regulation concerning a cleaner form of recycling in the shipping industry is a difficult process.

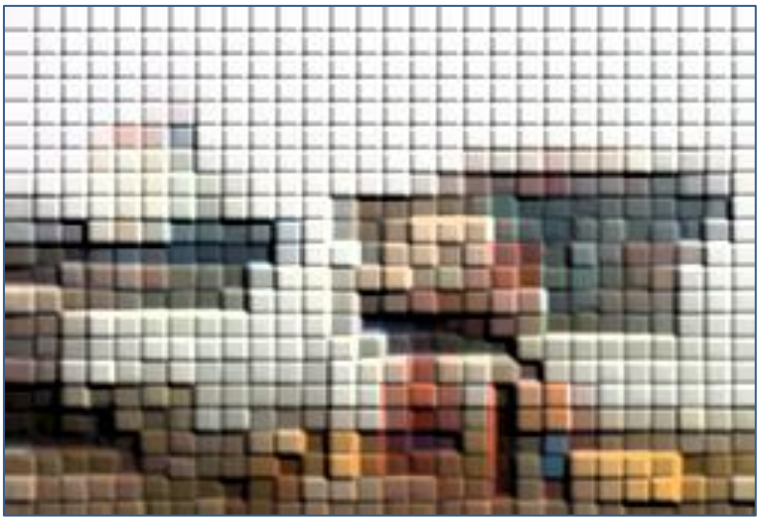


Figure 56: Scrapping of Ship

Two EU projects have resulted in tools for this type of industry, where Divest was a continuation of the project ShipDismantl:

- Decision support tool for ship breaking industry including guidelines for ship dismantling and recycling operations (ShipDismantl)
- Decision support tool for ship recycling to assess the economic, environmental, health and safety implications of numerous scenarios within which recycling might take place (DIVEST).

Analysis of trends and developments

In the following an analysis of trends and developments is presented, whereby the focus lays on the above presented results and developments in ship maintenance, repair, retrofit and end of life. The analysis firstly discusses the rapid developments in information technology and the pressure on ship-owners to comply with legislation. It then continuous with the trend towards more autonomous ships and the effect this has on maintenance activities and the people having to perform these tasks. It then shows that more and more tasks will be shifted towards shore based organisations, leading to a redefinition of responsibilities between seafarers and shore based experts. Finally an assessment is given on the effect of this trend on the business of shipyards.

Incentives for Life cycle Asset Management

As a result of the seemingly unstoppable developments in computing power, data storage, software algorithms to process large amounts of data, 3 dimensional graphics and communication technologies, means become available to optimise the "life cycle management" of capital assets. This in combination with the pressure on ship owners to take their responsibilities as actor in the Maritime Transportation System, will affect the design of new ships, the need to retrofit existing ships and the pressure to maintain them in optimal condition. The latter was addresses by the IMO in the following statement:

(Near) future ship operation

> *In order to provide a seamless and reliable service in the most efficient manner, the Maritime Transportation System must deliver safe, secure, efficient and reliable transport of goods across the world, while minimizing pollution, maximizing energy efficiency and ensuring resource conservation. To achieve this, the complexity of the interrelation among actors in the Maritime Transportation System should be recognized and taken into account when addressing specific actions.* [World Maritime Day 26th September 2013 – IMO's contribution Beyond Rio+20 "a concept of a sustainable maritime transportation system"]

Whereby captains and chief engineers in the past received their orders and run their ship to the best of their knowledge and experience, various forms of shore support are readily in operation or under development. This despite the fact that some seafarers experience this as a serious threat to their independence.

When following the trends in the development of robotic systems like autonomous cars, Unmanned Aerial Vehicles and Remotely Operated Underwater Vehicles it is unavoidable that ships of the future will be designed as "a remotely operated or autonomous robot". Such a design will lead to a minimisation of crew and a shift in their tasks. It will also lead to ship designs that are constructed to support an optimum maintenance and repair philosophy, primarily performed by the "robot" itself or by organisations performing these tasks during the time in port. Finally design measures will be taken to ensure safe operation in confined waters like rivers and harbours, and in support of complex operations like anchoring and mooring.

Design measures
Keeping in mind the image of a ship designed as robot, many shipboard functions will require automation of systems and an integral control, monitoring, decision support and communication system. This is shown in Figure 57, which is included in the H2020 proposal project Smart Autonomy for Green Shipping (SAGE Ship).

Shipboard functions when automated must cover many functions, including:

- The **safe navigation** of the vessel in all weather conditions, in open sea and confined water. For this smart systems must continuously monitor the ship's geographical position, the traffic in vicinity of the ship, the ship's movement as a result of seaway and wind, and other relevant factors like fuel usage. This information must be analysed and feed into a process of autonomous decision making or reported to a shore control and monitoring room for decision-making.
- The **safe operation** of the vessel while navigating from one location to the other. For this smart systems must continuously monitor the condition of the ship's stability, structure, and on-board systems. This information must be analysed and feed into a process of autonomous decision making or reported to a shore control and monitoring room for decision-making in case of identified deviations. E.g. advanced acoustic emission testing technologies will provide continuous status information on the structural integrity in terms of fatigue cracking and active corrosion.
- The **maintenance and repair** of the ships structure and on board systems **while underway**. For autonomous repair of critical ship structure elements, the future use of self-healing materials as developed for e.g. aerospace industry[8] might prove a solution. For systems and equipment in depth analysis of failure modes and gaining insight in parameters as Mean Time Between Failures (MTBF) must be done, but is already common practice in many technology areas. Based on this knowledge decisions on system layout including the need for (partly) redundant systems must be made. In addition systems need to be designed to predict preventive maintenance activities to be executed during the ship's stay in a port. This can be done by introducing a condition based maintenance philosophy, already used in many industries.
- The **maintenance, inspection and repair** of ships structures and systems **during port visit**. When the ship arrives in port there is little time to perform these tasks. Having insight in the condition while underway of the ship systems etc., maintenance and repair tasks can be prepared before the arrival of the ship in the harbour. For inspection and maintenance tasks robot systems will become available in many forms, such as robots already incorporated in the ship design as system and robots available ashore for performing these tasks.

[8] **Self-healing materials** are a class of smart materials that have the structurally incorporated ability to repair damage caused by mechanical usage over time.

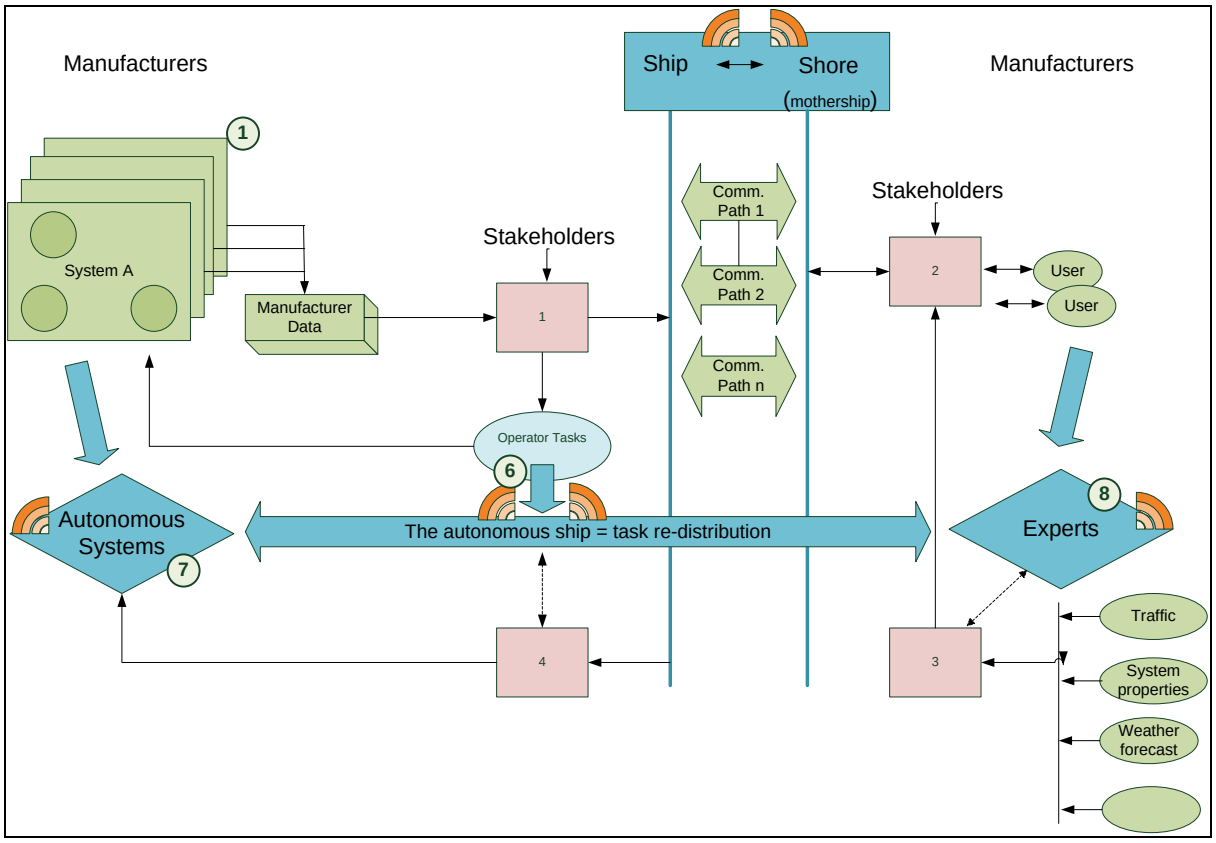


Figure 57: Re-distribution of tasks in support of an autonomous ship

Example
RoboShip is an independent, intelligent robotic platform on rails for use within the shipping industry. The parties involved in the RoboShip project brought together a number of innovations in it. Imotect, for example, developed a smart, cost-efficient rail, while DFKI was responsible for an autonomous vehicle to run along the rails. Incas developed the sensors, Xsens developed the tank navigation system, and the University of Twente was responsible for ensuring that a thorough inspection of the ballast water tanks is carried out using the equipment. The Meyer Werft shipyard in Germany had also joined the project, with the intention to integrate RoboShip into the ships it builds. However the outcome was that commercially the result did not payback for the Shipyard, stopping this trajectory at this time. (German-Dutch INTERREG IVA subsidy program).

Human factor
A general observation is that not enough youngsters make the choice for a technical profession. For shipping industry this translates into a shortage of skilled technicians, both for sea duties and for shore support. As a result operators are forced to man their vessels with less experienced crewmembers, creating a situation of a greater dependency on support from shore based expertise. This combined with already discussed advancements in remote monitoring, control, decision-making and maintenance philosophies, will lead to different types of tasks for “remaining crewmembers”. And further to a redefinition of responsibilities between shore based experts and crew members at sea.

It is inevitable that these technical advancements and demographical trends will influence the mind-set of stakeholders, forcing them to decide on the introduction of a more chain oriented business model. This will then lead to the introduction of real-time integrated data information and decision support systems between ship's, operators, owners, shipyards and suppliers for operating, maintenance, supply and other purposes.

In order to realise above mentioned shift in paradigm, research is needed to explore possible stakeholders barriers as a result of differences in mind-set, interest, culture and abilities in weighing risks. Especially in the shipping industry, where many seafarers will explain that it is impossible to operate ships unmanned. And ship-owners feel that they will be faced with legal procedures, leading to large sums of compensation in the event of accidents or other calamities.

Further as the number of crew members will reduce and their technical knowledge will move towards system overview, vice technical knowledge in depth a different type of seafarer will be needed. This might result in a situation that the profession of seafarer becomes less interesting, which trend will be strengthened when operational decisions are also be made ashore, taking away the traditional independency. Research in this area is essential, to support these future developments

Shore based support
As distant monitoring and control of ship's equipment will be further developed and further integrated into a total ship's system remote monitoring and control system, supported by new data standards and data communication systems, the land based organisation will need to reorganise in order to provide the needed services.

Maintenance and repair activities must be planned based on the operating schedule of the vessel and the limited hours the ship is in port. This requires experienced technicians, who can analyse the received data of ship's systems and transform this in a maintenance task, including required spares, drawings, supportive mobile maintenance equipment etc. Further inspections must be carefully planned, making use of matured technologies like portable robotised inspection, cleaning and repair devices to minimise in port time. This also requires skilled operators, who can operate these systems, interpret the measurements and explain them to inspectors of class societies.

Finally the supply chain must be optimised ensuring timely arrival of need spares and other goods. This process can be supported Enterprise Resource Planning systems (ERP) which are already worldwide implemented in the shipping industry and Navies. Such systems can support configuration management, maintenance workflow, supply chain, finance, and maintenance project planning.

Example Floating Production, Storage and Offloading Vessel (FPSO)
In 2014 Netherlands Maritime Technology organised a workshop at Bluewater Energy Services B.V. as part of Project Shore Support (www.shoresupport.eu). In this workshop representatives of the owner and operator, system integrators, suppliers, maintainers and researchers discussed the topic " how to operate and maintain an unmanned FPSO". The idea was to discuss a roadmap towards such a future concept.

Effects on the business of shipyards
The above described trend will influence the business model, processes and activities of the various types of shipyards. Not having the intention to be complete, examples are:

- Shipyards may need to reconsider their business model on the customer value the yard is offering. One the one hand the yard can concentrate on doing the maintenance and repair tasks, that are offered by the customer. On the other hand it can provide a service in support of the customer, interpreting the maintenance data as automatically measured by ships' systems and equipment's and providing the owner with a tailored proposition, which the shipyard then executes at the shipyard or maybe at a partner yard somewhere along the route of the ship. The latter model requires knowledgeable persons within the shipyard and/or strategic partners to perform these tasks.
- In order to remain competitive shipyards must ensure sufficient knowledge of shipboard automation in order to interpret presented information and to maintain/repair/modify such systems. This requires workshops, equipment's, skilled personnel etc.
- In the maintenance process the shipyard must decide whether or not to investigate in new technologies like inspection and cleaning robots, robotised welding machines, etc. If not they should need key partners to perform such tasks.
- In order to be able to maintain ships of the near future, the yard must be invest in knowledge about new technologies such as scrubbers, LNG driven propulsion system, energy saving devices etc. If not they should seek key partners to perform such tasks.
- It must be expected that the need for dry-docking will remain, but legislation will put more pressure on the activities performed in these dry docks.

Conclusion

In overviewing the state of the art in the field of maintenance, repair, retrofit and end of life for the shipping industry, it can be concluded that both individual companies and various RDI projects have investigated and realised solutions/products in support of these branches.

The prime challenge lays in the ability of the different actors in the Maritime System to understand the consequences of the swiftness of technological advancements and the demographical trends, in order to remain competitive.

Rules and regulations

In the following some aspects on Rules and regulations are addressed.

Review

Ship's operation and maintenance

Ships are designed and maintained in accordance with rules of the Class Society under which supervision the ship operates. In order to support the trends as outlined in this chapter, rules must be analysed and adapted.

Policies and legislation for reducing energy and greenhouse gas emission is an incentive for owners of ships to retrofit existing ships, thus creating a new market for shipyards and suppliers.

Retrofitting

Perhaps the more urgent issue relates to developments related to the greening of ships, in particular in cases where multi-fuel, abatement and renewable energy issues are concerned. For example, the retrofitting of ships with dual fuel engines or with gas engines is not yet covered by generic classification rules and regulations, being presently handled on a case-by-case basis. In addition, existing rules and regulations limit the possibilities of retrofitting, for example the location of LNG within 20 % of the ship beam on both sides. Uncertainties regarding classification issues are a major impediment in advancing retrofitting solutions.

Reference documents have been drawn as part of the exchange of information in the framework of Article 13(1) of the Industrial Emissions Directive (IED, 2010/75/EU), which commits European Union member states

to control and reduce the impact of industrial emissions on the environment. The Best Available Technique Reference Document[9] (BREFs) have been adopted under both the IPPC Directive (2008/1/EC), that concerns integrated pollution prevention and control and the IED. The "BAT conclusions" is a document containing the parts of a BAT (Best Available Technique) reference document laying down the conclusions on best available techniques for particular branch of industry. According to Article 14(3) of the IED, BAT conclusions shall be the reference for setting the permit conditions to installations covered by the Directive. A relevant BAT is for example: Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics, August 2006.

A study in the safety aspects of retrofitting and the impact on existing Rules and Regulations is needed, to lower the thresholds to acceptance of retrofitting ships with green technologies.

- Conventional operation and maintenance of ships is regulated by Ship Classification Societies
- Development of new and innovative retrofitting methods is limited because of lack of appropriate rules
- A study of the safety aspects of retrofitting and the impact on existing rules and regulations is needed, to lower the thresholds to acceptance of retrofitting ships with green technologies.

Conclusion

In order to support the trends as outlined in this chapter, rules must be analysed and adapted.

Research and development

In the following an overview of the results of various RDI projects is summarized and how they mutually relate. Available information is stored in the MESA database.

Review

Table 25 summarises the results of analysed projects per research domain and (sub) topic.

Table 25: TSA3-G –Projects per research domain and (sub) topic

Research topics	Analysis	Projects
Energy saving technologies and devices	1. Integration of energy saving technologies in early design stage, using advanced simulation models for the energy grid of the ship	JOULES
	2. Methodology to evaluate fuel saving and emission reduction	RETROFIT
	3. In order to support retrofitting investment by technical feasibility and cost benefit analysis, the developed system will provide sufficient insight into the energy performance of the ship.	REFRESH
	4. Design tools, procedures and databases that can be applied in practical propeller design (conventional fix pitch propeller)	SUPERPROP
	5. (1) energy saving device for powering performance improvement; (2) physical mechanisms behind different available energy saving devices	GRIP
Decision support for & inspection planning	1. Decision support & inspection planning using standard descriptions of structural components and defects and standardized calculation methods along with experience based calibration factors and based on reliability analysis.	RISPECT

[9] BREFs are documents, which contain a description of the most effective and best available techniques for preventing of the environmental pollution. For every industrial sector in EU a BREF is available. It enables faster knowledge transfer within EU.

Research topics	Analysis	Projects
	2. In support of inspection process by the use of robotic systems 3. (1) tool for ship owners for quick decision making on retrofitting ships; (2) tool for determining hull lines; 4. (1) guidelines for ship-dismantling and recycling operations (design dismantling site, facilities and processes); (2) decision support system 5. To assess the economic, environmental, health, and safety implications of numerous scenarios within which recycling might take place.	INCASS GRIP ShipDismantl DIVEST
Inspection and monitoring of ship's hull structure	1. Standard Hull Condition Model (HCM), prototype tools, condition assessment process, interfaces 2. Monitoring technology based on acoustic emission testing (AT) combined with follow up NDT for monitoring the status of structural integrity in terms of developing and proceeding fatigue cracking and active corrosion 3. Underwater vehicle, able to perform underwater visual inspections and thickness measurements, particularly in tanks 4. Lightweight magnetic crawler for close up visual feedbacks & heavy weight magnetic crawler for preparing the surface and ultra-thickness measurements 5. Remotely operated vehicle with 6 cameras and a NDT ultrasound probe 6. In EU funded research project BESST, research have been carried out to improve Reliability through Model-Based Design and Condition Monitoring?. In BESST, a "Damage Detection Method" for monitoring composite structures in the hull have been developed. This detection software consists of passive non-linear acoustic techniques dedicated to data acquisition for the damage detection and monitoring. There is also an internet communication interface wherein on board status of the hull structures can be monitored	CAS CORFAT MINOAS MINOAS ROTIS II BESST
Inspection and monitoring of ship's machinery	1. Micro aerial vehicle (robot) to provide an overall view of the state of the vessel and to detect potential critical areas 2. A fully automated self-navigating, multifunctional underwater hull maintenance robot with the primary objectives of structural inspection and cleaning of marine vessels." 3. Diagnostic device for small marine generators 4. Sensor based processing unit that can continuously monitor ship lubricated systems in order to provide an effective scrutiny over its serviceable life, enabling non-skilled operating crews to predict degradation, anticipated problems and take remedial actions before damage and failure occurs 5. Two sensor array (per cylinder) of acoustic emission transducers used for to monitor wear and degradation of critical machine parts	MINOAS HISMAR MEPEMS POSSEIDON AE WATT
Repair and retrofitting	1. Repair and/or reinforcement method for large steel structures with defects. Using composites 2. Blueprint for a technologically advanced and environmentally friendly ship repair/conversion yard, with a target of productivity improvements over today's European Yards and to investigate the opportunities available in terms of ship breaking (general process, steel cutting&	CO-PATCH SHIPMATES

Research topics	Analysis	Projects
	joining, repair/replacement of cabling and pipework, controlled process for converting/retrofitting ships ballast and waste water systems to make operation more environmentally friendly, exploring ship breaking & recycling as alternative market 3. In order to support retrofitting investment by technical feasibility and cost benefit analysis, the system will provide sufficient insight into the energy performance of the ship. 4. Retrofit management tool (process simulation and life cycle analysis)	 REFRESH Eco-REFITIC
Life cycle simulation	1. Retrofit management tool (process simulation and life cycle analysis) 2. Concept for joint life-cycle services involving shipbuilding and repair yards as well as owners and operators focussed on the following business cases (1) ferries operating in Mediterranean, (2) river cruise vessels; (3) medium range cargo vessels. Techniques : (1) lightweight structures; (2) coatings 3. (1) guidelines for ship-dismantling and recycling operations (design dismantling site, facilities and processes); (2) decision support system 4. To assess the economic, environmental, health, and safety implications of numerous scenarios within which recycling might take place	Eco-REFITIC TROUGHLIFE ShipDismantl DIVEST
Business model for through life asset management	1. Concept for joint life-cycle services involving shipbuilding and repair yards as well as owners and operators focussed on the following business cases (1) ferries operating in Mediterranean, (2) river cruise vessels; (3) medium range cargo vessels. Techniques : (1) lightweight structures; (2) coatings	TROUGHLIFE

Figure 58 gives an overview of the analysed projects and their relation to each other.

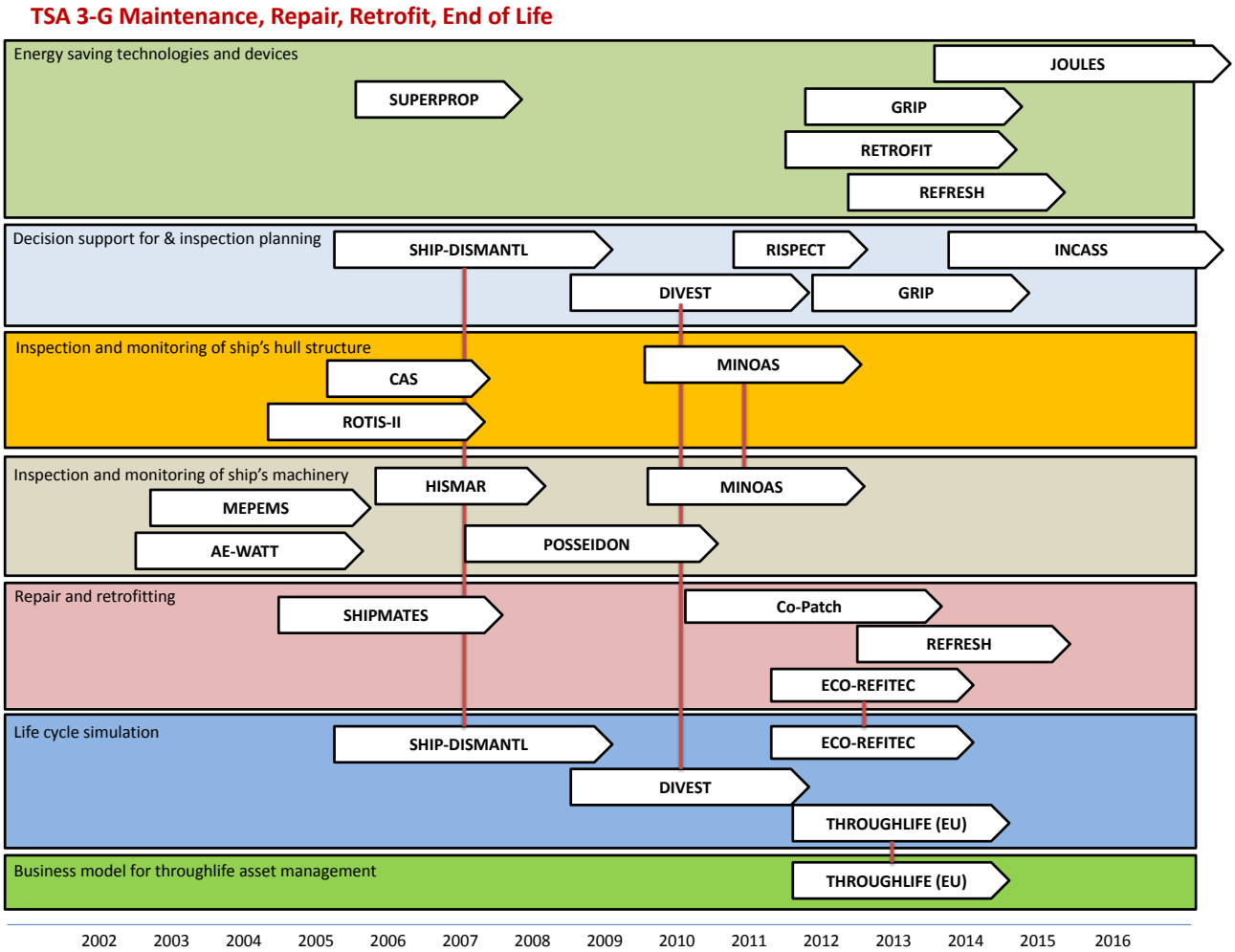


Figure 58: TSA 3-G Maintenance, Repair, Retrofit, End of Life – Project timeline

Conclusion

Above figures summarize the results of the various projects and their relation to each other. The outcomes have been used in support of this chapter of the State of the art report.

Suggested show cases

It is suggested to write a showcase on retrofitting ships. This showcase intends to show that EU policies translated in to legislation, resulted in solutions in support of this policy. The following two projects will be part of this showcase, as well as other yet to be identified projects. And further solutions developed by technology providers and technology integrators (yards).

1. **RETROFIT,** www.retrofit-project.eu

- Scope of project: "Retrofitting ships with new technologies for improved overall environmental footprint"
- Partial Result: Pilot application on Acciona ship:
  - Retrofit alternatives determined
  - Energy management simulation
  - Decision support system for energy management
- Commercial application:
  Prototype Decision Support developed by Imtech

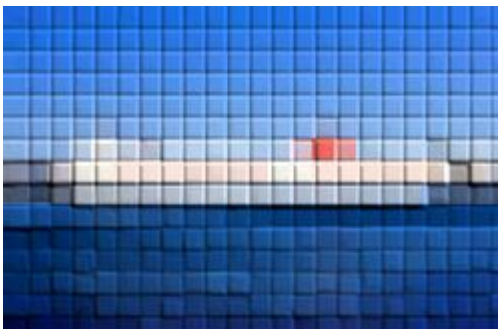


Figure 59: Ship used in RETORFIT project for retrofitting

2. **GRIP,** www.grip-project.eu

- Scope of project: to provide a significant reduction in fuel consumption in shipping operations through retrofitting of ESDs to existing ships
- Partial Result: Design of new optimal energy saving devices for the ship types contributing most to the CO2 emissions from international shipping.
- Commercial applications:
  Not yet available

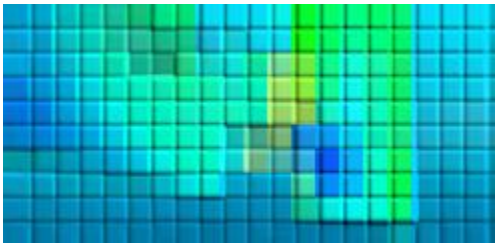


Figure 60: FEM analysis on effect of ESD (Pre-Swirl Stator)

List of Figures

List of Tables