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Defining a Framework for Implementing the Circular Economy Principles into Ship Design

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ABSTRACT

This research addresses the importance of sustainability in shipping beyond fuel selection, stressing the need for responsible material usage in vessel construction and maintenance. Transitioning to a circular economy is crucial for sustainable waste management in the industry, yet current ship design neglects circularity considerations, prioritising functionality and cost. The research evaluates frameworks such as the butterfly diagram, Cradle-to-Cradle, 10R, and ReSOLVE to integrate circularity into ship design. Combining the 10R framework with the Material Circularity Indicator method, this study offers practical insights for circularity in ship design. Challenges include integrating these methods into standard design processes, which are mitigated by fusing 10R strategies with systems engineering. A case study on wheelhouse redesign demonstrates the effects of this approach, highlighting the importance of supplier collaboration for circularity enhancement.

KEY WORDS

Circular Economy, Systems Engineering, Ship Design, Sustainability

INTRODUCTION

In 2015, 193 world leaders have agreed to 17 global goals to end extreme poverty, inequality and climate change by 2030. Goal number 12 states: ”Responsible consumption and production” (The Global Goals, 2015). The aim of this goal is to ensure sustainable consumption and production patterns. To achieve this goal eleven targets have been set to create action. One of them also being: ”Substantially reduce waste generation”. By 2030, the aim is to substantially reduce waste generation through prevention, reduction, recycling and reuse.

In the maritime sector, currently virgin materials are used for the construction of vessels which all have to be taken care of again at the end of a ship’s life. Ships are broken down at ship recycling yards, where steel is recycled, but often with disregard for the environment (Mikelis, 2019). In 2018, 90.4% of the ships (measured in the gross tonnage) were recycled by shipbreaking and recycling industries in Bangladesh, India, and Pakistan. These are popular countries because of the absence of strict environmental regulations (Alam et al., 2019). Also, recycling is a valid option but when looking at retaining value, recycling is not the best way and other methods such as reuse or refurbishment are preferred (Cramer, 2020). Not only at the end of a ship’s life, during demolition, the materials need to be processed but also during the ship’s lifetime of approximately 25 years, components on board are replaced, creating a lot of waste. Additionally, little is known about how all other parts except for the steel of the hull are handled, such as electronic systems or furniture.

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At the moment shipbuilding is not considering the reuse of materials at the input and output side of the process. As a result, circular economy would offer many opportunities for improvement and could increase the sustainability of this key sector. In a circular economy there is no waste since waste is seen as a raw material for new products (Stahel, 2016). Currently, vessels are designed with a focus on functionality, cost and operability. Next to that, designers mainly reuse existing knowledge to establish assumptions and probability to deal with uncertainty. This makes it difficult to take higher levels of uncertainty into account, whilst due to the ongoing energy transition there is uncertainty about the required refits and updates of systems in the future (Zwaginga and Pruyn, 2022). Taking into account the circularity of products when designing a vessel could reduce waste and improve the sustainability of vessels since up to 80% of a product's environmental impact is determined already in the design phase (European Commission, 2020a). The circular economy principles, also known as cradle-to-cradle, are therefore seen as a sustainable strategy.

This paper explores a method of implementing the circular economy principles into the ship design approach. Where circularity is considered to be any process that improves the reuse of equipment, components, parts and materials, where the maintenance of value is a key priority. This is achieved by first assessing the current state of circularity in the shipping industry. Next, there is a selection of a definition of circularity and a way to measure it. After that, the goal is to identify important system properties that enable identifying the level of circularity that is currently prioritised in the design of the system by looking at these system properties. Combining these topics, a framework will be drafted to guide future ship designers in also taking circularity into account alongside the current design drivers such as functionality, cost and operability. As a case study, the framework will be tested on the wheelhouse of a Damen RSD2513 tug. In the case study, different system levels will be examined on their current circularity level and improvements to increase the circularity level will be proposed.

THEORY

In this section, the current state of circularity in the shipping industry is researched to determine the potential of applying (more) circularity in the sector. After that, the theory behind the circular economy will be elaborated upon. Lastly, approaches for both circular design and ship design will be discussed to look for opportunities of combining these two approaches.

Circularity in Shipping

Literature research on the topic of circularity in the shipping industry was done by the use of the databases of Scopus, WorldCat, the TU Delft repository and Google Scholar. To achieve relevant results, search terms were determined in advance. The keywords such as "Circular*", "Ship Design", "Ship recycling", "Ship repair", "Systems Engineering", and any combination of these words were used. This research revealed no scientific resources on the topic and by use of Google and the same keywords, an understanding of the circularity in shipbuilding was obtained.

Sustainable Shipping Initiative and 2BHonest (2021) state that the shipping industry is already applying reuse, repair and recycling, which are all circular principles. However, the circular economy is more than those three principles and the current practice is primarily cost-driven, so other principles of the circular economy have great potential to be implemented in the shipping industry as well. To ensure this, more and more rules and regulations such as the Hong Kong Convention (IMO, 2015), EU Ship Recycling Regulation (European Commission, 2020b), the Circular Economy Action Plan, The European Sustainability Reporting Standard (EFRAG, 2022) and ISO standards are put into place (Balder, 2021). During the process of this research, the requirements to put the Hong Kong Convention into force were met and on June 26th 2025, the convention will enter into force (IMO, 2023). However, the fact that the HKC took almost 14 years to be signed by enough states, shows that many states are not very eager to comply with the regulations that would improve circularity, most likely because of the cost and extra work that will come with it. If the maritime sector wishes to become more circular and more sustainable, all stakeholders in a vessel's lifetime need to be on board. How circularity can be achieved will be researched in the next section.

The Theory of the Circular Economy

The current 'take-make-dispose' economy is called a linear model (Di Maio and Rem, 2015) (Bocken et al., 2016). Di Maio and Rem (2015) state that in Circular Economy (CE) models, products maintain their added value for as long as possible and minimise waste. The aim is to keep resources within the economy when products no longer serve their functions so that materials can be used again and therefore generate more value. Thus circular business models create more value from each unit of resource than traditional linear models. Stahel (2016) describes the linear economy as a flowing river, whilst the circular economy can be seen as a lake, where the goods and materials are reprocessed.

The World Business Council for Sustainable Development (WBCSD) concludes that the concept of the circular economy is relatively vague and amorphous, resulting in companies moulding and defining circularity in ways that are most relevant to their core business (wbcsd, 2018). As a result of this, most companies have their own approaches for the implementation of the circular economy. Popular approaches are Cradle-to-Cradle, 10R, the butterfly diagram and ReSOLVE. Even though the frameworks differ in name and exact approach, there are many overlapping principles. First of all the main takeaway for every circular framework is to have as little waste as possible and ideally never throw any materials away by closing the loop. But also the way materials are kept in the loop shows some overlapping principles within the frameworks; words such as reuse, refurbish, recycle etc are in the butterfly diagram of the Ellen McArthur Foundation (2019) but also in the 10R framework. The environmental impact besides material circularity is not part of these frameworks. This was also defined in the scope, to not look at other environmental impacts but purely circularity in terms of material reuse and using as little material as possible. The 10R framework is widely cited and shows clear steps for the circularity level of a product/material in every stage of the life cycle of a product; from design until the end of life (in its current function). The different R-levels are Refuse, Reduce, Redesign, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover. Additionally, even though R0 until R8 can all be seen as circular, it is important to make a clear distinction between the levels of circularity, something that other frameworks have a less clear definition of. Therefore, to continue this project, the 10R framework will be chosen to work with (Cramer, 2020). In Figure 1 the order of the 10R's is shown together with their applicability in the lifetime of a system.

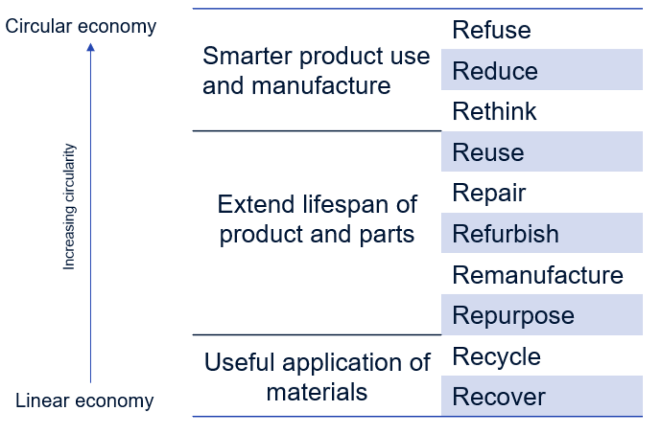


Figure 1: The 10R framework from Refuse (R0) to Recover (R9) based on Cramer (2020)

This framework does not have a clear way of measuring on which step of the circularity ladder a system is currently functioning, but to measure how circular products are, again multiple frameworks and methods exist. To measure circularity, the Material Circularity Indicator (MCI) method is selected (Goddin et al., 2019). This is because it makes a clear distinction between the different circularity levels of the 10R method, the formulas are clear and open access, and the focus is on the product level. The method calculates circularity by taking the average of the circular inflow, which can be a combination of recycled, refurbished or remanufactured materials flows, and the circular outflow, which can be a combination of recycling, refurbishing, remanufacturing or repurposing, measured in percentage of mass. During the lifetime, the utility is calculated based on the lifetime and intensity of use of the system compared to the industry averages of similar systems. The different material flows are visualised in Figure 2.

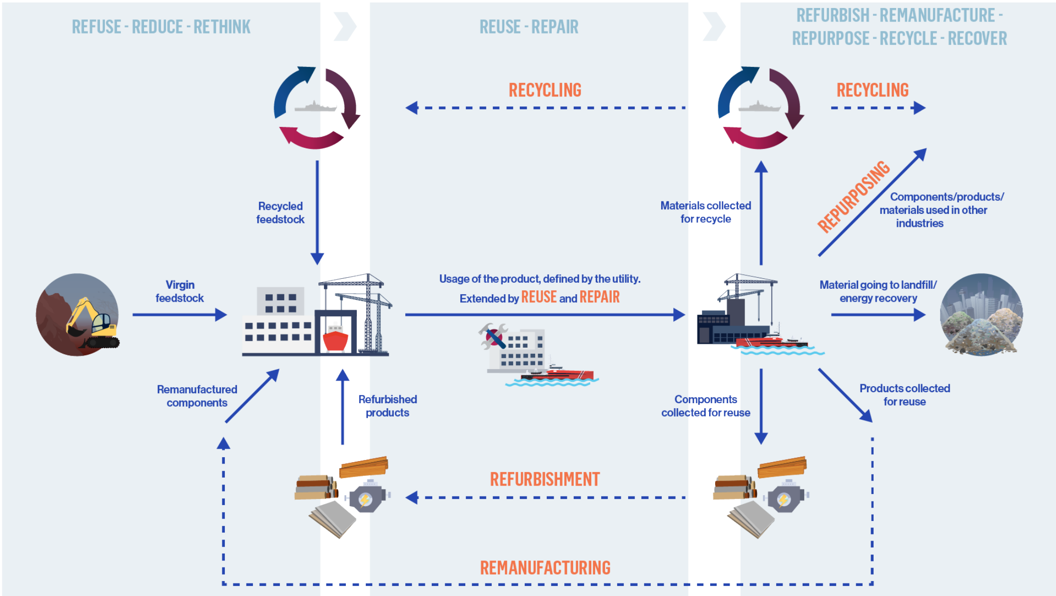


Figure 2: Visual of the material flows when combining the 10R framework with the MCI tool

Design Approaches

Looking at design approaches, two types of design approaches will be discussed in this section; Ship design approaches and circular design approaches.

Ship Design

In ship design, four classes of high-level design strategies are often distinguished; Point-based design, Set-based design, System-based design and Optimisation-based design. Of the four presented design approaches, system-based design, also known as systems engineering, is the preferred method for this research because it defines the customer needs and required functionality early in the development cycle, focuses on documenting requirements and after that proceeds with design synthesis and system validation while considering the complete problem. Kossiakoff et al. (2011) states that ”The function of systems engineering is to guide the engineering of complex systems”. Where a system is seen as ”a set of interrelated components working together toward some common objective” ((Kossiakoff et al., 2011)). In systems engineering, a system can be broken down into systems, sub-systems, components, sub-components, and parts (Hopman, 2021). Systems engineering solves some of the problems that occur in the other methods such as the point-based design where the design spiral is often used and the starting point is so important that it is hard to implement innovations. Next to that, the method considers both business and technical needs of all customers in order to provide a quality product that meets the user’s needs. The fact that the system is broken down in a modular way also helps in including circularity, where modularity plays a big role in the circularity of a system. Modular products can be divided into different modules and each module can be repaired/replaced separately ((Kimura et al., 2001)). The determination of size and content of each module is complicated to decide and are determined by multiple factors such as cost, functional independence, standardisation, ease of maintenance, etc.

Within systems engineering, an application of the theory is the Requirement-Functional-Logical-Physical model (RFLP). The complexity of systems is not only determine by the amount of connected physical components, but also the functional interdependencies play a huge role (Li et al., 2020). By working together, various systems can achieve one function. This so-called functional integration is associated with the different power sources and information flow between the systems. The requirements need to be validated against the higher level of requirements and user needs, therefore there are horizontal validation rules.

None of the four design approaches for ship design takes circularity into account. This can be because circularity is hard to express in terms of an optimisation code or functional requirement. Therefore there is a need to explore design approaches for a circular product since circular design is already quite common for consumer goods.

Circular Design

For circular design, there is no step-by-step guide on how to apply the circular economy principles to the design process. However, for every R-value, one or multiple design focuses can be identified. Many of the current circular design strategies are focused on consumer goods and are not yet applied in technical fields. The first three; refuse, reduce and reuse, focus on the cut down on raw material usage by use of design for reduction of resource consumption (Cramer, 2020)(Bocken et al., 2016). The design focus for the strategies Reuse, Repair, Refurbish, Remanufacture and Repurpose focuses on product life extension. For Recycle and Recover, the focus is mostly on designing for resource recovery or using materials for multiple cycles.

Combining the Approaches into Circular Ship Design

According to Ashby and Johnson (2003), there is a difference between engineering design, under which the art of ship design could be seen, and industrial design which involves the design of consumer goods. First of all, engineering is systematic; it follows well-established and commonly accepted procedures, whilst industrial design does not. Industrial design is strongly influenced by fashion and advertising. Industrial design is less about functionality and efficiency, but the focus is more on qualities such as form, style, and texture; the ones that cannot be measured. Engineering designers often use formal guidelines such as ISO standards whilst industrial designers have representations which are imprecise, ill-defined and less established (Pei et al., 2011). Pei et al. (2011) also states that engineering design is more about associating models with engineering principles, production issues, and functional mechanisms, whilst appearance and usability are the most important focus points for industrial design. The need for clear guidelines and standards is also bigger when looking at ship design since a vessel is way larger and more complex than consumer goods. Inside a ship, many systems, sub-systems, components and parts are present, whilst consumer goods such as chairs and tables, often consist of significantly fewer parts and components.

To include circularity, the systems engineering method has to be combined with the ten design methods complying with the 10R framework. Because systems engineering follows a clear step-by-step approach, circular design principles are best to be included in the steps of systems engineering. To include these principles, the differences between the design methods should be kept in mind and where possible the circular principles should be added in every step of systems engineering.

METHOD

Now that the definition of circularity is clear, the circularity measurement method is chosen and the different design approaches have been reviewed, the next step of combining all this into a framework on how to design a vessel whilst applying the circular economy principles can be made. The framework consists of six steps that will all be separately elaborated upon in this section. The framework is visualised in Figure 3. The first step is to identify an overall goal the system needs to achieve, after which the system is broken down using the RFLP-approach in step 2. After this, in step 3, the MCI score of a comparable, existing design will be determined. After this, the system's life cycle and associated stakeholders will be identified. Finally, in step 5 the system is (re)designed by use of the RFLP approach and the use of circular principles, after which the new design will be validated in step 6. Looking at the method and comparing it to the "classic" V-diagram which is often used to visualise the RFLP approach, it becomes clear that the new method adds a few steps. The steps that differ from the classic approach are highlighted by the orange blocks.

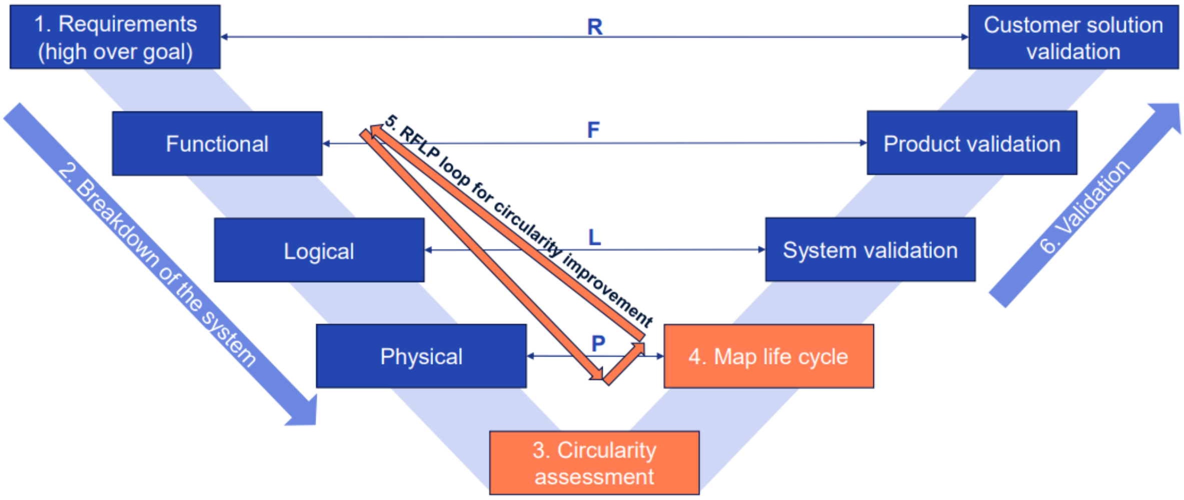


Figure 3: Visual of the framework for including the circular economy principles the classical V-diagram visualisation of the RFLP approach

Step 1: Identify the Goal and Overall Mission

In systems engineering, the first step is a needs analysis. During the needs analysis, the goal is to show clearly and convincingly that there is a valid operational need for a new system or an update of an existing design. To do this, it needs to be assessed whether or not a system already exists that is meeting the needs or whether a (re)new(ed) system is required. The general or main requirements are often dominated by three main parties; customers, production and regulations (B. Vink, Personal Communication, June 28, 2023). Where, in identifying the high-over mission, the customer often has the biggest say. Requirements are, in non-circular design strategies, often operational and functional requirements. However, when looking at the circular design, there should also be a circular goal from the start. Not only do circular aspects have to be a part of the performance and physical requirements, but also general things such as the quality of the product can be performance and physical requirements. Ideally, the goal might be to have one hundred per cent circular systems, but this might not always be achievable. For the general circular requirements, it would be wise to specify this wish into different material streams. Examples of this would be to set a requirement that ninety per cent of the inflow of materials needs to be non-virgin, or at least ten per cent of the outflow of materials should be used in remanufacturing.

Based on the set requirements there are three possible scenarios:

1) A system exists that fulfils the high over requirements
2) A system exists that fulfils the operational requirements but not the circularity requirements
3) No system at all exists that fulfils the operational nor circular requirements

In case a system already exists that fulfils all requirements (scenario 1), no need exists to design a (re)new(ed) system. In case a system exists that fulfils the operational requirements but not the circularity requirements (scenario 2), step two of the framework should be carried out. In case no system at all exists that can fulfil any requirements (scenario 3), steps two and three of the framework can be skipped and step four of the framework should be carried out.

Step 2: Identify and Breakdown System, Sub-System, Components, Sub-Components, and Parts

As mentioned before, the theory of systems engineering divides systems into sub-systems, components, sub-components and parts. According to Kossiakoff et al. (2011), the term ”system” should only be used ”for entities that 1) possess the properties of an engineered system, and 2) perform a significant useful service only with the aid of human operators and standard infrastructures” (Kossiakoff et al., 2011). How far a system can be broken down for analysis is very dependent on the information provided; if no information is there on the structure of the system because, for example, the system is designed by a separate company, this is hard to break down further. Next to breaking the system down, it is also important to identify the boundaries of a system to define what is inside the system, and what is outside. Several criteria can be used to help determine whether an entity is part of a system or not; Development control, operational control, functional control and unity of purpose. For every criterion, questions can be asked such as; ”Does the system developer have control over the entity's development?” and ”In the functional definition of the system, is the systems engineer ”allowed” to allocate functions to the entity?” (Kossiakoff et al., 2011). Additionally, entities that are not part of the system, will still interact with it.
Once the boundaries have been set and the system has been broken down, the connections within the system can be analysed. The interactions on multiple levels of a system can be evaluated by the use of architectures. Architectures help to capture the relationship between the different elements of a system. There are functional, logical and physical architectures, all visualised in Figure 4.

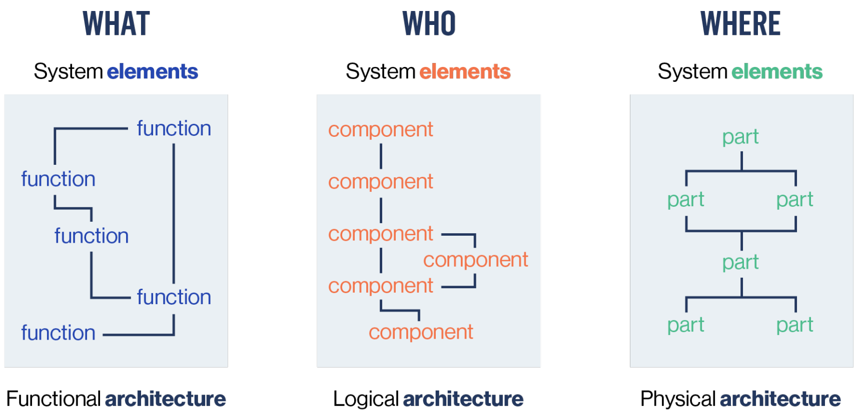


Figure 4: Visualisation of a functional, logical and physical architecture, based on The Mathworks (2020)

After all these theoretical boundaries and frameworks on how to identify the system, practice might prove to be different. In reality, one needs to work with the information available. This information could be retrieved from drawings of systems, material lists or other documentation. The level of detail per system might differ since some systems might be designed and built by the company performing the analysis whilst others might be designed and built by suppliers. Since the circularity of the systems is measured based on weight, resulting in the heaviest components or parts having the biggest influence on the total circularity level of a system. Thus selecting a heavy system when having the choice between multiple systems to assess is an effective way to increase the circularity level.

Step 3: Determine the Current Level of Circularity of Existing Design

To have a baseline and be able to measure improvement in terms of circularity after redesigning it, the previously selected MCI method will be applied. During the assessment of a system on its current level of circularity, mostly material choice, modularity, reliability and cost play an important role. For the outflow, the material should allow for a certain level of circularity, the modularity should be high enough to allow for easy dismantling and the cost of the value retaining steps should not too high, otherwise system will be disposed of.

For the determination of the input and output values of the MCI method, the key indicators identified can be used. For every input, multiple questions can be asked in order to determine the contribution of the input. For the inflow of materials, the key indicator of material choice is the most important. The most important question here is; have non-virgin materials been used, and are these materials reused or recycled materials? The inflow is often controlled by designers and suppliers. Therefore this is where this research can have the most impact. A very important aspect here is good communication with suppliers to get information about used materials, but also to ensure the reuse of non-virgin materials in the future.

The same type of questions can be asked about the utility and end-of-life of the product: Is the product reliable enough to reuse? Is the product built modular so it can be dismantled into different materials? Does the material choice allow for recycling? Since the MCI calculation is based on weight, the mass of the product also needs to be determined, preferably split out all the way to the part level. To acquire all this information, contact with the supplier of the system and its materials needs to be established. If the resource of the materials is unknown, industry averages can be used based on a material database such as Ansys Granta Edupack (Ansys Granta Edupack, 2006).

Based on the circularity calculation, it needs to be verified that a valid need exists to (re)design a system that fulfils the overall goal and mission.

Step 4: Map the System's life cycle and Associated Stakeholders

To know which stakeholders need to be involved in the (re)design process, the life cycle of the system and its associated stakeholders need to be mapped. The first step is to map the life cycle, which encompasses all the necessary steps involved in taking a product in service from its initial idea stage through the various stages of production (including physical transformation and the involvement of different producer services), delivery to end consumers, and ultimate disposal after use (Kaplinsky and Morris, 2000). General example life cycle steps for a vessel are engineering, manufacturing, commissioning, operation and decommissioning. To help guide a designer in mapping the life cycle, Kossiakoff et al. (2011) suggests mapping or modelling at least the following circumstances:

1. storage of the system and/or its components,
2. transportation of the system to its operational site,
3. assembly and readying the system for operation,
4. extended deployment in the field,
5. operation of the system,
6. routine and emergency maintenance,
7. system modification and upgrading, and
8. system disposition.

Once the life cycle has been mapped, stakeholders in each step of the life cycle can be identified. For the mapping of the stakeholders, not every stakeholder is of equal importance. Additionally, often the needs that different stakeholders have are in conflict. Stakeholders can be divided into the direct beneficiary and several indirect beneficiaries (Erikstad, 2018). When looking at stakeholders and their needs with regard to circularity, often an outside incentive is required. Here, the regulations that were mentioned in the theory section can be the main driver. For every stakeholder, a different regulation will be of the appliance. A strategy to reach more circularity within companies is to set goals on company-wide goals that are measured by indicators; Key Performance Indicators (KPIs) (Coalition circular accounting, 2023). These indicators can help stakeholders in guiding them in defining requirements they have with regard to circularity. In case a company does not have KPIs on circularity yet, it is recommended to first draft these before setting needs for a specific system.

Step 5: (Re)design the System by use of the RFLP method, Applying Circularity Principles

The selected RFLP method uses requirements to define functions, which are connected by logic and then put into a physical form. It is essential for every step that the level of detail of the previous step is sufficient to make the next step.

The first step of creating a (re)new(ed) system is to set up the requirements the system has to comply with. These requirements are determined by the stakeholders as identified in Step 4. There are different types of requirements; operational, functional, performance and physical requirements (Kossiakoff et al., 2011). To check requirements, a requirements analysis can be executed. Requirements need to have certain characteristics; they should for example be feasible and verifiable. In addition to the currently common practice of operational and performance requirement defining, circular requirements should be defined. These can be seen as operational, performance and physical requirements. For circular design, there is a higher urge to reach a higher level of detail in the requirements. During "normal" design it might be enough to specify the need for, for example, a pipe with a certain length and diameter. In the case of circular design, it is important to also specify the material the pipe needs to consist of and in which way it should be attached to other parts of the system.

Once the requirements have been identified, the next step in defining the system is to define the functions. A function often consists of a verb and a noun/object (The Mathworks, 2020) and the in and outflow of a function is information, energy and/or material (Hopman, 2021). So it is a task or activity that must be performed to achieve a desired outcome. Functions are mostly the result of operational requirements. Because functions describe an action that needs to be performed, circularity is hard to capture in terms of functions. This means, that the influence of the circular requirements is minimised in this step of the systems engineering because the operational requirements, such as "lift objects and materials" say nothing about circularity.

Once the requirements and functions have become clear, logic comes into place to see where logical connections can be made. However, this is also a step that needs feedback, because in the next step, the physical components will be defined based on requirements and functions. When multiple components can be combined into a logical module, this step needs to be repeated to enable that. Applying logic to the design is something that comes back in the key indicator of modularity; if systems or parts are connected in a certain way, they will be or not be suitable for repair, remanufacturing, recycling, etc. This means that in the phase where the components, which then again consist of parts, are identified, these components need to be connected in a modular way that allows for these actions.

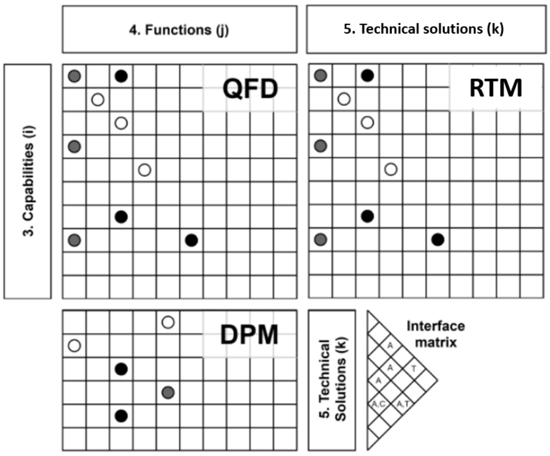
By use of the identified requirements, functions and logical connections, physical elements for the system can be selected. There is no clear step-by-step process on how to do this, but it is an iterative process where the level of detail gets more and more clear with every step. A way to explore the options and make a decision between different possibilities is a morphological chart as presented by Zwicky (1969). The goal of the Morphological chart is to provide a structured approach to concept generation to widen the area of search for solutions to a defined design problem (University of Cambridge, 2016). To visualise this, the functions are listed in the first column, and the possible solutions are listed in the rows.

Every time the requirements, functional and logical structure have been defined, the market or in-house availability of a physical element should be checked that meets the RFL structure. In case it is not available, the RFL structure should be brought to a deeper level of detail. In case there is no further level of detail possible then it should be checked if multiple parts or components can be combined into a logical module. This stresses the need to constantly make the connection between the physical and logical analysis.

Step 6: Validate the (re)design

As a way of checking whether or not the physical (sub-)system fulfils the desired functions, and whether these functions meet the requirements, a validation matrix can be filled in and to check the circular requirements the level of circularity can be measured. The validation is also known as a Product Management Map (PMM) and is shown in Figure 5. The PMM consists of four matrices where requirements are checked to functions (QFD), requirements to physical solutions (RTM), functions to physical solutions (DPM), and one where the interfacial connection is mapped between physical solutions. The colour of the dot indicates the strength of the relationship between the requirements, functions and physical solutions. The darker the dot, the stronger the relationship. After the PMM has been filled out, the designer can see whether the physical solutions match all functions and requirements and if this is not the case, the designer can adjust the design or the requirements/functions.

To see whether or not a system meets the requirements in terms of circularity, the level of circularity needs to be measured throughout the design process and at the end of the design process. This can be done following the same procedure as described in Step 3. However, an advantage is that during the design a good overview of the whole system and its connections is already available. This makes it ”easier” to make the breakdown of systems, sub-systems, components, etc. For this step, it is very important that, in case the circularity was also measured in step 3 an existing system, the same level of detail for the measurement is taken. Otherwise, the comparison is not fair and can result in an unreliable outcome. In case the outcome of the circularity measurement is not sufficient to meet the requirements, the design is not finished and there is a need for a designer to continue making alterations until all requirements are met.



(a) Product Management Map

QFD/DPM	MIM	Score	Symbol
Strong relationship	High impact	9	●
Moderate relationship	Medium impact	3	◍
Weak relationship	Low impact	1	○
No relationship	No impact	0	

(b) Legend of the product management map

Figure 5: The Product Management Map and the meaning of its connections (Kana, 2021)

CASE STUDY

To test the suggested framework, a case study is executed. This case study will focus on the wheelhouse of a vessel. The choice for the vessel and the wheelhouse will be first elaborated upon and after this all steps of the framework will be completed.

Step 1: Identify the goal and overall mission

This goal and mission are often defined by a client that has a need for a (re)new(ed) system or is caused by a change in regulations which makes the existing system obsolete. In this case, Damen Shipyards wishes to create a new design for a wheelhouse. The chosen goal for the system is; To create a space from where the crew can operate and control the complete vessel. The choice for this goal is consistent with the capabilities of a current wheelhouse.

Regarding circularity, the overall mission and goal is to design and build the systems in the most circular way possible whilst following the 10R principles

Figure 6: Visual of the RSD Tug 2513 (Damen Shipyards, 2023)

for a circular economy. This does not mean that the goal is to make a 100% circular product or system, but that the system should be as circular as possible with the current technologies whilst also meeting the general requirements.

Damen Shipyards made a new, graphic design for a wheelhouse of a tug in 2019. Because the design of the ”new” wheelhouse is in line with the design of the current tug boat type RSD Tug 2513, this is the vessel type that will be assessed. It can be concluded that there is a system present on the RSD Tug 2513 that meets the general goal but does not meet the circular goal (scenario 2). Therefore the current wheelhouse will be assessed in Step 2 and 3 of the case study.

Step 2: Identify and breakdown system, sub-system, components, sub-components, and parts

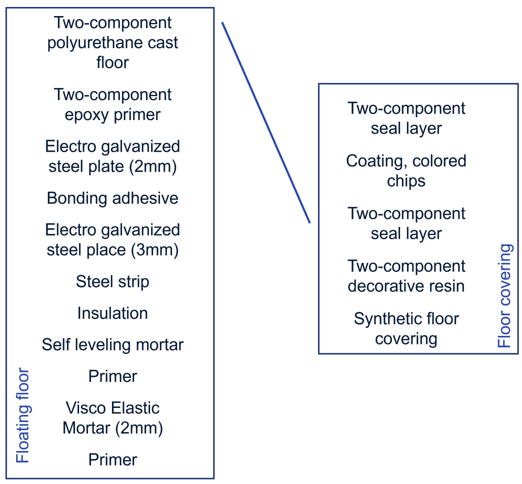
The wheelhouse is seen as the main system here and will consist of sub-systems. These sub-systems are identified by the information available at Damen Shipyards To limit the physical boundaries of the wheelhouse, it has been chosen to view the wheelhouse as everything inside (and including) the superstructure of the wheelhouse until the floor of the bridge deck. it is almost impossible to discuss every component in the wheelhouse and after that every part since there are so many components and parts. Therefore it has been chosen to select five sub-systems and examine them further. The sub-systems' names might sound like they are components or parts but sub-systems consist of multiple components and these components again out of parts.

- The captain's chair
- The consoles
- The windows
- The superstructures
- The floor

As an example, the breakdown of the floor will be shown. Similar steps have been taken to analyse the other four sub-systems. The floor that will be assessed is not the floor presented in the RSD Tug 2513 at this moment, but the floor present in the ASD Tug 2312. This is because the floor in the RSD Tug 2513 is supplied by an ”old” supplier, whilst Damen Shipyards is shifting toward the new supplier for their standardisation of the tug. This new standard is already present on the ASD Tug 2312 and this vessel has dimensions comparable to the RSD Tug 2513, therefore the floor on this vessel will be analysed. All the components and parts are identified and shown in Figure 7a

Sub-system	Components	Parts
Floors	Floating floor	Two-component polyurethane cast floor
		Two-component epoxy primer
		Electro galvanized steel plate (2mm)
		Bonding adhesive
		Electro galvanized steel plate (3mm)
		Steel strip
		Insulation
		Self-levelling mortar
		Primer
		Visco Elastic Mortar (2mm)
		Glue
	Floor covering	Two-component seal layer
		Coating, Coloured chips
		Two-component seal layer
		Two-component decorative resin
		Synthetic floor covering

(a) Breakdown of the components and parts of the sub-system ”Floor”.



(b) Logical and Physical architecture of the floor

Figure 7: The breakdown into components and parts on the sub-system ”Floor”

As can be seen in the breakdown, the floor consists of sixteen layers made from a lot of different materials. The layers are glued together and quite some layers are cast. The floor is made of primers, followed by isolation, covered with steel plates, and on top of that cast floor covering. The physical and logical architecture of the floor are shown in Figure 7b.

Step 3: Determine the current level of circularity of existing design

The circularity level of current sub-systems will be analysed to show the need for a redesign when the circularity level does not meet the requirement. To measure the circularity of the five sub-systems, the weights need to be known, but also information about the key indicators needs to be acquired. To acquire the weight of different sub-systems, the ”weight calculation” of the whole vessel can be used. In the weight calculation, the weights of all systems in the vessel are listed per system code. The system codes are specific for Damen Shipyards and divide the vessel into sections. To gather information about the key indicators, multiple paths have been explored. For the inflow, the most important indicator is the material choice. Information about the material of the components and parts can be often found on the bill of material of the sub-systems. However, the process of figuring out exactly what part of the material inflow which is stated on the bill of material is circular, is very hard. To determine the source of the material that is used in the four different sub-systems, the suppliers of the parts were contacted. Where data about the type of inflow was unavailable, use was made of the material database of Ansys Granta Edupack (2006). The lifetime of the sub-systems that were selected is therefore very likely to be equal to the industry average because they set the industry average. For this reason, it was chosen to not use the calculation of the utility (X) in the calculation of the MCI because the value for the utility will be equal to 1. Because the systems that are analysed are not yet at the end of their lifetime, the outflow is not 100% sure. However, looking at the key indicators we can make an estimation or determine the potential regarding the destiny of the sub-systems at the end of life. For the outflow of materials, no standardised database exists and common practices were researched that will be discussed per sub-system

Finally, the calculated circularity of every sub-system is divided into circular inflow, outflow and the total circularity. The results are shown in Table 1.

Table 1: Results of the circularity assessment of the five sub-systems

	Inflow	**Outflow**	**Total MCI**
The Captain’s chair	64%	94%	79%
The Consoles	19%	100%	59%
The Windows	14%	97%	57%
The Superstructure	35%	93%	67%
The Floor	19%	0%	9.6%

The combined circularity of these systems comes to 60%. This is mostly due to the superstructure’s significant influence caused by its weight. Out of the five sub-systems, the floor has the lowest MCI mostly due to the lack of modularity and material choices in this sub-system. Due to the lack of modularity and the use of glue, the materials are not separable at the end of life, resulting in a circular outflow of zero per cent. Looking at the weight of the five sub-systems that were selected in comparison to the total weight of the vessel, the systems represent a small fraction of 2.62% of the total vessel weight.

It is important to note that the percentages show the potential circularity and not the actual circularity since the systems are still operable and have not been shifted towards the end-of-life phase. Recycling is at this moment the most commonly used method to keep materials in the loop. However, recycling should be a last option when looking at the 10R principles and therefore the application of refurbishment, remanufacturing and repurposing should be considered more often. To do this, companies need to communicate with their supplier to explore the options of taking back products by the suppliers but also contact with other organisations that can help enable these strategies. Because the floor has the lowest MCI score and there is room for improvement, the floor will be worked out in more detail in the next steps. The low circularity of the floor is a result of the lack of non-virgin materials in the inflow and the low modularity, making it hard to separate materials for recycling/reuse/refurbishment at the outflow. Step four will still look at the life cycle of all five systems with an additional focus on the floor, and steps 5 and 6 will only be completed for the floor.

Step 4: Map the system life cycle and associated stakeholders

The life cycle of the five presented sub-systems is different. This is because the chair is designed once and then manufactured many times because it is a universal product made by an "independent" supplier. This is contrary to the superstructure and windows, which are specifically designed for the RSD Tug 2513. The consoles are a bit in between the two since they are also used on other vessels but are still quite specifically designed for vessels built by Damen Shipyards. The floors have a standard design but are tailor-made in size for the application on the RSD Tug 2513. The Damen RSD Tug 2513s are not so-called "one-off" vessels so this means that there will not be a specific design for every new vessel that is requested but will be sold multiple times based on the same design. It can be concluded that the chosen sub-systems can be divided into two categories; Unique products and Multi-user products. A Unique product is identified as a product that is designed specifically for this vessel type and which cannot be used on other vessels, an example being the windows and superstructure. A multi-user product is a product that is usable in multiple vessel types or maybe even other types of systems, an example being the captain's chair and the floor. These two products have different life cycles because the design and manufacturing process is not the same. Multi-user products can be built in stock whilst unique products are built once the product has been sold.

Looking at the current floor, the design process was done in close collaboration with Damen Shipyards' Research and Development department. The most prominent stakeholders in this process were thus the development departments of both the supplier and Damen Shipyards, but also other suppliers of the floor were involved to see what the physical options were that met the requirements. Next to that, a classification was involved with the RSD Tug 2513 design to get the vessel class approved. At this moment, the floor is quite a linear product following the flow that is presented in Figure 8 with associated stakeholders.

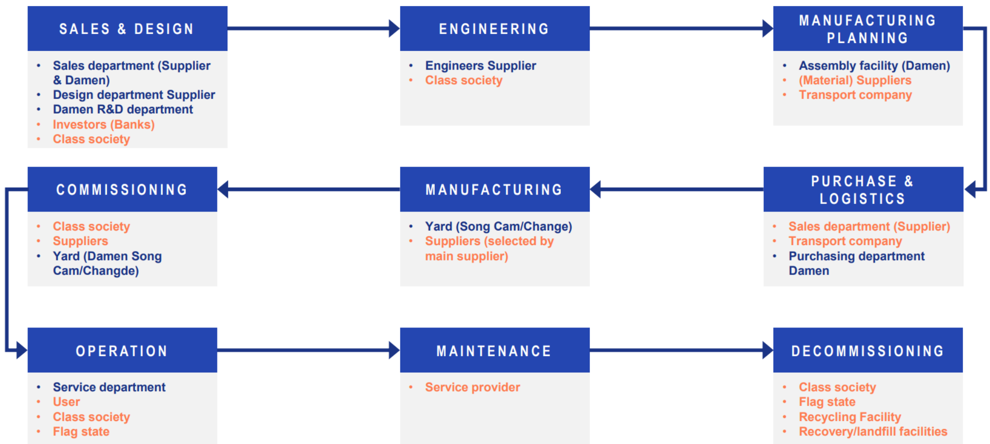


Figure 8: The life cycle and associated stakeholders for the current, linear floor

The figures show the current situation, but to shift to a circular approach, the flows will also have to shift from linear to circular loops. The circular loop is shown in Figure 9. In this shift, the connection needs to be made between the end-of-life stage and the design stage. This connection is not necessarily a material flow connection but needs to be a knowledge connection. Also, other flows start playing a role. Maintenance is extended with repair, refurbishment and remanufacturing and will loop back to the purchasing and logistics. Decommissioning is extended with recycling and will also loop back to purchasing and logistics It is convenient for a client such as Damen Shipyards if the suppliers have a take-back process to repair, refurbish and remanufacture their systems. The role of suppliers in a circular material flow can be way more important than in a linear flow. Ideally, the supplier is willing to take back their supplied system at any time so in case of obsolescence of any kind the system can still come to good use. However, this means that a repair, refurbishment, remanufacturing or even recycling process needs to be set up by the supplier. This supplier might in itself also be dependent on suppliers and so on. This means that to get the re-looping cycles in place a new supply chain needs to be set up where decommissioning parties, suppliers, purchasing and logistics and all circularity-enabling companies play a role.

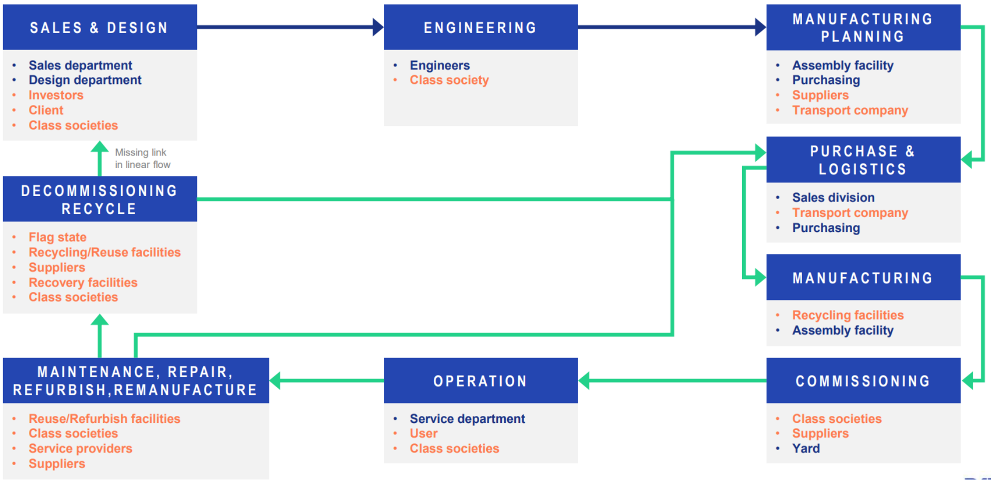


Figure 9: The life cycle and associated stakeholders for a circular floor

Step 5: (Re)design the system by use of the RFLP method, applying circularity principles

With all stakeholders identified, their requirements can be analysed. After that, these requirements translate into functions, these functions into a logical structure and in the end into a physical system. It is important to note that the goal is not to design the best floor technically, but the goal is to test the framework and show ways in which circular design strategies can be used for maritime systems.

During the design phase, there are three main stakeholders having a say: The design department of the supplier, the client (Damen) and class societies. Where the design department has to implement the requirements of the client and class societies. The eventual overview of requirements has been visualised in a breakdown shown in Figure 10.

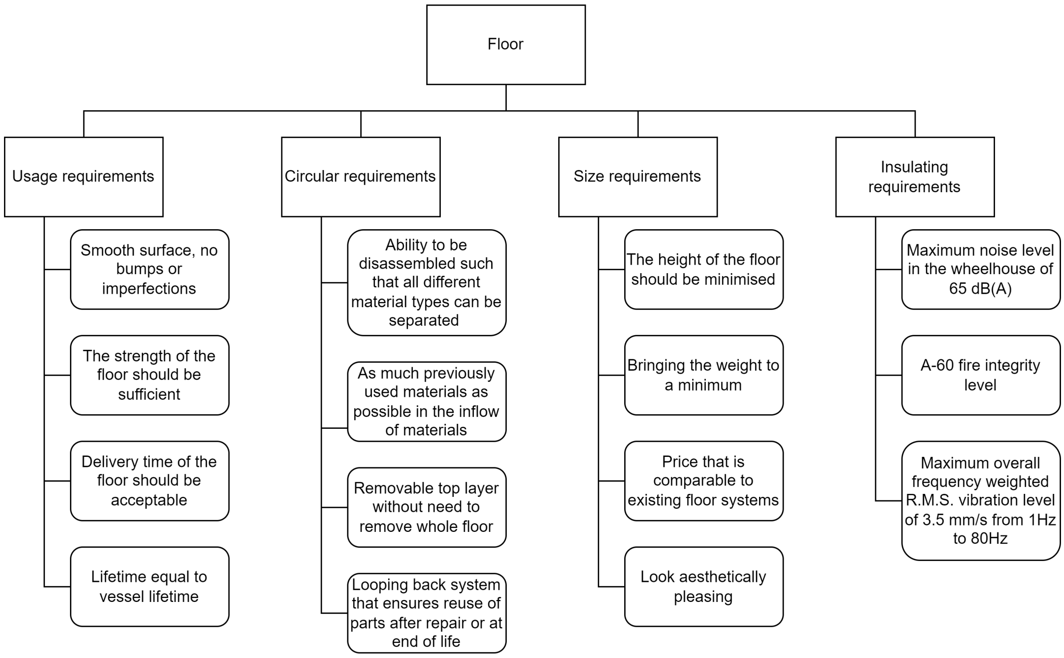


Figure 10: Requirement breakdown structure for the floor in a wheelhouse

The main function of a floor is to be an isolating layer whilst providing a standing surface. The requirements can also be translated into more detailed functions. These functions can again be visualised in a breakdown structure. This is done in Figure 11. It can be concluded that quite some requirements cannot be translated to a function, but are more performance and physical requirements. The circular requirements also can be categorised as this type of requirement and are therefore not translated into functions.

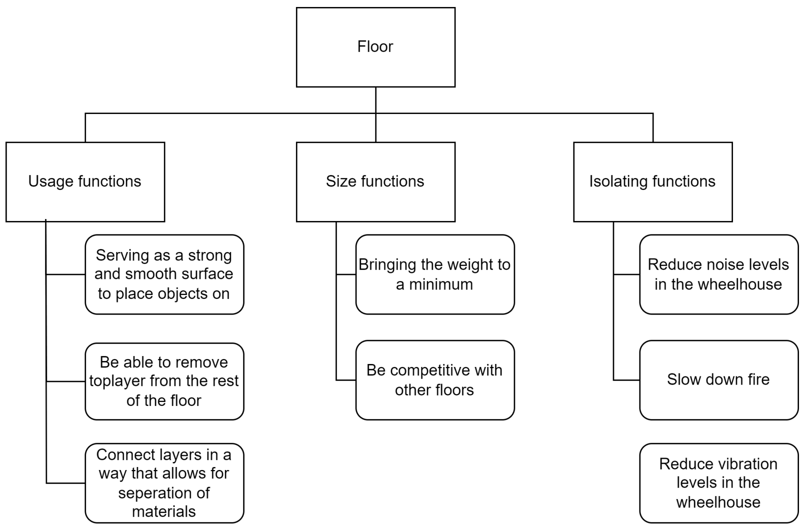


Figure 11: Functions breakdown for the floor

In the logical phase, the focus should be on the composition of the system and the connections between the different components and parts. Common sense plays a role here in making logical connections between parts to combine them into components and in the end combine the components into systems. Some of these connections have already been made by categorising the requirements and functions into different subjects.

To come from the RFL overview to a physical solution, all possible options have to be considered. This is by use of a morphological chart. For the functions, multiple viable solutions have to be researched. This is done by literature research into materials, shapes, forms and other solution types that can fulfil the set functions. A morphological overview of the solutions linked to the functions is shown in Table 2. In the morphological overview, several lines have been drawn that show the best solutions in terms of price, weight, circularity and height. This way, several combinations of options can be explored.

Table 2: Morphological overview of the physical solutions matches with the functions

Function	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6	Solution 7
Smooth surface	Synthetic cast floor	Carpet	Laminate	Steel plates	Vinyl	PVC	Carbon fibre
Removable top layer	Carpet	Laminate	Vinyl	PVC			
Strong surface	Galvanized steel	Carbon fibre	Aluminium	Cement			
Connecting two layers	Primer	Glue	Welding	Bolds and nuts	Magnets	Robe	Staple
Reduction of noise levels	Isover isolation	Visco-elastic mortar	Self leveling mortar	Stonewool	Cement	Steel plates	
Slowing down fire	Steel plates	Fire resistant glass	Concrete	Fire-retardend treated wool	Iron		
Reduction of vibration levels	Stonewool	Isover isolation	Visco-elastic mortar	Cement	Steel plates		

Cheap
Lightweight
Circular

After looking at the circularity of the current floor, it can be concluded that even though the lower four layers of the current floor might not be the most circular option for isolation, they are the best solution in terms of functionality and it is not technically possible to find another, more circular solution that still fulfils all functions. However, the primer can be made with a higher recycled content. The isolating layer will be further complemented with recycled isolation material and two steel plates made of recycled content. On top of the steel, many options are possible and the best option might be to let the client buying the vessel choose the surface as long as it is not a cast floor. For recycling purposes, PVC is the best option preferably in the form of planks that can be clicked together. If preferred, a sub-floor can be added but in terms of noise or vibrations, this should not be necessary. A visual of the redesigned floor is shown in Figure 12. However, to ensure a long lifetime and a good purpose for the materials at the end of the floor's life, agreements need to be made between different stakeholders. Agreements such as the stone wool supplier taking back the wool for recycling or the supplier of the PVC laminate to reuse the laminate again on other vessels.

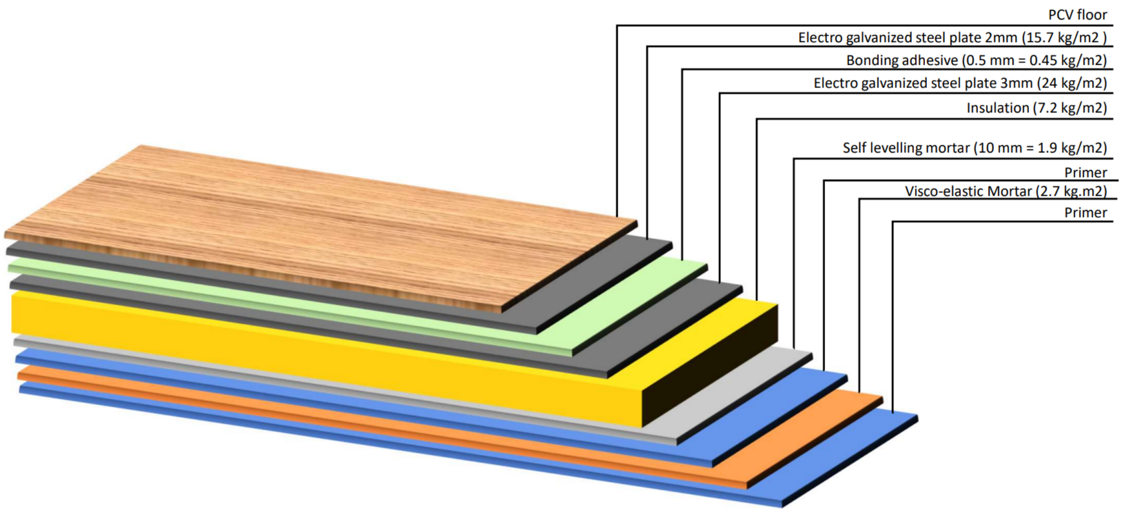


Figure 12: Visual of the redesigned floor

Step 6: Validate the (re)design

As a final step of the framework, the redesign will be tested to the set requirements and functions, but will also be tested on the new circularity level. After this, it can be concluded whether or not the proposed solution is an improvement compared to the existing system.
In Table 3, the PMM is filled out for the redesigned floor. It can be seen that all requirements are matched to functions and the other way around. Additionally, all requirements and functions are translated into physical solutions. Therefore it can be concluded that, in terms of requirements and functions, the redesign is a viable replacement of the current design. However, for some requirements, there is only a weak relationship matched to a function or physical solution. So in case a new design is made, these requirements are where improvements can be made.

To further validate the design, once again, the circularity of the system will be measured. To compare the "old" floor and the redesigned floor, the circularity level of the "old" floor will also be calculated at the same level of detail as the new floor is built up. It can be seen that with the higher level of detail, the circularity of the "old" floor has increased a bit. However, comparing it to the new floor, the redesign shows a way higher circularity outcome. The table with the calculation is shown in Table 4.

The circularity of the floor has gone up from 15% to 90.5%. The biggest difference can be spotted in the outflow of the materials. For the "old" floor, there is no potential to win back materials due to the construction of the floor, but also due to the lack of agreements between stakeholders. For the redesign, all stakeholders will have to be on board to be able to keep the parts and materials in the circular loop. This means that with every supplier, agreements have to be made for taking back materials, or a separate stakeholder needs to be found that will reuse the materials. As an extra in-depth analysis, also alternative scenarios were researched where different requirements were left out.

Table 3: Filled in Product Management Map for the redesigned floor

		Functions								Physical solution			
		Serving as a strong and smooth surface to place objects on	Be able to remove toplayer from the rest of the floor	Connect layers in a way that allows for separation of materials	Bringing the weight to a minimum	Be competitive with other floors	Reduce noise levels in the wheelhouse	Slow down fire	Reduce vibration levels in the wheelhouse	Combination of Primer, VEM and Self leveling mortar	Isolation wool	Steel plates with bonding adhesive	PVC floor covering
Requirements	Smooth surface, no bumps or imperfections	●	○	○			○					◉	●
	The strength of the floor should be sufficient	●	◉		○		○	○	○			●	
	Delivery time of the floor should be acceptable					○				○	○	○	○
	Lifetime equal to vessel lifetime	○	○	○						○	○	○	○
	Ability to be disassembled such that all different material types can be separated		◉	●	○	○	○			○	●	○	●
	As much previously used materials as possible in the inflow of materials				○	○				○	●	◉	●
	Removable top layer without need to remove whole floor	○	●	○		○						◉	●
	Looping back system that ensures reuse of parts after repair or at end of life		○		◉	○					●	◉	◉
	The height of the floor should be minimised				○	○	○	○	○	◉	◉	◉	◉
	Bringing the weight to a minimum				●					◉	○	◉	◉
	Price that is comparable to existing floor systems		○			●				◉	◉	◉	◉
	Look aesthetically pleasing	◉				○				○	○	○	●
	Maximum noise level in the wheelhouse of 65 dB(A)						●		○	●	●	●	
	A-60 fire integrity level							●			◉	●	
	Maximum overall frequency weighted R.M.S. vibration of 3.5 mm/s from 1Hz to 80Hz						◉		●	●	●	●	
Physical solution	Combination of Primer, VEM and Self leveling mortar				○	○	●	○	●				
	Isolation wool		◉	◉	◉	○	●	◉	◉	C,S			
	Steel plates with bonding adhesive	●	●	○	○	○	●	◉	●	S	C,S		
	PVC floor covering	●	●	●	○	◉				S	S	C,S	

The goal was to design three alternatives for the floor by leaving out requirements, compared to the previous sections. Since this research is about increasing circularity, the circular requirements were not left out. Looking at the influence of requirements on the design, it can be concluded that there is a big difference between the influence of the requirements on the design. The requirement to reduce the noise and vibration levels has by far the biggest influence. Since it is a requirement also by class to have a maximum noise and vibration level in the wheelhouse, this is not a requirement that is likely to be dropped, but one that might change with the ongoing developments regarding alternative propulsion options. To increase circularity, it could be seen that giving in on weight and cost can contribute in a positive way.

Next to that, this case study focused only on a few sub-systems in the wheelhouse, whilst when a whole vessel has to be designed, this will be a more time-consuming process, with more stakeholders and more agreements to be made. Also from this point of view, it is important that stakeholders assess their own process on the topic of circularity to make of designing circular vessels possible for the design and shipbuilding companies. Additionally, agreements have to be made with the owner of the vessel to actually use the supplier agreements to keep the materials in the loop.

Table 4: Comparison in MCI level of the ”old” and ”new” floor design

System	Parts	Mass	Inflow		Outflow					MCI	
		Mass [kg]	Virgin	Recycled	Refurbishment	Remanufacturing	Repurposing	Recycling	Recovery	MCI	Total MCI
Redesigned floor	PVC laminate	63,84	0,00%	100,00%	100,00%	0,00%	0,00%	0,00%	0,00%	1	0.905
	Steel plate	125,286	0,00%	100,00%	0,00%	100,00%	0,00%	0,00%	0,00%	1	
	Bonding adhesive	3,591	100,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0,00%	0,5	
	Steel plate	191,52	0,00%	100,00%	0,00%	100,00%	0,00%	0,00%	0,00%	1	
	Insulation	57,456	50,00%	50,00%	0,00%	0,00%	100,00%	0,00%	0,00%	0,75	
	Self leveling mortar	15,162	100,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0,00%	0,5	
	primer	0,1	70,00%	30,00%	0,00%	0,00%	0,00%	100,00%	0,00%	0,65	
	Visco elastic mortar	21,546	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Primer	0,1	70,00%	30,00%	0,00%	0,00%	0,00%	100,00%	0,00%	0,65	
Original floor	Two-component seal layer	1,1172	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	0.149
	Coating, Coloured chips	0,399	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Two-component seal layer	1,1172	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Two-component decorative resin	19,152	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Synthetic floor covering	0,27132	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Two-component polyurethane cast floor	16,758	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Two-component epoxy primer	0,1	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Steel plate	125,286	62,50%	37,50%	0,00%	0,00%	0,00%	0,00%	100,00%	0,1875	
	Bonding adhesive	3,591	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Steel plate	191,52	62,50%	37,50%	0,00%	0,00%	0,00%	0,00%	100,00%	0,1875	
	Steel strip	57,456	62,50%	37,50%	0,00%	0,00%	0,00%	0,00%	100,00%	0,1875	
	Insulation	18,8328	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Self leveling mortar	15,162	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Primer	0,1	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Visco Elastic Mortar	21,546	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	
	Primer	0,1	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100,00%	0	

DISCUSSION

This study has shown that circularity can be implemented in ship design, with relative simple process adjustment. After testing this framework by a case study where the wheelhouse of an RSD Tug 2513 was subjected to the framework, it becaume clear that the framework has multiple limitations:

- The analysis/optimisation only looks at the inflow and outflow of materials in the end product, not at the materials used during the production or dismantling process, nor does it look at recycling efficiencies.
- The MCI calculation is based on weight, whilst hazardous and rare materials should also be considered an essential factor during the design phase.
- It is hard to compare a system’s lifetime and use frequency to industry averages because the systems that are analysed set the average.
- The level of detail of the framework is highly dependent on the information available from suppliers, often resulting in an estimation based on industry averages with general weights.
- The use of industry averages is not a representative way of calculating the circularity level of a product.

Looking at all these limitations, it can be concluded that the provided framework is a concrete step in the right direction but further extensions can be made to solve these limitations. However, to implement the framework several steps are required.

First of all, a universal definition of circularity needs to be set to make sure all stakeholders are on the same page. After this, all stakeholders need to assess their own part of the supply chain in order to map the current status of the systems and set a circular baseline. Starting with the material extraction and ending with the final product going to the recycling facility, or even better, being reused, remanufactured, refurbished or repurposed. After successfully inventorying the current status of the circular economy in the ship design process, KPIs can be set for companies to determine a vision and future goals with regard to circularity. These KPIs can help a company with designing a new system or selecting (new) suppliers. After all this, the framework can be used. Since, in the ideal case, all stakeholders have already mapped their progress in terms of circularity, designers can now optimise their design based on all requirements, functions and logical structures set based on the needs in terms of general and circular demands.

For all this to work, incentives should be there for designers, such as the design department of Damen Shipyards, to start designing vessels with circularity in mind. Incentives can be government regulations and rules, but also clients asking for this. Additionally, the new CSR reporting requirements will help to give a push in the right direction for companies to start thinking about their circularity.

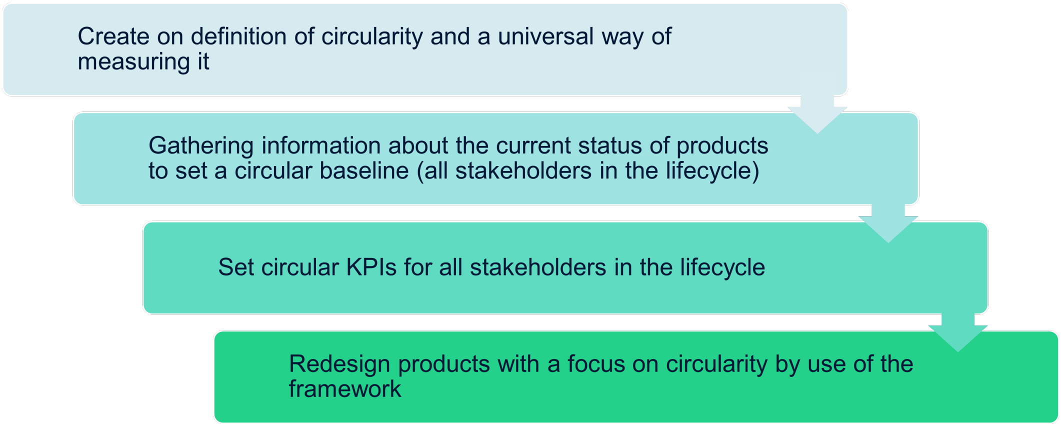


Figure 13: Steps for the implementation of the framework

Additionally, to continue research on the topic of circular ship design, multiple recommendations are formulated:

- When performing an analysis of the environmental impact of a system, often only the CO_2 emissions are taken into account (Heijungs and Suh, 2002). It would be preferable to have a method that performs a life cycle analysis that takes both the "general" environmental impact and the circularity of the system into account. This way, trade-offs can be made between different systems whilst having a complete image of the possibilities.
- At this moment, circularity does not have a value that is expressible in a number. This results in companies having a conservative view towards circularity, often assuming it is more expensive than systems that follow a linear lifetime. Therefore it would be wise to perform a study into the reduction of the environmental impact a fully circular product makes, but also review the reduction or increase of the cost and lead time of a circular product and compare this to a non-circular product.
- The goal of a shipbuilding company such as Damen Shipyards can be to become 100% circular, but the process to get there involves many stakeholders. To start with implementing more circular components in the end product, a start could be to perform research similar to this research at an equipment manufacturer to see the more practical potential and also have the potential to change the business model of this manufacturer towards one where used products are taken back and directly reused in the production process to (re)new(ed) products.

- To help organise the available information on a system with regard to circularity, it would be helpful to set up an (international) system that captures all relevant information in a document (Circularise, 2023). This document could then be used during the lifetime and at the end of the life of a system to see the potential of all materials used in the system. This way, a client will also be able to compare products on their circularity level.

CONCLUSION

To include circularity in the ship design process multiple principles and frameworks were combined. First of all, for the definition and ranking of circularity, the 10R framework was deemed the most appropriate, in combination with the adjusted MCI method for the calculation of the circularity level. With the 10R framework also come 10 design strategies for consumer goods that have been compared to the ship design approach of systems engineering. As a last theoretical step, key indicators were identified that influence the circularity of a system. After all this, the 10R framework for the definition of circularity, the corresponding circular design strategies, the method of systems engineering, and several key indicators were combined into a framework that represents a step-by-step guide on how to design a circular system. The main purpose of the framework is to prove there is a valid need for a (re)new(ed) system and starting at the beginning with the design process is to fully focus on a system's function instead of trying to improve an existing system that might not be the optimal solution for the function it needs to fulfil. To make the framework work, contact with the suppliers is a very important aspect since the information required to fill out the steps has to come from them. Next to that, changes to make products more circular will also require suppliers to change with regard to design and be more involved during the whole life cycle of a system to ensure that materials are kept in the circular loop.

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