Why can’t a ship be bought as easily as a car?

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Imagine you go to a car dealer and ask the manufacturer to produce a vehicle that has a maximum speed of exactly 218 km/h and must not weigh more than one tonne. Furthermore, it has to have a range of exactly 1,000 km with one tank filling. Surely, it must also have three airbags on each side, while the trunk cannot be bigger than 500 litres. Of course, it has to be a three-seater and painted in high gloss candy pink. Silly, isn’t it? Then why does everybody do that in shipbuilding?

Ship design is characterized by individual solutions like hardly any other industry. Typically, every vessel is developed from scratch to meet the specific requirements for the planned route, the designated operator, and national regulations. This is also because ships are usually ordered through bidding procedures and tenders, set up for individual cases. The requirements communicated this way are fixed; though, there are many ways in which they can be met. One can even go further by stating that there is no transparency in the actual intention behind the requirements, i.e., what the future owner actually wants to achieve (e.g., why specify a certain top speed if a vessel only uses it 10-15% of the time, while the actual intention was to keep the route sailing time according to plan?).

**Tension**

There is nowadays a dominant belief that complete optimisation is the only way to design a ship. This is a result of today’s extremely specified tender processes, which lead to one-off ships due to all the requirements vessels owners include in their order specifications. As such, the final ship design is the result of an iterative, successive, and cost-intensive optimisation process, in which the best solution is selected from a range of possible alternative solutions. Those variants are based on a variety of optimisation criteria such as stakeholder requirements, target speed and route length, or national and international regulations. The resulting ship is then a fit-for-purpose design. As an effect, small changes in requirements have a strong impact on the final design.

The connection between compulsory technical requirements and physical restrictions is even more evident for battery-powered vessels, as there is a high degree of dependency between individual systems and physical characteristics (e.g., battery weight, range, speed, the actual number of passengers on-board, etc.). However, battery-powered ships can have a significant impact on the emission reduction of the urban transport sector. When discussions of decreasing emission limits began in 2013, the European Commission presented the first measures to reduce greenhouse gases in its strategy for reducing emissions from the shipping industry; coastal & river cities such as London have also adopted their own emission targets.

The shipbuilding industry, with its described one-off design and production, faces the challenge of supplying many municipalities and cities with environment-friendly passenger ships in the short-to-medium-term. This leads to a tension between, on the one hand, coming up with (expensive) individually-designed state-of-the-art ships and, on the other hand, the need for quickly available, cheap, and ecological mobility solutions. Shipbuilders, their customers, and urban transport companies have a great (public) interest in putting eco-friendly ships into service as soon as possible, hence drive up shipbuilding demand. At the same time, though, the differing use-cases do not make the task any easier.

**Internal complexity & external variety**

Modularisation is an established methodology from other industries (e.g. automotive or aviation), providing the necessary instruments to solve the contradiction of individuality and standardisation. By developing modular product architectures, it is possible to combine single modules that adapt the product to individual customer needs or boundary conditions. At the same time, the reuse of modules allows for the shortening of the development and production processes.

However, modularisation is tricky and should not be mistaken for block construction. The latter method is used from a manufacturing point of view in order to be able to build large ships where crane, weight, or other production limitations are preventing an integral production. In contrast, utilising modularisation methods is an active decision already made during the product design.

From the system theoretical perspective, modularity is a concept for handling internal complexity while allowing external variety. This complexity can have different dimensions; one approach to solving it is to subdivide complex systems into individual subsystems, which are functional mostly independent from other subsystems. The subsystems, or ‘modules,’ can be described by different characteristics, structured by requirements of all product life phases. Moreover, modularisation refers to the targeted development of modular product structures and the concrete definition of modules and interfaces. An essential aspect of this is to group systems by their functions, links and interfaces with other systems – and not according to their shape or proximity.

With the previously described challenges in mind, the development process has to consider incorporating the so-called ‘Systems Thinking.’ Model-Based Systems Engineering (MBSE), for example, is an integrated and interdisciplinary approach to achieve this goal. It defines the concept of a consistent description and analysis of a system to be developed based on models, from the early phase of conception through the entire product life cycle. The models describe the development object from different perspectives and illustrate different aspects (like the system’s functions). For each of these aspects,
The modularisation alphabet

Within the EU-backed TrAM H2020 project (Transport Advanced and Modular), our solution approach is based on the idea of supporting module identification using a consistent, domain-spanning system model. The logical system architecture is used to analyse relations and connections between system elements and to determine the optimal system interfaces. We have developed an overall three-step procedure to identify the modules and build up a modular architecture for the vessel-family.

The first step is to develop a universal ship architecture for a battery-powered fast ferry. In the second step, this logical architecture is adapted to real use cases. Within TrAM, a demonstrator vessel will be built and put into operation in the Norwegian Stavanger from 2022 (a replicated unit will also be developed for London). The Stavanger demonstrator will be elaborated in close cooperation with the Fjellstrand ship-yard. Both use cases differ in main requirements, e.g., route length, maximum speed, the number of passengers to be served, etc. Finally, a change impact analysis will be carried out; by comparing the individual adaptations, system elements in the architecture that have remained the same will be identified. These are potential candidates for future modules. It will also be relevant to see which systems will change for every use case because the definition of standard interfaces between varying and remaining parts of the architecture is what allows the individualization of the ship.

The development of the general logical ship architecture has followed a multi-step procedure. Different partial models have been developed to create a logical architecture. In particular, the relationship between individual partial models, other support tools, and the resulting system architecture is illustrated in Figure 1. The starting points of the procedure are the environment analysis (A) and requirements (B) of the CONSENS modelling method. In the former, the integration of the 'Ferry' system into its environment is systematically analysed. By evaluating the interactions of the 'Ferry' system with its environment elements, conclusions about required system elements of the logical architecture can be derived very easily. In the present case, it can be concluded from the environment element 'Water Station' of the quay, e.g., that the hull requires water to be taken up by the system element 'Water Tanks.' The requirements part specifies goals and restrictions for the later solution and might thus impose certain limitations (e.g. legal requirements of the approval authorities may require that batteries have additional fireproof insulation).

In the next step, functions are derived from the results of the requirements analysis and, starting from the main function 'Generate mobility,' are transferred to a function hierarchy (C). The system elements of the logical architecture realize functions very concretely so that there is a link between the functions and the system elements. Individual functions can be implemented by one or more logical system elements. As a high-level example, the system element 'Engine' can provide the function 'Generate Propulsion.'

The SFI code (D) describes a design and production-driven classification system. Due to its highly functional subdivision of a ship into generic categories (hull, equipment or machinery), it provides an ideal basis for the derivation of the logical ship architecture's system elements. After passing through the environment and requirements analyses as well as the establishment of the functional hierarchy, the system elements already created can be compared with the elements of this quasi-standard, restructured and, if necessary, renamed.

In addition to the SFI code, other resources can be used to develop the logical architecture. For example, ship architectures from previous similar projects (E) can be used to supplement the logical architecture. The resulting architecture is finally reviewed through interviews with ship development experts (F).

As simple as

Despite the high potential, modularisation approaches can hardly be found in the maritime industry due to the high degree of dependency between the ship's individual system elements. If approaches like the presented procedure and Systems Thinking become more popular, effects on the current tender processes should become visible – forming a future where you can buy a ship as simple as a car.