Systematization of product conceptual redesign for the environment

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Abstract: This article presents a methodology of redesign for the environment (RePMA), giving emphasis to the phase of modifications in the product's original conception, henceforth called conceptual redesign. According to RePMA, the process of redesign consists of four phases: informational, conceptual, preliminary and detailed redesign. The progress of this process relies on the level of redesign adopted, which, according to RePMA, can be: original, adaptive or parametric. This article presents conceptual redesign, the first phase of the original redesign, in which attempts are made in order to modify the product's original conception. Such changes can happen in the functional structure or in the solution principles. These forms of modification are the ones that allow more fundamental changes, such as functional grouping, inclusion or exclusion of functions, change in solution principles, among others. RePMA presents a set of guidelines so as to include the ecological concern in methods that support the activities of conceptual redesign such as: functional synthesis, morphologic matrix and Pugh's evaluation matrix. The application of conceptual redesign for the improvement of an electric coffee-machine is presented at the end of this article.

Key-words: design for the environment, product redesign, design methodology.

1. Introduction

Nowadays the ecological concern passes by all human activities. Governments have adopted stricter environment legislation. Citizens, in turn, have demanded environment-friendly products and processes. These new attitudes constitute pressures that have led companies to improve their processes and products environmentally, presenting the environmental differential of their products as one more competitive element.

This work deals with the presentation of a methodology of redesign for the environment – RePMA and, in particular, the specification of the conceptual redesign phase. The purpose of RePMA is to support the redesign process with the aim of providing the product with an environmental differential though the reduction of environmental impact in its life cycle. The conceptual redesign phase, in turn, comprehends the environmental improvement of the product though changes in its original conception.

2. RePMA – methodology of redesign for the environment

RePMA is characterized as a methodology of prescriptive nature, as it prescribes a set of guidelines and methods that help the redesign team in their activities of analysis, synthesis and evaluation EVBUOMWAN, 1996.

With regard to the environmental demand, RePMA is classified as an approach that deals with the whole life cycle of the product BRAS, 1997, as it incorporates elements (guidelines and methods) that deal with the environmental impact, from production to disposal. Such elements allow greater opportunities for environmental gain, as the improvements will not be limited to one characteristics or phase of the product's life cycle.

The overall structure of RePMA is shown in Figure 1. The establishment of this structure was based on:

♦ a model of consensus for the process of project considering the analysis of different project methodologies OGLIARI, 1999. This model presents the project process in four phases: informational, conceptual, preliminary and detailed project;

♦ the guidelines for the development of project methodologies MARIBONDO, 1999. From such guidelines, those used for representing the methodology through a fluxogram and for unfolding the methodology phases into stages and tasks are specially relevant; and

♦ the consideration that there are different levels of redesign: original, adaptive and parametric OTTO, 1998.

The initial activity prescribed in RePMA consists in determining the realization of redesign. In this activity, the first step is to translate the strategic plans of the company into operational terms for the development of the product. Then, based on previous information, the redesign team tries to determine a set of priorities necessary for improving the product. To be more specific, it is important to determine a set of priorities in order to reduce the product's environmental impact.

In order to determine the realization of redesign, both sets of information have to be confronted, checking whether the priorities of redesign are coherent with the company's strategies. If there is such coherence, the redesign team will be sure that the improvement of the product in environmental terms fits the strategies of the company.

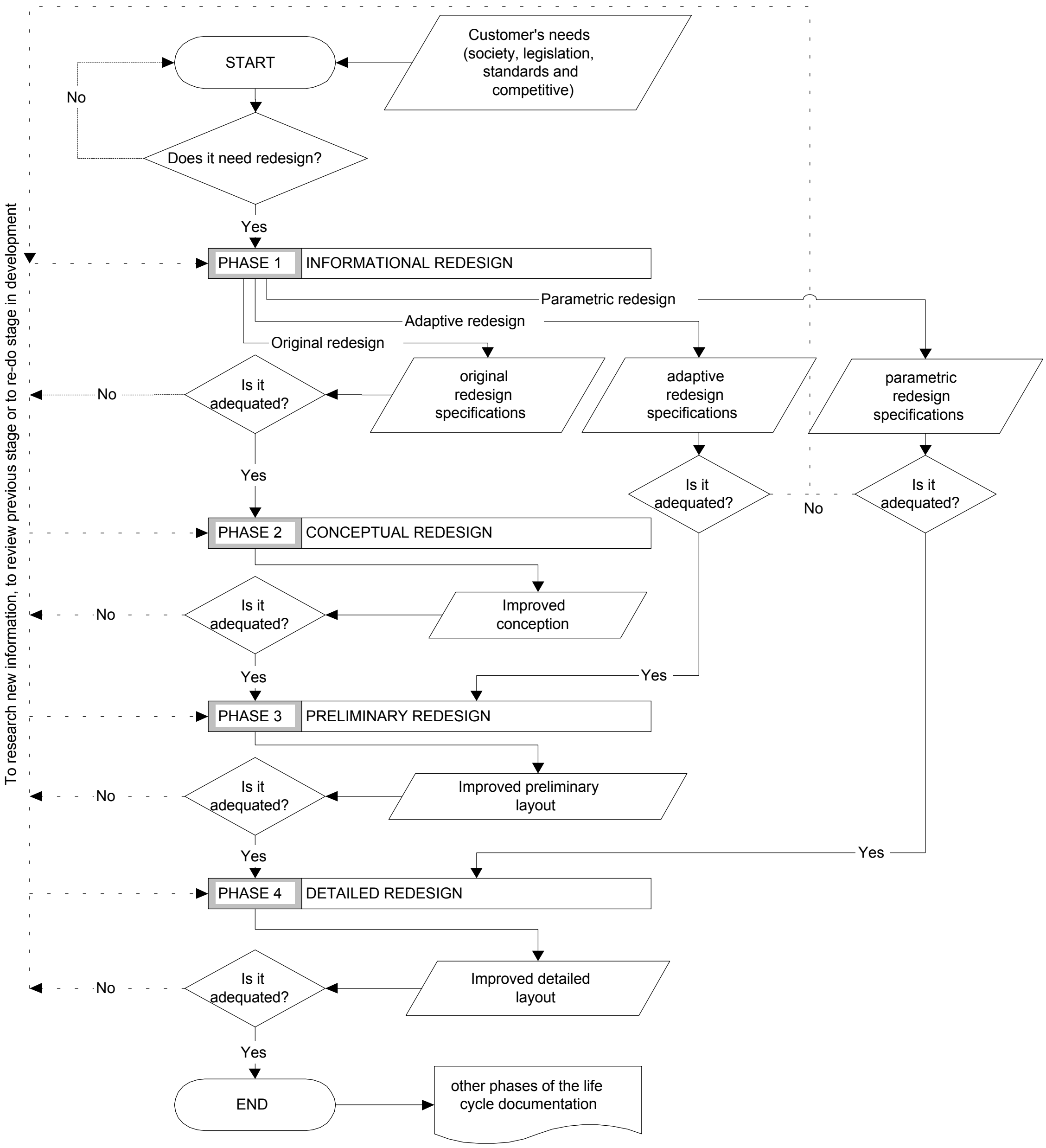

Figure 1 - General structure of RePMA.

Thus, the redesign team will have an indicative that the product's environmental improvement will be supported by the management. On the contrary, there is no guarantee of support for the realization of redesign for the environment . Support form the management helps the redesign team in their decisions about the realization of redesign.

Once the realization of the product's redesign has been decided, the first phase prescribed in RePMA follows.

2.1. Informational redesign

This phase has characteristics similar to those of the phase of explaining the design task proposed by PAHL & BEITZ, 1996. It comprehends the set of activities necessary for dealing with the available information about the original product.

The phase comprehends the activities that begin with the acquisition of information regarding the original product and end with the definition of the level of redesign and the elaboration of specifications for redesign. In this phase, RePMA prescribes methods as a simplified life cycle analysis (SLCA) to support the elaboration of environmental requirements; a method to determine the level of redesign best suited to reduce the product's environmental impact is also proposed.

With the results of this phase, level of redesign and specifications, the process of redesign follows according to the level of redesign chosen:

- ♦ In the original redesign, conceptual redesign follows;
- ♦ In the adaptive redesign, preliminary redesign follows; and
- ♦ In the parametric redesign, detailed redesign follows.

2.2. Conceptual redesign

Conceptual redesign corresponds to the first phase of an original redesign. Changes in the product's original conception are sought in this phase. These changes can happen in the functional structure or in the solution principles. These forms of change are the ones that allow more fundamental changes of the product, such as: functional grouping, inclusion or exclusion of functions, change in solution principles, among others. The specifications of this phase, which is the main purpose of this article, will be presented in item 3.

By the end of this phase, the improved conception that best meets the technical, environmental and economic criteria is selected.

2.3. Preliminary and detailed redesign

Once the product's improved conception is achieved, or in the case of adaptive redesign, the preliminary redesign phase follows, in which the realization of changes in the product's layout is prescribed. These changes are implemented according to the design specialties (DFX's) best suited to reduce the product's environmental impact. By the end of this phase, the modified preliminary layout is obtained.

The next phase is the detailed redesign, which begins with the product's modified preliminary layout or with the option for parametric redesign. In the first case, the specification of the preliminary layout shall be made, whereas in the second the product's detailed layout shall be recovered from documents retrieved from the informational redesign.

From the detailed layout, the optimization of engineering parameters shall be carried out, in order to allow greater environmental gain. Then, the environmental gain shall be compared to the original product. If gains are satisfactory, the construction of prototypes for environmental and functional tests is proposed.

By the end of this phase, a set of documents that will help the product's production is prepared. It is also possible to prepare other documents that will help to guide the reduction of environmental impact in the other phases of the product's life cycle, such as recycling plan, reuse plan, among others.

3. Conceptual redesign

The specification of the conceptual redesign is presented in this item. Such specification consists in unfolding the phase into steps and tasks, as presented in Figure 2.

The conceptual redesign corresponds to the first phase of an original redesign. Once the choice for the realization of the original redesign has been made, and the specifications for redesign are obtained, changes are made in the product's original conception.

Such changes are performed through activities of analysis, synthesis and evaluation, both in the functional structure and the solution principles. In RePMA these activities are aimed at those changes that allow the reduction of the product's environmental impact.

The items below present the guidelines and methods prescribed in RePMA to support the activities of the redesign team in each stage of this phase.

3.1. Stage 2.1. Recuperation and evaluation of the product's original conception

This stage consists basically of two tasks. The first one corresponds to recuperating the products original conception, supported by the inverse functional synthesis method. The product's conception is described through the morphologic and functional structure.

The first description is the set of the product's functions, structured according to the flow of material, energy and information among them.

The second description corresponds to the set of solution principles (SPs) that perform the product's functional structure.

The next task is the evaluation of the product's original conception. This evaluation consists in confronting the original conception and the redesign requirements, in which values are attributed to the relationship between them, so that a hierarchization of SPs/functions can be achieved.

The hierarchization of SPs/functions helps to identify the aspects of the product's original conception that need more changes.

The matrix of evaluation of the product's original conception is prescribed as a support to this task.

3.2. Stage 2.2. Establishment and selection of the modified functional structure

This stage corresponds to the activities of modification of the product's functional structure. The greatest difficulty in this stage consists in considering the environmental demand in an abstract context, characteristic of the functional description. On the other hand, this is the stage in which the redesign team has more freedom to change the product, as they are performed through abstraction from the solution principles.

The first task in this stage is to evaluate the influence of the functions upon the product's environmental impact. It is important to notice that the main influences of the functions

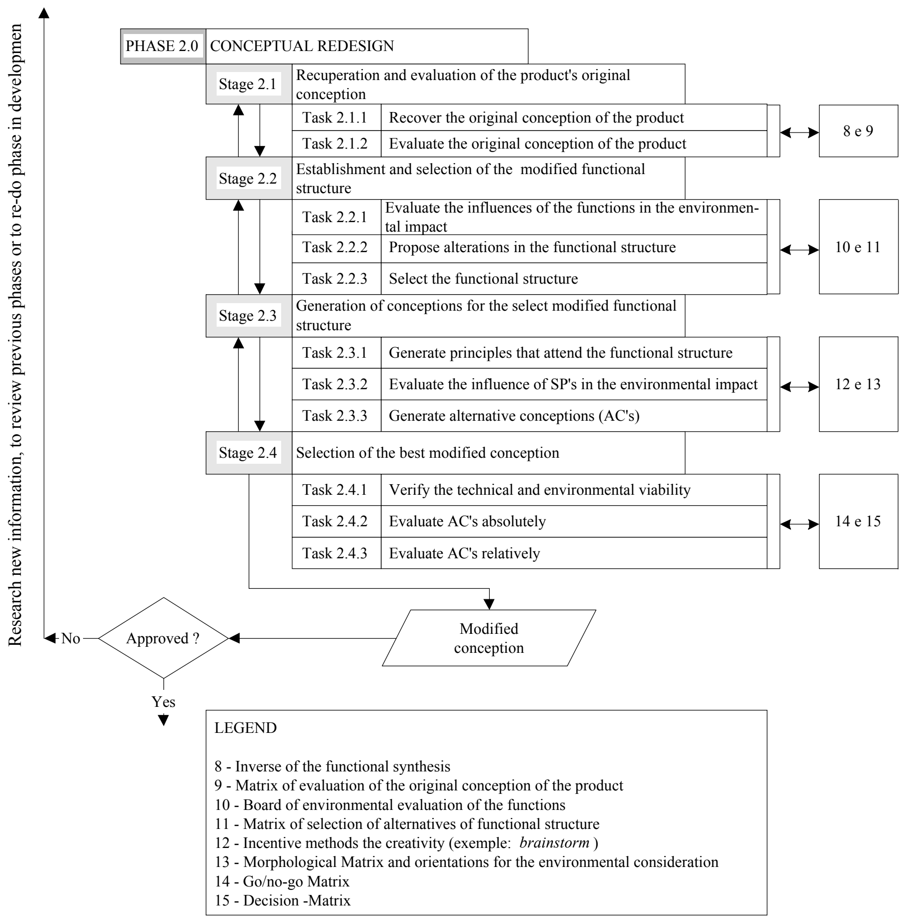

Figure 2. Deployment of conceptual redesign.

upon the product's environmental impact happen in the phase of life cycle use, so it is necessary to identify the functions that influence the consumption and emission of resources in this phase.

The results of this evaluation are organized according to Table 1, which shows the type of influence the function has upon the product's environmental impact. This table is filled with the consumption and emission of material and energy of the product in relation to each function.

Table 1 - Board of environmental evaluation of functions

Func.	Consumption		Emission	
	Material	Energy	Material	Energy

The data in Table 1 and the hierarchization performed in stage 2.1 serve as support to the activities of the next stage, which consists in proposing changes in the functional structure. The changes in the functional structure correspond to generating alternatives based on the product's original structure. These changes shall be oriented towards the reduction of the product's environmental impact and also to the fulfillment of other customer needs.

The redesign team must develop alternatives to the functional structure through operations with the functions, such as insert, suppress, group, and ungroup, among others. For example by including the function *Auto turn off* after a determined period of time, energy is saved.

Another change that can produce environmental gain is the grouping of functions with a high degree of importance into functional modules that can be reused when the product's life cycle ends.

The changes in the functional structure are activities of synthesis, with the aim of generating alternatives to the original functional structure. In this stage, the redesign team must be based on the information in Table 1 plus the following questions:

♦ Is it possible to reduce the consumption of any given function by including or suppressing another function?

♦ Is it possible to reduce the emission of any given function by including or suppressing another function?

♦ Can the functions with high importance be grouped into functional modules with the possibility or reuse by the end of the product's life cycle?

♦ Which are the possible alternatives to the functions best positioned in the hierarchization performed in Stage 2.1?

♦ Is it possible to add more functionalities to the product, suppressing the need of other products?

Further questions can be prepared by the redesign team in order to meet the product's specific features. The answers to the questions guide the elaboration of alternative functional structures. There are other changes that can represent environmental improvement in functional terms without necessarily representing changes in the functional structure. For example the inclusion of guidelines so as to avoid misusing the product.

Besides these questions, the generation of alternative functional structures must be guided by the redesign requirements. The redesign requirements must be read so as to identify the need of functional changes.

Once a set of alternatives to the functional structure has been produced, the next task is performed; it consists in selecting the functional structure that best meets the requirements of both customer and environment. The matrix of selection of functional structures proposed in MARIBONDO, 2000, is used for that purpose.

Once the modified functional structure that best meets the customer needs is selected, the next stage proceeds, consisting in the generation of physical conceptions for the selected functional structure.

3.3. Stage 2.3 Generation of conceptions for the modified functional structure

This stage consists in generating SPs and their combination in alternative conceptions (ACs) that perform the functional structure selected in the previous stage. In this stage there is a shift from an abstract description (functional structure) to a more concrete description (ACs). In more concrete terms, this description increases the facility of environmental consideration, even if the conception is not yet presented as a detailed configuration nor with a definition of the engineering parameters. A sequence of tasks with guidelines for the consideration of environmental demand in the activities of this stage is proposed in RePMA.

The first task is to generate principles able to meet the functions of the selected functional structure. The creativity of designers is highlighted in this task, as attempts are made in order to generate alternatives to SPs for each function. Different authors who have considered the theme of creativity explain that, even though it is difficult to systematize creativity, it is possible to stimulate it through methods that provide support to the redesign team. Such studies present a set of methods that can help designers in this task.

RePMA suggests that the redesign team should carry out research about these methods in order to select those that are best suited to the specific problem of the product being redesigned. Anyway, it is recommended that restrictions should not be made at the moment of creation in order to avoid blocking the team's creativity. The use of a morphologic matrix, presented in Figure 3, is proposed in order to help organize the SPs produced.

The first column of the morphologic matrix is filled with the functions of the functional structure selected in the previous stage. The transcription of these functions into the morphologic matrix depends on the decisions of the redesign team, and they can be grouped or detailed in more elementary attributes so as to facilitate the generation of SPs for the function.

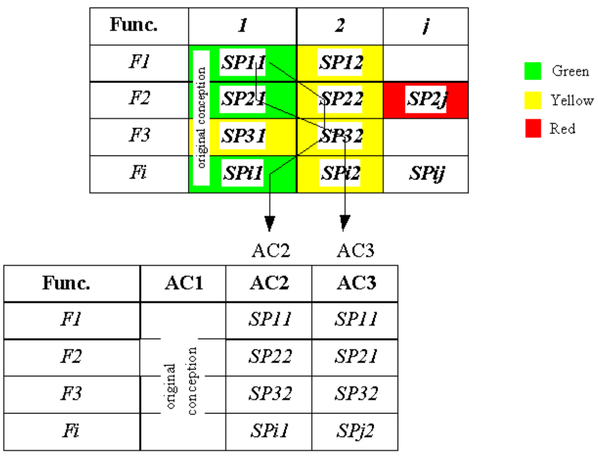

Figure 3 - Combination of SPs in ACs.

The SPs are filled in the columns beside each function. It is recommended that they be described through schematic drawings but, if this is not possible, a textual description can be applied. It is also suggested that the SPs of the product be the first ones to compose the morphologic matrix, immediately followed by the SPs produced by the team.

With the morphologic matrix filled, the next step is to evaluate the influence of SPs upon the product's environmental impact. In this task, it is important to highlight the SPs in relation to the product's environmental impact. For that purpose, it is suggested that the redesign team compare each PS with the results obtained in the SLCA. After that, the SPs are highlighted in the morphologic matrix according to the following guidelines:

♦ The SP is not highlighted in cases in which it is not possible to evaluate its influence upon the environmental impact or when the use of that SP does not change the product's environmental impact;

♦ Green, in case the SP represents reduction of the product's main environmental impacts;

♦ Yellow, in case the SP represents reduction of part of the product's main environmental impacts; and

♦ Red, in case the SP represents an increase in the product's environmental impact or disobedience of any environmental laws.

This qualitative evaluation of SPs helps the redesign team in the task of generating alternative conceptions (AC) to the product. This task consists in combining the SPs listed in the morphologic matrix, as shown in Figure 3.

The combination of SPs can be regarded as a creative process, in which the redesign team should not be constrained in their freedom of action. However, in order to make the generating process faster and devoted to environmental improvement, it is suggested that preference be given to the combination of green SPs, followed by yellow or unmarked and finally by the red ones.

Besides paying attention to the environmental criteria, the compatibility among the solution principles must be considered.

3.4. Stage 2.4. Selecting the best improved conception

The selection of the best AC consists of three selection tasks ULLMAN, 1992: technical-environmental viability, absolute evaluation of each AC and, finally, relative evaluation of each AC.

In the first task, technical viability is understood as the technological availability needed for the realization of a given

AC. In turn, environmental viability is the non-existence of characteristics that transgress environmental laws.

Each alternative must be evaluated according to the technological and environmental viability for its realization. Prejudice regarding novelties that might be present in the ACs must be avoided in this evaluation; however, the discard of any alternative, according to these criteria, must be clearly and coherently justified.

In the other two tasks the evaluation takes as selection criteria the requirements of both environment and user, as well as the redesign requirements, respectively.

These evaluations use a set of well-known methods, such as the go/no-go matrix and Pugh's decision-matrix, PUGH, 1990. In these methods, the environmental concern is characterized by the adoption of environmental requirements as selection criteria.

The best AC for the product is achieved at the end of this process.

The next item presents the application of the guidelines and methods prescribed in the conceptual redesign in the environmental improvement of an electric coffee-machine.

4. Conceptual redesign of an electric coffee-machine

This item refers to the application of the guidelines and methods of the stage of conceptual redesign with the aim of reducing the environmental impact of an electric coffee-machine. Figure 4 shows a vista explodida desta cafeteira.

The entries of the redesign projects are the option for the original redesign and the list of requirements of hierarchized redesign with the application of the house of quality. The most prominent requirements were **amount of information about the environmental impact**, **cost of production**, **energy to keep the coffee hot**, **consumption of energy**, **weight of the coffee-machine** and **number of points that offer risk of security to the user** BITENCOURT, 2001.

The first entry implies the realization of the phase of conceptual redesign, whereas the second serves as a base for decision-making in the stages of conceptual redesign.

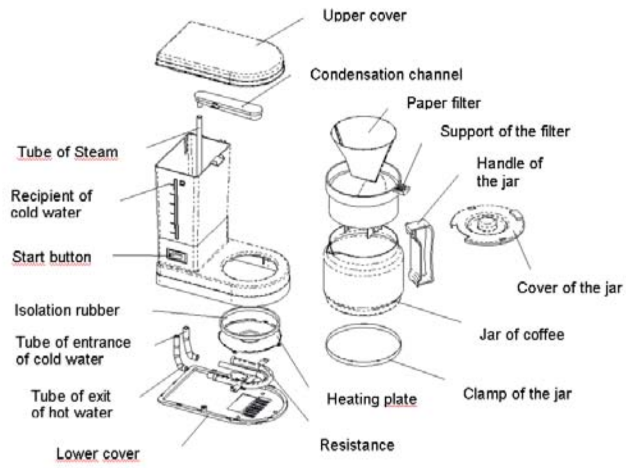

Figure 4 - Exploded view of the coffee-machine.

The first stage of the conceptual redesign consists in the recuperation and evaluation of the product's original concept. For that purpose, the inverse functional synthesis method was applied.

The original conception of the coffee-machine is represented though the functional and morphological structure. In the first, the functions that compose the product and its interrelation though the flow of material, energy and information are presented, as shown in Figure 5. The morphologic structure, in turn, presents the solution principles (SPs) that perform the functions previously mentioned in BITENCOURT, 2001.

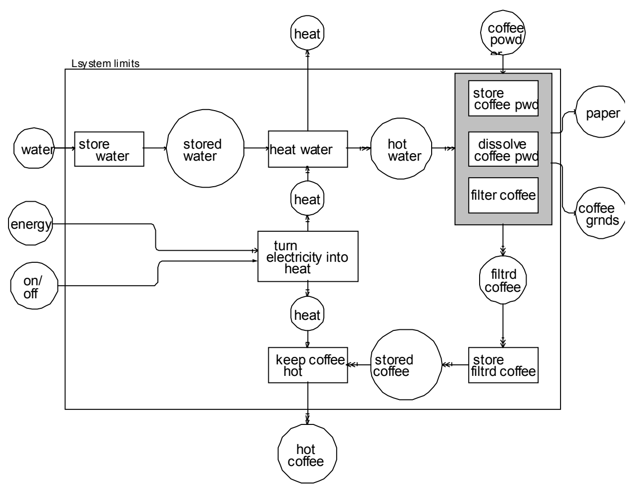

Figure 5 - Functional structure of the coffee-machine.

In the evaluation of the conception of the electric coffee-machine, the following functions deserved attention: *Keep the coffee hot, Transform electricity into heat* and *Heat water*.

The next stage refers to the generation of changes in the coffee-machine. The first task is the evaluation of the influence of the functions upon the product's environmental impact. The result of this evaluation is shown in Table 2.

Table 2 - Environmental evaluation of the functions of the electric coffee-machine.

Function	Consumption		Emission	
	Material	Energy	Material	Energy
Turn energy into heat		Electricity		Heat transmitted by conduction to the water heating tube and heating plate
Heat water	Water	Heat to vaporize water	Water steam	Heat passed to environment
Filter coffee	Hot water and coffee powder		Coffee, coffee grounds and filter	
Keep coffee hot	Stored coffee and heat		Hot coffee	Heat transmitted to the jar by glass conduction and then by making coffee and heat passed to the environment

Data from Table 2 and the evaluation of the original conception of the coffee-machine show that the following functions have closer relation to environmental impact: *Turn electricity into heat, Heat water, Dissolve coffee, Filter coffee* and *Keep the coffee hot*. Thus, changes in the product's functional structure were made, as shown in Figure 6.

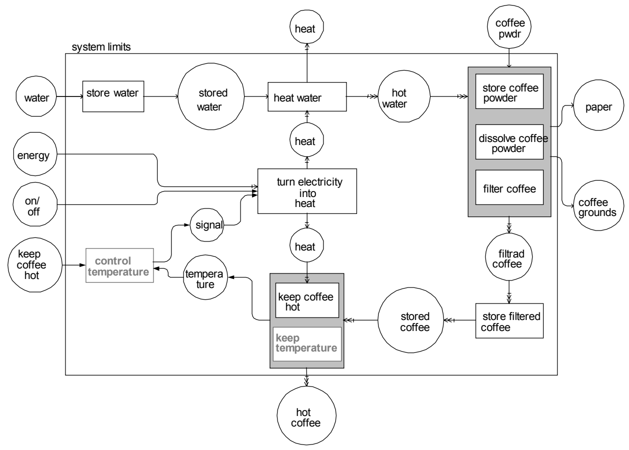

Figure 6 - Modified functional structure of the coffee-machine.

The proposed changes consist in the inclusion of two functions:

Control temperature – this function consists in controlling the consumption of energy of the function *Turn electricity into heat* through two signals: one coming from the user and the other from the temperature of he coffee recipient. This function would then decrease energy consumption, leaving just enough to keep the coffee temperate; and

Keep the coffee temperature – this function would allow keeping the coffee temperature with low (or no) energy consumption.

The requirements reported by users do not indicate the need of changes in the global functioning of the coffee-machine, BITENCOURT, 2001. However, more functionality could be added to it, like *Making express coffee or cappuccino*.

On the other hand, as no alternatives to the functional structure were produced, it was not necessary to perform the task of selecting a functional structure.

Once the modified functional structure is achieved, the generation of conceptions that meet this functional structure follows. *Brainstorming* was chosen as a method to generate SPs. This method was applied in two ways: in the first one the team members prepared their suggestions at their work place and in the second a meeting was held with members of NeDIP (Nucleus of Integrated Product Development).

The SPs produced during the previous task were organized into the morphologic matrix for the redesign of the electric coffee-machine. These SPs were evaluated according to their possible influence upon the environmental impact of the electric coffee-machine.

Finally, the combination of SPs was performed in alternative conceptions (ACs) to the electric coffee-machine. Ten different ACs that had gone through the processes of selection prescribed in RePMA were produced. Two of them were especially relevant. The first one relates to the use of a thermos flask as a coffee recipient not offered with the coffee-machine. The other alternative is the one with the best position in the process of selection, including the positive aspects of other ACs.

The first alternative is more promising, even though it presents a very innovative conception for electric coffee-machines. It is important to make sure that the market is willing to accept this conception, and also to investigate the consequences of this option for the productive sector of the company. The second alternative offers a lesser amount of changes in the original conception of the coffee-machine, which are believed not to imply significant risks of rejection by the market.

As long as neither the necessary evaluation about the acceptance of the first alternative, nor about its influence in the system of production of a company were possible, the second alternative was chosen as an improved conception of the coffee-machine, as illustrated in Figures 7 and 8.

The main changes and implications of adopting this conception are:

♦ Two resistors perform the heating of water and coffee and a manual selector that determines which configuration of resistor shall be used. Thus, the user can make a choice for a lesser use of electricity to keep the coffee hot by choosing the smaller resistor. The main limitation of this approach is the increase of complexity in the assembly of the circuit and the configuration of the lower support to allow replacing the resistor;

♦ The water heating tube is involved by the resistors, allowing better heat transmission;

♦ The filter support is attached to the body of the coffee-machine by a detachable hinge; besides, it has a valve that prevents liquid from flowing. These characteristics facilitate handling the filter as well as cleaning; however, they require more developed production techniques than the support currently used;

♦ A permanent filter will still be offered with the coffee-machine; however, the use of paper filters must be predicted; and

♦ The jar has the shape of a cone with rounded vertices; besides, it has side covering with thermal isolation and its base has a thermal conductor. These changes can increase the environmental impact of disposal, but they lessen the impact of use, due to the consumption of energy to keep the coffee hot, which is the main environmental impact of the coffee-machine.

These changes have negative consequences upon the cost of production and the productive system; however, they allow better fulfillment of the redesign requirements, and also promote the decrease of the environmental impact of the coffee-machine.

The final remarks about the development and application of RePMA follow.

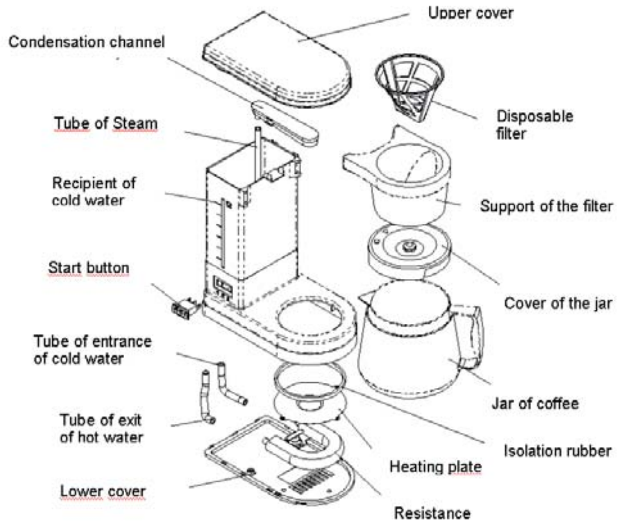

Figure 7 - Improved conception of the electric coffee-machine.

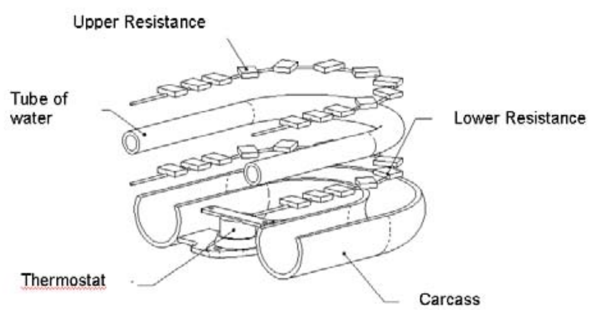

Figure 8 - Detail of the improved conception heating system.

5. Final remarks

Different environmental pressures have motivated companies to establish strategies of environmental improvement for their products and services. RePMA presents a way to help the design team realize these strategies in their activities. The guidelines and methods of RePMA, mainly in the phase of conceptual redesign, allow the redesign team to perform changes in the product's original conception considering the environmental demand of the market, transcribed in the form of a set of redesign environmental requirements.

The application of RePMA is facilitated when carried out by a multidisciplinary redesign team with expertise in systematic design of products, as its development was based on NeDIP's experience in methodologies of product design and consisted in the inclusion of elements that meet the specificity of product redesign and design for the environment in this methodological structure.

More specifically, in the application of the conceptual redesign phase to environmental improvement, it was possible to note:

♦ The ease to apply the guidelines and methods prescribed in RePMA;

♦ The inclusion of the environmental demand was facilitated, as a systemic structure and well-known methods were taken as base; and

♦ The improved conception for the electric coffee-machine allows the reduction of the biggest environmental impact of this product, which is the consumption of energy to keep the coffee hot.

6. Acknowledgments

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