TOWARDS A DIFFERENT VIEW ON SHIP DESIGN
The development of ships observed through a social-technological perspective.

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ABSTRACT
The research this paper reports on aims to develop a design and engineering strategy for complex ships in between incremental and radical innovation.
The majority of European ship-design industry concentrates on the development of complex, one-off ‘specials’ for the offshore industry, like dredgers, drill ships, pipe-laying ships, et cetera. This industry is complex, not just in terms of the industrial structure but also in the terms of the object. To control the complexity the industry uses large and expansive knowledge bases that support the design, engineering and manufacturing activities. The focus of the academic research in this field is close to practice and dominantly aims at developing knowledge and tools that supports the present engineering practices. As these strategies are aimed at controlling the complexity, they leave very little room for more innovative developments. On the other side of the spectrum there is a ship-design practice that does allow radical ship design: design and engineering from a blank sheet of paper. Not surprising that these projects are laborious and expensive. The space in between those two design strategies seems unaddressed in literature and is only occasionally found in practice. The *design of complex structures* literature appears to be scarce, even though this is an area where European ship-design industry is heavily involved.

We interviewed stakeholders from ship industry, looked into the design literature to describe the present situation and finally performed cases studies in other fields of application for inspiration. Based on the case studies we illustrate an alternative design strategy that leaves more space for innovation without starting from scratch. This focuses on the complex interactions between the different levels of

decomposition in a complex structure such as a ship. We will illustrate that the wide range of actors involved in these designs make such a change in industry to a socio-technical challenge.

KEYWORDS
Ship Design, Innovation, Design, C-K theory

INTRODUCTION

The European commercial ship-design and production industry is an interesting industry from a research perspective. Even though large, complex structures are developed, the design-process is heavily segmented, both in time and organisation: design, production, component-design, classification but also project ownership, vessel ownership and operation are spread over different companies and different stages in the design process. The industry is even more remarkable when considering that, in general, projects are developed for a specific client and within a limited time-frame: the time between contract-signing for concept design, to delivery of a custom vessel can be as quick as 3 years.

In other industries, the development, production and operation of complex structures is incorporated and controlled within large companies and government agencies such as Airbus, Boeing and NASA, or vastly standardized and based on product platforms, and product development time goes up to 10-15 years.

Figure 1, European owned, European Design, Korean built vessel

Furthermore, the industry is oriented globally with European shipyards delivering to international clients, European designers working in cooperation with Korean or Chinese shipyards and European owners building vessels in the south-east to European designs (Figure 1). This provides a very volatile and challenging environment for designers, shipyards and owners to maintain their competitive edge.

This paper concentrates on the early design stages of vessels in the European maritime cluster, often called the ‘sales’, ‘preliminary’ or ‘concept’ design phases. In these stages the design of the vessel is still very fluent, and decisions taken during these phases have a considerable impact on both the eventual result and the overall process.

However, this limitation is not sufficient as boundaries for this paper. Ship-design projects can have considerable differences in project-organisation or operation-type: container vessels and tankers are built in large series by Korean and Chinese shipyards (Figure 2), even the Dutch DAMEN shipyard is known for their standard vessels. However, this is only part of the industry’s business-cases: the European ship-design and -building industry distinguishes itself in the design and production of large offshore construction vessels, drill ships, cruise vessels and dredgers (amongst others), all considered complex-specials (Figure 3).

Figure 2, Vessels built in series

Figure 3, Complex Specials

This paper concentrates on the development of these complex-specials: tailor-made, high value assets in a maritime environment, which are built for a specific client with a designated purpose. These vessels are generally built in (very) small series or as one-offs. Based on these premises, each individual design project which is part of this research can be described as innovation-processes: a new product is developed for a very specific client, in either one-off or small series.

However, there is still a large difference between different one-off ‘complex specials’. Some vessels represent enormous leaps in technology and ship-design, while others are based on previous designs. Based on the definition of incremental and radical innovation by Garcia & Calantone, (Garcia & Calantone, 2002), two examples of incremental and radical innovation are provided in Figure 4 and Figure 5. The incremental complex marine force ship showed in Figure 4 is complex, but is based on previous designs. The example shown in Figure 5 is considered to be radical since it is not based on any earlier ship design.

Figure 4, Incremental Innovation

Figure 5, Radical Innovation

The differences in design projects on both types of innovations are considerable: Radical designs are often owner/client owned and start with a clean sheet of paper: during these projects both duration and number of iterations is high. Incremental innovation is more common in commercial projects of shipyards and design offices; the developed vessel is a derivative of a previously designed vessel.
Interestingly, Garcia & Calantone present a third type of innovation: “*really new innovation*” between incremental and radical innovation (Garcia & Calantone, 2002) Within the ship-design industry this approach is rare, but when it is observed, it is often in designated (time-consuming and expensive) projects and developed almost similar to radical innovation projects.

This paper is based on ship design processes in literature and on an in-depth study of the design-processes applied in the European commercial ship-design industry. A first paper was presented that describes the design and project-parameters of this industry (van Bruinessen, et al., 2012). A second paper provides a more theoretical discussion of the decomposition problem, including the model based on this decomposition problem (van Bruinessen, et al., 2013). This paper will look more into detail into the social-technological background of the problem: The paper will briefly discuss a concept approach in solving these challenges, and providing perspective on the application of such an approach on (commercial) ship-design.

The paper is structured as follows: the next section discusses the objective and research approach taken. The third section will discuss the current status of ship design research, and identify several limitations of the current models. The 4th section will provide insight in different types of design projects in the ship-design industry, supporting the analysis in section 5. The last section will conclude this paper, and provide some insight in subsequent phases of the research.

RESEARCH OBJECTIVE AND APPROACH

Objective of the research project of which this paper is part is to improve the design-strategies of the maritime industry, by specifically focusing on increasing the innovative performance of the European ship-design industry. The research explores the possible application of a strategy that aims at realising *really new* innovations (Garcia & Calantone, 2002) in commercial projects of complex specials.

This research separates itself from the other ship-design literature by two things: first it aims to take a more fundamental approach to ship design as being part of an innovation process and second it includes a socio-technical perspective by looking at the communication, support and judging in relation to the design activities aimed at *really new* designs. This is in contrast to standardization, engineering and optimization which is the main focus in ship-design practice and as well as in academic research.

In this project we took a blended research approach since it dominantly aims at the development of an actionable design strategy. Therefore we needed to develop theoretical insights simultaneously with observing in practice designer activities. The initial phases of this research are based on a review of the literature on innovation, design and ship design as well as on in depth interviews with key stakeholders from the ship industry. Later steps in our research were based on depth analysis of case studies from ship industry as well from other industries in parallel to early probe cycles in ship design. The latter being the first steps into a design inclusive approach (Horváth, 2007), involving the development of a new design strategy, including several supporting methods.

This paper discusses the first part of the research, including the developed theoretical model.

THE CURRENT STATUS OF SHIP DESIGN RESEARCH

This section discusses the current status of ship-design research based on the design-models which are at the basis of recent papers in this area. A complete review of all design-models and related tools and methods within the confines of this paper is

impossible: in this respect, more extensive reports can be found in (Andrews, et al., 2009), (Andrews, 2012)and (Brett & Ulstein, 2012).
This section discusses the Ship design spiral and two of its derivatives in System Engineering, which is considered as an alternative approach for the design of complex systems. Within each respective section the validity for use in innovative, commercial designs will be discussed.

Ship-design spiral and its derivatives
One of the most common descriptions of the ship-design process is the Ship Design Spiral (Andrews, et al., 2012), first presented in 1959 (Evans, 1959) and shown in Figure 6. The model describes sequential steps and recurring activities often found in the design process. The presented model is a highly iterative approach, starting from a selected solution, which by increasing the level of detail zeroes into a single solution.

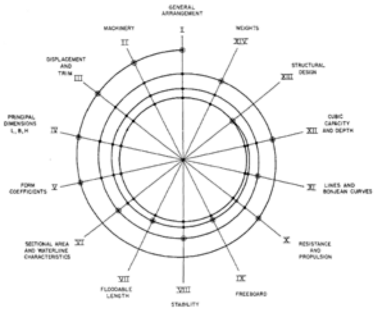

Figure 6, General Design Diagram (Evans, 1959))

Although the design-spiral is very successful of describing the increasing level of detail during the design process, it is incapable of responding to changing system choices, solutions or requirements. Within this process, the design choices that have the most impact are made *before* the design spiral commences. The initial input of the general design diagram presented by Evans (Evans, 1959) is a General Arrangement, implying that the design of the ship, in essence, forms the input of the spiral. The spiral process addresses mainly the engineering of the vessel, *after* the main design-choices are made.

However, since the development of the design-spiral several researchers addressed its limits and proposed different solutions to overcome these limitations. The subsequent section will discuss three of the most influential researches: System-based design, Requirements elucidation and more tooling-oriented approaches such as the Concept exploration models.

System-based design was first presented in 1991 (Levander, 1991) with a more recent application in 2012 (Erikstad & Levander, 2012). Their approach straightens the design spiral (Figure 7), striving to reduce the number of design iterations to find a technically feasible and economically preferable solution.

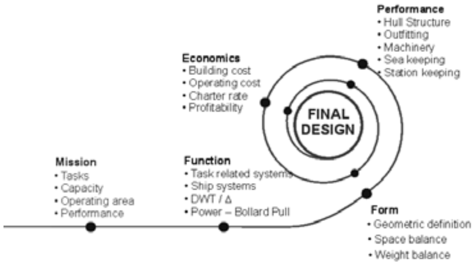

Figure 7, straighten the design spiral (Erikstad & Levander, 2012)

In order to achieve this, the vessel is divided broadly into ship-systems and task/function-related systems (often called payload). Information from previous, similar designs is derived to build databases estimating the gross area and volume of the new vessel. The area and volume is used to derive a geometric definition, weight balance and main dimensions. Based on these main dimensions a modular concept sketch is developed (Figure 8).

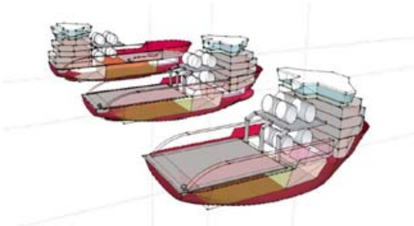

Figure 8, Alternative configurations (from (Erikstad & Levander, 2012), original (Vestbøstad, 2012))

This approach makes it possible to generate early estimations which will lead to feasible designs. However, the method has important limitations: The system definition, the geometric sizing, weight balance and data set are based on regression based information, implicitly using a pre-defined geometric definition. This automatically limits the newly developed vessel to known designs. The use of this ‘higher level form’ is explicitly shown in the process presented by Erikstad and Levander (Erikstad & Levander, 2012).

Requirement Elucidation concentrates on the initial stages of the design, independent of subsequent phases. It touches on an important point that the development of requirements occurs simultaneously with the development of the ship design. As stated in (Andrews, 2004) *“'Requirement Elucidation' is, above all, a process which demands to be jointly undertaken by the requirement owner and the preliminary ship designer”* This statement explicitly shows the complex relation between form and requirements and directly doubts design-models based solely on requirements and functionalities.

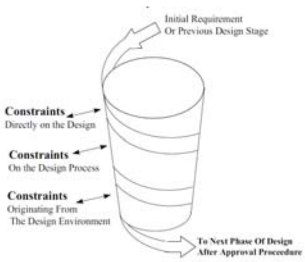

Figure 9, 3D design spiral (Andrews, et al., 2009))

The approach, even though it tackles the communication between client and designers directly, is limited in its nature: changes and innovation occur on different levels and areas, not solely on the overall concept of the ship. The requirement elucidation process assumes a stable and continuous engineering process in subsequent phases, similar to the design spiral.

System Engineering

System Engineering (SE) provides a different perspective on the design, engineering and operation of complex projects. The approach is championed by INCOSE, the International Council On Systems Engineering. And orients itself on: "*the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem*" (INCOSE, 2004). Even though SE as a discipline concentrates on the entire life-cycle approach, this section will focus on the 'design' and early stages of SE.

The basis of SE is the decomposition of systems into more manageable sub-systems and components (Figure 10). Design at these decomposition 'levels' is independent (Figure 11), and based on the requirements of the client and other stakeholders (INCOSE, 2006). The figures provided here only give a selection of representations within SE, others are, for example, the SIMILAR process, or waterfall representation (INCOSE, 2004), but as SE spans many industries the application and models differ significantly. As the INCOSE website observes: "*This representation of Systems Engineering process is just one of many that have been proposed. Some are bigger, some are smaller. But most are similar to this one*" (INCOSE, 2004).

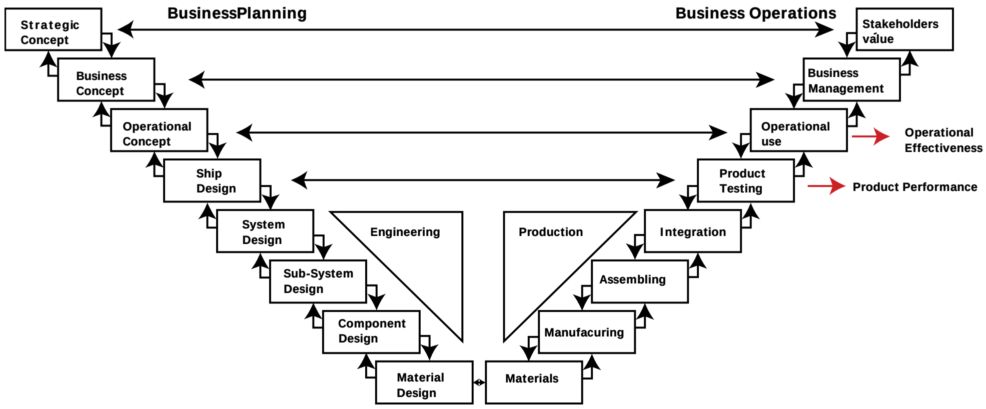

Figure 10, Process of System Engineering in Ship-design (Delft University of Technology, 2013)

System of Systems (SoS) versus Family of Systems is a recent development in system engineering which discusses the interaction between the different sub-systems. Clark (Clark, 2009) makes a distinction in the design of a Family of Systems (FoS), where there is limited interaction between the different elements, and the System of Systems (SoS). Based on this discussion we can easily see that a ship, with its limited size and extensive interaction is a SoS.

The SE from a design and innovation perspective has limitations. As shown in (van Bruinessen, et al., 2013) innovative solutions have a strong interaction between the required performance, function and shape of the ship-design *and* the systems it is decomposed in. Meaning that the systems were not developed independently, the systems impact the overall concept and vice-versa. The *independent* design of the different decomposition levels as proposed by System Engineering appears to be invalid for design projects.

Griethuysen (Griethuysen, 2000) also provides an extensive discussion of the application of system-engineering in the Marine industry; he recognizes that SE places engineering at the heart of management processes, but that the processes should be tailored to specific projects.

For the application discussed here, the decomposition into systems shows merit: The approach is capable of handling the complex systems discussed in this research. However, the design of innovative solutions appears to occur *between* different levels of decomposition: This communication is not solely through 'requirements' and 'design feedback' as SE describes in Figure 11, but contains continuously changing designs, performance requirements and functionalities.

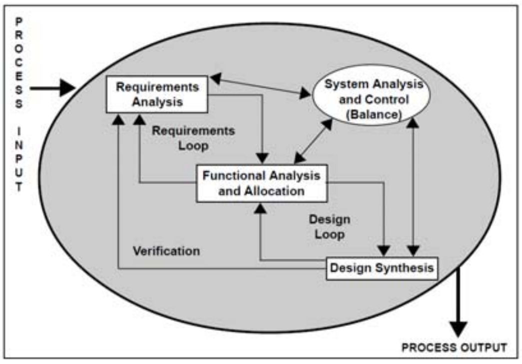

Figure 11, Design of a system (DoD, Systems Management College, 2001)

Constraining design to the separate levels of decomposition could result in stove-piping: the strictly independent development of systems without offering the opportunity to propose innovative solutions across these levels as often mentioned being one of the challenges in the SE processes.

INNOVATION IN PRACTICE

The previous section presents the models often used to describe the design activities within the ship-design industry. But as we have seen, these models leave very little space for innovative solutions. As we will illustrate here, they seem to be more oriented towards the engineering process than towards conceptual design. This section will extend and illustrate these observations further by taking a look at different projects in the ship-design practice.

To evaluate these projects we make use of one of the fundamental design theories, the C-K theory (Hatchuel & Weil, 2009). This theory provides us with a lens that helps to determine the innovative (conceptual) space within the present ship design processes.

Each system is determined by a form (*design synthesis*), function (*functional analysis and allocation*) and performance (both '*requirements*' and '*analysis*'), similar to the design of a system, as discussed in Figure 11. This provides insight in what elements are still conceptual and have innovative potential.

The first section will discuss the theoretical C-K framework as we have applied it to evaluate the case studies. The second section discusses two different ship-design projects: an incremental and a radical innovation project. The third section will show a well-documented innovation project from another industry as a reference. The section will conclude with an analysis of the different projects.

C-K theory

C-K Theory or Concept-Knowledge theory is based on the distinction between two spaces: The Concept-Space and the Knowledge-Space (Hatchuel & Weil, 2009). The knowledge-space contains all established truths and objects from a designer's perspective. The Concept Space contains all concepts: statements and objects that do not have a logical status in the K-space (yet). One of the main findings of the C-K theory is that concepts are a necessary departure point for designing, because without concepts the design reduces to optimization and/or rational problem-solving. If the design process in practice leaves no space for creativity then it has become to a rational problem solving process using existing forms of logics and reasoning, i.e. running from straight forward from problem to solution. For creative design to take place one needs to explore the C-space by disjunction from the K-space. It is disjunctive behaviour of challenging the composition of existing integrated bodies of knowledge, knowledge that is valid and proven in the K-space that supports the designer to enter the C-space. The subsequent exploration of the C-space is aimed at slowly getting grips of the unproven conceptual ideas. Getting 'grips' could be seen as conjunctive behaviour in which the designer (s) aims to create or identify supporting logics from the K-space that transform conceptual ideas, how crazy they might look, slowly into knowledge of the K-space.

In this paper, the theoretical model provided by C-K theory will be used to analyse the approach taken in the three different projects where the design of a complex structures is central. The analysis will provide insight where the design-space is available, and where choices are made based on the previously available knowledge.

Ship-design projects: an example of incremental and radical innovation

The first section will discuss two projects at the extremes of ship design; the first case is based on a derivative design, discussing an incremental innovation process. The second case-study concentrates on a radical design. Each case-study will start with a short introduction of the project; the second part will discuss which parts are conceptual (C-space) or based on the designer's knowledge (K-space) throughout the design process.

Incremental innovation in commercial ship-design

The first case-study is based on a request for a foundation-installation vessel in the North Sea area. Based on the initial discussions with the client the sales-division showed the potential of the proven SOC-5000 design (Figure 1): The first already in operation, the second recently delivered by the shipyard. With minor modifications, this vessel would fit the project perfectly.

During the concept design phase, the design was further refined and evaluated. In some cases, a new design was made for a system to improve the individual performance, to improve the functionality requested by the client. Based on these modifications, the overall design was presented to the client for approval.

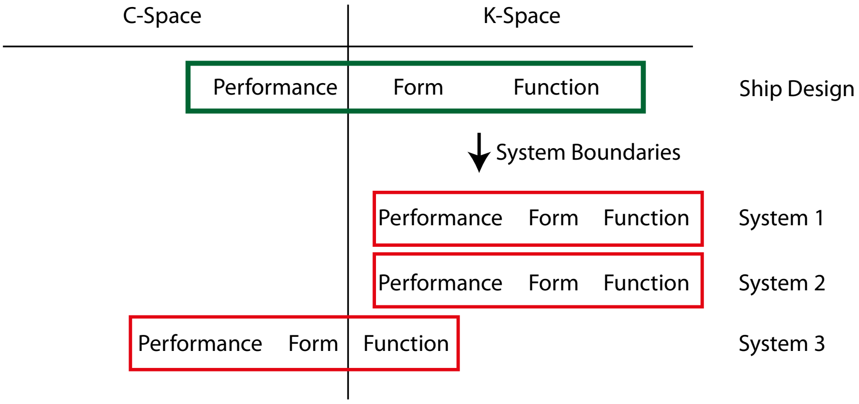

Figure 12, K- and C-space during incremental design of a ship

In this particular project, the design-process was primarily organised to determine the performance of the proposed vessel. The ship-design's and the majority of system's "*form*" were defined at the outset of the design process by using existing knowledge and systems, hence solutions from the K-space. These system descriptions, supplemented by a known objective for the vessel (function[0]) resulted in a well-defined (well-known) and stable system definition (Figure 12).

These fixed system boundaries limit the design space: the majority of systems are based on previous projects. Even though a selection of systems is redesigned, they are developed within strict system boundaries. From a design perspective, the elements of the complex vessel that could be addressed in the C-space are limited to the performance of the vessel and a limited amount of systems, which should be developed within very strict boundaries.

This case clearly resonates with what we observed in relation to system design and the design spiral: the design is almost given at the outset of the design process.

Radical innovation in commercial ship-design

The second case-study is based on a radical design for the offshore construction market. The design was developed from a clean sheet of paper, defining both the overall concept as well as the majority of systems from scratch. The project was initiated by a large ship-owner/operator in the offshore industry and was developed for heavy-lift using very stable platform. Based on this functionality the system boundaries were derived and individual systems were developed in more detail, (Figure 13).

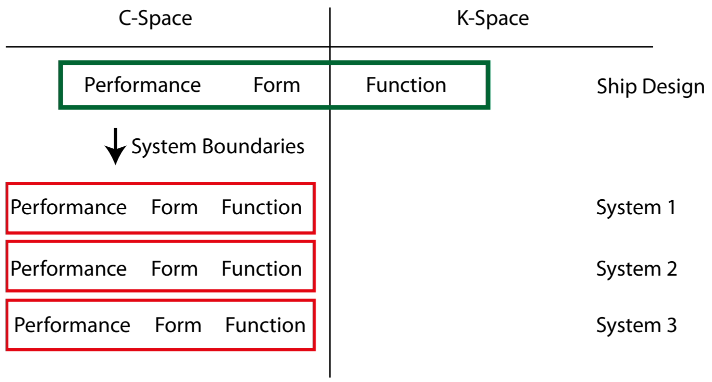

Figure 13, Knowledge based and Conceptual elements in Radical Innovation, Phase 1

In subsequent phases, the ship-design progressed and became more refined and detailed, moving from C-space towards the K-space. During that process the functional decomposition, on which the initial system-boundaries were based on, were insufficient as more form-interactions were identified. The shifting of these boundaries resulted in the re-design of systems, new performance analysis and new functionalities.

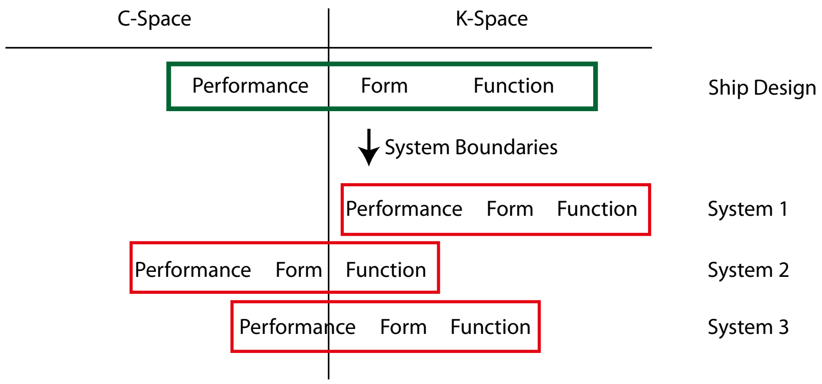

Figure 14, Knowledge based and Conceptual elements in Radical Innovation, Phase 2

When the design process matures, system-boundaries become more fixed and the design process changes into an engineering process dominated by rational problem solving making use of proven knowledge. At the same time the number of design iterations reduced considerably. During this process the systems are developed and more detailed.

Gordon Murray's Radical F1 design

Our final case study is aimed at the identification of a design process belonging to the middle part of innovation, really new innovation. To get inspired we stepped out of ship industry into the world of Formula 1 design. Gordon Murray is one of the most influential Formula 1 designers of the last century and is often documented as a radical designer and innovator (Cross & Clayburn Cross, 1996). Based on the classification of innovation provided by Garcia and Calantone (Garcia & Calantone, 2002), we consider the case-study described by Cross (Cross & Clayburn Cross, 1996) as an example of *really new* innovation. The case presented here, even though a tremendous advance in technology, was applied in a Formula 1 car and resulted in a very, very quick F1-car.

The case-study shows the Gordon Murray's design approach after the governing F1-body (FISA) strived to reduce the cornering-speeds of Formula-1 cars. To accomplish this, the FISA banned 'sliding skirts' and introduced a minimum ground-clearance of 6 cm early in the 1981 season.

Gordon Murray developed a new system based on a slightly different requirement: The system kept the car low while driving around the track, but increased ground-clearance to 6 cm while static, without any interference of the driver. While measured by the FISA the car complied with all the rules, but when on the track, the combination of the hydro-pneumatic suspension with the aerodynamic designed down-force kept the car low in the corners. Both the car design as the majority of the systems were similar to their previous design, but Murray's conjunctive behaviour is found in redefining and discussing the system boundaries as they were proven knowledge for all the car designers. By doing so he created the required design space necessary for such a large improvement.

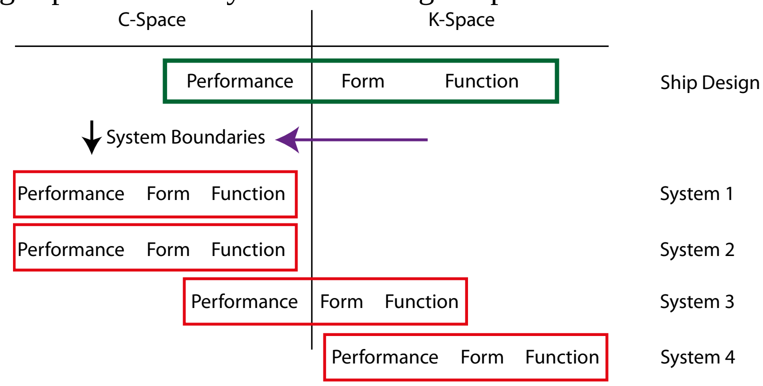

Figure 15, Knowledge and Concepts in Gordon Murray's Really New design

Even though the majority of systems, including the overall car concept remained similar to the previous designs, in that respect, Gordon Murray was still able to generate a *really new* innovation within these boundaries.

Reviewing the description of Cross & Clayburn Cross, it shows that, during intense deliberation, Gordon Murray rephrased system boundaries and thus created C-space opportunities. In this case he explored the possibilities by redefining inter-system relationships. He made a new connection of sub-systems by connecting the aerodynamic design with the suspension system. This provided him with design-space to redefine (develop new knowledge) first the performance, form and functionality of these two interconnected systems and as a result of that, secondly design the two individual systems with their interconnections. He did not only apply disjunction to individual systems as such (common in incremental innovations), but applied disjunction on the system boundaries, creating more design space, far beyond incremental innovation approaches. This was done without starting on a clean sheet of paper to design a revolutionary new racing car. Such a design process is what we are looking for in ship-design.

ANALYSIS

The previous sections discussed three different case studies: two from a ship-design perspective, one design project in another industry. In all three case-studies the design of a complex object is the main scope. In each study the design is based on an integrated set of systems: however, the design processes are vastly different: from developing within known constraints to starting with a clean sheet of paper.

The *Incremental design* is developed from existing knowledge and creates very little design space within known and familiar boundaries. System boundaries remain consistent throughout the whole design and engineering process, which limits the design activities to enter and explore the C-space considerably. From a management perspective, these designs can be controlled more easily, and have relative low risks.
The *Radical design* has a system-definition which is based on the functional requirements of the vessel only. This opens up the necessary opportunities to enter and explore the C–space looking for potential new knowledge. As the design progresses and the overall ship design is defined in more detail, system boundaries are mandatorily redefined, requirements change, system functions alter and forms are reshaped. This results in major revisions and design iterations but also in the end in new knowledge belonging to the K-space. From a management perspective these projects are vast and have relative high risks, but offer plenty of opportunity for innovation.

The *Really-new design*, even though not related to the ship-design, identifies and stretches these system boundaries, redefining systems and especially system combinations in unexpected ways, creates enough design opportunities in the C-space without jeopardizing control over the design and engineering process: There is no redefinition of the overall form & function of the object (in this case the car). Because of the relation to both radical and incremental design it could possibly result in a commercialized solution of innovative design.

The observations on the *really-new* innovation are especially interesting for our research: The definition of fixed system-boundaries early in the design process appear to constrain the overall innovative potential of the design. However, opening up the system boundaries completely cause significant design iterations to occur, as observed in *radical innovation* projects. These are very time & resource consuming and risky, and therefore unsuitable for a commercial environment.

Future Research

Based on these case-studies, we can start questioning what defines these system-boundaries, when only limited information is available. This is contrary to the system engineering approach presented by the INCOSE (INCOSE, 2006), where the functional decomposition, system decomposition and architecture choice are developed independently, primarily during the ‘project start-up’.

The research will continue to challenge the approach on boundary definition early in the design to influence, control and improve the innovative character of commercial ship design, without the pit-falls such as time-consuming design-iterations.

Furthermore, Gordon Murray had the advantage of developing both the overall design and the independent systems. This made it possible to shift between the car-design and system-design. The ship-design industry is not that lucky: the industry is heavily segmented, with different actors involved in both ship and system-design. A change in these design processes will require us to take a socio-technological approach to reformulating ship-design methods as well as applications (de Sitter, et al., 1997). Questions like, what is required for present ship designers and their co-designing colleagues each with their discipline based development routines to enter the world of designing for really new innovations? What changes will the present socio-technical system need to undergo in order to accommodate to such a new practice? And this practice in addition to the present incremental innovative practice that we do not want to loose? What tools could be of help here? These and other questions will be addressed during the future stages of our research.

CONCLUSIONS

Based on an extensive literature survey it appears that this paper explores a new area in the (ship) design literature. Whereas there is a wide range of publications related to the 'engineering of complex objects' and the 'design of objects', the literature theorizing the *design* of *complex objects* appears to be scarce. Especially, if one doesn't want to start from scratch.

This paper studies the initial development of these complex structures, with the objective to improve the innovative capacity of the (ship-design) industry. For *really-new* innovations, this can potentially be in the redefinition of system boundaries, without radically changing the overall concept. As discussed in this paper, the interaction between the different levels of decomposition with, in a segmented industry as ship-design, the interaction between the different actors has a major impact. We have learned from our analysis that, if one aims to bring in more innovative design space, it is necessary to redesign the resent design and engineering process of the industry of complex special ships.

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BIBLIOGRAPHY

Andrews, D., 2004. Marine Design, Requirement Elucidation rather than Requirement Engineering. *Journal of Naval Engineers*, December, Volume 42, pp. 34-51.

Andrews, D. J., 2012. *Is Marine Design Now a Mature Discipline?*. Glasgow, IMDC2012 Secretariat.

Andrews, D. J., Papanikolaou, A., Erichsen, S. & Vasudevan, S., 2009. *State of Art Report on Design Methodology*. Trondheim, s.n., pp. 537-576.

Andrews, D., Percival, V. & Pawling, R., 2012. *Just how valid is the ship design spiral given the existence of cliffs and plateaux.* Glasgow, s.n.

Brett, P. & Ulstein, T., 2012. *Critical Systems Thinkin In Ship Design Approaches.* Glasgow, s.n.

Clark, J. O., 2009. *System of Systems Engineering and Family of Systems Engineering from a standards, V-model and dual-V model perspective.* Vancouver, s.n.

Cross, N. & Clayburn Cross, A., 1996. Winning by design: the methods of Gordon Murray, racing car designer. *Design studies*, pp. 91-107.

de Sitter, L., Hertog, J. & Dankbaar, B., 1997. From complex organisations with simple jobs to simple organisations with complex jobs. *Human Relations*, 50(5), pp. 497-536.

Delft University of Technology, 2013. *Systems of Systems approach, Ship Design Lecture.* Delft, s.n.

DoD, Systems Management College, 2001. *System Engineering Fundamentals*, Fort Belvoir, Virginia: Defense acquisition university press.

Erikstad, S. & Levander, K., 2012. *System Based Design of offshore support vessels.* Glasgow, s.n.

Evans, J., 1959. Basic Design Concepts. *Naval Engineers Journal*, pp. 671-678.

Garcia, R. & Calantone, R., 2002. A critical look at technological innovation typology and innovativeness terminology: a literature review. *The Journal of Product Innovation Management*, p. 110—132.

Griethuysen, W., 2000. Marine Design, can systems engineering cope?. *Naval Engineers Journal*, 39(2), pp. 233-245.

Hatchuel, A. & Weil, B., 2009. C-K design theory: An advanced formulation. *Research in Engineering Design*, Volume 19, pp. 181-192.

Horváth, I., 2007. *Comparison of three methodological approaches to design research.* Paris, International Conference on Engineering Design, ICED'07.

INCOSE, 2004. *What is System Engineering?*. [Online] Available at: http://www.incose.org/practice/whatissystemseng.aspx [Accessed 2012].

INCOSE, 2006. *Systems Engineering Handbook*, s.l.: International Council on Systems Engineering.

Levander, K., 1991. *System Based Passenger Ship Design.* Kobe, s.n.

van Bruinessen, T., Hopman, J. & Smulders, F., 2012. *Improved models in the design of complex specials: Success or Failure?*. Glasgow, s.n., pp. 19-36, Volume II.

van Bruinessen, T., Hopman, J. & Smulders, F., 2013. *Towards a Different view on Ship Design.* Nantes, OMAE2013, ASME, p. 10.

Vestbøstad, Ø., 2012. *System Based Ship Design for Offshore Vessels, MSc Thesis,* Trondheim: NTNU.