DOI – https://doi.org/10.5965/2316796313252024165

SUPPORT METHODOLOGY TO THE INFORMATIONAL AND CONCEPTUAL DESIGN OF SMALL RECREATIONAL POWERBOATS

METODOLOGIA DE SUPORTE AO PROJETO INFORMATIVO E CONCEITUAL DE PEQUENAS LANCHAS RECREATIVAS

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**Este Artigo possui parte adaptada da dissertação de Mestrado de um dos autores, disponível em: https://repositorio.ufsc.br/xmlui/handle/123456789/177592*

Abstract

This article proposes a methodology for the design of motor recreational boats which are a crucial part of the Brazilian nautical industry. Although there is a strong demand for smaller boats, there is a lack of research on design approaches for small leisure vessels in the literature. This has resulted in unexplored areas such as the treatment of design information, requirements engineering, and trade-off conflicts. The proposed methodology aims to systematize the obtaining of design specifications, generation and evaluation of solution concepts, employing design support tools. The methodology was evaluated by applying it on a small recreational motorboat, and the results were positively evaluated by nautical industry and academic specialists, leading to acceptation of the methodology and some suggestions for improvement.

Keywords: product development, small boat design methodology, motorboat design, information design, conceptual design.

Resumo

Este artigo propõe uma metodologia para o projeto de embarcações de recreio a motor que são uma parte crucial da indústria náutica brasileira. Embora exista uma forte procura por barcos mais pequenos, há uma falta de investigação na literatura sobre abordagens de design para pequenas embarcações de lazer. Isto resultou em áreas inexploradas, como o tratamento de informações de projeto, engenharia de requisitos e conflitos de trade-off. A metodologia proposta visa sistematizar a obtenção de especificações de projeto, geração e avaliação de conceitos de soluções, utilizando ferramentas de apoio ao projeto. A metodologia foi avaliada aplicando-a em uma pequena lancha de recreio, e os resultados foram avaliados positivamente pela indústria náutica e por especialistas acadêmicos, levando à aceitação da metodologia e a algumas sugestões de melhoria.

Palavras-chave: desenvolvimento de produto, metodologia de projeto de pequenas embarcações, projeto de lanchas, design de informação, projeto conceitual.

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ISSN: 2316-7963

1 INTRODUÇÃO

Motorized recreational boats can serve a variety of functions and according to the Brazilian Navy, mechanically propelled boats refer to any boat moved by machines or motors [1]. The industry responsible for the manufacture of these boats is called the nautical industry and it offers a wide range of products to customers, varying according to the intended use of the boat. Efficient product development requires a suitable procedure for the systematic application of technical knowledge, combining the development of design with scientific methods to analyze technical systems and their interaction with the environment and users [2]. This method should fulfill multiple requirements, including a focus on problem-solving, fostering innovation and seamless integration with other disciplines.

However, the current methodology followed by the nautical industry is deficient in understanding customer needs and generating concepts in the Informational and Conceptual Design phases. Therefore, the objective of this study is to propose a methodology that meets the requirements put forth by Pahl and Beitz [2], supporting the design of motorized recreational vessels in Brazil.

The article aims to organize literature on boat design methodology and understand practical expert knowledge to identify how boat design occurs. Then, propose a methodology to support boat design in the Informational and Conceptual phases. In the end, evaluate the proposed methodology, highlighting positive aspects and presenting opportunities for improvement. The proposed methodology provides a systematic evaluation and construction of user requirements and project specifications, taking into account the life cycle of vessels, as well as systematizing the process of creating and choosing a solution for the vessel design. Additionally, it should assist in the development of the mindset of industrial product development for the national nautical sector.

In summary, the study is based on Fonseca's (2000) Integrated Product Development Reference Model and proposes a methodology to support the design of recreational motorized vessels that meets the requirements of a suitable product development methodology. The proposal aims to improve the current deficiencies in understanding customer needs and generating concepts in the Informational and Conceptual Design phases, contributing to the development of the nautical sector in Brazil.

The proposed methodology is based on a Master Thesis intituled "Methodology to Support the Informational and Conceptual Design of Small Motor Recreational Boats" developed by André Amâncio de Moraes in 2017 at Federal University of Santa Catarina, Campus Joinville. This Research was coordinate by Professor Cristiano Vasconcellos Ferreira and Thiago Pontin Trancredi.

2 Material and methods

The methodology to be used in the construction of this work is based on Gil's work [3] and is grounded in exploratory research on the topic in order to make it more explicit, assisting the construction of hypotheses. The research design will involve the following procedures: literature review of naval design methodology's, interviews and statements from people with practical experience, case studies, and evaluation application. Therefore, the first part demonstrates the survey of bibliographic research to obtain an overview of publications on yacht design methodologies and present a picture of the generic model of ships development process. The second part will present the consulting with the naval industry. And then the proposed methodology will be explained.

2.1 Literature Review

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was used to conduct a systematic literature review of the relevant literature on yacht design. The following databases were searched: Web of Science, Scopus, and Engineering Village. Also, the search was limited to articles published in English between 2010 and 2021. A total of 63 articles were included in the review.

The literature review showed that there is not a significant amount of scientific production regarding the topic of ”methodology for designing recreational boats”. When there are articles, it focuses on optimizing engineering systems, subsystems, and components of these vessels, leaving the development process aspect open.

The literature review also indicates that the methodology for recreational boat design is mainly based on the design knowledge applied to larger vessels (ships, tugboats, i.e), which do not share the same scope. In the contrast, for ship design there is a large content of publications.

Ship design has historically been seen as an artistic activity, where the naval designer’s experience and intuition were key factors. However, with the advancement of computational technologies, heuristic approaches have been replaced by empirical and parametric methods. The International Marine Design Conference seeks to organize ship design to address the needs of the ship’s life cycle, which includes construction, operation, demolition, and recycling. The design process can be organized in various ways, depending on the required expertise, people involved, and activities delivered in each phase. This segmented structure enables efficient project management and allows for continuous phase adjustments, resembling the conventional product development approach.

Papanikolaou [4] , Taggart [5], and Lamb [6] divided the ship development process into: Conceptual Design, Preliminary Design, Contract Design, Detailed Design. The authors agree that the Conceptual Design stage is the first phase of the ship design process. The main objective is to study the shipowner’s requirements, such as the mission, performance attributes, and cost variables. Next, the development of concepts that satisfy these requirements is pursued. Elaboration of these concepts is achieved through several cycles of synthesis and analysis, resulting in a set of performance requirements, hull dimensions, weight estimates, and stability study, among others. During the Preliminary Design stage, the ship concept generated in the previous phase is validated and expanded. Main systems of the vessel are selected, and the performance of the ship is quantified. Additionally, a refined estimate of acquisition and operation costs, construction process, and strategies are carried out. The product of this stage should include specifications of performance, hull lines, arrangement, structure, weight report, machine and propulsion arrangements, speed, and power curves.

In the Contractual Project phase, the product acceptance objectives of the previous phases are defined under capacity and cost criteria. Production packages for shipyards responsible for building the ship and a range of criteria for evaluating the acceptance of the design process by contractors are developed. The ship undergoes refinement based on trade-offs identified. In this phase, studies are conducted for ship system performance requirements, and concept alternatives are developed and evaluated. Finally, the Detailed Design, is where the entire structure, specifications, construction, and onboard equipment of the ship are detailed.

However, the development of recreational boats should not follow the same design methodology as other types of boats, as they have different functions, subsystems, and variables. That is why the importance of these article and the proposed methodology.

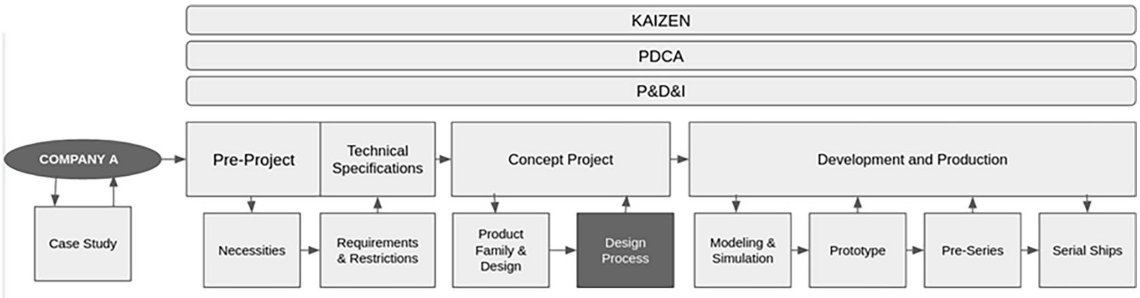
2.2 Interview Knowledge

Consulting with experts is crucial to investigate the development of recreational boats in the nautical industry. Therefore, 60 companies that produce motorized recreational boats for domestic and international markets were contacted, all located in Brazil. It became evident that most companies out- source their product development process, relying on project offices. Thus, among the companies that design boats, only two were willing to participate in the interview. Company A, a large luxury boat producer presents in three countries with over 300 employees. The interview was conducted with a quality specialist who has been dedicated to the company for over ten years. Company B is a micro enterprise that serves the design demands of shipyards in their region and the interviewee has over 20 years of experience in nautical projects and also owns a factory where they produce conceptual models.

According to the interview results, Company A's design process follows the stages of Pre-Design, Preliminary Technical Specification, Conceptual Design, and Detailing of Production, as depicted in Figure 1. Moreover, their design process is based on a PDP model that focuses on their internal manufacturing process. As a result, during the product design stage, they explore concepts that align with their family of boats.

The company determines the course of a project by determining what it refers to as "essential prerequisites.", a set of characteristics that the boat must have inherited from previous production lines that will be discontinued. However, these same requirements are redefined based on the information gathered throughout the boat's life cycle. Since the design team is always in contact with production, they follow the philosophy of continuous improvement. Therefore, the information generated during the production of the prototypes, or the boats, is reiterated in the boat's design from the engineering development phase, which is analogous to the Preliminary Design phase of the reference methodology. Further, the most mentioned information pertains to time and costs, with an emphasis on the concept of time to market. For the company, meeting time demands is crucial due to the race against the competition, whose processes are continuously streamlined to add speed and quality to their products. Also the interviewee refers to "must have" requirements, which directly reflect fundamental user needs and expectations, and reflect the status and characteristics of the luxury boating market.

Figure 1- Design Process Company A.

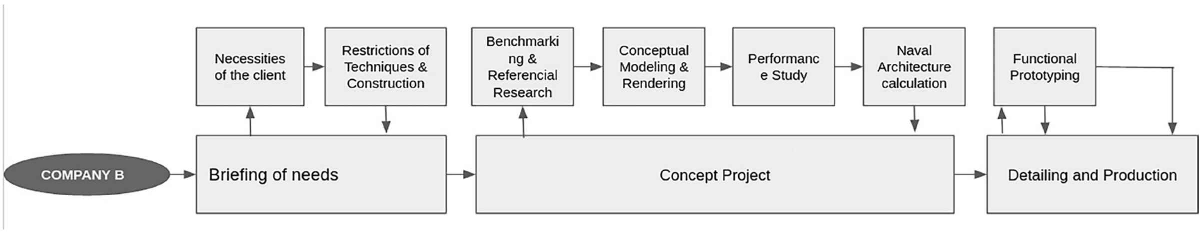


Source: Autor (2023).

These pieces of information are mapped out by the figure of the project leader. In this company's organizational structure, this person is responsible and has sufficient powers to manage schedules, manage projects, make scope changes, and explore pre-project processes, which focus on obtaining preliminary technical specifications. This leads to the construction of pre-series, or the first boats called registrations 1, 2, 3, etc., as a form of prototyping: functional prototypes to be tested, corrected, and taken to the market.

In the other way, Company B, organizes the development process of boats in a less systematic way, but following a linear flow of information. Due to the development of customized projects and projects for aesthetics, as a differential factor in its culture, the company sells projects on demand. Project management and development are assigned to the same person, which, according to the interviewee, is a common practice among its competitors. In Figure 2 of the company's EDT, the model of a project-based company is evident, with a Needs Briefing phase, its Conceptual Project, and finally, the Detailing for Production.

Figure 2- Design Process Company B.



Source: Autor (2023).

In addressing customer needs, the interviewee states that there is no particular tool or method, however, argues that there is an unstructured interview process between him and his client where primarily the attributes of aesthetics and usability are discussed, such as personal preferences, proportionality, autonomy, and cost. His procedure after collecting this information is to study and ground his new project in requirements, very similar to the language attributed to the expression of user requirements in the reference methodology, such as "strong, durable", "easy to produce", "practical", "safe", etc. Then, he formats a document containing sufficient information, called a briefing of needs. This document feeds into the process category of this company, which adds to its response the use of various project support methods, such as developing sketches and it applies common naval architecture techniques through a process represented by the Spiral of Design. Additionally, it was highlighted that functional prototypes developed using computer tools and manufactured despite being a small-scale company.

In summary, both companies have a formal design process with a need for multidisciplinary knowledge and a focus on continuous improvement. Documentation is crucial for developing better solutions based on the product's life cycle, and both companies have databases to record needs, suggestions, statistics, and failures. It's possible to conclude that for the two companies the development process of recreational boats has three stages, with market research, design, modeling, and simulation, prototyping, and other stages linked in the project's value stream.

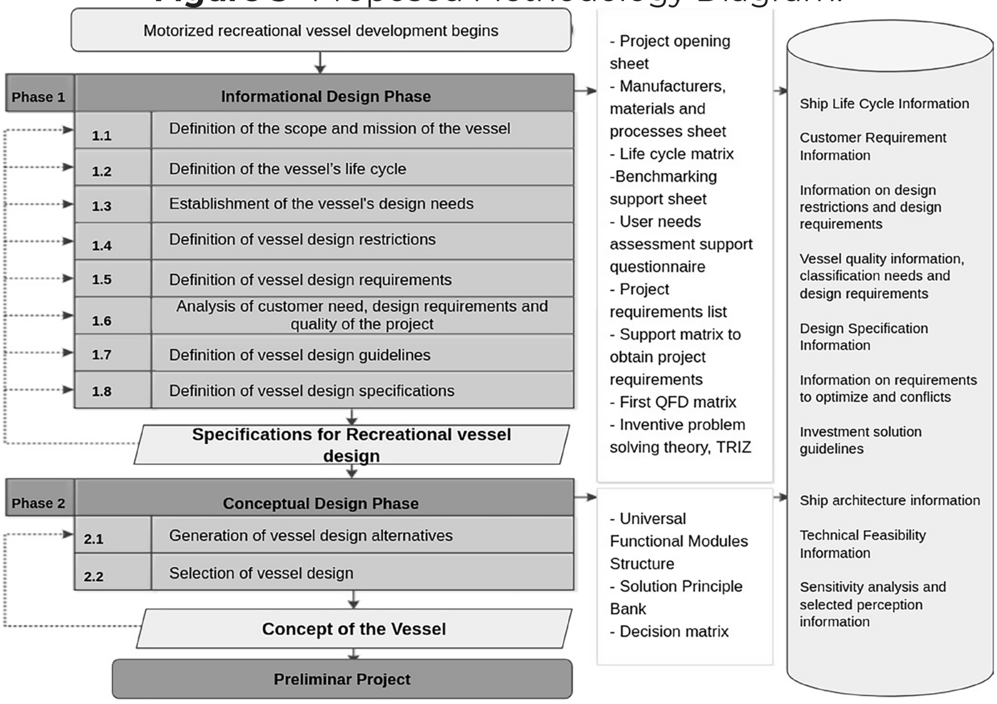
2.3 Proposed Methodology

This subsection will propose the methodology, focused on the design of recreational motorboats with an emphasis on the informational design and conceptual design phases, based on the literature review and the mapping of the company's knowledge. Figure 3 shows a diagram of the proposed methodology, and it is composed of two phases: the first with eight stages about the informational design and the second of two-stage concerning the Conceptual design.

The first step of the information design phase is defining the scope and mission of the vessel. This is achieved by determining some basic information related to the product scope. To carry out this first Stage 1.1, three tasks are proposed:

- Task 1.1.1: Identify the end users of the vessel and other direct customers of the project.
- Task 1.1.2: Define the scope and/or mission of the vessel, its primary characteristics, and estimate its primary dimensions.
- requirements. The form also includes a list of basic project requirements for vessel design, such as the housing project, navigation area, vessel autonomy, and safety. Each of these project requirements can be classified according to an order of preference by the end user, and limit values can be added, corresponding to a preview of values for the design specifications.
- Task 1.1.3: Identify potential manufacturers, processes, and materials. The information collected in this task should be part of the list of vessel design constraints.

Figure 3- Proposed Methodology Diagram.



Source: Autor (2023).

The Definition of the vessel's life cycle, stage 1.2, has two proposed tasks:

- Task 1.2.1: Determine the phases of the life cycle of the vessel to be designed. The project team should review the information provided in the specific stages of the recreational vessel life cycle and indicate whether they are applicable to the vessel being designed. The project team should consider adding any relevant stages to the vessel design, considering the input of their clients.
- Task 1.2.2: Identifying the clients for each chosen stage. Once the stages have been identified, the internal, external, and final clients for each stage should be identified. This group of clients constitutes the knowledge involved in the vessel's development. The final clients will be the users of the vessel.

The next Stage 1.3, Establishment of the vessel's design needs, involves identifying the needs of the vessel's clients through the application of a questionnaire in the form of an interview with both direct and indirect clients. The questionnaire can be found in Appendix A. It presents the basic life cycle and specific attributes of the vessel, which have been broken down into different questions. The answers should be stored along with the attributes that originated the questions, which are presented in the first column of the questionnaire.

Following, for the Definition of vessel design restrictions (1.4) is suggest establishing restrictions of: normative, legal, ergonomic, manufacturing, materials and components. Normative restrictions include international design standards that must be followed to ensure the product is approved for commercialization, based on safety and function criteria. Legal restrictions refer to the compliance with national laws and regulations, such as environmental laws or military standards. Ergonomic restrictions consider the physical and physiological characteristics of the users, which can vary depending on their nationality. Manufacturing restrictions are related to the manufacturing process and limitations, such as the geometry of the vessel. Material restrictions are related to the cohesiveness of aquatic environments, and component restrictions consider factors such as geometry, weight, and susceptibility to corrosion. These restrictions must be carefully considered during the design process to ensure that the vessel is safe, functional, and compliant with regulations. Therefore, Stage 1.4 will have for tasks:

- Task 1.4.1: Gather information on regulatory, legal, and ergonomic requirements for ships from relevant institutions and organizations.
- Task 1.4.2: Identify the characteristics and properties of manufacturing processes, materials, and components through collaboration with suppliers and manufacturers.
- Task 1.4.3: Define restrictions associated with the manufacturing process, materials, and costs based on user requirements, as identified in the manufacturing, materials, and process data sheets.
- Task 1.4.4: Define restrictions associated with the region of navigation, markets, norms, and laws.

Definition of vessel design requirements (Stage 1.5) is composed by system characteristics that determine physical parameters such as dimensions, mass, energy, volume, density, and other related factors. These requirements reflect the attributes of the vessel to be designed, guiding its development and the decisions of the design team. Stage 1.5, use information from Stage 1.4 as input to be processed by the design team to generate design requirements. So the design team must associate the clients' needs with one or more design requirements, and if necessary, add new design requirements.

In the Stage 1.6 a series of analyses are carried out in relation to customer needs and project requirements, seeking a better understanding of the project. To do so, the stage is divided in 10 tasks and the Quality Function Deployment (QFD) methodology is proposed, which is traditionally represented by the House of Quality matrix. This matrix enables the project team to systematically develop the interrelationships between customer needs and project requirements, identify conflicts between project requirements, and design the desired quality for the vessel, based on the analysis of competing vessels. The tasks are describe bellow.

- Task 1.6.1: Determine the degree of importance of customer needs, which is the first input parameter of the first matrix in the QFD. This is accomplished using Analytical Hierarchy Process (AHP). The evaluation is used to assign points to user requirements, and lower scoring or less important requirements can be excluded from the design process.
- Task 1.6.2: Identifying similar vessels to the one being designed by gathering relevant information such as dimensions, power, number of cabins and bathrooms, materials, and manufacturing processes.
- Task 1.6.3: Compare similar boats based on customer needs and analyzing which needs are strong selling points. This analysis is done using the House of Quality.
- Task 1.6.4: Use the information gathered in task 1.6.2 and customer needs to plan the quality of the boat.

- Task 1.6.5: Develop the body of the House of Quality by relating customer needs to project requirements and assigning strength of relationship factors. These factors are rated on a scale of 1 until 5 and represent the strength of the relationship between customer needs and project requirements.
- Task 1.6.6: Identify correlations between project requirements using the QFD Correlation Matrix, so, the team can understand which requirements may interfere with or hinder the completion of the project. Positive correlations indicate that developing one requirement will have a positive effect on another, while negative correlations indicate that developing one requirement will have a negative effect on another. The team should pay special attention to strongly negative correlations as addressing these requirements properly can lead to a bigger impact project outcomes.
- Task 1.6.7: Identify the most important project requirements. The importance of each requirement can be calculated by analyzing the degree of correlation between user requirements and project requirements, as well as the degree of correlation between project requirements using the QFD Correlation Matrix. This information is used to compute the importance index for each project requirement.
- Task 1.6.8: Identify project requirements to be optimized, along with their conflicting requirements. The team should remove negatively correlated project requirements from the QFD Correlation Matrix and analyze each pair of conflicting requirements. The requirement with the highest importance index should be classified as the one to be optimized, while the other is classified as the conflicting requirement.
- Task 1.6.9: Plan the quality of the designed vessel based on project requirements. The team should evaluate the desired quality by considering the project requirements correlated to customer needs.
- Task 1.6.10: Determine the factors that make implementing project requirements difficult. These factors will act as guidance criteria for later stages of vessel development, where specific technologies and decisions may be prioritized based on the difficulty factors obtained in this task.

It has been demonstrated by Evans [8] and corroborated by Lamb [6], Mistree [9] (1990), Glowacki [7] and Nazarov [10] that the design of vessels is not the optimization of individual components to form a whole. On the contrary, optimizing individual components without considering their impact on the entire vessel can lead to adverse effects. To address these conflicts or contradictions the concept of design guidelines is introduced. Guidelines are expressed as strategies, design rules, and solution principles. That's why for the Stage 1.7 (Definition of vessel design guidelines), we suggest employing the Theory of Inventive Problem Solving (TRIZ) and there are three tasks:

- Task 1.7.1: Associating optimized and conflicting design requirements to engineering parameters: With the optimized and conflicting design requirements evaluated in task 1.6.8, we proceed to associate them with engineering parameters. This method is based on identifying and associating the design requirements, to be optimized and conflicting. The proposed mode of association is through similarity: the design team must interpret these requirements and verify their understanding based on the parameters provided by the TRIZ.

- Task 1.7.2: Identify inventive principles by inputting optimized and conflicting engineering parameters into the Contradiction Matrix of the TRIZ. The resulting numerical list of inventive principles should be observed throughout the project.
- Task 1.7.3: the team will use the results obtained in Task 1.7.2 as inspiration to develop potential solutions for the specific domain of the vessel's design.

In Stage 1.8, the definition of the vessel design specifications is determined as the final outcome of the transformation process of customer needs. These specifications establish what is necessary, verifiable, and achievable for the vessel design project. Thus, to assist the execution of this activity it is proposed to fill in the Vessel Design Specifications Chart.

- Task 1.8.1: Based on the information gathered so far, the design team must organize the design requirements, describe their desired and undesired outputs, according to their experience and other available sources of information.
- Task 1.8.2. With the information gathered throughout the project, the design team must set goals for each design requirement, based on the outputs from task 1.8.1.

Finally, the Conceptual Design Phase will be placed and the general shapes of the vessel, the conceptual layout, and the previously defined subsystems will be outputs. As mention in the Figure 3, the Stage 2.1 is the generation of vessel design alternatives and it intent to explore the creativity of the design team in proposing alternatives that can solve the design problem of the vessel, based on the design specifications obtained in the informational design phase. It has five tasks:

- Task 2.1.1: To begin with, concept development can be based on a selection of possible functions or modules, identified by common boundaries in the architecture of existing products in the market. To define the necessary functional modules to solve the project problem, the team must select the desired functions and highlight them, as well as the paths between the global function (recreational motor vessel) and the partial functions. At the end of this task, the project team will have a scheme of the vessel concept ready to receive appropriate solution principles. To organize the process of generating concept alternatives, is proposed to use the Morphological Matrix tool [11].
- Task 2.1.2: Generate principles solution for the identified functions.
- Task 2.1.3: Generate concept alternatives for the boat. As each solution principle presented is a solution for a specific subsystem of the boat, they must be combined and grouped together to build a solution alternative for the boat. To construct this grouping, the procedure is to choose, for each line of the Morphological Matrix, a solution principle among those listed in Task 2.1.2. Once a solution principle is chosen, move on to the next line and so on, obtaining combinations of solution principles and, as a result, concept alternatives.
- Task 2.1.4: Generate sketches of the boat's style. The design process of recreational boats and other products of appreciation is closely linked to aesthetics.

The task proposes the creation of manual drawings or sketching to explore the concepts generated in task 2.1.3. The participation of trained professionals in industrial design, with a focus on product, capable of identifying trends in aesthetics, form, function, and ergonomics among the Human Factors, is ideal for this activity. To apply these concepts to the boat's design, a quick and cheap visual exploration is required before the concepts are modeled a crucial but slow and expensive activity.

- Task 2.1.5: Generate presentation of exterior and interior concept alternatives. So, rendering is the next step after drawing and aims to communicate ideas with more rigor and clarity. For Enry [12], drawing or sketching aims at quick exploration of ideas in profusion, free in space, gravity, or context, while rendering grounds and contextualizes the object-concept aiming at greater clarity: it also brings gains in fidelity and realism in a composition of light, shadow, and environment.

The next stage, known as Stage 2.2, involves selecting a vessel design. This stage requires choosing the concept alternative that best aligns with the design requirements determined from the design specifications, out of all the options developed throughout the previous product development process. This task is concern to review the project needs and specifications so that they can reflect the project objectives in a satisfactory manner, so the stage is divided in two steps:

- Task 2.2.1: Treatment of the generated solutions. To carry out the screening of the concepts generated so far, the project requirements from step 1.8 should be arranged in the Decision Matrix, followed respectively by their importance obtained in step 1.6 and the concepts generated in task 2.1.3 and visually and ergonomically developed in
- tasks 2.1.4 and 2.1.5, each with a characteristic designation that distinguishes them from the others. In this comparative method, it is important to emphasize that the selection is based on a reference product, which can be the most promising product resulting from the analysis of similar vessels by tasks 1.6.3 and 1.6.4 in field 3 of the QFD matrix. Each concept is characterized in this decision matrix, at the intersection of project requirements and comparison with the reference, with three possible values: (+), the positive sign indicates that the concept is better than the reference for that criterion; (0), the numeral zero indicates that the concept is equivalent to the reference for that criterion; and the negative sign (-) indicates that the concept is worse than the reference for that criterion. Therefore, the judgment of the participants will be exposed by the sum of each (+) and (-) value, in addition to the overall result of this sum.
- Task 2.2.2: Select the concept alternative. The evaluated concepts will have an indicative degree of their position among themselves. However, this positioning should not define the definitive concept, except when the values of each alternative are very close. These indices should be compared and validated through an analysis by the project team and thus choose the most viable alternative to proceed with the project [11].

The phases, stages and tools presented aimed at organizing the Informational and Conceptual Design of recreational vessels in order to obtain the design specifications and a promising solution concept that, despite containing a level of abstraction, defines the general line of the project being economically and technically suitable.

3 Methodology Application

The objective is to develop the Informational and Conceptual Projects for a small recreational motorized vessel commonly found in rivers, lakes, estuaries, and sheltered bays. These vessels are preferred by emerging classes as an entry point into the nautical world due to their economy, ergonomics, navigability, and aesthetic appeal. Therefore, the proposed methodology was applied on a small motorized recreational vessel to be constructed with fiberglass with epoxy resin and a round of development for the Informational and Conceptual Projects was carry out.

In the informational phase step 1.1, the project opening form identified client data, product scope and some basic design requirements: maximum and cruising speeds, autonomy, number of passengers and crew, external dimensions, estimated cost and navigation region. With this information, the vessel's life cycle was defined in step 1.2. The clients included manufacturing experts, dealers, maritime inspection agents, and potential users. These clients expressed their needs through the questionnaire, step 1.3, and the client value comfort, appearance, aesthetics, power, and costs were identified as the needs. From regulatory, legal, and ergonomic information, as well as manufacturing, processes, and materials information and the constraints was gathered, step 1.4. Subsequently, step 1.5 involved obtaining the design requirements for the recreational motor vessel, Table 1.

The Quality Function Deployment (QFD) method was applied, step 1.6, and three vessels in the same product category were identified. These vessels were evaluated in relation to customer needs with benchmarking and the performance results of competitors served as a basis for the desired quality design. of the vessel. The information resulting from step 1.6 assists in formulating design guidelines using TRIZ in step 1.7. With this tool and the optimizing design requirements, guidelines for the project were proposed. Then, the identification of desired and undesired outputs, as well as the acceptable range of specifications, is carried out in step 1.8.

Table 1- Design Requirements.

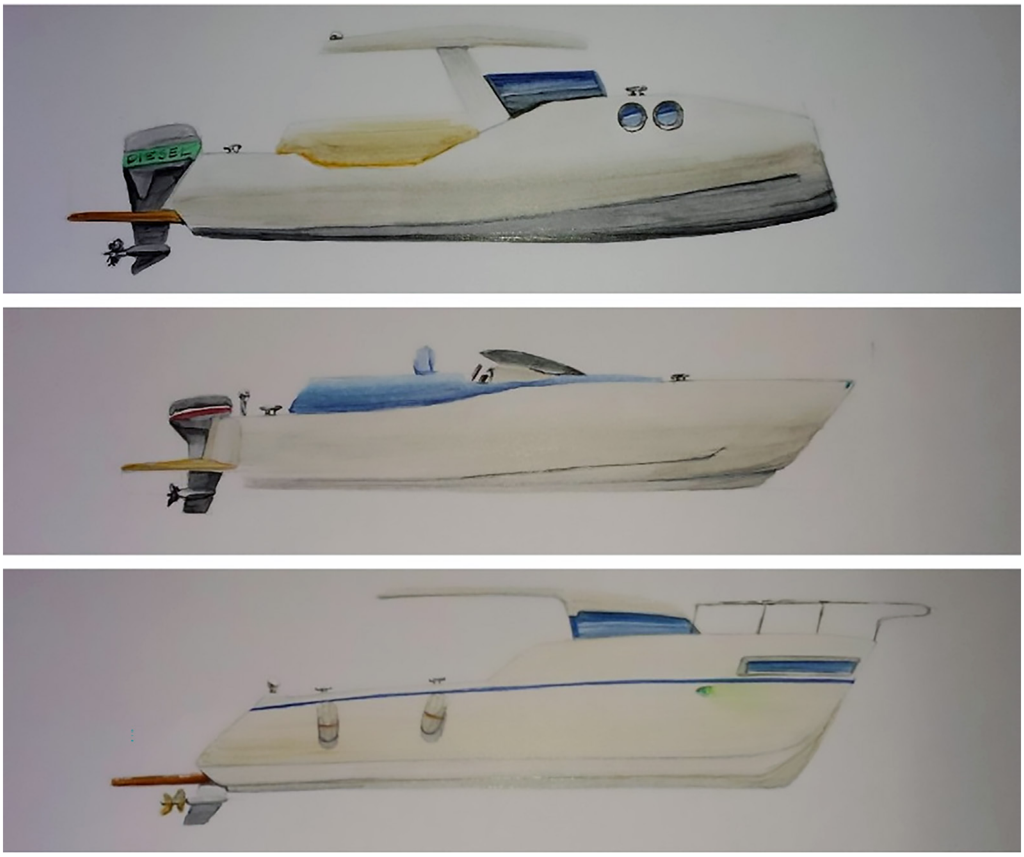
Project Requirements		
Draught (m)	Cruising speed (knots)	Maximum speed (knots)
Length (m)	Vertical acceleration (m/s²)	Number of crew members
Width (m)	Range (nm)	Number of Standard met
Height (m)	General noise level (dB)	Number of boats produced
Freeboard height (m)	Structural vibration level (mm/s)	Manufacturing cost (R$)
Max. wave height (m)	Electric power (KW)	Volume of potable water (l)
Displacement (Kg)	Number of passengers	Hull lifespan (year)
Command post height (m)	Block coefficient	
Second of visibility from the control station (o)	Prismatic coefficient	

Source: Autor (2023).

The conceptual project phase is carry out, beginning with step 2.1, the generation of concept alternatives for the vessel, where the design team identified the functional modules from the functional structure. These modules describe the users needs and the projected quality from step 1.6, interpreted by the design team to generate a proposed functional architecture of the vessel, its spaces, and its systems. Therefore, the vessel will consist of the highlighted modules: ”command post, bathroom, and cabin” comprising the Interior; ”stern platform” for the Superstructure; ”hull sides, bottom, bow, and stern” as necessary and essential elements of the Hull; ”GPS, depth sounder, radio, and compass” as elements of the Navigational system; ”rudder” for Steering; ”engine, transmission, and propeller” forming the Power train; ”battery” for the Electrical System; ”lighting and firefighting equipment” for Safety and Lifesaving; and ”lighting and entertainment” for Comfort. Therefore, these modules will be addressed by specific solution principles to be chosen in task 2.1.2. By organizing these modules in the first column of the morphological matrix, solution principles can be derived for each row of the matrix. This way, the design team was able to evaluate the combination of these elements according to the overall function of the vessel, as well as the characteristics that each element contributes to the overall design. The result of these combinations is three concept alternatives for vessels, which will be studied using sketching and rendering techniques proposed in tasks 2.1.4 and 2.1.5. Alternative A comprises a V-hull architecture, inverted bow, inverted stern, cabin, bathroom with toilet and sink, central command, external diesel engine, twin propellers, battery pack, LED lighting, fire extinguishers, and sound system. Alternative B is built on a catamaran hull with a standard bow, straight stern, no cabin, bathroom with toilet and sink, side command, Powertrain with an external four stroke gasoline engine, twin propellers, battery pack, regular lighting, fire extinguisher, LED lighting, and sound system. The last alternative, C, consists of a cathedral type hull, standard bow, inverted stern, cabin, complete bathroom (toilet, sink, and shower), side command, center stern drive powertrain with surface propellers, battery pack, LED lighting and spotlights, fire extinguisher, and sound system.

Sketches and renderings were developed for each alternative, as shown in Figure 4. These visuals are part of the selection process in step 2.2, the Selection of the Vessel Concept, as they provide visual appeal and facilitate communication of ideas to project clients. In ship concept selection, denoted by step 2.2, concept alternatives were screened and evaluated for their technological feasibility.

Figure 4- Sketches and renderings.



Source: Autor (2023).

The ranking analysis demonstrated that the vessel named Concept B achieved the best results and will be taken forward to the next stages of development: Preliminary Design and Detailed Design. In these stages, the general arrangement, element layout, and vessel architecture are carefully observed and defined. With this information, the sizing analysis, stability assessment, determination of required power, and sheer determination are carried out through iterative processes, represented by the Design Spiral and other processes not described in this dissertation. It is also emphasized the importance of considering decision criteria, evaluated by the project team and based on project specifications, for these more advanced stages of design.

4 Results and Discussion

The next step was to evaluate the proposed methodology and diagnose its potential for use in the design of motorized recreational boats, as well as to identify opportunities for improvement. The evaluation is based on the guidelines for composing a project methodology presented by Rozenfeld [13] and Back [11]. Two groups of evaluators will be involved in the process and be expose to an evaluation questionnaire that contains a series of questions in order to obtain a qualitative analysis of both groups. The evaluation is based on eight guidelines, as can see in Table 2.

Table 2- Systematic evaluation criteria and questions.

No	Guideline	Evaluation Question
1	Proposition tools	Does the system propose tools for project execution ?
2	Definition of project information	Does the system contribute to the understanding of the project problem by presenting the scope, mission and needs ?
3	Proposed evaluation of desired quality	Does the proposed methodology assist in the development of the desired quality ?
4	Proposition of information registration	Does the proposed methodology offer means and tools capable of registering information during the execution of the project ?
5	Guidance for the contribuition of resources	Does the structure of stages and tasks guide the distribution of resources, i.e. does it assist in its distribution ?
6	Reduction in the number of iterations of the project spiral	Does the proposed methodology, through its results: a boat concept, help in reducing the number of iterations needed to develop the preliminary and detailed design of the boat ?

Source: Autor (2023).

Regarding the evaluation criteria for the proposed methodology as a design process, the following criteria were considered: Applicability, Representation (graphical clarity, rigor of presentation), and Content (completeness, robustness, reusability, and efficiency). The evaluation was carried out inside the university by a project team composed of advanced phase undergraduate students in naval engineering and members of a nautical design company, (a naval engineer and an industrial designer) totaling four members. In addition, five external evaluators who responded to the guidelines and criteria questionnaire were included. The evaluation results are presented below.

The first guideline is the Proposition of Tools that aims to evaluate the presence of tools that assist designers in the project execution. In addition, it identifies the perception of users of the proposed methodology for its use in the suggested phases and stages. The evaluation showed that those who had deep contact with the proposal, evaluated it favorably. However, the external evaluators identified that the methodology does not provide tools for the informational and conceptual project of the vessel. Nevertheless, these evaluators did not specify which tools could be appropriate for the proposal. The second guideline aims to assess the understanding of the design problem, that is, whether there is a complete comprehension of what is intended to be designed and achieved as a final result. In this guideline, the evaluation was unanimous. Both internal and external evaluators agree that, given the way the methodology is organized, the stages that aim at informational understanding return enough information for the construction of scope specifications, mission, and customer needs for the vessel.

The Proposed Target Quality Assessment is if the methodology assists in determining the desired quality, that is, if it aids in producing an adequate and feasible interpretation of a quality state to be achieved in the vessel design. The results showed a parity relationship between both the internal and external evaluations. Although some evaluations showed satisfaction with the methodology proposals, a smaller proportion still believes that there is room for improvement in this regard.

In the fourth guideline, the evaluation repeated the variation of the previous one. The purpose of this guideline is to verify the methodology's ability to retain and manage the information generated during the informational and conceptual design phases of the vessel. The representation of both internal and external evaluations can be interpreted as a reflection of the proposition of tools, as they hold the role of producing and storing information, often in the form of tables and visual diagrams, such as the first QFD matrix. However, it is suggested that these tools do not always explicitly provide a field for summarizing the information obtained, such as the product of the customer needs assessment questionnaire, which can be presented in the form of a list.

The next guideline, Resource Input Orientation, refers to the number of people and time made available for the execution of the phase, stage, and task, respectively. In this guideline, there was unanimity and can be interpreted that the very disposition in a hierarchical, systematized structure contributes to the allocation of teams and time according to the level of maturity of the manager and their subordinate team, thus contributing to the generation of schedules for each project, based on planning of distinct products.

Finally, the last guideline, Reduction of Iterations in the Project Spiral, seeks to understand the impact of the proposed methodology on the reduction of the number of iterations in the traditional representation of the Project Spiral for the development and detailing of the vessel. According to the evaluations, there may be a reduction in the number of these iterations. That is, there is an indication that the product of the conceptual design phase is already mature enough to eliminate, according to Taggart's [5] representation of the Project Spiral, the exploration phase of a vessel concept, thus reducing the iterations responsible for this stage. And, more deeply, iterations responsible for determining the nature of components, or possible solutions, for the systems of these vessels, which are already determined in the concept generation phase.

The results regarding the evaluation criteria are presented. To begin with the Applicability of the Proposed Methodology, that is an extension of the evaluation of the applicability of the methodology in the business and academic environment. As a result, the internal evaluation, being predominantly composed of naval engineering academics, believes that it can be applied, but it would not fully reflect their needs, while external evaluators already see the proposal as a project support tool that would meet their needs, with more evaluations in a "total" character and fewer in a partial character, denoted by the response "very".

The Graphic Clarity criterion aims to evaluate the methodology itself based on its representative scheme in phases, stages, and tasks, as well as how input and output information is organized, sequenced, and interconnected. However, this criterion presents a global dispersion among the evaluators, with the average concentration in the "very" category. This may indicate a characteristic of heterogeneity among the evaluators, with those less experienced in the design process being more demanding regarding the characteristics of this type of development in a more concise and relevant scheme, as represented in the responses of the internal evaluators. However, external evaluation exposes a mirrored image of this distribution, indicating that the representative scheme fits their demands, is clear, intuitive, and user friendly.

In the Presentation Rigor criterion, there is a complementing of the previous evaluation to observe if there is redundancy between the phases, stages, and tasks. The evaluation identified that the methodology presents them objectively. Both internal and external evaluations.

The content criteria Completeness aims to discuss the constitution of the methodology regarding its gathering of information, denoted by the completeness sub-criterion. The objective is to evaluate the extent of the necessary information to carry out the informational and conceptual design of motor recreational vessels, the theme of the methodology. Observing Figure 49, it can be noted that the internal evaluation, due to their deeper contact with the methodology, demonstrates that this criterion reaches a lower level. That is, for them, not all the necessary information would have been contemplated for the informational and conceptual design of these vessels. The external evaluation, on the other hand, believes that the methodology meets the criterion, concentrating its evaluation on ”very,” with some evaluators believing that the proposal is complete according to the ”completely” alternative.

Following the idea of the content criterion for Robustness and Re-usability, the evaluation continues to verify the versatility of the methodology, pointing out its structural robustness and re-usability for the design of other vessels, such as sailboats, service vessels, inflatables, etc. In this criterion, external evaluation approves the versatility of the structure and sees that it can be adapted to the design of other types of vessels. The characteristics that may suggest adaptation for the design of sailboats, still within the scope of recreational vessels. The internal evaluation still presents skepticism about the possibility of transforming stages aimed at the design of these other products but agrees to some extent with the external evaluation.

Finally, the evaluation of the content criterion for Efficiency. That is, the objective is to evaluate the economy of resources and time for project development. Thus, the resources used are of an intellectual nature, encompassing the capacity of people, while the time resource characterizes the duration of tasks. Internally, low efficiency is evaluated, which can be interpreted as a lack of previous training in its use since it was applied step-by-step concomitantly with its explanation, which required project team preparation time for its understanding. The external evaluation, suggesting a connection between the structuring and the ease of resource allocation previously evaluated by guidelines and criteria, characterizes an efficiency that can contribute to the economy of human resources and time.

Therefore, the application demonstrated the execution of the Informational and Conceptual Project of a recreational motor vessel of approximately 22 feet. The methodology was able to obtain necessary information to address the design problem around its recreational use for short duration outings for families and groups of up to 10 passengers, considering the needs of user clients and other clients in the product’s life cycle.

With the use of tools, there was a tendency for innovative contributions from the project team members and other stakeholders, given the leverage in generating needs supported by the observation of combinations of product attributes and its life cycle. The representation of these needs as organized design requirements facilitated tracking attribute by attribute. In addition, the QFD method, together with benchmarking of similar vessels and the use of TRIZ, contributed to generating solutions from competitors and other areas of knowledge.

From a personal evaluation standpoint, the methodology was able to contribute to the organization of project tasks, guiding their execution towards members with more relevant skills for the task scope, thus leveraging their stronger competencies. In this sense, both quality and time, as well as other human and material resources, and costs, benefited.

Finally, it is understood that the methodology assists in the treatment of project information and in the generation and selection of conceptual alternatives but does not enter the domains of detailed dimension. However, the proposal helps to expand the range of possibilities for concepts and combinations of systems, subsystems, and components to take on the task of selecting forms, equipment, and installations of advanced stages of the project, which can focus directly on specific sizing for a particular solution of a functional module, whether it is an off-the-shelf system, such as commercial propulsion solutions, or forms such as hull shape and interior layout.

Conclusions

The article proposed a methodology for supporting the informational and conceptual design of recreational boats in line with the integrated product design reference model. The methodology drew upon various naval design approaches and experts' tacit knowledge to develop requirements and alternative boat design concepts. The article highlighted the importance of information quality and processes inherent in recreational boat design and discussed a formalized design and production process suitable for large demands and high quality standards. The representation method demonstrates a continuous stage of the design information acquisition process, with limited opportunities for iteration. In this way, the design information can be studied in specific stages that, over the course of the exercise, increase the degree of understanding of the design problem: the vessel and its specifications. The same can be said for the conceptual design, in which the study stages are subverted into stages of creativity, in which the concept is constructed on a broad basis that is sequentially refined.

The methodology was applied step by step, task by task, leading to conclusions regarding organization, tools, and human aspects. Regarding organization, representation, and sequencing, the logic and intuitive aspect were observed, although understood by trained project personnel. While the logic was intuitive, the use of tools required more attention due to the explanations required. Therefore, formal study and application may require some prior knowledge of project methodology. Common points were found among the project team, as the knowledge of project methodology was present to a greater or lesser extent, but very similar. Thus, the results contribute to the consolidation of an integrated product development process for the nautical environment.

Based on the findings of this articles, several potential avenues for future research and development are proposed:

- Further refinement and expansion of the Modular Functional Structure presented herein.
- Investigation of opportunities for enhancing the organization and relationships between various systems and subsystems.
- Creation of a comprehensive platform for the integration of design principles, featuring a user-friendly interface that offers accessible information on a variety of solutions, including their typical uses, benefits, drawbacks, suppliers, prices, and competitive advantages.
- Exploration of ways to enhance the aesthetic, semantic, and stylistic properties of recreational boats.
- Development of both Preliminary and Detailed Designs for small recreational boats.
- Creation of specialized software to optimize the proposed design process and the management of the resulting data.

Finally, the methodology proposed in this article is intended to integrate elements of the work of Lobach [16], Murari [15] and Baxter [14], as demonstrated by an analysis of their respective works.

In the context of Baxter [14], the objective is to evaluate consumer desires, novelty, the highest-quality products, compatible prices, differentiation, competitive advantages, simplicity of manufacture, and new materials, among other factors. The proposed methodology, similar to Baxter [14], aims to achieve a compromise by addressing a variety of interests in relation to cost and value.

In the case of Löbach [15], the author's vision is to organize a product development process to achieve a mission, which is the pursuit of a solution to a problem. This is accomplished by collecting information about the issue, developing solutions, and evaluating them in accordance with established criteria to ultimately develop the most suitable solution. The model is structured into activities and aims to resolve the issue through a sequence of actions, as Munari [15] suggests.

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Appendix A. QUESTIONNAIRE USER NEEDS ASSESSMENT

Operation - What is the main function of the vessel? What are the secondary functions of the vessel? What are the esteem functions associated with the vessel?

Ergonomic - How are the interactions between man and vessel? What spaces are needed? What needs can be met by Universal Design? What are the functions of these spaces? What are the tolerance levels of passengers? What about the crew? How are the conditions of use of the vessel? What are the climate control needs? What are the ventilation needs? What are the lighting requirements?

Aesthetic - How is the vessel identified? What is the message to be conveyed? What are the style identification marks of the vessel? What are the finishing aspects of the vessel?

Safety - What are the environmental conditions of use of the vessel? What are the preventive safety needs? What type of navigation region? What are the internal and external influencing factors on safety?

Reliability - What are the estimated failure rates for the vessel components? Are there behavioral histories?

Legal - Are there any legal aspects that should be considered in the design of the vessel? Are there environmental laws that must be respected in the design of the vessel?

Normalization - Should the vessel design follow the recommendations of any technical standards? What technical standards are used to test the vessel?

Modularity - Should the product be designed considering the design philosophy for modularity? How is the connection with other components and the system realized?

Environmental Impact - What are the material characteristics of the components in relation to environmental impact?

Economic - How much is the user willing to pay for the vessel? What costs are incurred in the manufacturing process? What additional costs are involved in assembling the product?

Navigability - What is the vessel's mission? What responses are expected from the vessel when in motion? What are the wind conditions, region and sea state? What is the most damaging combination? What are the limits to the vessel's response? Movements, acceleration experienced by crew and passengers? What are the comfort criteria? What is the expectation of seasickness rates?

Manufacturability - Which regions may present manufacturing difficulties? What technical documentation is required to manufacture the vessel?

Assemblability - What are the assembly operations of the components in the systems and how can it influence the design of the vessel? How can the project be conducted in a way that does not use these tools?

Transportability - What is the weight/volume of the vessel? Are there any weight/volume limitations? Can bad weather during transportation influence the prop- erties of the product? Painting, deformations...

Launchability - What are the launching requirements of the vessel? What restrictions exist for launching the vessel?

Testability - What tests should, or will, be carried out? What classifications, standards and laws must the vessel meet?

Storability - What area is needed to store the vessel?

Procurement - How will the vessel be identified by the end user? What resources are available to publicize the vessel? Where will the vessels be marketed? What guarantees should the vessel have?

Usability - Are there draught restrictions in the navigation regions? Are there mouth restrictions in the navigation region? Are there any vessel command restrictions? What level of training is required? What are the main movements of the vessel performed when in use?

Maintainability - What are the conditions associated with the maintenance of the vessel? What maintenance is frequently carried out? What is the average maintenance period?

Recyclability - What are the indications of obsolescence of the vessel? What operations are required to dismantle the systems? What is the desired degree of recyclability of the vessel? What will be the destination of non-recyclable materials? How will the recyclable/non-recyclable material of the com- ponent be identified?

Disposability - What are the end-of-life indicators for the vessel? What will be the destination of recyclable/non-recyclable material? How will these materials be packaged? What legislation will be respected in this activity?