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IMPROVED MODELS IN THE DESIGN OF COMPLEX SPECIALS: SUCCESS OR FAILURE?

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ABSTRACT

The European Maritime cluster remains a very important player in the design, production and operation of Complex Specials, but under pressure of competitors in the Far East both the design and the design approach has to be improved to maintain its market position. The problem of any new method is that it should comply with boundary conditions such as client influence, schedule, budget, resources, and scope but still has to improve the risk mitigation and quality of the product.

KEY WORDS

Ship; Design; Design Method; Procedures; Complex Specials; Design Approach

INTRODUCTION

The maritime cluster in Europe is an industry with a large economic importance; while a large portion of production has been transferred to the South-East the European Union still controls approximately 40% of the world fleet (Wijnolst & Wergeland, 2009). To be more specific: the Dutch maritime cluster is an important player in the design, production and operation of complex, special vessels such as dredgers, heavy offshore vessels and yachts (Hopman, 2007)The European, and in that respect the Dutch maritime cluster, obtained this position by increasing productivity, reducing costs and applying system innovations to deliver unique, complex and quality vessels within a reasonable price (Hopman, 2007).

However, the delivery of these vessels, further called Complex Specials will not be enough to maintain this competitive position: South Korea, China and Singapore are already producing drill-ships, trailing suction hopper dredgers and cruise vessels (Figure 1), (Rigzone.com, 2011), (Niemela, 2011); Ships that are considered "*Complex Specials*" and thus provide a **considerable threat to the market position of the European Maritime Cluster**, which is quickly losing its technology advance.

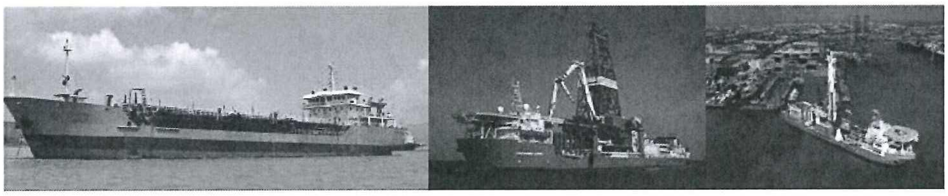

Figure 1, Complex Specials Built In the South East

This paper is part of an on-going research by Ulstein Sea of Solutions and the Delft University of Technology to maintain the market position of the European maritime cluster by consistently improving their products, not only by applying ad-hoc system innovations, improving productivity or reducing costs. But also by consistently developing better products than their competitors: reducing risks and producing vessels that comply to *and* supersede our client's wishes.

Developments in the *ship design process* or *maritime product development* have long been the territory of the Naval industry, where projects are commenced to evaluate methods such as set-based design (Frye, 2010) or test techniques such as the automatic generation of ship layouts (van Oers, 2011), (Daniels & Parsons, 2007) and the withdrawal of design knowledge (DeNucci, 2009). Because these researches are all fuelled by a naval application, they subsequently forego several key aspects of the commercial industry.

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In the *commercial ship design industry* research is mainly focussed on improving techniques, technologies and communication such as Computational Fluid Dynamics (CFD)-optimization or improved import and export of design-data among programs. Only on rare occasions research concentrates on the design process, with its best known result in the Design Spiral of Evans, dating back to 1959, (Evans, 1959). This *ship design spiral* is still the most commonly used approach, even though Andreasen makes a very strong case for innovating the way of designing under pressure of market dynamics and technical developments (Andreasen, 2003) This is supported by (Rahim & Baksh, 2003) in their review of several Engineered to Order (EtO) and Make-to-stock companies (MtS).

This paper will discuss the boundary conditions that should be fulfilled to develop a new method in the commercial ship design industry. To determine these boundary conditions the paper will discuss the Complex Specials industry, the product development approach within that industry and the available tools. These findings will be integrated into a problem statement to provide a starting point for a new method, developed to support the development of complex specials in a commercial, maritime setting.

COMPLEX SPECIALS

As mentioned in the introduction, this paper concentrates on the Complex Specials Industry in the European maritime cluster. Complex Specials are tailor-made, high-value assets in the maritime environment; they are built for a specific client with a designated purpose. In general only a small series or a single vessel is built to this exact specification; this is different to the majority of the engineering disciplines, including the cargo vessel industry, where multiple products or vessels are built on a single engineering project.

The product development process in the design of Complex Specials can generally be subdivided into four main stages shown in Figure 2, eventual leading to Design N, via the different design products after each phase: Ds (Design after Sales), Dc (Concept design) and Db (Basic design). The paper concentrates on the early stages of the design process: the Pre-Contract/Sales and the Concept design phases, where the design is still very fluent, and the changes in the design have considerable impact on both the eventual result and the remainder of the process. Figure 3 presents the committed costs, the incurred costs, or actual costs, and the remaining design influence for both the client and the designer based on research of (Bernstein, 1998), providing a strengthening of the view that the initial phases of the product development make considerable impact in subsequent phases.

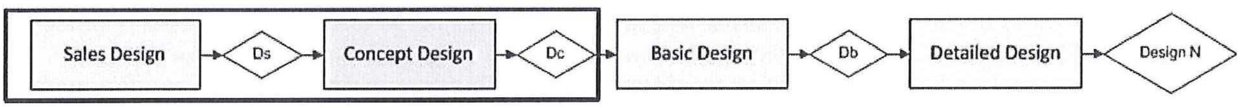

Figure 2, Design Stages in the Design of Complex Specials

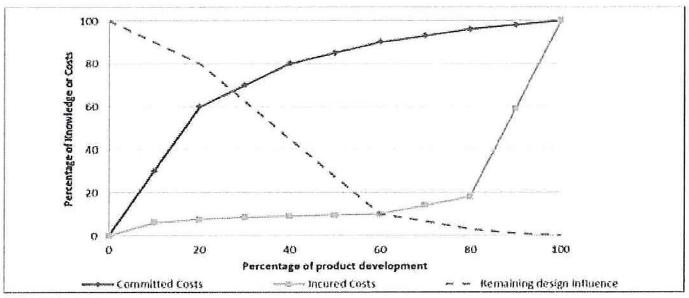

Figure 3, Committed Costs and Stakeholder Influence during Product Development (Bernstein, 1998)

For the remainder of this paper the focus will be on the product development in a commercial environment, in which a product is developed for an external client; compared to the naval industry, where product development is often done in-house, with considerable higher budgets. In brief, this paper and the related research will concentrate on the design processes used to perform *early stage design* of *complex-special vessels* in a *commercial* environment.

Section 2.1 will discuss the product development process in this industry in more detail, working towards several areas where improvement is recommendable, discussed in section 3.

Product Development of the Complex Specials

The product development *process* in the commercial, complex specials industry is an ill-defined area in the literature, the majority of papers is either focussed on product development tools or the development of processes for naval (*governmental*) design. This part is based on an initial, empirical review which aims to evaluate the current practice in the Commercial Maritime Industry, both from a project (2.1.1) and design (2.1.2) perspective. Data from a wide review in design methodology research, supplemented with data from a set of company reviews will be used to create a basis for subsequent research.

In section 2.1.3 the available product development tools, in this case primarily software tools, will be discussed, providing insight into the basic principles used in product development technology, reviewing both the available software tools and the tools currently in use in the maritime industry.

The selected perspective, based on a Design and Project related aspect is a further elaboration of the Socio-technological view presented in (Bruinessen, Hopman, DeNucci, & van Oers, 2011), showing that product development processes are based around three main components: Process or project, People and Technology, the latter which includes the Design and Tool-aspects. This paper will not discuss the 'People' component, related to the implementation and response of actors on a new method, although this area will be explored in subsequent papers. The split between the two perspectives perspectives *Project/Process* and *Design/Technology* is further supported by (McDonald, 2010), who uses the seven characteristics defined by (Erikstad, 1996) and discusses the complexity and problems of ship design split among the two perspectives.

The next few paragraphs will discuss these elements in more detail and provide a framework for subsequent research. This section will end with a set of conclusions drawn from this preliminary review.

Product Development of the Complex Specials: Project Challenges

The project's challenges in the development of new complex specials will be discussed based on two perspectives. First of all a review of the industry, represented by four companies, will be given based on the most recent *project management book of knowledge* (Project Management Institute, 2008). In a second step the research of both Bernstein (Bernstein, 1998) and McDonald (McDonald, 2010) will be used as an extra reference. In a third and final step the link will be provided between the two perspectives and the four (project) characteristics from the research of (Erikstad, 1996):

- ***Multi-dimensional, partly non-monetary performance evaluation:*** Even though the factors that directly influence the profitability of the vessel are very important a lot of factors are difficult to perform into monetary terms, such as safety issues, environmental impact and technical performance such as sea-keeping and stability.
- ***High Cost of Error, costs includes a wide range of parameters, incl. money, time and resources:*** Decisions made in the early stages of the design have a considerable impact on the eventual performance of the vessel. Considering the magnitude of the life-cycle costs making the wrong choices in the early stages will have serious consequences.
- ***Strict time and resource constraints on the design process:*** To remain competitive a design office needs to respond to tender requests in a very short amount of time, on the other side, the results of this initial phase determines the majority of characteristics in a later stage
- ***Predominantly 'one of a kind' and 'engineering to order' solutions:*** The current (European) industry predominantly offers one-of-a kind solutions to specific clients, developing a product for a specific client.

Perspective 1: The Project Management approach

To identify the key variables of the product development processes the basic principles from the most recent *project management book of knowledge* (Project Management Institute, 2008) are used, which show that a project is balanced between six variables: Scope, Quality, Schedule, Budget, Resources and Risk. When quantifying the **balance** between these parameters we can visualize the emphasis and behaviour of companies and project teams in product development, which eventually led to the development of approaches for each individual industry and project type.

After evaluating the different companies, an incomplete picture emerged: the *project management book of knowledge* presents the image that the Project Manager can influence and modify your project independently of external factors. In commercial product development the major stakeholders, and in particular the clients (or 'sponsors') have tremendous impact on balancing the different parameters. This leads to the addition of a 7th variable: **Client Influence,** to the variables defined earlier.

The seven variables discussed above are illustrated in Figure 4, introducing the approach used to visualize the variables. The graph reads as follows: the further a variable is on the outside of the graph, the more this parameter is seen as a strength of the industry. The *'perfect'* project would have a high client influence, a full scope, high quality, short schedule, low budget, limited resources and low risk (Figure 4). As this is a 'utopian' project, any real-life situation is a balance between these variables. The different variables and how they were estimated is discussed in the following parts.

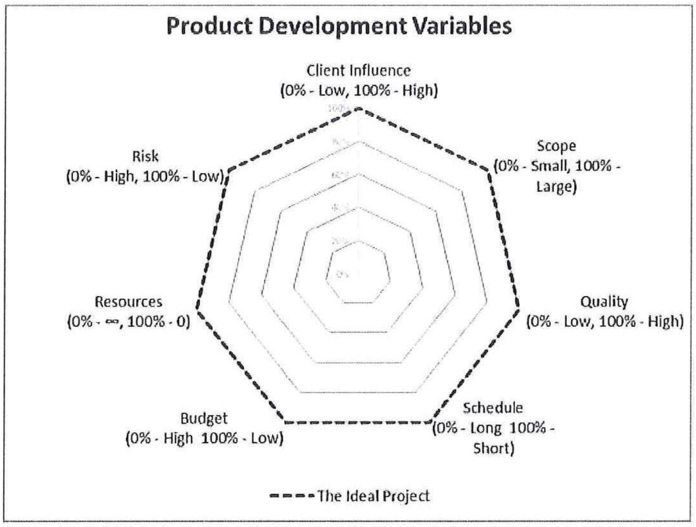

Figure 4, Product Development Variables

(1) *Client Influence:* Not all clients have an equal amount of impact on the development of the product they are going to use. In the Maritime Cluster the objects are of very high value and contracted by a single client, furthermore: during the product development the client is involved in every stage and every decision. On the other side, when looking at the car or consumer electronics-industry the product is developed based on market research, where individual clients have little impact on the product development projects.
(2) *Scope:* The scope shows how large the company involvement is in product development projects, either from inception to the start of production or only in a selection of stages.
(3) *Quality:* The quality shows the degree to which the inherent properties of the product comply with the requirements of the client.
(4) *Schedule:* This parameter shows the time projects run from conception to start of construction. The schedule is concentrates on the actual time to run the project, without taking decision-time for the client into respect.
(5) *Budget:* The (Project Management Institute, 2008) makes a distinct difference between the budget and resources for a certain project. When evaluating this aspect it became clear that both the Budget and the Resources were closely linked, but for the completeness of this research both elements will be evaluated separately.
(6) *Resources:* This aspect contains the available resources to develop products in the company. The quality of the resources will not be discussed, although a combination of a high budget and smaller resources would suggest an abundance of high level personnel.
(7) *Covered Risk:* The risk in the design process is determined by situations or circumstances that are likely to occur and cause negative impact, for example errors or involuntary changes in subsequent phases.

Based on these 7 variables, the four companies in the maritime sector were evaluated and characterised. Three companies showed similar behaviour in their Product Development projects. The fourth company had, because of its slightly different market segment, a different balance. The variables were withdrawn from a set of interviews in a wide range of companies, and provided a qualitative view into the design projects in the Maritime industry, both in the Netherlands, supported by further investigation in a Norwegian company.

The generic image of the maritime design industry can be described as follows: A high client's influence (1) is supported by a very short schedule (4), low budgets (5) and little resources (6). The scope (2) is fairly small: The design offices are usually responsible for the early design stages and not for the entire product development process from inception to production. The quality (3) is low, as a large portion of the inherent properties of the product are determined in a very early stage of the design process, as Figure 8 shows, even before the majority of requirements are determined. In the subsequent process, under pressure of external decisions the inherent properties have to be changed, creating a sub-optimal solution. The risk (7) is still within acceptable boundaries, primarily because the majority of solutions are within a comfortable range of previously produced designs, an aspect which will be explored further in section 2.1.2.

The fourth company differs from the other three because it is involved in a market segment that has considerable budget, time and resources compared to the other companies. This subsequently relates to a higher quality, less risk and, as part of a shipyard, also a larger scope in product development projects. This company is an important player in the naval industry and provides little insight into the difference between commercial and *governmental* or *naval* product development projects.

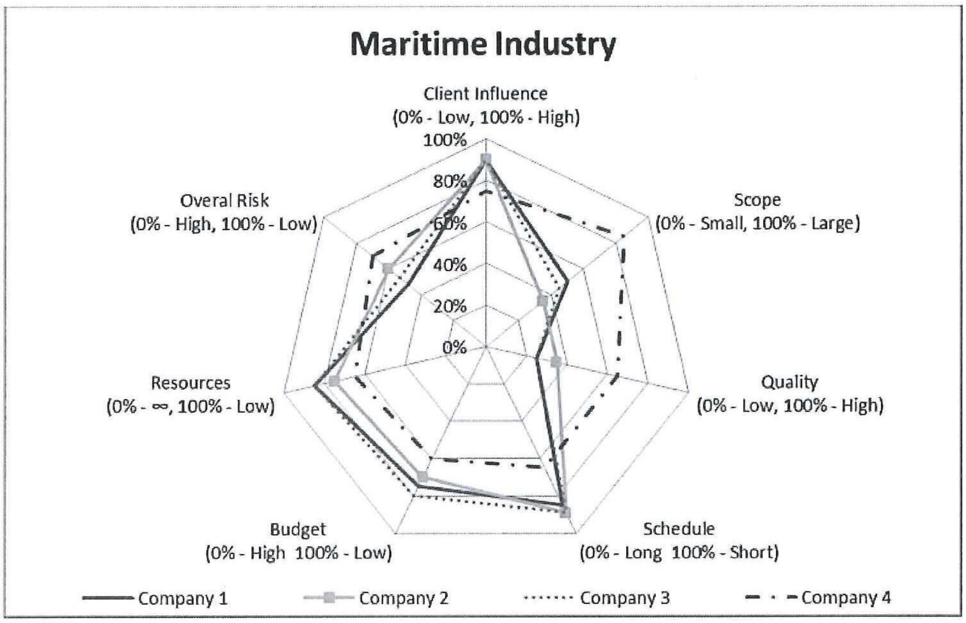

Figure 5, Maritime Industry Based On 3 Dutch and 1 Norwegian Company

Based on the previous discussion, the three reviews of Company 1 to 3 are used as a benchmark to qualitatively describe the current boundary conditions of product development projects in the Commercial Maritime Industry. The benchmark is used in comparison to other industries in the next section and as a baseline for subsequent research. The average graph for all companies and a graph for the eventual benchmark situation, excluding company 4 are shown in Figure 6.

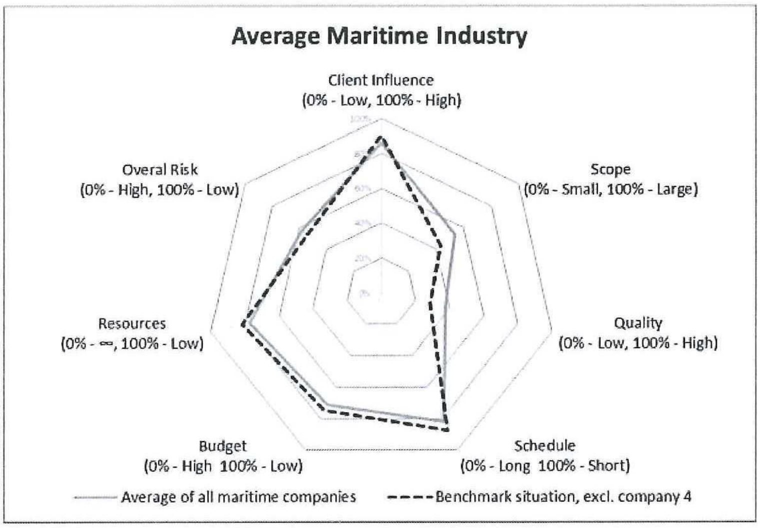

Figure 6, Average Maritime Industry Based On 3 Dutch and 1 Norwegian Company

Comparison to other industries: In a similar approach several other industries were evaluated that produce similar valued, engineered products. In the majority of industries the products are either Made to Stock, Made to Order or Assembled to Order, compared to the Engineered to Order products of the Commercial, Complex Specials industry. The company shown in Figure 7 is one example where the boundary conditions of product development projects are significantly different compared to the maritime industry in Figure 6. In this particular case, the company can sustain its position as market leader by producing the most innovative solution available: making it very important to deliver quality products, within a very short schedule. On the other hand, the company takes a large risk, inherent in their company policy: new, innovative products are delivered to clients before the product is completely finished making it possible for their clients to incorporate new products into their production line. Inherently, the client is led by the company toward new products, which the company provides from virtually unlimited budget and resources.

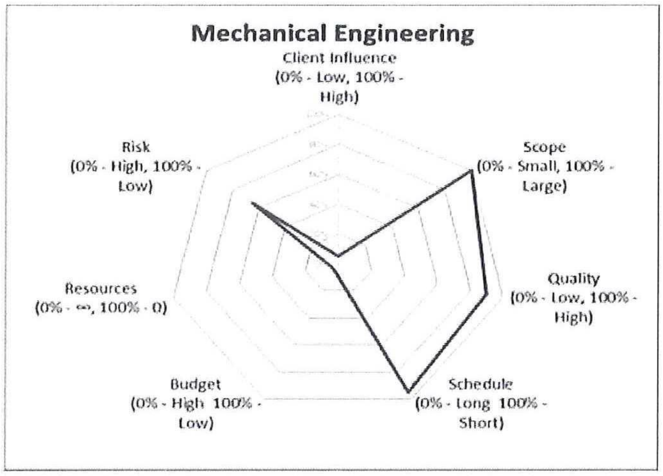

Figure 7, Boundary Conditions of Product Development Projects in the Mechanical Engineering

Perspective 2: Research perspective

The second perspective is provided by the research of both (Bernstein, 1998) and (McDonald, 2010). Both researches provide insight in the product development process within the maritime industry using graphs sketching the development of certain aspects during the product development phases. When combining the stakeholder influence, number of requirements known and risk, placed on a normalized project-progress frame, it becomes clear that in the early stages the 'design influence' is lower than the 'risk' remaining in the project. In a commercial setting, a design is sold with a set of inherent properties, creating a situation where the risk is transferred completely to the design office, a very undesirable situation.

Table 1: Project Progress Framework

	Percentage of Product Development
Project Start	0%
Conceptual Design	0-20 %
Basic Design	20-40%
Engineering	40-100%
Start Production	100%

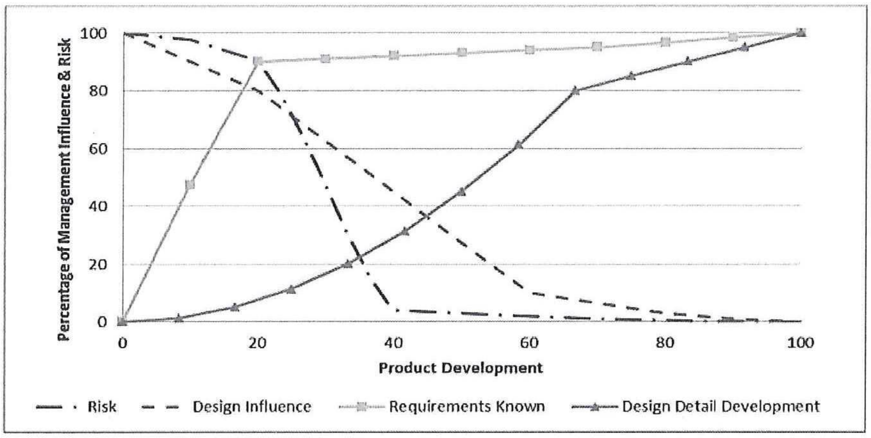

Figure 8, Progress of Risk, Design Influence, Requirements and Detail Development during Product Development Processes

Two perspectives in respect to the invariant characteristics

The first four characteristics, defined by (McDonald, 2010) as project challenges in the development of complex, special ships relate strongly to the seven characteristics defined in **Perspective 1: Project Management**, withdrawn from the Project Management Book of Knowledge (Project Management Institute, 2008). The relationship between both approaches is described in Figure 9. As discussed before, the research of (Erikstad, 1996) omits the influence of the client as an individual factor, but places this within his invariant characteristics. The remainder of this paper uses the project characteristics defined in **Perspective 1: The Project Management approach**, as they support a more complete overview of a product development project. The second perspective, based on research will be used as an extra reference, as these graphs show the development of the product characteristics during the process.

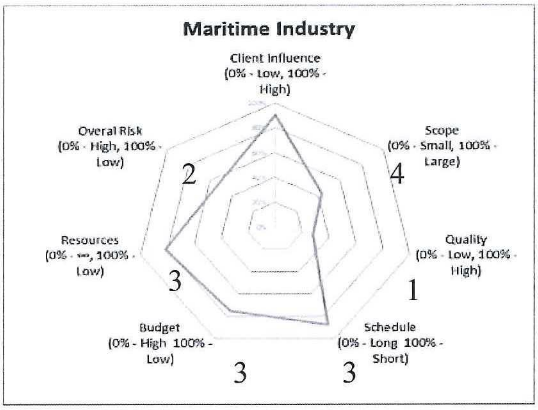

Figure 9, Product Development Variables Related To Invariant Characteristics of (Erikstad, 1996)

Conclusions

Based on the information in this part of the thesis several conclusions can be drawn. First of all, product development characteristics in the commercial ship design industry are significantly different from Naval (or *governmental*) product development, implying that methods and tools developed for the naval industry should be evaluated to commercial industry constraints before implemented/or applied in the commercial industry.

The maritime industry does very well in developing products within a short schedule, low budgets and limited resources while maintaining a lot of client influence. On the other hand, during ship design engineers have to make concessions to the quality and covered risk, generating rework in later stages and developing a product which only complies to the client's requests, even though in some cases better solutions are available.

In several other industries high quality and low risk constraints are essential elements of their product development processes, especially when series are produced. The maritime industry could benefit significantly from the lessons learned in other industries to increase quality and reduce risk; on the other hand, it is important to develop methods which comply with the other constraints set by the industry, an interesting concept.

Product Development of the Complex Specials: Design Challenges

Ships, and in particular service vessels, are one of the most complex objects produced in the engineering design disciplines. According to (Lamb, 2003) the number of unique parts is a factor 10 higher than other comparable products (Table 2). The number of parts with a unique geometry is not directly related to the number of parts in a vessel: a complex hull-form of an aircraft carrier will have a considerable higher amount of unique parts than a more conventional VLCC, even though the size is similar.

Table 2, Number of Unique Parts in Different Products (Lamb, 2003)

Product	Number of Unique Parts
Aircraft Carrier	2,500,000
Submarine	1,000,000
Very Large Crude Carrier (VLCC)	250,000
Boeing 777	100,000
Fighter Aircraft	15,000
Automobile	1,000

The research of (Erikstad, 1996) provides three characteristics related to the *design* of complex specials:

- ***Complex mapping between form and function:*** The representation of the ship as an initial input is based on the function of the vessel; the output of the eventual design process is a description of the form, given as a specification vessel as it should be built. The relation between those aspects, the analysis, is very complex: primarily because the system is highly integrated and has significant uncertainty about both the outer environment and the interaction the system and the environment.

- ***Shallow Knowledge Structure:*** The ship design problem is an open problem, which cannot be described by a single, closed theory. The ship design industry relies on a large extent on shallow knowledge: empirical relations, rules of thumb and previously built ships.
- ***Strong Domain Tradition:*** The organisational structure is very open, lean, informal and flexible: the industry builds on a long, historic tradition where involved factions have similar expectations of the resulting product: a designer can rely, on a large extent, on the design practice.

When evaluating these three characteristics, it appears that (1), the complex mapping between form and function, can be seen as an invariant characteristic. The characteristics (2) and (3); the Shallow knowledge structure and the Strong domain tradition, appear to be solutions for solving the complex mapping of form and function within the boundaries set by the project characteristics shown in paragraph 2.1.1. The most familiar method in solving these problems and implementing the characteristics (2) and (3) is the Ship Design Spiral, defined by (Evans, 1959), which will be discussed briefly in the next paragraph.

The design spiral

The evaluation of the design spiral was based on a similar approach used to evaluate a wide range of Abstract and Procedural design methods (50 in total) , using the research of (Clarkson & Eckert, 2005) it provides a set of evaluation parameters concentrating on the practical aspects of the discussed method, used to gain insight in the intent of the author.

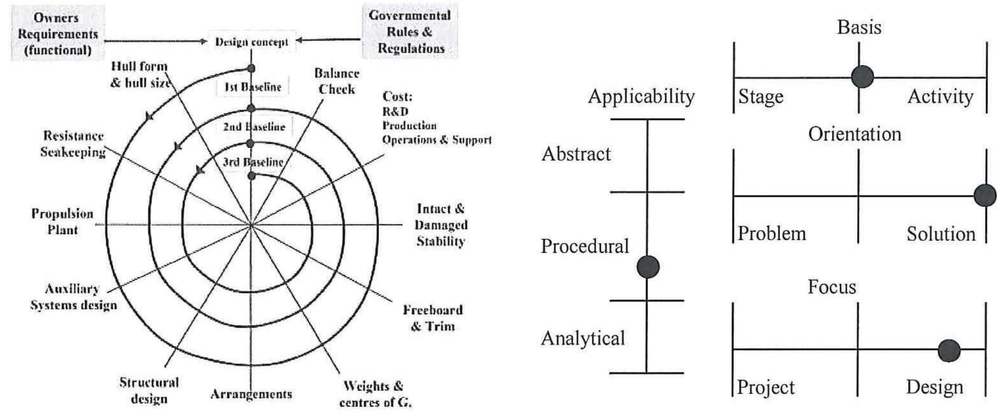

Figure 10, Ship Design Spiral (Evans, 1959)

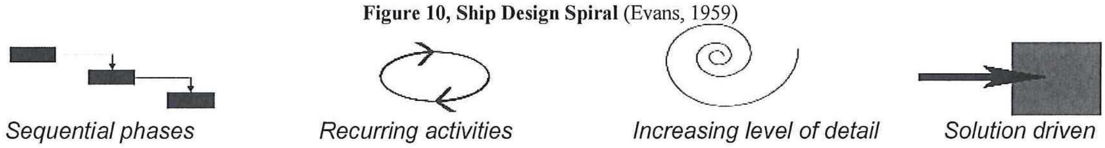

Figure 11, Basic Principles of the Design Spiral

The design spiral is a procedural method, because it provides a more concrete and focussed view on a particular aspect or industry; procedural methods are less generic in nature, but provide more guidance compared to the abstract models. The method discusses both stages and activities: it particularly concentrates on the recurrence of activities during the different design stages. The approach is extremely solution oriented, as it works according to a 'design → evaluate → re-design' principle, always starting with a certain solution. Furthermore the method concentrates on the design of the vessel, omitting the surrounding project requirements (Figure 10, right).

Based on the very common ship design spiral, combined with the evaluation of four maritime companies it became clear that in general, the sales design is initiated from a design which is developed in earlier product development projects, in an approach similar to Figure 12.

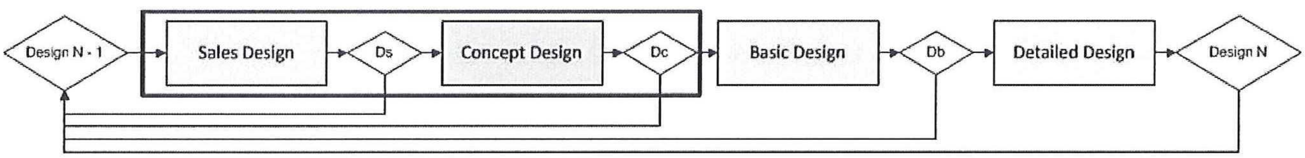

Figure 12, Ship Design Process, Project Initiation Designs

The re-use of design-data is not a direct problem, but it does provide an interesting angle into the diversity and innovation in the ship design industry. Especially the question what is part of the 'Design N-1', as a starting point of the ship design process is an interesting one. A simplified example, based on observations, is provided in Figure 13 and provides insight into possible problems resulting from the re-use of data.

Simplified Example:
Certain parameters such as length, width and depth are already agreed upon during the sales design phase, even though the implications of these parameters are only calculated in the concept and basic design phases. Changes to these main parameters can cause considerable problems and stress company- client relations

Figure 13, Simplified Example of Re-Using Incorrect Data

The ship design spiral, and the four basic principles (Figure 11) behind it, were found in the four maritime companies evaluated during this research, and are used as a reference in a wide range of papers as the most common design approach in the maritime industry (((Hopman, 2007), (Wolff, 2000), (McDonald, 2010)). Even though the basic principles are found in a wide range of companies, the fixed and rigid sequence of activities the method implies is not.

Conclusions

When evaluating the commercial ship design industry from a design perspective it became clear that the majority of the companies works according to the four basic principles behind the ship design spiral, shown in Figure 11. The fixed sequence implied in the design spiral was not evident, as the sequence was usually dependent on the experience of the designer and the requirements of the design. Secondly, the re-use of data whether it is successfully applied or causes problems similar to the simplified example in Figure 13 provides an interesting insight into the current product development processes in the maritime industry.

Tools and Technologies in Product Development

In the last decennia the engineering design disciplines have made advances in product development: each individual industry has made significant steps by using computers in calculations, simulations, generation of drawings. This section discusses the technology used in the current product development of complex, special ships, as an extension of the review in (1). Subsequently it evaluates several alternatives found in other industries based on two key differences: *drafting* versus *modelling* and *First Principle evaluation* versus *experience, or regression based* software. This part will end with several conclusions.

The commercial software packages provided in this section is used to illustrate the different principles, not to provide judgement about the applicability of different packages in different industries. The majority of companies use commercially available software, in some cases with extensive adaptation and scripting to reduce time-consuming tasks and increase flexibility.

Product Development tools in use

It is interesting to notice that the technology used in the design of complex specials differs significantly over the four phases of the design process shown in Figure 14. Especially the detailed design phase is significantly different compared to the earlier stages in the design. To give an indication of the software tools within the different phases all stages will be discussed briefly.

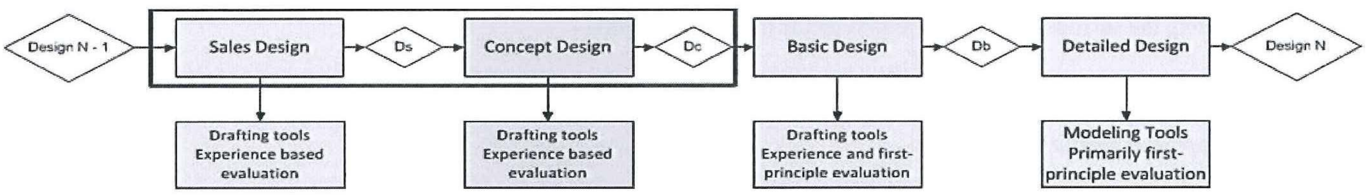

Figure 14, Design Stages in the Design of Complex Specials

(1) Pre-contract/Sales Design: In the majority of companies the pre-contract or sales design phase is dominated by 2D drafting packages (such as AutoCAD, Bentley Microstation or Eagle 2D) supplemented by conventional desktop programs such as text processors and spread-sheets (Microsoft Word, Excel). Calculations are supported by knowledge /experience based calculations, usually in the form of spread-sheets. In some cases these programs are supplemented by specialist programs to produce design documentation and to generate 3D-renderings of the vessels in software such as Rhinoceros 3D.

(2) Concept Design: In the concept design phase the drafting packages mentioned in the (1) Pre-contract/Sales Design phases still play an important role in generating and developing general arrangements and principle diagrams. During these stages the 2D drawings are often supplemented by 3D drafting packages for the fairing of the hull (Rhino, Fairway) and specialist software to calculate for example the stability, resistance and propulsion and dynamic positioning. These programs are usually supported by their own input files and 2D or 3D drafting packages to provide a correct starting point for their calculations. In some cases, scripts are written to increase communication between the different design packages, but in the majority of cases the communication is controlled by the engineers and project managers.

(3) Basic Design: The basic design phase is in the majority of cases a continuation of the concept design phase, where the designs are developed into a higher level of detail and increasing level of fidelity. During the basic design phases similar packages are used as the concept design phase. The increased design-granularity makes it possible to increase the level of detail in all calculations, creating a more complex and extensive phase. Even though the level of detail is increased, the method is still supported by similar tools as the basic design phase.

(4) Detailed Design, Engineering: During the detailed design or engineering phase, the design is fully defined and all production drawings are generated. In the majority of cases the engineering phase is done by the yard or the organisation responsible for the production of the vessel. The design is, in this stage, developed in 3D-Modelling software. There is a wide range of 3D modelling software available, but they can be roughly subdivided into two main types: The first type is developed specifically for the ship-building industry (Nupas-Cadmatic, Aveva-Marine/Tribon and ShipConstructor); the other type has its roots in the mechanical engineering, with packages such as Siemens NX and Dassault System's Catia, adapted for the maritime industry.

Different approaches in Product Development

During the review of the technology behind *product development* it appeared that the technology could be identified based on four characteristics in two areas: The first area is related to the design of the product, which can be done via a *drafting* package or via a *modeller* (1). The second area was more related to the evaluation of the design, which can be supported via *First Principle* software or via *Experience-based* packages (2). Both will be discussed to more detail in the subsequent paragraphs, eventually leading to conclusions.

(1) Drafting versus Modelling: The geometrical layout of a vessel can be fixed by two different approaches: drafting and modelling. Both approaches are used in developing designs in different engineering design disciplines, as discussed in the previous part, the majority of ship design companies use drafting tools such as AutoCAD and Bentley Microstation.

Drafting applications visually describe objects, either in two or three dimensions, as geometric lines and surfaces. In a two dimensional packages the different views are not interrelated as they consist of separate drawings. In 3D drafting packages the views are related and the program can visualize the actual shape of the object. In both two and three dimensional drafting packages the surfaces and lines are *not* used to from objects and add additional knowledge to these objects as an inherent part of the model.

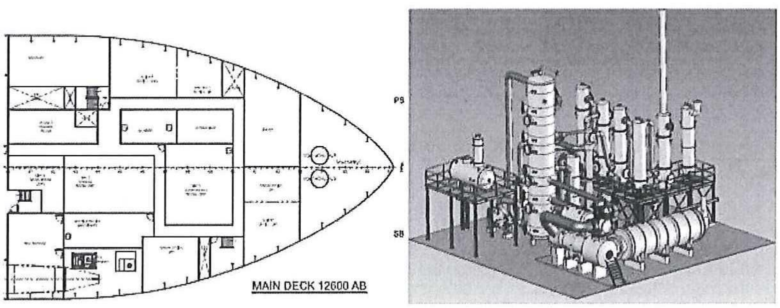

Figure 15, Drafting (Left) Versus Modelling (Right)

In modelling tools knowledge is inherently added to the design, a modelling tool understands that objects are not only lines, surfaces and volumes but represent classes, associations and contain properties. This additional knowledge can be used by the program to recognize and evaluate designs, or to export additional information to create input files for external evaluation tools. Another major advantage of *modellers* is that drawings are often constructed in a parametric approach, making it possible to adapt drawings quicker and without significant rework of a wide range of drawings.

As mentioned in the previous paragraph, the difference between a drafting tool such as AutoCAD or Rhino and a modelling package such as SolidEdge or Catia is the addition of *knowledge* to the geometric information. When looking into the wide range of software-packages available for the Maritime industry several interesting examples can be found which add knowledge to drafting tools: one example is the ShipConstructor software, combining design management tools such as data-basing and parametric development to the two and three dimensional drafting environment of AutoCAD (ShipConstructor Software Inc., 2011).

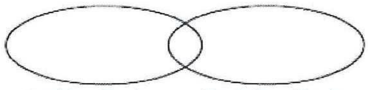

Figure 16, Drafting Tools versus Modelling Tools

Knowledge-rich modelling tools are not limited to the later stages in the design, in a wide range of engineering industries modelling packages such as Inventor, SolidEdge and SolidWorks are used the development of concept designs, were models subsequently can be used for FMEA (Failure Mode and Effects Analysis) and CFD calculations, parts-list, production drawings and design databases.

The implementation of modellers can be time-consuming, and because there is a thin line between modelling tools and drafting tools it is important to realize what kind of knowledge the company wants to add to a design: In some cases a geometric description is sufficient, in other cases a more detailed description of the product and all involved properties is required.

(2) First Principle versus Experience Based: The evaluation of a design can be based on two different approaches: First Principle Software evaluates the design based on the established laws of physics, and does not make assumptions such as curve-fitting parameters. Experience based software is based on databases, regression or other known data, which, in combination with certain assumptions and boundary conditions lead to empirical models.

- Experience based software has the advantage that it is quick and ensures a risk free answer, *when* the requested information remains within the scope of the used data, the correctness of this software depends on the scope, quality and size of the database used to evaluate the design: interesting examples are regression based weight and regression based resistance calculations.
- First principle evaluation provides a correct solution (if properly applied) independent of the previously developed solutions and can therefore evaluate designs outside the current scope of the available data. First principle software used in engineering design are, for example, FEM (finite element method) calculations and CFD

The maritime industry is based on relative small companies who perform specialist evaluation of designs and products, these evaluations are based both on experience based software (resistance and propulsion, motion behaviour, class regulations) and first-principle calculations (stability, dynamic positioning). With the development of computer power, first principle calculations are slowly gaining on the regression based evaluation tools.

The first principle software does have an important drawback: the calculation models usually require extensive geometric data before a calculation can commence. CFD calculations require a detailed hull-shape, drafts (and related weights), appendages and propulsion-information to provide a valid answer. Even simple Dynamic Positioning (DP) software requires the disturbance forces, propulsion-locations and generated thrust, information which is scarcely available in the early concept design stages.

In several other industries first principle calculation methods are already incorporated in the earlier stages of the design, for example the car industry develops multiple concepts and uses first principle evaluation software to determine which concept is dominant over the others. Both concepts have their merits and applicability in different situations, but one should always consider the available information before applying the answers.

Conclusions

When evaluating the product development tools in the maritime industry it becomes clear that the first three phases (from pre-contract to the end of the basic design phase) is dominated by the top-of-the-line drafting tools, supplemented by both first-principle and experience based software. Each evaluation-software is often supplemented by designated modellers, to provide sufficient and detailed data for each calculation. This software is often specific for either the maritime industry, or the company, as they are based on regression and knowledge, developed in-house, or with specific constraints.

When comparing these results with Figure 12, where a common approach of re-used designs is presented, an interesting problem arises: even though we are continuously re-using design data, a discrepancy appears between the available design at the end of the process: 'Design N' and the start of the process: 'Design N-1'.

Other industries like the car or airplane industry use a more integrated approach, with a single software-model containing all geometric and non-geometric information. This model is usually extensively linked to primarily first-principle evaluation tools, to maintain design consistency independent on the wide range of designers working on the product. The maritime industry only uses this technology in a detailed engineering phase: while other industries use this technologies in all phases of the product development.

THE PROBLEM OF PRODUCT DEVELOPMENT FOR COMPLEX SPECIALS

The previous sections of this paper have given an introduction to the present situation of the product development in the commercial, complex special industry. In an early stage two mayor issues could be identified when working towards an improved product development process:

1. There is a gap in the literature concerning the design processes in the commercial maritime industry, the majority of the literature is based on the software tools, or concentrates on the naval industry, which has considerable different project parameters as the commercial industry. Methods and software tools found in the literature *can* be applied in the commercial sector, but should be handled with care and adapted to fit the variables of the commercial sector.

2. The commercial complex special industry is significantly different from the majority of Engineering Design disciplines, including the naval *(governmental funded)* ship design industry. This has the consequence that the majority of product development procedures cannot be copied directly into the commercial ship design companies. When developing Product Development processes these boundary conditions of the industry should be taken into account.

Both problems are especially evident in the early stages of the product development in the maritime industry. The project is still very fluent and aspects have a considerable impact on the remainder of the product development process. In the remainder of this paper, the improvement areas of both the project and the design will be discussed. In this paper the remaining element of the socio-technological model: the People, will not be discussed in this paper.

Improvement Areas: Project

Based on the preliminary research presented in the previous parts the new approach will concentrate on increasing the quality while reducing the risk in the design process, visualized in Figure 17. The main difficulty is to comply with both elements, even though the remaining constraints such as: client influence, scope, budget, schedule and resources should remain within certain boundaries.

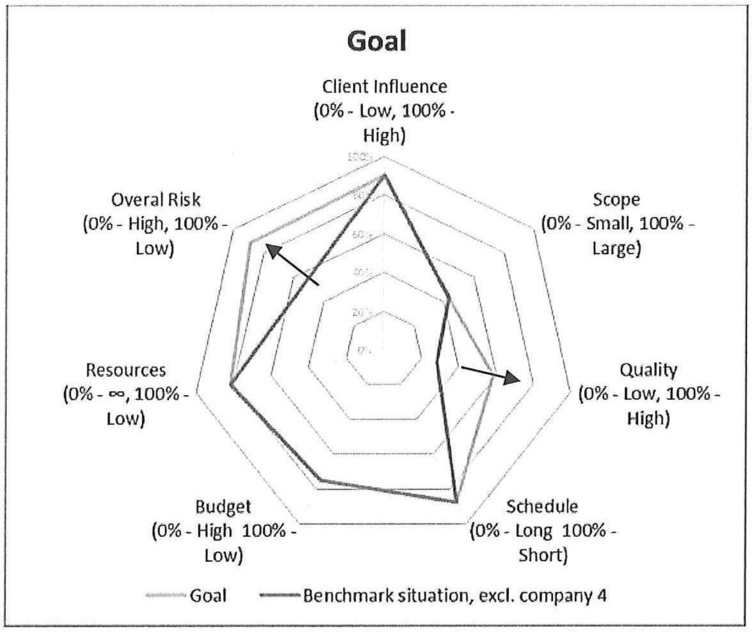

Figure 17, Goal of Subsequent Research

The concepts 'Quality' and 'Risk' are often the subject of extensive discussions (Pirsig, 1974), which are, although interesting, not the subject of this paper. In the remainder of this paper the following definition for Quality and Risk are used:

- Quality: *Degree to which a set of inherent characteristics fulfills requirements (ISO9001),* (International Organization for Standardization, 2011 (1))
- Risk: *An undesirable situation or circumstance that it is both likely to occur and likely to cause negative consequences, risk is always future oriented (ISO9000)* (International Organization for Standardization, 2011 (2))

Both variables: The remaining risk, and the degree to which an inherent set of characteristics fullfills the clients requirements are particular evident in the early design stages, as shown in Figure 8, where the first 20%, or the sales and concept phases show that the requirements are still under development, the design influence is degrading rapidly and the risk is significantly high. Following the reasoning in the previous paragraph, the goal of a new product development process should be to lower the risk and increas the design influence, to a point where the requirements of the client are known.

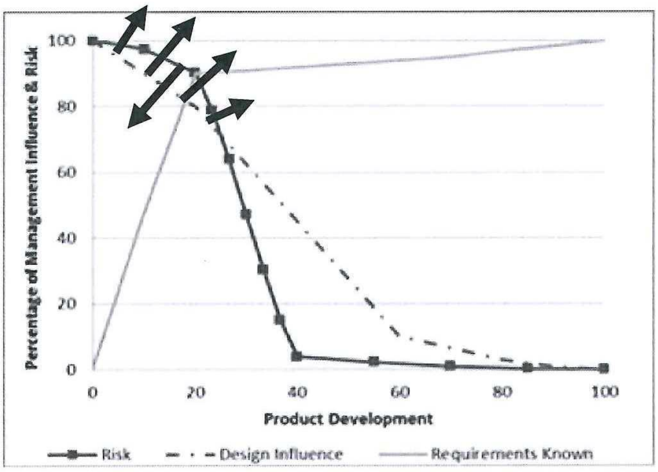

Figure 18, Goal of Increased Knowledge and Boundary Conditions

As expected, the variables of Risk and Quality are strongly interrelated, as both the inherent characteristics and requirements are unknown and continuously changing in the early stages of the design, making these design factors part of both the Quality and Risk parameters of a design project.

Based on the two definitions discussed above, and the expected correlation between the two variables both definitions are further developed into three main elements part of the product development process. These elements form the basis of the goals of the design method which will be presented in the next section.

Quality, *the degree to which a set of inherent characteristics fulfils the requirements*, can be defined in three main elements:

1.1 Design a product best suited to the client's requirements
1.2 Reduce uncertainty on design characteristics
1.3 Increase flexibility in subsequent phases for ever changing requirements

Risk, *an undesirable situation, that is likely to occur and have negative consequences,* can similarly be defined in three main elements:

1.4 Reduce re-work in latter stages of the design project, both involuntary and caused by client requests
1.5 Increase design fidelity, reducing involuntary errors in the subsequent phases
1.6 Increase knowledge of the design, reducing risk by avoiding the implementation of incorrect solutions.

Improvement Areas: Design & Technology

The improvement areas in the Design and Tools (aspects from the 'technology' side in the socio-technological model) are considerable clearer than the research required in the project side of the product development in the Complex Specials industry. The Design challenges lead to two main improvement areas: when supporting a similar approach, the re-use of data should be supported to avoid the use of incorrect knowledge or values, furthermore the approach should support an increased evaluation in the early stages.

The design challenges

2.1 Support Re-use of data
2.2 Increase evaluation in early design stages

The technology challenges are especially fueled by the changes in product development technology over the different phases, where the re-use of data, a familiar method shown in the section 2.1.2, is insufficiently supported by the packages used in the early stage design. The first technology is to increase the coherency in the approaches used in product development over the different phases, this is also the drive of the second technology challenge, to support the use of evaluation tools, especially First Principle software in the early stage design.

The technology challenges

2.3 Coherency in product development software over the different phases

2.4 Integration of evaluation and design in the initial phases

Goals

The improvement areas of both the design and project areas have a considerable overlap, furthermore the six elements of the project improvement areas are future-oriented it is difficult to measure and predict the results in the early design stages. Based on these elements four concrete goals are developed, providing guidance and direction for the development of the method, working towards the global goal of reducing risk and increasing quality.

- Increase knowledge about solutions and their application area *(Part of the solution to both quality element 1.1, 1.2 and risk element 1.6 and design challenge 2.1):*

When increasing the knowledge regarding solutions and their boundary conditions we reduce the uncertainty surrounding the objectives, but we can also provide a client with the results and the boundary conditions of their choices, and subsequently increase the awareness of the impact of certain changes. By increasing this knowledge and making it available in an early stage we can make more founded decisions, or additionally, leave multiple options open for a longer period of time.

- Improve design exploration *(Part of the solution to both quality element 1.1, 1.3 and risk element 1.4)*

Increased design exploration, with or without a client, leads to a more global optimal solution for a set of problems. Even though a more extensive design exploration implies a more time intensive approach a correctly developed approach can increase knowledge about the integrated solutions and reduce rework in a later stage.

- Improve design consistency (*Part of the solution to the risk element 1.5 and technology challenge 2.3)*

Design consistency among the wide range of software packages and evaluation tools is an important and difficult factor in the ship design industry, this technology aspect of this research extensively discussed in other papers. A subsequent paper will discuss this aspect more in detail.

- Improve evaluation of solutions (*Part of the solution to the quality element 1.2, risk element 1.6, design challenge 2.2 and technology challenge 2.4)*

The generation of new and interesting designs is less worth when the solutions cannot be evaluated.

Even though this paper will not discuss the concept solution proposed during this research in detail, the basic principles of a proposed solution will be provided, both as a basis for discussion and as an introduction of the eventual solution tested during subsequent research.

CONSTRUCTING A NEW APPROACH FOR THE DESIGN OF COMPLEX SPECIALS

Based on the four concrete goals defined in the previous section a new method will be developed to improve the product development process for the commercial ship design industry. Although the method is still under development, an indication of the proposed solution is provided in the next few paragraphs. If we want to develop a design method for use in the commercial complex specials industry we need to have criteria to evaluate a new method. The new method should fall within the following parameters, based on the review of the current approach discussed in section 2.1.2 to evaluate the ship design spiral. The evaluation parameters are visualized in Figure 19, and will be further discussed in the next paragraph: Each element will be discussed in general, after which the parameter chosen in Figure 19 will be further discussed.

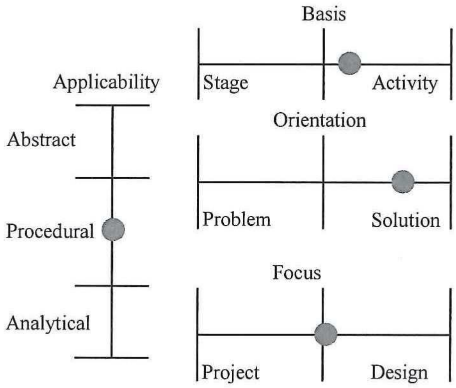

Figure 19, Classification of a New Approach to the Design of Complex Specials

(1) Applicability: Design methods are classed in different groups based on their relevance and applicability for specific design projects. The subdivision is based on three levels:
- Abstract: These methods discuss the design-process in a high level of abstraction; although relevant to a wide range of solutions the methods do not offer much guidance for individual design projects.
- Procedural: Procedural methods are more concrete and focussed; these methods usually concentrate on aspects of the design process, but are therefore less general and more relevant to a particular industry or project.
- Analytical: Analytical methods contain techniques, procedures and tools used to develop designs, these methods are applied to a specific problem, and are therefore omitted in this paper.

Similar to the Ship Design Spiral the method will be a procedural method, not detailing the techniques, procedures and tools in detail but providing insight in one particular area.

(2) Basis: This subdivision discusses whether the process is based on the stages in the process or on the activity of the engineer/designers. Dependent on the intentions of the author, combinations of both aspects can be found in a single model.
- Stage: Stage-based models discuss the different phases of a design process progresses from concept to detailed design.
- Activity: Activity-based models discuss the repetitive activities used in problem solving and designing

The method will primarily be based around the activities of the designers, but as it focusses on the first two design stages the basis in stages cannot be forgotten. Even though some activities will be recurring, both stages will be organized differently.

(3) Orientation: This classification discusses the problem or solution orientation of the model.
- Solution: Solution oriented processes start with an initial solution or solutions which are analysed and modified during the process.
- Problem: Problem oriented design process start with a thorough analysis of the problem before generating either a single or multiple solutions.

The method will consist of a ***solution*** *driven approach, generating a solution in an early stage of the process, presenting the possibilities in a visual way. Both Figure 20 and Figure 21 show two different abstract solution driven approaches, respectively Darke & March (* (Darke, 1979), (Clarkson & Eckert, 2005)*); both can be used as a starting point for a new design method. The alternative is a problem driven approach which requires an extensive analysis of the requirements, but as shown in Figure 18, the majority of the requirement is still being formed in the earlier stages, making it impossible to start with a problem driven approach.*

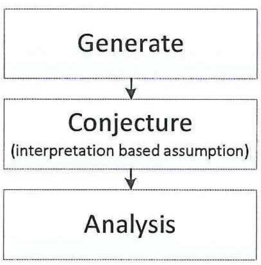

Figure 20, Solution Driven Approach of Darke (Darke, 1979)

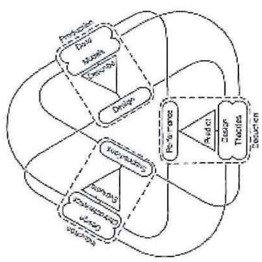

Figure 21, Solution Driven Approach of March, (Clarkson (Clarkson & Eckert, 2005)

(4) Each method either focusses on the specific design of a new product, or on supporting the entire project from start to finish.
   - Project: Project focussed approaches support the management of the entire design project, including the project portfolio and company structure.
   - Design: Design focussed approaches concentrate on the generation of better products by the application of these methods.

The method will concentrate on both the design of the product (the vessel) and the project in a balanced way. Certain goals mentioned in the previous section are related directly to the design of the vessel, although some of them require a broader approach, especially in the design exploration and knowledge increase.

Based on the parameters discussed above and the problem statement in the previous paragraph we can work towards approach which can be evaluated and tested. The following section will only discuss a selection of features based on the new method, which is still under development.

Possible Features of the new method

Three main features will be discussed as starting points for the development of the conceptual method. These features give an indication of the solution, which will be discussed more extensively in future papers.

(1) Split Systems and Configurations. By splitting systems and configurations we can develop principle solutions independent of the selected equipment and systems. The configurations of the systems are usually developed in-house and contain the knowledge of the individual engineer and the company; they can be developed on different levels of detail, from abstract-ship configurations to detailed piping and electrical configurations. This approach would lead to a set of designs, combining known systems and configurations with innovative solutions, shown in Figure 22.

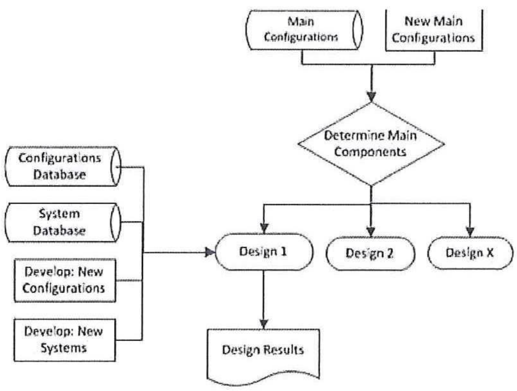

Figure 22, Designs Based On Systems and Configurations

In essence, a configuration should contain a set of functional requirements and capabilities, a functional layout, geometric constraints or system boundary conditions and an overview of the products where the configuration is used. This approach is considerably different to the modular design already applied in several shipyards as it omits two main features: the geometric location of the objects and the individual systems. The development of such configurations is currently underway in both the related research as an additional MSc thesis and will be reported in due time.

(2) Disconnect substantial innovation from incremental, continuous innovation. In a more project-oriented focus the method should support both incremental, continuous innovation within the known products and more substantial or radical innovations. This is supported by the approach mentioned in feature (1), where configurations can be developed continuously and, if necessary, independent of the product development process for clients.

(3) Single design model: Each individual design or concept should consist of a single model or 'design mock-up', containing the required information for evaluation and viewing purposes. By using such a design model we can improve the design consistency and increase the evaluation by generating intelligent links from or to software. As discussed in the section 'Product Development in use' it would be advisable to work with a modelling tool to reduce the programming effort. An example is given in Figure 23, where a single model is used to develop multiple concepts in deck-layout. In this case, the deliverables can be standardized as viewports into the single model, providing a consistent design model.

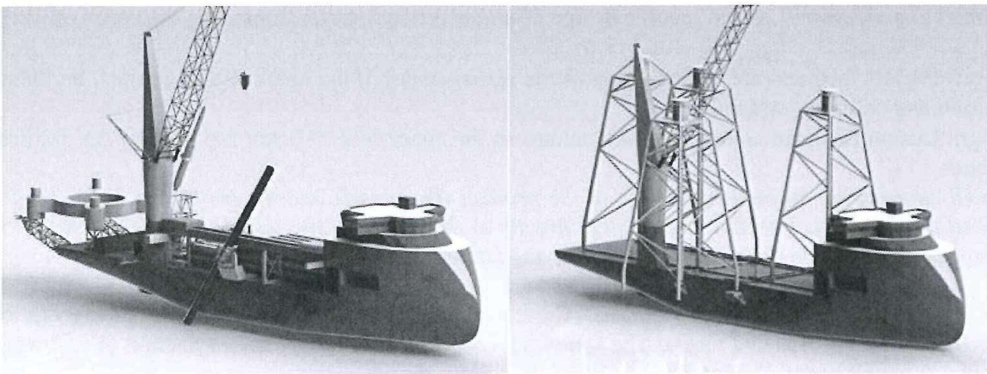

Figure 23, Example of a Single Design Model with Multiple Deck-Configurations

CONCLUSIONS

Based on the research discussed in this paper, several conclusions can be drawn:

In an early stage two conclusions could be drawn: The commercial industry has several characteristics that set it apart from other engineering disciplines, including the governmental, naval industry. Even though developments in other industries should be tracked and learned from, it is impossible to copy developments, methods and techniques directly and without modification into the commercial ship design industry. Secondly, the available literature about product development in the complex specials industry is limited: the majority either focusses on the tools and technologies or the naval industry which foregoes several aspects of the commercial industry.

The product development of Complex Specials has several key challenges, in the project area the variables 'Risk' and 'Quality' require significant work compared to the other industries, from a technology perspective the coherency over the design process, improved re-use of data and coherent and improved evaluation can make a considerable difference. Even though the Maritime industry has several strong points in their product development process, to improve the process even further these areas should be considered for improvement.

The challenges provided in this paper provide a starting point for subsequent research into Product Development in the commercial Maritime industry at Ulstein Sea of Solutions, supported by the Delft University of Technology. The subsequent phase is briefly discussed in this paper in the form of goals and possible features of a new product development method, but will be presented in subsequent phases, where the research will also include an expansion of the initial problem statement and the changing environment wherein the designer operates.

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Session 5.1 – DESIGN FOR X

Life Cycle System Analysis Methods in Ship Design - A Review of Current Status, Opportunities and Challenges

Multivariate Short-term Prediction of Ship Responses Using Onboard Measurement Data

Risk-based Approaches in Design for Ship Safety