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OBSERVATIONS ON THE ABILITIES OF DESIGN METHODOLOGIES TO PRODUCE DIFFERENT PRODUCT STRUCTURES

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ABSTRACT
The ways of working in the industry have changed within the last 20 years. The products delivered are increasingly collections of assemblies produced by different companies in the supplying network. The segmentation of the product emerges also the need of the division of the design work. How this effects to the design process is interesting topic for the design methodology research. In this paper the actual design processes in shipbuilding industry network were documented on the basis of an empirical study. The results are compared to existing design processes in the research field. Design methodologies with similar decision-making sequences are to be identified. It appears that a certain design methodology is most able in producing a product structure with certain properties. Because the properties of the product structure are linked to business goals, the choosing the design process has a strategic aspect, which should be taken in consideration. The results also raise the question about possible limitations of the use of the conventional systematic design process.

Keywords: Design Methodologies, Product Structuring, Systematic Design, Project Industry

1 SCOPE AND METHOD OF THE RESEARCH
This research has been made in co-operation with Finnish ship building industry. The companies observed were two shipyards in Turku and Rauma owned by Norwegian Aker Yards ASA. In addition to the shipyards nine other companies in the Finnish maritime cluster were studied. Four of them are design offices making contract designing of the ships and they are important partners for the shipyards. Three companies are suppliers of major interior and machinery elements of the ship. Two companies are delivering smaller building elements for shipyards. The most important product segments for these companies are cruise ferries and passenger ferries. The research was focused on deliveries of these types of ships.

A passenger ship is a one-of-a-kind type project delivery. Every ship is unique, but on the other hand most components or assemblies are used in many ship deliveries. Therefore there is great potential for design re-use by configuration and modularisation. The level of re-use is different from ship to ship. There is so called "prototype" ship-delivery, which is the first ship of its class. The re-use in these ships is rather low. Same ships of same class to same customer are called "serial ships". The re-use in these kinds of ships is up to 70-90 % (depending the way of calculation).

The customer requirements are naturally the most important source of variation, but there is also another source of making changes in deliveries from ship to ship. The design work on ship can be more or less given to the supplier network according how skilful contractors are available for this particular ship delivery. It is possible that the Finnish shipyards are in the top of the world in using outsourcing. The outsourcing is standard way of working in the design tasks as well as in component manufacturing and assembly tasks. In the design, even a part of the conceptual design is bought from the design offices. A great part of the embodiment design (called "basic design" in this area) is made outside the shipyards and subcontractors make practically all of the detailed design. The way, in which the division of work between the shipyard itself and the subcontractors is made, is taken for main criteria for defining different ways of delivering the ship. It is suitable main criteria because it changes process significantly. The change effect in the process is actually much bigger than effects coming from the customers or technical requirements.

Empirical method was used in studying the different ways of making ship delivery. The information was gathered from shipyard quality management books, documentation from previous deliveries and by interviewing the personnel in the shipyard and in the marine cluster companies. The process models were drawn according to the information exchange model, and thus the sequence of design decisions can be seen. In this study, four different ways of making delivery were found. The empirical material is presented more detailed in the final report of the research project [13].

The sequences of decisions were then compared to the design processes presented in the field of design science. A threshold of more than 80% match is required to accept a theoretical design process to fit an empirically defined actual process. It was possible to identify design methodologies for all four delivery methods. The results brought up interesting observations.

2 REASONS FOR VARYING PROCESSES

The way of building passenger and cruise ships in Finnish yards is changing. There are three main factors causing this change. The first one is moving away from "one big company" policy where the shipyard makes everything by itself. The second one is changes in the "shipbuilding philosophy" originated from changing cost structure. And the third is urgent need of changing from the craftsman paradigm to the industrial manufacturing paradigm. There are many underlying reasons for these changes as discussed later. One reason is however above all other: Increasing size of the ships. As shown in the Figure 1 cruise ship "Genesis" which is under construction now is almost twice as big as "Voyager of the Seas" that was build less than ten years ago. Have either the building time or the size the shipyard doubled accordingly? No – those solutions would have lead to losing the competitiveness and so new ways of working are the only possibility to keep on going in this business.

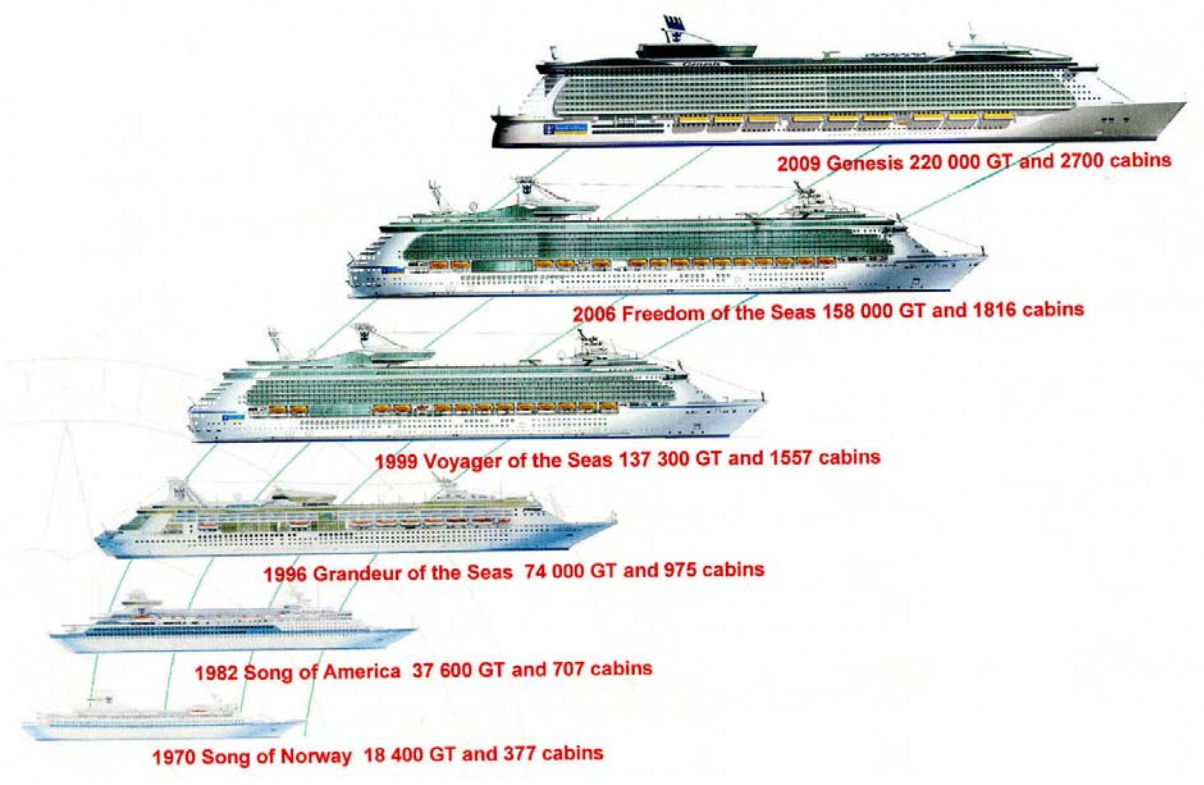

Figure 1: There has been significant growth in the size of the ships. The "Genesis" which is now under construction is almost 12 times bigger than "Song of Norway" from 1970. However the design and building time is not multiplied to tenfold – if the technical complexity is taken in calculations the calendar time needed in building are something between the same and doubled. [Picture and data: Aker Yards]

Very few – if any – shipyards in the world build the whole ship by themselves. As mentioned earlier, the subcontractor network is particularly wide and important in the Finnish marine industry. Not only actual work is subcontracted but also responsibility of design work and process control are increasingly coming to the responsibility of the subcontractor. There are four different complexity levels concerning the work bought from the subcontractors.

- Work according the instructions
- One physical area of the ship made complete
- One functionality of the ship project made complete
- One functionality of the ship developed and maintained

The reasons for this change and the discussion on whether it is the right direction of development would need another article to be thoroughly discussed. Putting it shortly, the main factor in this development is the seasonal nature of the ship building business. When the order books are full, there is plenty of work available and a shipyard having all designers and builders on their own payroll can live and prosper. But when there are no ship orders, the reducing of laborforce can not be avoided. It is just not possible to sack people and then hire them again, because skilful workers will find other jobs. The smaller contractors are more flexible. Many of the Finnish subcontractors are involved also in other business areas than shipbuilding and therefore they have better possibilities to balance their labor supply. The other business areas may not be so profitable, but they make it possible to live on until new shipbuilding contracts could be attained.

The traditional way of regarding the building of the hull as the most important task in shipbuilding is not feasible when building cruise ships and passenger ferries. The amount of investments in interior and equipment is far bigger than the investments of the hull. Thus there is no longer business logic in constructing the ship by the terms of building the hull. Neither there no longer exist technical reasons for designing and building the hull first. This leads to changes in “shipbuilding philosophy”. The standardization and effective producing of these parts of passenger vessels is required.

Building of cargo ships in Far East has achieved a very high efficiency level by standardizing the work. The ships made there are very much alike. The problem is that there is no “standard luxury cruise vessel” and, most probably, never will be. In the cruise ships business, it is a value in itself that every ship is an individual. The more the demanding travelers are among the ships passengers, the more important are the ship specific solutions also in the passenger ferry business. Thus there is a urgent need of building different ships by using same parts. The obvious solution is modularizing the ship and encapsulating the variance inside the modules. This again supports the division of the contract to the “module experts” in the network.

There is also need to change the industrial paradigm. The profit margins in the ship building could nowadays hardly afford traditional craftsmanship. More industrial approaches are needed. According to the visionary ideas presented in this research and development projects with European shipyards, the shipbuilding should became more assembly work than actual building and manufacturing. One slogan presented here is “from ship to shop”. The idea here is that the actual manufacturing work on the deck of a ship is transferred to workshop on the land. The motivation to this is a fact that the efficiency of the work done in the workshops is much higher than the efficiency on the board of a ship. The ultimate goal is to achieve a level where manufacturing of the parts and prefabricated elements are made in industrial manner, and only assembly work is done at the shipyard. The transferring of the work from the ship to the workshops on the land will increase the possibilities to divide the work to subcontracting network.

These trends are the reasons for a change which has lead to the different delivery processes. There are no two ships exactly alike when observing the building process. And there is no two ships with similar product structure when we consider “as delivered” -structures. However four generic processes can be found. The actual ship delivery processes are combinations of these generic processes.

3 FOUR DELIVERY PROCESSES

The empirical research revealed that there seems to be four ways how the ship delivery is done. The processes are following.

1. The first way was conventional main contractor centered project delivery. The shipyard coordinates all the design work and the actual design. Component manufacturing and final assembly on the board of the ship can be divided to different subsuppliers. This is the traditional way of working in the ship building industry. However this is nowadays largely considered as ineffective and inflexible causing higher costs and longer delivery times.

2. In the second way of making delivery the ship is divided in spatial areas, which then are made by turn-key type deliveries by a team of subcontractors. A team normally consists of partner who is responsible of the design and another partner responsible of the physical realization of the delivered area. At the moment this way of working is more and more in use. The co-operation within network becomes more efficient. When constructing the ship of turnkey deliveries, the importance of general architecture and the definition of interfaces will become important. The building blocks of the ship are not functional but defined on the spatial terms by the layout.

3. The third way of making the ship delivery is to start to utilize modular structures and configurable product paradigm. In this model the subcontractors are not selling their work effort for building a ship, but instead they have modules that are building blocks for the delivery. These modules are not necessarily physical assemblies, but so called process modules are also used. This kind of module can include, for example design and coordination of certain process phase. This is emerging way of working. The main motivation in this is the possibility to convert hand made single parts to industrially made products with the benefits of serial industrialized production. This approach should be utilized from the very start of negotiations with customer to make sure that modules available could be used in the ship. If ship can be sold as a modular product, this enables a lot of re-use of design.

4. The fourth way of making delivery is more a plan than reality, but it is considered as a strategic goal of tomorrow. The aim is to develop the sub supplier network to an Extended Enterprise. The idea is that strongest partners in the network could come to the level of the shipyard to share the responsibilities and rewards. [1] This requires that part of the value chain is transferred from the shipyard to the first tier partners. The common opinion is that this kind of network would be very agile and could achieve very high cost efficiency without compromising the end product quality.

Different parts of a same ship delivery can be done with different delivery process type. This requires good coordination where only certain combinations are possible.

4 THE PRODUCT STRUCTURE – PROCESS STRUCTURE RELATION

We are now claiming that there are four different processes in ship delivery and we can distinguish their main properties. Can this claim be validated? In earlier research the dependencies between product structure and the order-delivery process has been studied and the synthesis is shown in the following figure. The main finding in these was that there are suitable combinations of product and process structures, but not all combinations make sense. [12] According to this we must check that the proposed processes have also corresponding product structuring strategies supporting the same goals as the order-delivery process.

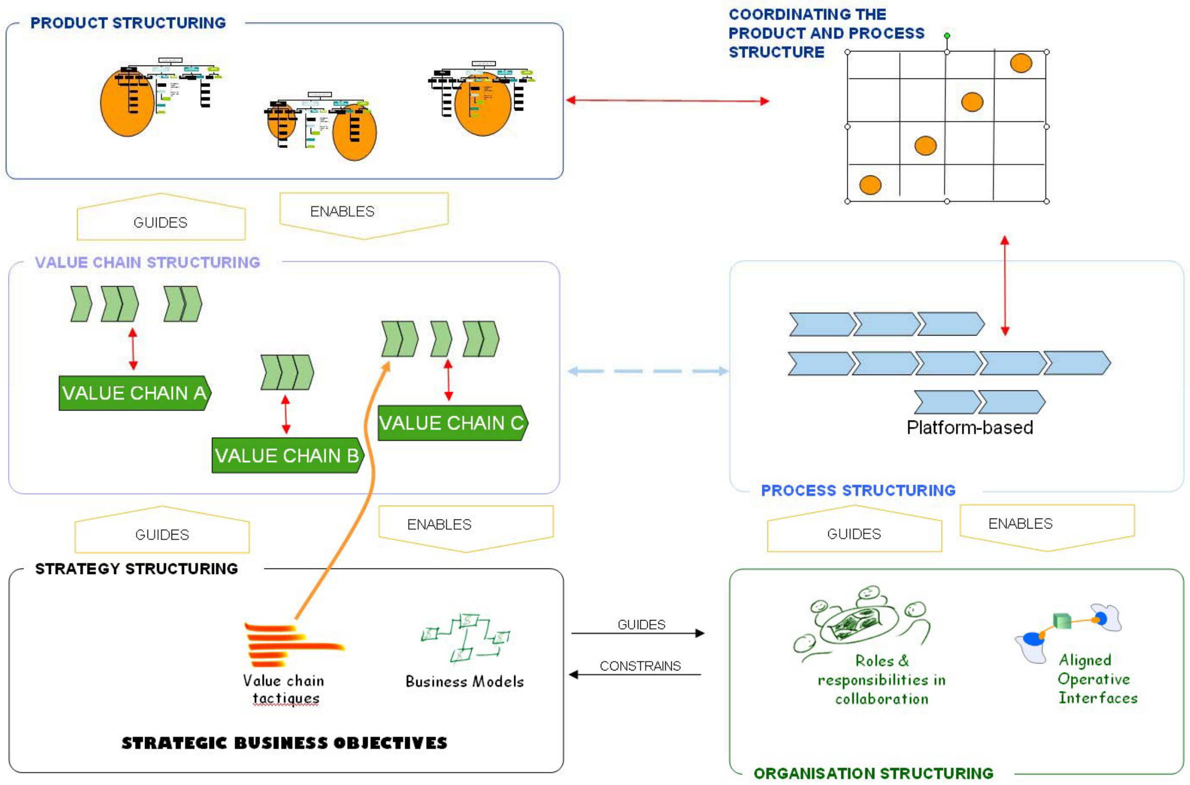

Figure 2: The right combination of product structure (matrix in the upper right corner) and process structure is beneficial in achieving business goals. The reasons for different process structures and value chains come from resource/network structures and from the strategic business goals. In this paper it is discussed, whether different design methodologies produce different types of product structures. If this can be proven, it underlines the strategic aspects of decisions made in the design management.

In the first way of making ship delivery, the goal is to maintain flexibility so that ship could be made up with any possible team of subcontractors consisting of individuals of any skill level. In this kind situation, a strict product structure is more a nuisance than asset, because the aim to exploit “targets of opportunity”. That’s why the product structure here comes from the restrictions from the part structure and requirements from the functional structure. The conclusion here is that the way of working is mainly unstructured and thus no special product structure is required.

In the second way of making the delivery, the process requires spatial division. The ship is welded up from ready made steel blocks. The goal is to handle the interior the same way. In this case the product structuring method is the division into subassemblies according to the spatial structure. This could be called “industrial assembly based modularisation”. The word “modularisation” must be put in parenthesis here, because the division has connection to functionality only by change, not by intention. (Thus these are no modules, for example according to references [2, 3]. On the other hand this type of modularity exists in the industrial history [4]).

In the third way the product structuring paradigm is actually mentioned. The aim is to use functional based product modularity and, in addition to accept some kind of mixtures of product and process; process modules.

In the fourth way the corresponding product structuring methodology is more obscure. It is connected to life-cycle management of the product offering. Because this way of working is only at the stage of planning, the actual product structuring method cannot be pointed out. However suitable product structuring methodology for these goals could be found or developed.

As a conclusion: Two of the proposed product structures have corresponding product structuring method. One is likely to have corresponding method. One does not seem to require any special product structuring methodology at all. According to the framework presented in Figure 2, we can validate that two of the processes do exist and they are likely to be optimal. The traditional process does also exist, but its optimality can be doubted. The fourth process is within the possibilities, but it is not possible to say whether its properties are defined right.

5 THE CORRESPONDING DESIGN METHODOLOGIES

As the research continued, a comparison between the proposed delivery processes and the design processes presented in the research community was done. The result was very satisfactory. For every delivery process found, equivalent design process can be found.

It is easy to recognize the design process matching to conventional main contractor centered project delivery: The design decisions are made very much according the Systematic Design process proposed by Pahl and Beitz [2]. The empirical process model was compared to VDI2221 [5] process model. Only one significant difference was found in the area of interior architecting.

In this kind of shipyard process, the first step is negotiations with the possible customer. This phase corresponds directly to the phase *"Clarify and define the task"*. Next phase in shipyards process is so called preliminary design, which includes the systematic conceptual phases of design process: *establishing the function structures, searching the working principles and defining and selecting the concepts.* After that the contract is made and actual shipbuilding can start. In shipyard process the following phases are "basic design" and "area design" which correspond with the *embodiment design* phase. Next phase of making the production drawings corresponds to "*prepare production and operating documents"*.

As shown in the Figure 3 below, the only significant difference between the traditional shipyard process and the systematic design process is in the area of designing ships interiors. In the "basic design" phase the interior architects draw layout for important interior areas of the ship. In this work they actually make design decisions which belong to concept phase in systematic design process. In theory this should cause rework and iteration. The results from interviews proof that this do happen also in reality.

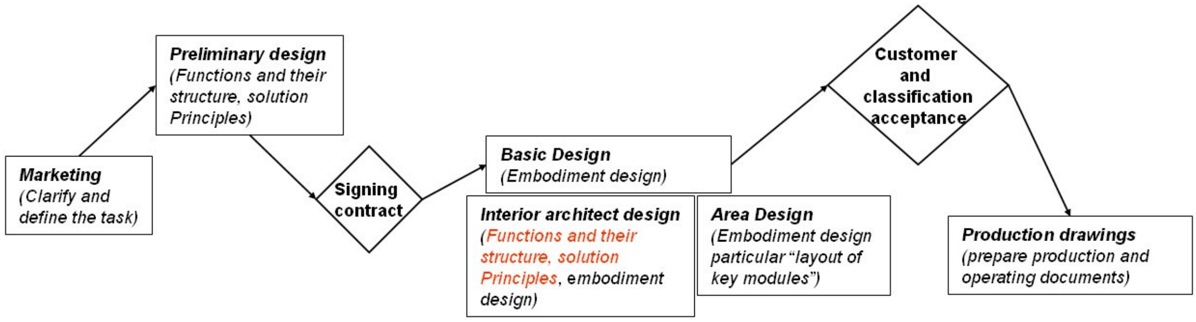

Figure 3: In the traditional main contractor centered project delivery, the design process follows the steps of Systematic Design. In this simplified picture the shipyard process phases are above and the Systematic Design phases are in the parenthesis. The only significant difference is in the area of designing ships interiors.

In turn-key delivery the system and its architecture should be designed first in order to define the elements which are bought from subcontractors as turn-key deliveries. The focus is in the defining and managing the interfaces between different turn-key deliveries. This is the starting point of holistic view of the ship. The elements of the ship are designed and realized more or less separately. The integration of the separate turn-key elements into a final ship is equally important part of the process.

The design process near the empirical findings was the one presented in the area of Systems Engineering, so called V-model.

In the systems engineering process according eg. VDI 2206 [6, 11] the overall function of a system is broken down into main subfunctions. These subfunctions are realized by suitable operating principles or solution elements and the performance of the functions is tested in the context of the system.

The more precise steps of this design approach are shown in Figure 4 below. The figure is drawn using the terminology of software engineering, where this approach is widely used. First step is clarifying the requirements. The system analysis is made according to these requirements. Then architecture is developed. At this phase the principal division of product architecture is made. On the high level design phase, the interfaces and main characteristics of the subsystems are defined. In the detailed design phase, the subsystems are designed and the elements in them are defined. The last step is designing/making the units of the subsystems. (In the software production the designing and building are much nearer to each other than in the heavy construction industry like ship building and the actual building includes part of the design task). There are equivalent testing and integrating phases after these analysis and design phases.

The VDI 2206 defines that inside every design step, there is "a micro-cycle", which consists of problem solving procedure. The V-model process is called "macro-cycle" because there are design tasks on two levels. The system level designing is made according to the steps of V-model and "micro-cycle" design tasks made by appropriate methods. In the area of engineering design appropriate method for making the "unit" design is systematic design process.

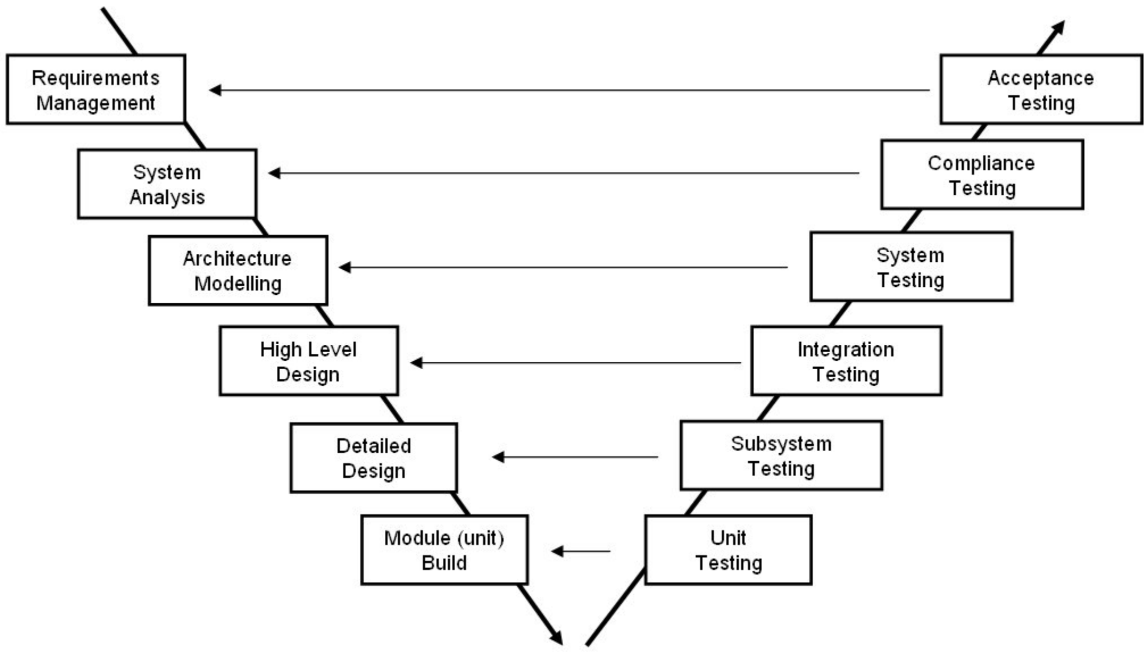

Figure 4: The Systems Engineering V-model.

The elements of systems engineering can be found to detail in ship delivery made consisting of turn-key deliveries. The requirements management and system analysis are made in the bidding phase before the actual order of the ship. The result of these phases is a specification document called "contract specification". According to this, the layout of the ship is designed; the result is two-dimensional drawings of the decks. This is called general arrangement (GA). The design stages equivalent to high level design are "basic design" and "area design". At this stage the areas in the GA:s are partitioned into turn-key deliveries, and the interfaces in between are defined. The actual detailed design is made distributed by the subcontractors. The integration testing phases are important when the ship is built in this way. For example completeness of all pipeline systems must be checked before they are filled with, for example with fuel oil.

When the ship is build up from modules and the idea is to use the same set of modules from delivery to delivery, we are very near to the idea of configurable products [7, 8]. In this design process, no new design is made, but only selection of modules and integration design. In the configurable product paradigm, only routine design tasks are allowed as a part of delivery process. The tasks are selecting elements and parametric dimensioning, in theory. In the reality also some layout and integration design are made as a part of the delivery. This kind of ship design process is shown in the following Figure 5. In this mode of operation the actual product development is made outside the actual delivery projects.

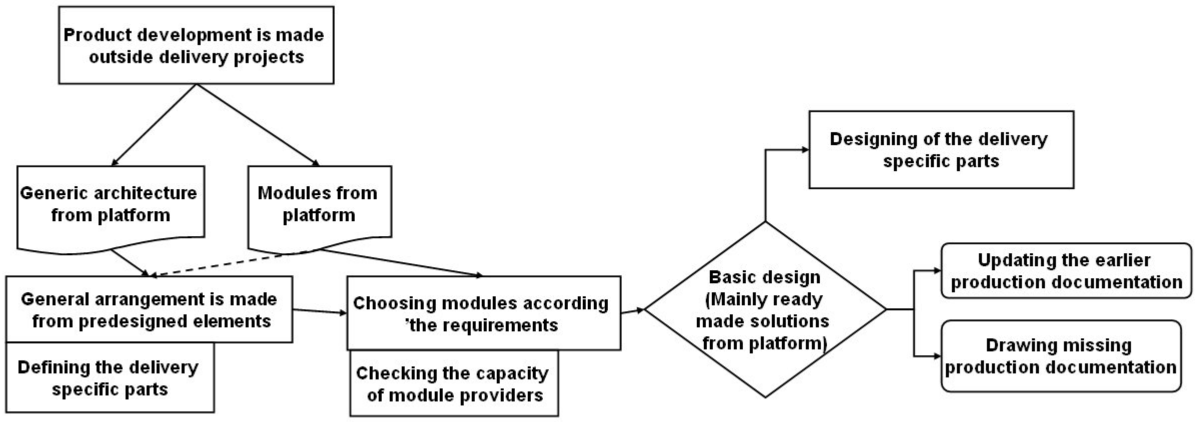

Figure 5: The configurable product design process is very near the process used when the ship (or part of it) is made of modules. The only theoretical difference is that in the shipyard process the sales configuration includes tasks normally included in engineering configuration (according to [7]).

The Extended Enterprise (EE) mode of operation requires the most advanced tools in product structuring. On the other hand, there must be adequate freedom for partners in EE to develop their sections of the products, but also the coordination and holistic properties must be handled. There are proposition of design process with these abilities. As this way of working is not realized yet, no empirical material can be found. Possible process models were drawn. These were tested by presenting them to project managers. The process drawn according to Dynamic Modularisation –paradigm (DyMo) [9,10] was generally accepted. It is shown in the following Figure 6.

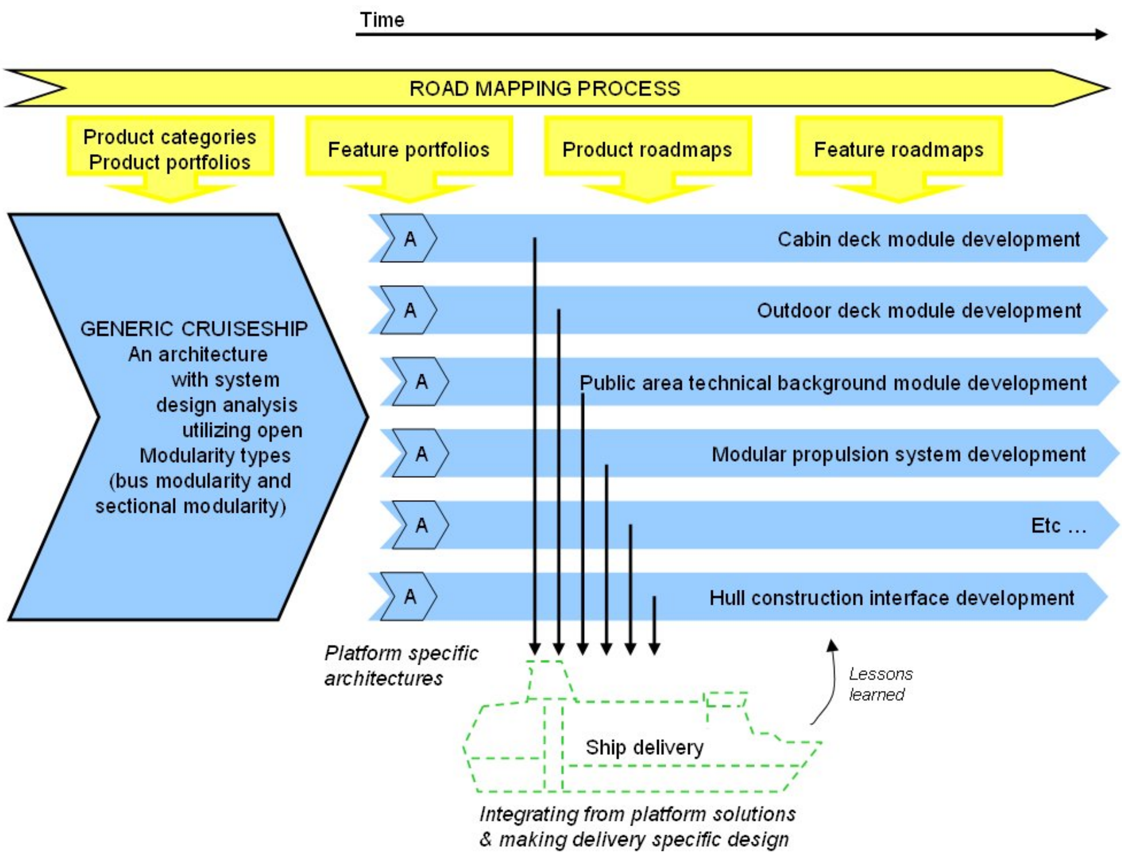

Figure 6: Practical implementation of DyMo-process in ship building. Starting from the left we see how product architecture is formed according to the business needs. The available generic product model has capabilities, which are constrained by system level architecture. Subsystems are derived from the system level architecture. Modules are released for the product delivery programs according to the roadmap. Delivery programs (actual ship building) integrate ready made (designed) modules into a ship.

The dynamic modularization process is based on product platform with open module architecture managed with roadmap process. Generic architecture defines the main building blocks of the product. The architecture design starts from defining *business needs* in various forms such as product categories, feature roadmaps, product roadmaps or product portfolios. The product level system architecture dictates interfaces and modular sub-systems, which can be used. Every sub-system has its own architecture and thus is a module system by itself. The module development processes are started according the road mapping process. The road maps define product categories and portfolios and feature portfolios. The roadmaps answer to the question: Whether and when it is possible to produce a certain product with certain features. The system level module structure is evaluated to establish platform capabilities. Features, functions of the product, product cost etc. are subset of capabilities. Then subsystems and their module structures are defined accordingly. In the shipbuilding business the possibilities of making roadmaps are very good, because the potential ship contracts can be predicted for more than five years ahead.

6 KEY CONCLUSIONS

There are different ways of making ship delivery. The sequence in the delivery process changes also remarkably. Design methodologies with similar decision-making sequences can be identified. Thus it appears that certain design methodology is most able in producing a product structure with certain properties. This is also linked to business goals.

The goals and the methods as observed here are:

Business goal	Design Process
Optimal design from the technical point of view	VDI 2221
Possibility to divide design and production work	Systems Engineering
Utilizing design re-use	Configurable product paradigm
Distributing the product development	Dynamic Modularisation

According to this, choosing the design process has a strategic aspect, which should be taken in consideration.

A remarkable observation is also that the Systematic Design process is not as universally usable as might been thought. It is a very good process when a actually new product is being designed and innovations and improvements are sought after. However it does not encourage design re-use. And it does not include special methods for designing product families and thus it leads to development of stand alone products. It does not give support in distributing the product development if the division is made according some other aspect than functionality.

Design process used in the traditional delivery process in the ship building industry is almost the same as the systematic design process. The origins of the Systematic Design are in the German heavy industry in the seventies. The business environment has been changed a lot from those days. At the moment the shipbuilding industry is confronting other kind of challenges. For example the time-to-market has in many cases become more important than optimal design work. Producers, who will have optimal solutions tomorrow, will be out of business before the “tomorrow” comes. The empirical data from shipyards shows that the traditional way is not the most successful in the reality of business today. The empirical data of this research is gathered from one industry branch observing two product segments. It is an open question how much the results are depending on the special properties of this industrial area. However, this kind of development can be seen also in other industrial areas.

The Systematic Design is aimed for designing a single product of best possible engineering quality. Earlier there was one product, one producer and fewer thoughts about the design re-use. There has been ideas that design re-use can be adopted in Systematic Design by taking it as a requirement. In this research, the findings show that this is not a matter of priority of requirements, but the differences are deeper in the process.

The systems engineering approach supports better the designing of large products divided in subsystems. The division can be made here within functional structure as well as in layout (or other) structure. The design re-use is not specially supported by SE.

The challenge with configurable product process is to be able to use two ways of doing design work. The configuring is used in the delivery processes, but because it is unable to produce new products, another process must be used in product development (maybe Systems Engineering as “macro-cycle” and Systematic Design in “micro-cycles”?). Inside a single R&D project, the Systematic Design approach is more feasible. There is a lot of research going on in the area of developing Systematic Design methods further. Thus the suitability for designing product families will probably become better. However this does not change the fact that the Systematic Design process is not applicable to high level design work in three out of four delivery process in this particular case.

In the Dynamic Modularisation the proposed abilities are very promising, but as no empirical data was available, its real potential is still matter of speculation.

7 DISCUSSION

Because this paper focuses on only one research case, the applicability of the results to other areas of industry is an open question. However here we can clearly see that Systematic Design is an inadequate approach to meet all requirements coming from the changing processes. We can also see that people in industry strongly believe that they can utilize “modular-type” structures, which are not based on functionality at all. Thus functional oriented design methodology lacking the processes of design re-use is not adequate at least in the area of shipbuilding. There are remarkable researches addressing to the challenges presented in this paper e.g. [14], but still more methodological research attention should be focused toward these topics.

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