Development of a modular product family for the mechanization of mussel farming and processing in Santa Catarina

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Abstract: In the last decade, Brazil has seen accelerated growth in commercial mussel farming in the state of Santa Catarina. However, similar technological and industrial development has not accompanied this evolution, and the processes used are still highly dependent on human labor. In order to solve this problem, this study proposes a product family design for the mechanization of the main processes performed during mussel farming and processing. To achieve this, a design methodology of modular products was used to create nine main modules, which, when combined, allow for the production of eight different products.
Key Words: Product Design; Design Methodology; Mussel Farming.

1. Introduction

The origin of mussel farming is attributed to Patrick Walton, the only survivor of an Irish shipwreck on the French coast in 1235 (CAMACHO and CASASBELLAS, 1991; NEIRA et al., 1990). With the purpose of catching marine birds to eat, the sailor placed some sticks with a net stretched overtop along the beach, and after a while, he saw that little mussels ended up covering the sticks. Since then, the farming of this type of mollusk on sticks became common all over the French coast. However, it was not until the middle of the 19th century that mussel farming started to have significant importance not only in France but also in some other European countries such as Holland and Italy.

In Brazil, mussel farming started in the state of Santa Catarina in the end of the 1980s (LCMM, 2000). Non-industrial fishermen who were not happy with extractive fishing were trained in farming techniques. Since then, there has been an increase in the number of producers in mussel farming as well as a proportional development in mussel production, which quickly made Santa Catarina the main producer in Brazil. Today, Santa Catarina is responsible for the production of over 10,000 metric tons of mussels (data from EPAGRI), which places Brazil as one of the twenty largest producers in the world (FAO, 2000).

Perna Perna, a species native to the Brazilian shore, was chosen for farming. Like many other mollusks, this species eats by filtering water, and phytoplankton is the main component of its diet. After a larval planktonic stage, the animals fix themselves on the substrata – either natural or not – through filaments called Byssus, a protainaceous substance secreted by a group of glands in the interior of the animals' feet, which polymerize themselves when in contact with a product of phenol glands and sea water itself (FERREIRA and MAGALHÃES, 1997).

The mussel farming process in Santa Catarina begins with the collection of these animals while they are still young – around 3cm long –, and their subsequent placement in tubular frames. This process in Santa Catarina is based on a modification of a system used in France in which a pair of tube-shaped nets are used – one made of cotton and the other made of nylon –, inside which the mussels are placed together with a rope made of nylon that better supports the system. After being placed in tubular frames the mussels are placed in long-lines, which are fixed structures near the beach, where they remain for about six to nine months, time enough for them to reach their commercial length of 7.5cm.

When the fattening period is completed, the mussels are collected from the sea and processed by the mussel growers themselves and then sent to the processing units in order to be cooked, packed and frozen, and prepared to be sold. It has been noticed that there is a heavy dependence on manual labor in performing processes during the entire mussel production cycle. In this sense, as indicated by 76% of producers in Santa Catarina (ROSA, 1997), the lack of mechanization of mussel farming and processing is one of the main problems for this industry in Santa Catarina, and its immediate development is essential so that this industry can attain international standards.

2. Project Overview

The design of equipment for the mechanization of mussel farming processes in Santa Catarina was developed at NeDIP (*Núcleo de Desenvolvimento Integrado de Produtos – Product Integrated Development Division*), a laboratory at the Mechanical Engineering Department of Universidade Federal de Santa Catarina dedicated to the study, application and improvement of the product development process. In order to achieve this, a methodological approach oriented towards the conception of a product family as a modular system was adopted. This measure would reduce the total cost of the product family through the development of interchangeable parts, so that by substituting only some components we would obtain different configurations of products that would perform different functions.

A methodology was developed with the purpose of achieving the highest degree of modularity possible between different products, regardless of the existing similarities between their functional or physical structures (SCALICE, 2001). This was done by investigating the state-of-the-art developing process of existing modular products, techniques, and tools (ERIXON, 1996; PAHL and BEITZ, 1996; ISHII and EUBANKS, 1995; GU and SOSALE, 1997; MARSHAL, 1997; HUANG and KUSIAK, 1998), and also by investigating other elements which involve this design modality such as interfaces (HILLSTRÖN, 1994), advantages and disadvantages (PHAL and BEITZ, 1996; ISHII et al., 1995; ULRISH and TUNG, 1991), types of modularity (ULRISH and TUNG, 1991; ULRISH, 1995) and those aspects related to the industrial impact of product standardization (KIM and CHHAJED, 1999; NAGARUR and AZEEM, 1999; PERERA et al., 1999).

This proposal, outlined in Figure 1, is divided into four different phases, just like the methodology proposed by PAHL and BEITZ (1996), which correspond to different levels of product detail: textual descriptions and information, a better defined concept, product dimensioning and documentation for product manufacturing. During this process, the greatest number possible of information and design alternatives is sought and evaluated within the initial phases in order to reduce the uncertainties deriving from the development of a new product.

PHASE 1	INFORMATIONAL DESIGN OF THE MODULAR SYSTEM	
	Task 1.1	Establishment of preliminary portfolio of products
	Task 1.2	Search and analysis of customer needs
	Task 1.3	Clarify the task
PHASE 2	CONCEPTUAL DESIGN OF THE MODULAR SYSTEM	
	Task 2.1	Establishment of modular function structures
	Task 2.2	Search for working principles
	Task 2.3	Concept variants establishment and selection
	Task 2.4	Module generation
	Task 2.5	Interfaces design
PHASE 3	EMBODYMENT DESIGN OF THE MODULAR SYSTEM	
PHASE 4	DETAIL DESIGN OF THE MODULAR SYSTEM	

Figure 1: Overview of the methodology for modular product family design.

The results obtained from the application of this proposal for product design in mussel farming in Santa Catarina are presented in the following sections. Subsequently, the results from the evaluation of both the designed product prototypes and the benefits from such a design are presented.

2.1 Phase 1 – Informational Design of the Modular System

According to the methodology adopted, the first step in the informational design phase is the selection of the product family that will be used in the design. In order to achieve this, a survey of all the procedures usually employed by mussel growers in Santa Catarina was carried out, and these procedures were then evaluated according to their technical feasibility for mechanization and for the market. The result of this survey is shown in Figure 2, which organizes the processes developed by the mussel growers in Santa Catarina as a flow chart. These processes were divided into three large phases: (1) seed manipulation, performed until the placement of the mussel stockings in the fattening systems;

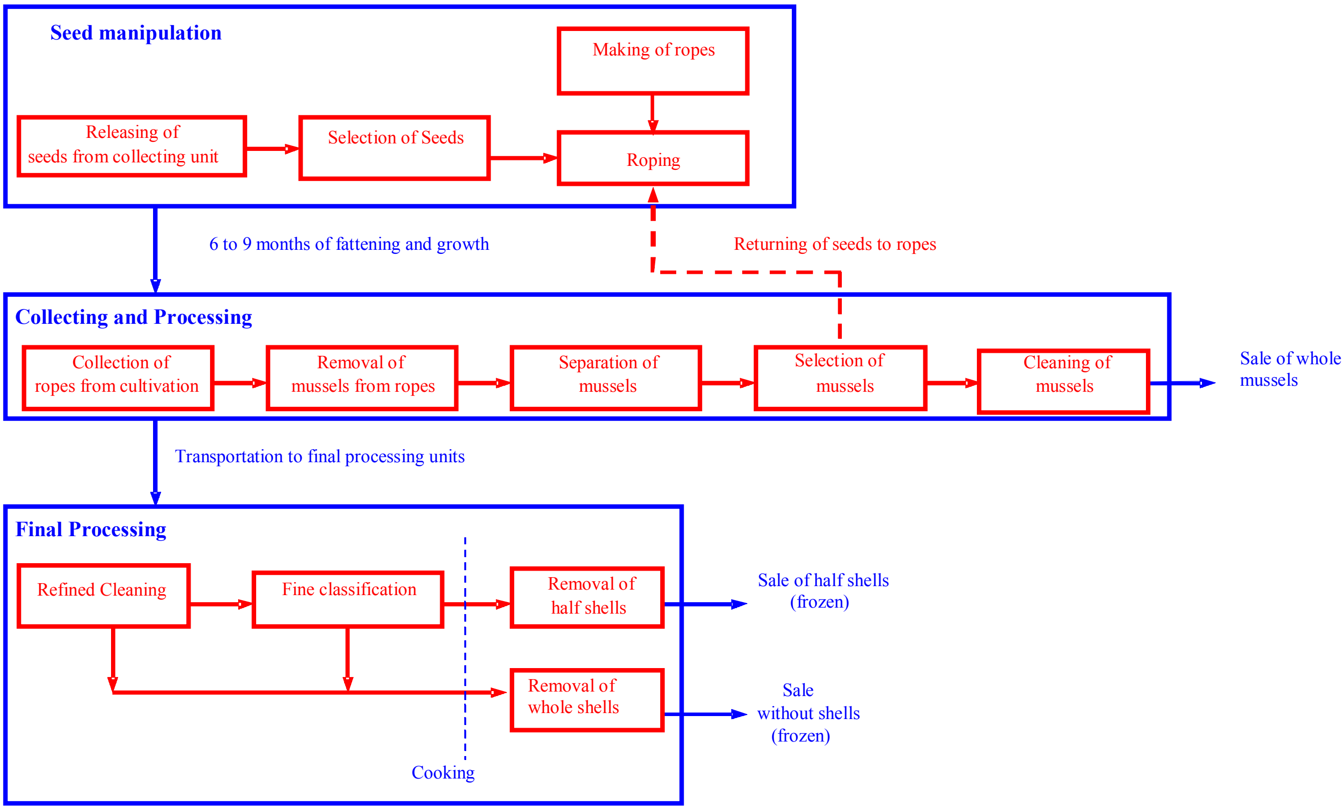

Figure 2: Flowchart of the processes usually practiced by mussel farming in Santa Catarina.

(2) collecting and processing, performed after the fattening period is finished; and (3) final processing, which usually takes place in final processing units.

Eight out of the thirteen processes studied were considered relevant for immediate mechanization. They are:

♦ *Placement in Ropes (or in bags)* – Consists of filling up the fattening systems with mussel seeds according to the placement method used.

♦ *Collection of the Farming Ropes* – Consists of the collection of mussels at sea after the fattening period is finished. It can be done either manually or with the help of cranes.

♦ *Removal of Mussels from Ropes* – The manual removal of mussels from the surface of the ropes used for fattening.

♦ *Separation of Mussels* – Besides getting attached to the ropes, the mussels also become attached to each other, and individually separating them is necessary. In Santa Catarina, this process is performed manually.

♦ *Selection of Mussels* – The separation of the seeds that become fixed to the mussel ropes during the fattening period with the further aim of homogenizing the size of the mussels to be sold. The separated seeds are then used for making new ropes (process called Returning of seeds to ropes).

♦ *Cleaning of Mussels* – The removal of mud, animal life and detritus from the mussels accumulated during the fattening period. In Santa Catarina, this process is done by scraping barnacles from the shell, using either a salt water bath or a pressurized fresh water bath. When the mussels are at the processing units, cleaning is performed by brushing the shell under running water.

♦ *Refined Cleaning* – The final and deepest cleaning process that works to achieve a polished appearance of the shell of mussels that will be sold whole.

♦ *Shell Removal* – After mussels are cooked, their meat must be removed from the shell. In Santa Catarina, this process is done manually by pulling the meat out of the shell, even when performed on an industrial scale.

After defining the product family of interest for the design, the next step is the Needs Survey. In this step, the design clients' needs are investigated with the use of market research techniques (MATTAR, 1999). Among the results obtained, the ones that stood out the most were those directly related to the product price, a fact that is deeply connected to the socioeconomic conditions of the producers.

Following this sequence during the step called the Needs Clarification, the House of Quality tool of QFD (Quality Function Deployment) was used in order to obtain the design requirements to be met during the product design. In this step, three aspects were considered most important for this analysis: the motor power to be employed, the process efficiency, and the production capacity obtained with the equipment. After being analyzed, the design requirements were quantified in a way that a list of design specifications could be created. Such a list served as the basis for all other decisions made during the product development process.

2.2 Phase 2 – Conceptual Design of the modular system

The process of the conceptual design of the modular system began with the step called Determining the Modular Functional Structures of future equipment, using a tool called Modular Functional Synthesis. This tool is divided into three different steps:

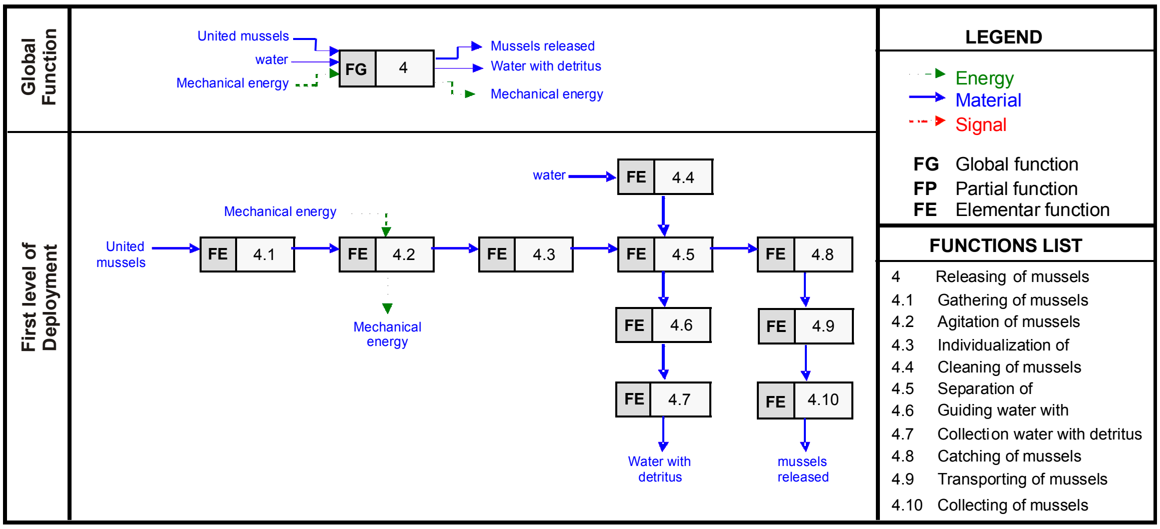

Figure 3: Functional synthesis for the process of mussel separation.

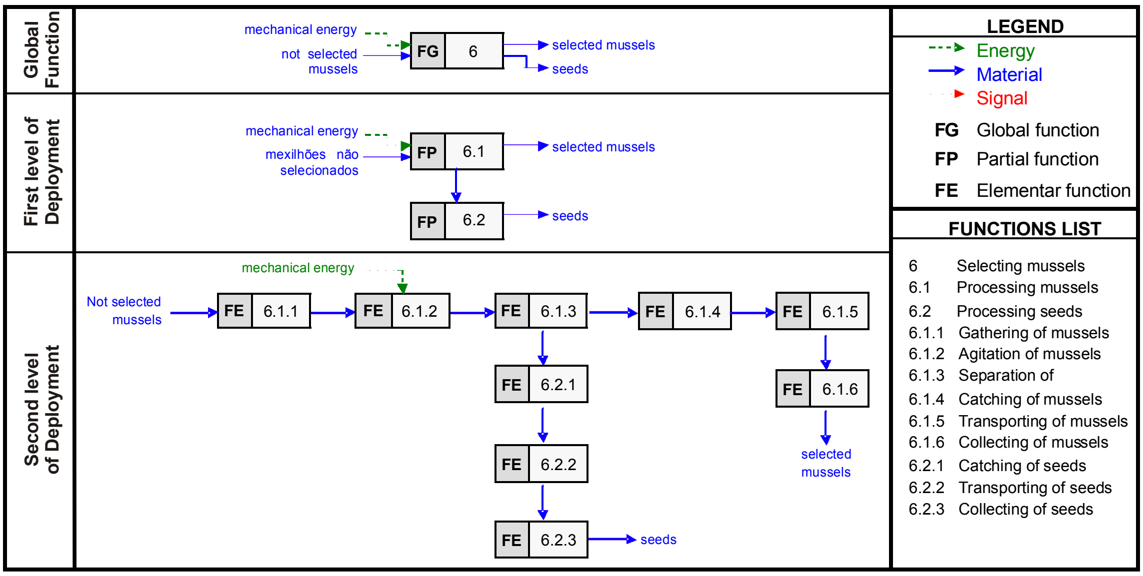

Figure 4: Functional synthesis for the process of mussel selection.

		COMMON FUNCTIONS									
		FC-01	FC-02	FC-03	FC-04	FC-05	FC-06	FC-07	FC-08	FC-09	FC-10
GLOBAL FUNCTIONS (processes)	FG-1	O	O		O	O					
	FG-2										
	FG-3				O	X					
	FG-4	X	X	X	X	X	X	X	X	X	X
	FG-5	X	X	X	X	X	X	X	X	X	
	FG-6	X	X	X O	X O	X O					
	FG-7	X	X	X	X	X	X	X	X	X	
	FG-8	X	X	X O	O O	X O			O	O	X

LEGEND

☐ Center 01

▨ Center 02

Figure 5: Application of the matrix for the determination of functional centers to the context of mussel farming in Santa Catarina.

♦ *Step 1* – Development of the functional synthesis for each of the selected processes, in an individualized way, by applying traditional techniques and procedures for functional synthesis of a single product. Figures 3 and 4 show the structures obtained in two of the processes studied.

♦ *Step 2* – Search for common functions. In this step, one seeks to confront each one of the functional structures obtained, aiming at finding similar elementary functions that can be shared by the different processes of mussel farming in Santa Catarina. Although it represents an increase in the quantity of comparisons to be made, a higher number of elementary functions ends up providing an increase in the number of common functions found. Ten common functions were found among the eight global functions under study in this project.

♦ *Step 3* – Determination of Functional Centers. Functional centers can be defined as the group of common functions that can define one or more modules. The procedure proposed for the identification of these functional centers is based on the use of a matrix, which relates the global functions under study (lines) to the common functions found (columns), mapping them among the intersections. The functional centers are determined by selecting the groups of common functions that can include the highest number of functional centers possible. Two functional centers were defined in this study, as illustrated in Figure 5.

Once the process of modular functional synthesis was completed, the step called Search for Principles of Solution for common functions and other elementary functions defined during this step was begun. Several sources were used including suggestions of principles made by mussel producers themselves. All suggestions were organized in morphological matrixes. In the step called Creation and Selection of Design Alternatives, these principles of solution were then used as the basis for product conception proposals, together with the modular functional structure obtained. Figures 6 and 7 present some examples of such proposals, which are related to the functional structures illustrated previously. It seems important to highlight that, among the codification of elementary functions, the common functions to which these elementary functions belong are also indicated between parenthesis.

The design alternatives were classified as PUGH Matrices (1991), using clients' needs (and their respective weights) as selection criteria. In the examples previously presented, the immediate analysis of the results would lead to the following classifications:

♦ *Process of mussel separation (FG-4)* – first place, alternative 4-2 and, second place, tie between alternatives 4-3 and 4-5.

♦ *Process of mussel selection (FG-6)* – first place, alternative 6-3 and, second place, alternative 6-5.

However, through a joint analysis of the results obtained in all of the processes studied, the employment of alternatives 4-3 and 6-3 for all processes exemplified was adopted, given that such alternatives were based on similar concepts with the best classification in the group of processes.

Although the modular functional structure of the products and the principles of solution to be employed are already known by now, it is still necessary to evaluate the possibility of modulating internal elementary functions for each group of functions (the functional centers and the other elementary functions remaining in each global function) so that total

ELEMENTARY FUNCTIONS	DESIGN ALTERNATIVES						
	4-1	4-1	4-3	4-4	4-5	4-6	4-7
4.1 (FC-1) Gathering of mussels	Spherical shell	Vertical drum	Funnel	Open reduction trough	Horizontal drum	Horizontal drum	Horizontal drum
4.2 (FC-2) Agitation of mussels	Rotating drum	Using a shaft	Using a shaft	Rotating drum	Using a shaft	Using a shaft	Rotating drum
4.3 (FC-10) Individualization of mussels	Agitator	Shaft with blades	Shaft with blades	Shaft with blades	Shaft with blades	Rotating cable	Shaft with blades
4.4 (FC-6) Cleaning of mussels	Water bath	Water bath	Water shower	Water shower	Water bath	Water bath	Water bath
4.5 (FC-7) Separation of detritus	Grate	Grate	Grate	Grate	Grate	Grate	Grate
4.6 (FC-8) Guiding water with detritus	Channel	Channel	Hose	Hose	Piping	Piping	Piping
4.7 (FC-9) Collecting water with detritus	Tank	Tank	Recirculate	Recirculate	Sewerage	Sewerage	Sewerage
4.8 (FC3) Catching of mussels	Opening a device	Opening a device	Constant flow	Constant flow	Using a tool	Using a tool	Using a tool
4.9 (FC4) Transportation of mussels	Pouring out	Pouring out	Material flow	Material flow	Manually	Manually	Manually
4.10 (FC-5) Collection of mussels	Basket	Basket	Basket	Basket	Basket	Basket	Basket

Figure 6: Design alternatives for the mussel separation task.

ELEMENTARY	DESIGN ALTERNATIVES						
FUNCTIONS	4-1	4-1	4-3	4-4	4-5	4-6	4-7
4.1 (FC-1) Gathering of mussels	Spherical shell	Vertical drum	Funnel	Open reduction trough	Horizontal drum	Horizontal drum	Horizontal drum
4.2 (FC-2) Agitation of mussels	Rotating drum	Using a shaft	Using a shaft	Rotating drum	Using a shaft	Using a shaft	Rotating drum
4.3 (FC-10) Individualization of mussels	Agitator	Shaft with blades	Shaft with blades	Shaft with blades	Shaft with blades	Rotating cable	Shaft with blades
4.4 (FC-6) Cleaning of mussels	Water bath	Water bath	Water shower	Water shower	Water bath	Water bath	Water bath
4.5 (FC-7) Separation of detritus	Grate	Grate	Grate	Grate	Grate	Grate	Grate
4.6 (FC-8) Guiding water with detritus	Channel	Channel	Hose	Hose	Piping	Piping	Piping
4.7 (FC-9) Collecting water with detritus	Tank	Tank	Recirculate	Recirculate	Sewerage	Sewerage	Sewerage
4.8 (FC3) Catching of mussels	Opening a device	Opening a device	Constant flow	Constant flow	Using a tool	Using a tool	Using a tool
4.9 (FC4) Transportation of mussels	Pouring out	Pouring out	Material flow	Material flow	Manually	Manually	Manually
4.10 (FC-5) Collection of mussels	Basket	Basket	Basket	Basket	Basket	Basket	Basket

Figure 7: Design alternatives for the mussel selection task.

Weak correlation (1 point)	○
Average correlation (3 points)	◎
Strong correlation (5 points)	●

Modularization Guidelines		FC 1 – Gathering of mussels	FC 2 – Agitation of mussels	FC 3 – Catching of mussels	FC 4 – Transportation of mussels	FC 5 – Collection of mussels
		Functions				
Product development	Multi-application (*Carry-over*)	●	●	●	●	●
	Technological evolution					
	Design modification					
Variation	Technical specification					
	Style					◎
Manufacturing	Common unity	●	●	●	●	●
	Process and organization					●
Quality	Separate tests					◎
Acquisition	Buying finished products		○			●
After being in marketplace	Maintenence and maintainability					○
	Updating					
	Recycling					●
	Σ	10	11	10	10	32
	Classification	3	2	3	3	1

Weak correlation (1 point)	○
Average correlation (3 points)	◎
Strong correlation (5 points)	●

Modularization Guidelines		FE 6.1.3 – Separation of mussels	FE 6.2.1 – Catching of seeds	FE 6.2.2 – Transportation of seeds	FE 6.2.3 – Collection of seeds
		Functions			
Product development	Multi-application (*Carry-over*)	○	○	○	○
	Technological evolution				
	Design modification				
Variation	Technical specification				
	Style				◎
Manufacturing	Common unity				
	Process and organization				●
Quality	Separate tests				◎
Acquisition	Buying finished products				●
After being in marketplace	Maintenence and maintainability				○
	Updating				
	Recycling				
	Σ	1	1	1	18
	Classification	2	2	2	1

Figure 8: Module Indicating Matrices for the functional center 1 and for the remaining elementary functions in the process of mussel selection.

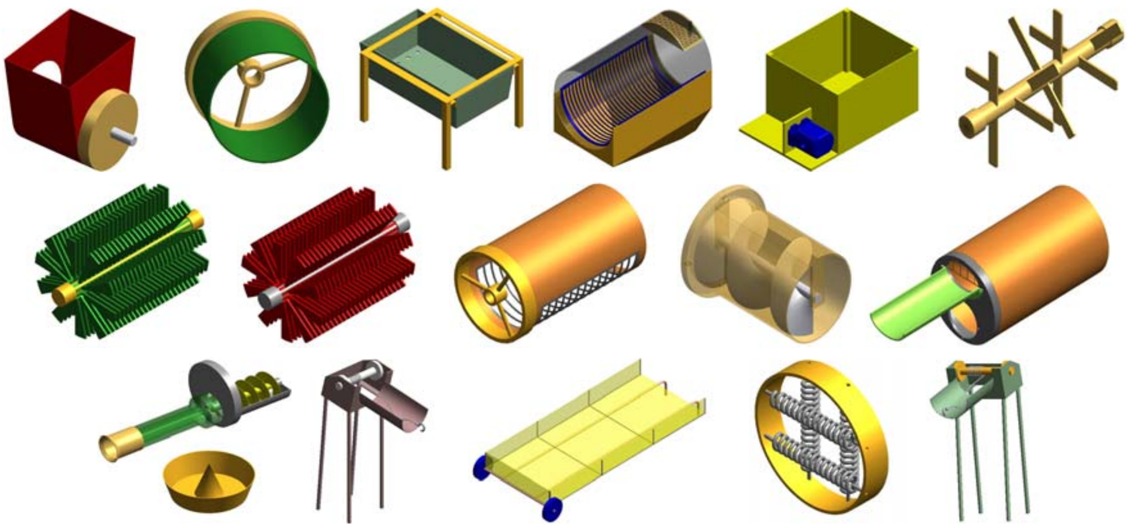

Figure 9: Conceptual Model of the designed modules.

knowledge of the product modularity can be acquired. In this process, developed during the step called Modules Creation, Module Indicating Matrices (ERIXON et al., 1996) were used, one for each group of functions. Some examples of the matrices used are presented in Figure 8.

At the end of this step, preliminary module layouts were created on the basis of the information obtained up to this moment, as illustrated in Figure 9. Such layouts are sketches of how the final configurations of each module of the system could be, but some modifications can still be made. The reason for this is that, during the conceptual design, the main concern was the functional feasibility of the product. These first sketches served as the basis for the following step of the design: the Interface Design.

Interfaces are considered as critical and fundamental elements for the good performance of a modular design, the

Module	Functions	Module 02	Module 12	Alternatives 01	02	03	04	05	06
01	Provide support	☞	☞	Fastener	Flanges	Pin-hole	Wing screw	Quick coupling	Screw
	Transmit power (Transmit motion)	-	☞ (☞)	Gears	Gears	Gears	Gears	Gears	Gears
	Locating component during assembly	☞	☞	Pin-hole	Pin-hole	Pin-hole	Wing screw	Quick coupling	Signalizing

Figure 10: Proposals of interface alternatives for the functions identified among module 01 and modules 02 and 12.

		01 / 02-12						01 / 06-07-08					02 / 04-09-11							02-04-09-11 / 06-07-08	
		Alternatives						Alternatives					Alternatives							Alternatives	
Requisitos	Weights	01	02	03	04	05	06	01	02	03	04	05	01	02	03	04	05	06	07	01	02
Tight	4	0	1	R	0	0	2	0	R	0	0	0	-1	-1	0	R	-1	1	0	R	0
Interchangeable	4	0	0	E	0	0	0	1	E	2	1	2	1	0	0	E	1	1	-1	E	0
Assembly	4	2	-1	F	1	1	1	-1	F	1	-1	2	2	2	1	F	1	0	0	F	-1
Disassembly	4	2	0	E	1	1	1	0	E	0	-1	1	2	1	0	E	1	0	0	E	1
Form	5	1	-1	R	1	1	-2	0	R	0	-1	0	-1	-1	-1	R	-1	0	-2	R	1
Material	4	0	0	E	0	0	0	0	E	0	0	0	0	0	0	E	0	0	0	E	0
Power, energy and movements	2	0	0	N	0	0	0	0	N	0	0	-2	0	0	0	N	0	0	0	N	0
Production	4	0	0	C	0	0	-1	1	C	2	-1	-2	1	1	-1	C	1	-1	-2	C	-1
Security and ergonomy	4	-1	1	E	-1	-1	1	0	E	0	-1	1	-1	-1	1	E	-1	0	1	E	-1
Cost	5	0	-1		0	0	-1	2		1	0	-1	1	1	2		1	1	0		-1
Maintenance	3	0	0		0	0	0	0		0	0	0	0	0	0		0	0	0		0
? (+)		**5**	**2**	**0**	**3**	**3**	**5**	**4**	**0**	**6**	**1**	**6**	**7**	**5**	**4**	**0**	**5**	**3**	**1**	**0**	**2**
? (–)		**-1**	**-3**	**0**	**-1**	**-1**	**-4**	**-1**	**0**	**0**	**-5**	**-5**	**-3**	**-3**	**-2**	**0**	**-3**	**-1**	**-5**	**0**	**-4**
?		**4**	**-1**	**0**	**2**	**2**	**1**	**3**	**0**	**6**	**-4**	**1**	**4**	**2**	**2**	**0**	**2**	**2**	**-4**	**0**	**-2**
Weighted sum		**17**	**-6**	**0**	**9**	**9**	**1**	**14**	**0**	**25**	**-17**	**7**	**16**	**8**	**9**	**0**	**8**	**9**	**-18**	**0**	**-8**

Figure 11: PUGH matrix (1991) applied to the selection of interface alternatives.

importance of which was already highlighted by authors like HILLSTRÖN (1994) and ERIXON et al. (1996). To achieve this, a tool called Interface Selection Process or ISP (SCALICE, 2001) was used, which is divided into three distinct steps: the Survey and Analysis of the Necessary Interfaces, the Search for Principles of Solution, and the Creation and Selection of Interface Alternatives. This process is based on the same principles of product design and begins with the study of the functions to be performed by the module interfaces, as previously mentioned. These functions are then used as the basis for the proposal of solution principles and, subsequently, the proposal of design alternatives to be selected by PUGH matrices, as illustrated in Figures 10 and 11, respectively.

The consistence of the results obtained with the application of the ISP was confirmed during the module preliminary design phase, in which all the interface alternatives proposed were employed in the module design. However, it seems important to highlight that, in a few cases, the alternatives that were better classified on the PUGH matrix (1991) were not, in practice, the best for the geometry of the system, and they were substituted by the second or third alternatives. This fact, however, only reinforces the coherence of the results presented and demonstrates the potential of the ISP as a tool for decision making in module product design.

Group	Designation	Performed Tasks
Main modules	M1 – Mussel receptor module	This module is responsible for receiving and transmitting the energy coming from the motor system to other modules, for providing support to the equipment and, mainly, for serving as a receptor for the material to be processed by the equipment
	M2 – Extension module for separation	This module's main function is to classify processed mussels by size, grouping them according to their comercialization possibilities.
	M3 – Hermetic extension module	This module separates the mussel's meat from its shell, after it has undergone a cooking process.
	M4 –Agitation shaft	It is a shaft with blades that can be coupled to the interior of the previously mentioned modules. Its purpose is to move, shake and, in the case of the separation process, individually separate mussels.
	M5 – Shaft with brushes	Used for cleaning the mussels' shells
	M6 – Extension module for roping	This module makes it possible to place the mussels in ropes by using the method now disseminated in Santa Catarina
	M7 – Rope stretcher	This module is able to remove the farming ropes from the cultivation process by itself.
	M8 – Mussel extractor	This module can be coupled only to the M7, which extracts the mussels fixed on the surface of the mussel ropes
	M9 – Power Source	This module corresponds to the motor system of the equipment
Constructive Modules	I1 – Intermediary bearing	Element responsible for the interfacing of modules M1, M2 and M3
	I2 – Fastening module.	A locking unit to secure the structure of modules.
	I3 – M1, M2 and M3 legs	Element that supports the equipment and regulates the working height.
Auxiliary Modules	A1 – Fish tray support	Structure used for optimizing the collection of mussels processed by the equipment.
	A2 – Water-collecting funnel	Device used for collecting used water.
	A3 – Water recirculation tank	Device used for recycling used water.
	A4 – Cart for mussel ropes.	System used for transporting young mussels that have just been placed in ropes.
	A5 – Rope support	Device developed for the placement of the central rope of the mussel rope during the roping process.

Table 1: Listing of the modules developed.

2.3 Phases 3 & 4 – Embodiment Design and Detail Design of the Modular System

In the preliminary design phase of the modular system, all the activities relating to the selection and optimization of forms, materials, capacities and manufacturing processes to be employed in the structure and in the production of equipment for the mechanization of the processes conducted in the mussel farming are performed. In order to develop these activities, the concepts defined during the phase called Conceptual Design of the Modular System are used as a starting point. During the dimensioning of the modules, the initial information suffered several modifications, so that the modules could follow style definitions, meet production capacity goals, adapt themselves to the characteristics of the materials employed, as well as present modifications in the design alternatives performed with the combination or division of modules and the introduction of new modules.

In Table 1, the modules resulting from this process of structural optimization are presented together with the nomenclature adopted to define them. The developed modules were divided into three categories: main modules, directly responsible for the development of the study, constructive modules which contained solutions for the interfacing problem between modules and for the adaptation of the equipment to its use, and auxiliary modules, which are directed to the development of complementary functions of the system, making it easier to work with the equipment, but not being essential for the development of the process.

Each of the processes related to mussel farming selected for design can be developed with the combination of the modules described. The possible configurations of modules are listed below and illustrated in Figure 12.

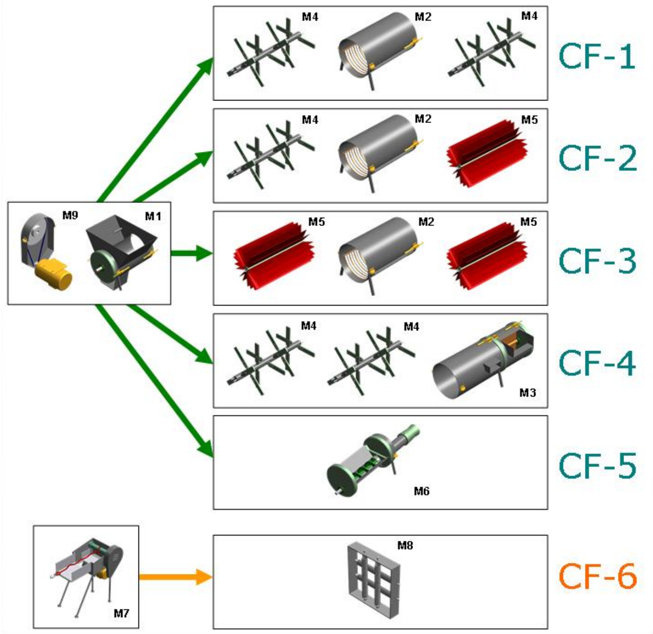

Figure 12: Diagram of the simple configurations of modules.

CF-1 – Mussel separation process / Mussel selection process.

CF-2 – Mussel cleaning process / Mussel selection process.

CF-3 – Mussel refined cleaning process / Mussel selection process.

CF-4 – Shell removal process

CF-5 – Roping process

CF-6 – Process of mussel removal from ropes

The way it was conceived, the developed modular system also supports the integration of other modules to some of the configurations described, either by broadening the capacity of the equipment in the performance of a certain task or by adding new tasks to the equipment. However, as shown in Figure 13, such versatility is restrained to combinations of modules M1, M2, M4 and M5, which makes possible the module configurations listed below.

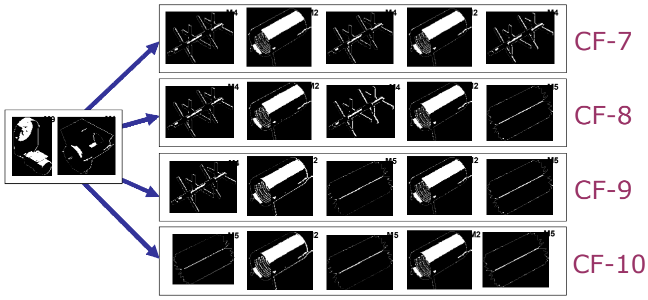

Figure 13: Diagram of mixed module configurations.

CF-7 – Strenghtened mussel separation process (for cases in which there is a greater difficulty in loosening byssus from mussels).

CF-8 – Mussel separation process together with the mussel cleaning process.

CF-9 – Cleaning process strengthened by adding a new brush (appropriate for cases in which a greater concentration of materials collects on mussels).

CF-10 – Strengthened process for refined cleaning of mussels.

PHASE 1	DEFINITION OF ANALYSIS PARAMETERS	
	Step 1.1	Selection of design specifications
	Step 1.2	Selection of failure modes
PHASE 2	PLANNING OF TEST	
	Step 2.1	Definition of supplying data sources
	Step 2.2	Determination of evaluation methods
	Step 2.3	Planning of resources
	Step 2.4	Planning of time
	Step 2.4	Elaboration of the test plan
PHASE 3	EXECUTION AND CONTROL OF THE TEST	
PHASE 4	RESULT ANALYSIS	

Figure 14: Outlining of the proposed steps for the planning of machine testing.

During the entire module dimensioning process, the objective was to create and update drawings and other prototype manufacturing information. Because this information is related to the detailed design of the modular system that occurs simultaneously with the development of the Preliminary Design, these two phases have been combined under a single topic. Having finished the design of the modular system for mussel farming, the manufacture and tests of the module prototypes was initiated as described in the next section.

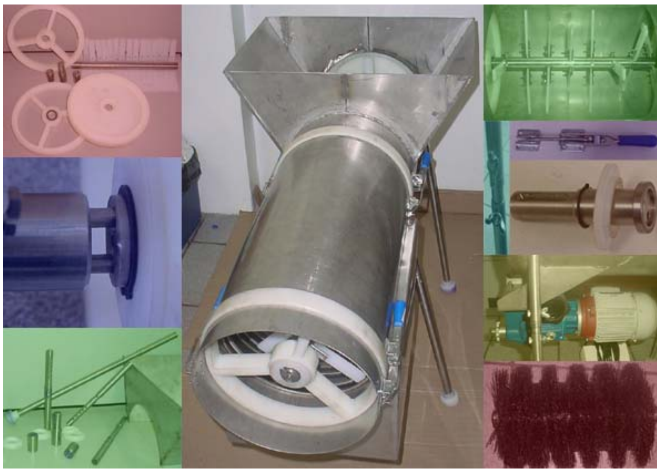

Figure 15 – Final configuration of the prototype and some of its components.

Figure 16: New basis for the mussel separator module.

3. Prototype Testing

The procedure used for testing the prototypes shown in Figure 14 was developed according to different pieces of research (MIALHE, 1996; DE CICCO and FANATAZZINI, 1988; PMI, 1996; SAKURADA, 2001; VINADÉ et al., 2001; MACHAD NETO, 2002), with the use of knowledge from areas such as machine testing, design management and failure analysis (FMEA). Testing was conducted only with those processes considered to be critical and those which, because of the similarity with those processes that had already been chosen, demanded less resources for the construction of the prototype. The processes chosen were: mussel removal from ropes (CF-6), separation of mussels (CF-1), mussel selection (in CF-1) and mussel cleaning (CF-2). Figure 15 illustrates the components and the final configuration of one of the prototypes developed: that of the configuration for the mussel separation process (CF-1).

The prototypes were manufactured in partnership with SENAI (*Serviço Nacional de Aprendizagem Industrial – National Service of Industrial Training*) and tested in two different steps at the Laboratory of Sea Mollusk Farming (LCMM – *Laboratório de Cultivo de Moluscos Marinhos*) from the Department of Aquaculture at the *Universidade Federal de Santa Catarina* (UFSC). In an initial testing phase, several problems were identified. Among them, the most critical was the presence of obstacles that would impede the movement of mussels inside the different configurations tested.

In order to develop the second set of tests, corrections of the problems found were implemented as well as the improvements suggested during the first test. The most radical modification was certainly the alteration of the grating system of the extension module for separation, for a system of three removable bulge-shaped parts, illustrated in Figure 16.

In the second testing phase, the evaluation of the prototype followed the design specifications and the analysis of the possible modes of equipment failure (FMEA). Only four out of the 34 parameters of analysis used were not considered satisfactory: the working life of parts, the efficiency of the separation process, the production capacity, and the possibility of short circuit via the motor system. Aiming to correct these problems and improve the product performance even more, new modifications were proposed targeting the commercial product. Among these alterations, the following stand out: improvement of the material flow in the interior of the equipment by the elimination of all restrictions still remaining in its interior; adoption of a higher slope of the set; modifications in form and materials in some parts, making these components last longer; adoption of a case that isolates the motor system from the environment; all in addition to several other small alterations that facilitate the use of the equipment.

4. Conclusions

The design proved adequate in several aspects. Considering the methodology used, it enabled the development of a whole modular system involving eight different tasks without limiting the functional or formal similarities in the equipment. Focusing on the products developed, it was possible to achieve the objectives proposed by the design with the creation of a modular product family whose cost is collectively less than what it would be if these products were developed on an integral architecture. It seems important to highlight that the process described in this study can be applied to other contexts, mainly in those cases in which a high modularity for the system is desired.

There remains a social contribution from this study given that, with the mechanization of processes performed by mussel farming, together with a low investment for the gradual acquisition of the whole system, it will be possible to achieve greater levels of mussel farming production in Santa Catarina.

This will lead to a growing professionalism and will consequently bring better living and material conditions for producers and their employees.

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