COLLABORATIVE PROCESS BETWEEN FUNCTIONAL ANALYSIS ET LIFE CYCLE ASSESMENT: INTEGRATING ENVIRONMENTAL CONSIDÉRATIONS INTO EARLY STAGES OF DESIGN PROCESS

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Abstract

Is in the early stages of design process where decisions can have most influence on the definition of product environmental performance. Nevertheless, is difficult to integrate environmental considerations into a phase where designers have a reduced knowledge about the product. In fact, functional requirements present in conceptual phase are qualitatively subjective to allow the prediction of environmental impacts in the future product. Anyway, some authors suggest that establishing environmental performance in a functional structure can influence a more effective eco-design practice for products. This paper present the construction of a collaborative process where functional analysis will be related with environmental considerations with the aim to help designer to propose products that have less environmental impact from the early stages. The chosen methods to carry out this proposal are Functional Analysis, based in Value Analysis and Life Cycle Assessment method.

Keywords: Early design phases, Ecodesign, Functional modelling, Life cycle concept

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1 INTRODUCTION

The conceptual design phase, at the beginning of design process, determines the principle solution of a design problem (Pahl and Beitz, 1996). Therefore, is in the early stages where decisions can have most influence on the definition of product environmental performance (Bovea and Pérez-Belis, 2012; Dewulf, 2003; Duflou et al., 2003; Kaebernick et al., 2003; Zwolinski et al., 2010).

However, the integration of environmental considerations into early stages faces some difficulties. The main obstacle is that eco-design methods and tools are insufficient to assist designers in the early stages (Dewulf, 2003). In fact, qualitative and quantitative methods and tools are considered as qualitatively subjective requiring an extensive experience or quantitatively complex and focused in a late stage of product development (Devanathan et al., 2010). In addition, designers have a lack of environmental awareness which prevents to understand environmental impacts of their products (Deutz et al., 2013).

Despite this, Deutz et al. (2013) suggest that establishing environmental performance in a functional structure can influence a more effective eco-design practice for the products. The functional approaches are seen as a strategic instrument to analyse and decompose in a systematic way design problems, in order to support synthesis of potential solution elements (Eisenbart et al., 2012). Thus, to carry out a better design practice at early stages, it is necessary to perform a targeted research related to Deutz et al. above suggestion. The idea is to bring together a functional structure with environmental considerations such as the future effects of the product during its life cycle phases. Consequently, this paper propose a collaboration between functional analysis (FA) (CEN, 1996) and Life Cycle Assessment (LCA) (ISO, 2006) where both approaches can benefit each other in a collaborative process.

The paper is divided in three parts. The first part shows the results of a comparative analysis where are presented the potential links between FA and LCA that are needed to build the collaborative process. The second part regards the integration of one link to generate environmental information early in the design process. The third part establishes the scientific obstacles that, once raised, could implement the collaborative process.

2 FA AND LCA TOWARDS A COLLABORATIVE PROCESS

In the early stages of a design process, the functional structure of a product must be determined, as well as the basic mechanism that definitely affect the performance and quality of the product (Umeda et al., 1995). At this level, significant environmental improvements can be defined. To improve the design process at early stages it is important to identify the best compromise between designer skills and a structured approach to involve environmental considerations in an effective and rigorous way. In search of a functional structure that welcomes environmental considerations at early stages, it was chosen working with FA, approach that is well known for designers. For its part, LCA the most effective method of environmental assessment is applied in general once the product has been finished. The motivation to link these approaches is that the relative chronological distance between FA and LCA does not allow perceive the potential mutual benefit.

2.1 Definitions

FA is performed in early stages of design process and its objective is the description of the product in terms of functional requirements (FR) to satisfy a need. FA is an approach that is part of "overall design toolbox" defined by Dewulf and Duflou (2005), it form part of designer known tools. FA allows a good understanding of the product by the expression of expected services (CEN, 2004) and functional performances.

To satisfy functional requirements, design parameters (DP) are conceived in the physical domain (Suh, 1990). FA approach includes the "Functional Performance Specification" tool (FPS). FPS is a document by which design parameters are expressed in terms of criteria and level. To avoid use of a premature technical solution this document allow the abstraction of problems across functions with the aim to provide operating principles that allow to propose a solution.

LCA is one of the most common and accepted impacts assessment method that allows to get quantitative information to assist the designer in the search for solutions to the environmental problems (Ehrenfeld, 1997). However, it is focused at a later stage of product development and their effectiveness is limited by the need for detailed product information (Duflou et al., 2003). The four phases involved in LCA method are: goal and scope definition phase, inventory analysis phase, impact assessment phase, and interpretation phase.

2.2 Connection between FA and LCA

To be consistent with the first suggestion, on one hand, LCA needs to be integrated in a functional structure in order to ensure adoption by the designers and establish environmental performance at early stages; on the other hand, FA is a well-known method that could ensure integration of environmental considerations. Consequently, these two methods will be connected for the creation of a collaborative process. This process pretend to benefit both, the designer and the environmental expert.

A comparative analysis with a descriptive purpose allowed to find equivalence between FA and LCA. The gains of this comparison were the potential links that can be implemented to share information between approaches in a win-win situation. The comparison was inspired from Pigosso et al. (2011), who developed specific criteria to compare eco-design tools. A total of 12 criteria have been included to evaluate methodological, operational and management aspects.

The comparative analysis proved that FA and LCA could be connected. Six connection possibilities were obtained from this comparison (Figure 1). The concepts of “functional unit”, “life cycle inventory” and “life cycle” from LCA were selected by regards to their potential in FA. Concerning the integration of the concepts from FA to LCA “expression of the need”, “function” and “functional requirements” were selected. The possibilities of connection are briefly explained in Table 1.

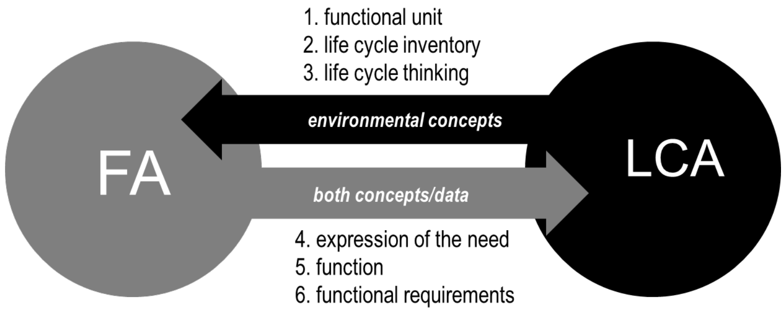

Figure 1. Reciprocal influence between methods.

Table 1. Six proposition to build the collaborative process

Concepts from LCA to FA	
1:Functional Unit (FU)	Is the quantified performance of a product system for use as a reference unit (ISO, 2006). FU can be integrated in FA when the functional requirements are defined to synthetize the main function of the product. That can prepare the FA practitioner at the environmental thinking. In addition, FU can be consulted in future realization of an LCA study.
2:Life cycle inventory (LCI)	The life cycle inventory catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment (ISO, 2006). In FA, functional requirements can be considered as a part of the inventory because they define the performances of the product by an exchange of flows with its environment. Consequently, the functional requirements should integrate at least the categories M (Matter) and E (Energy) and the direction of the flows (In or Out) to help the designer in finding the most appropriate specification (i.e. units and their associated level).
3:Life cycle	The identification of functions for the different phases of the product life cycle is recommended in the European standard on value management (CEN, 1996). However this recommendation is not sufficiently developed due to the absence of operational details to model the life cycle. In LCA this concept is central and is defined as the consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal (ISO, 2006). Create a life cycle model for FA,

	to study functions in all life cycle phases can be a response to show their environmental influences. The consideration of the influence of functions in all life cycle phases could allow the creation of an environmentally balanced product.
Concepts from FA to LCA	
4:Expression of the need	The need in FA is defined as desired or achieved action of the product to meet the client's expectations (CEN, 1996). In LCA, this concept can be introduced in its first step "goal and scope definition". Because this step doesn't need quantitative data, FA can guide the LCA expert in delimitating the boundaries of its product system.
5:Function	A function in FA expresses the relationship of the product with its environment. In the use phase, the main function justifies the existence of the product and can be consequently associated to the FU. The LCA expert can use the functional analysis and its specification to give a better definition of the FU which is recognized as a critical step in LCA.
5:Functional requirements	FR can be considered as a part of the LCI. The categorization (Matter, Energy, Input, Output) which has been added in FA (proposition 2) allows to format the flows providing from FR into adapted data which could pre-fill LCI. The Benefit is to simplify the LCI by pre-filling some data before finding technological solutions.*

2.3 The collaborative process

As seen above, LCA could provide concepts to be integrated into FA and FA could provide concepts and data to perform a LCA study. The collaborative process is a proposition where the six concepts/data are consider in a systematic continuous improvement process (Figure 2). Thus, in the case of the creation of a new eco-friendly product which has not the environmental feedback, the designer can use FA method that is enhanced with the introduction of LCA concepts. Then, the designer defines the FR by formatting his data for a next LCI. FU can be defined and the integration of life cycle can allow a better environmental appropriation. After the proposition of solution achieving FR, the pre-filled LCI is completed to quantify environmental impacts. Based on the impacts analysis, potential improvements of the product are proposed. If a redesign is engaged, a new functional analysis is consequently performed and the functional data are updated. The process restarts until the acceptance of the eco-designed product. Nevertheless, for the implementation of this proposition is necessary to develop the six concepts/data connection and several indicators. Due to the advancement of this research, this paper only concerns the integration of "life cycle". Inclusion of other concepts for the collaborative process construction will be proposed in a future paper.

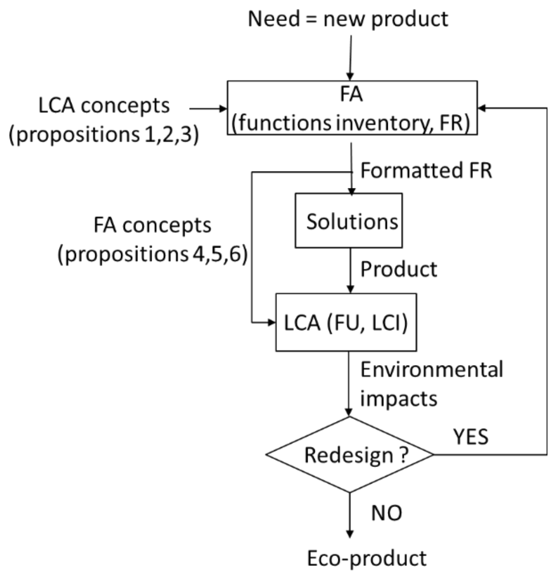

Figure 2. The collaborative process between FA and LCA

3 INTEGRATION OF LIFE CYCLE CONCEPT INTO FA

Defined in ISO 14040 (2006a), life cycle in LCA are the consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to final disposal. The modelling of life cycle in product system allows observing relationships between life phases and how resources are mobilized throughout life cycle to fulfil one or more functions. The standard ISO/TR 14049:2012 (2012), provides examples about practices in carrying out life cycle perspective.

Life cycle concept can be considered in FA like a set of all situations in which the product will be present during its life (AFNOR, 1996). EN 12973 - Value Management (2000) recommends the identification of functions for whole life cycle phases (for example transport functions, storage functions, end of life functions). Unfortunately, in standards of Value and Functional Analysis, this concept is not sufficiently developed. A standards revision (CEN, 2012, 2004, 2000, 1996), revealed the lack of operational details, guides and examples of how to model and manage the life cycle. This lack avoids to understand how the fulfilment of functions can mobilize resources and processes that will affect several life cycle phases.

To overcome this lack of information it is proposed to create a life cycle model in FA with the introduction of life cycle concept from LCA.

A survey that was conducted for this research revealed that 83% of FA practitioners perform functional analysis only for use phase. Thus, the proposition to model life cycle in FA is focalised in the use phase. The functions of use, which are crucial for the creation of a product, can affect the input and output of each life cycle phase and have environmental repercussions on decisions taken at other stages of life cycle. For example, to fulfil a use function is necessary choose the appropriate material, and then affects the phases of acquisition of raw material, manufacturing and end of life. Figure 3 conceptualizes how the decision taken in the use phase will affect other phases of the life cycle. To concretize this idea, extension of "Functional Performance Specification" tool (FPS), defined in 2.1, is proposed. With this tool, the designer can be able to implement the life cycle model in FA.

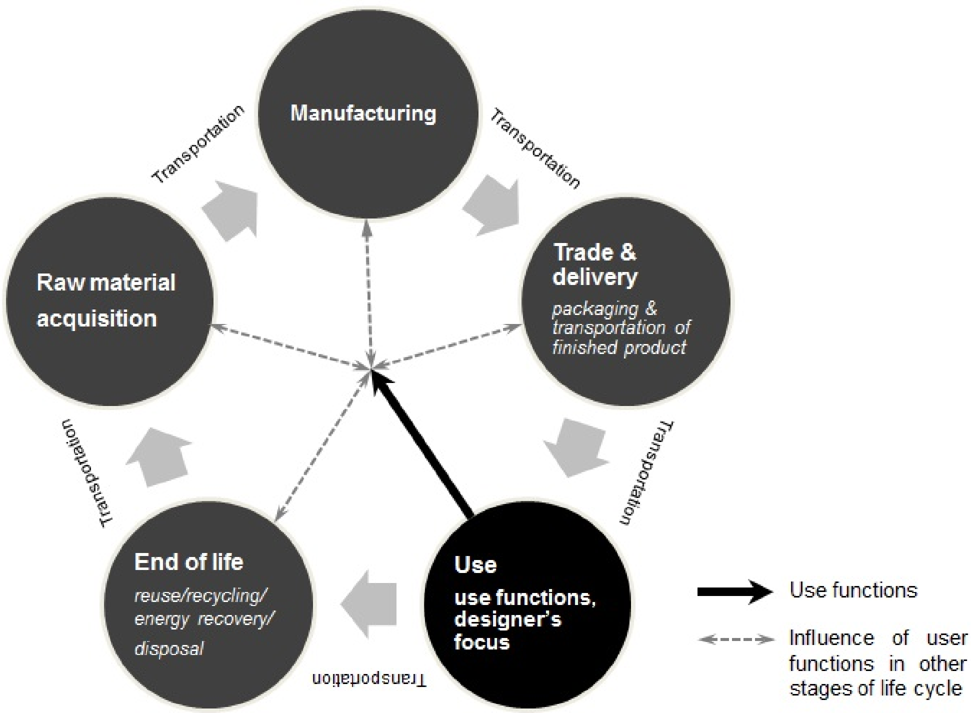

Figure 3. Influence of use functions in other stages of life cycle

3.1 Application of Life Cycle concept in FA

FPS (Table 2), is a document by which needs are expressed in terms of functions (1). For each function expected performance are expressed in terms of assessment criteria (2), levels of performance (3), with a certain degree of flexibility being assigned (4) (CEN, 2000).

Table 2. FPS, definitions from EN 12973 (CEN, 2000)

Functions (1)	Criteria (2)	Level (3)	Flexibility (4)
Effect of a product or of one of its constituents.	Characteristic used to evaluate the performance expected from a function.	Position on the scale of measurement for a function evaluation criterion.	A set of indications regarding the possibility of adjusting the level sought for an evaluation criterion.

As highlighted above, the main idea is that the use functions affect beyond the use phase and also aimed at other phases of the product life cycle. The proposition of a “FPS extension” seeks to follow a process to model life cycle where each function in use phase is questioned in relation to other life phases that it can potentially affect. FPS extension (Figure 4), takes advantage of the functional decomposition in FPS to intervene at the level of design parameters (criteria, level) and thus take into account the repercussions at other stages of life cycle. Repercussion on life cycle depends on the DP because they specify the technical characteristics which will take shape in the solution in terms of material, energy and information. The latter are primarily responsible for environmental impacts throughout the life cycle.The integration of life cycle concept in FA is divided in three steps:

1. Determining the use functions and assign criteria and levels (1). This part of the FPS is realized by following the traditional FA practice.
2. Assignment of a "solution factor" (SF) (2) to criteria and levels of each function. This step helps to connect the use functions with one or more life phases. The designer has to choose a solution factor that could accomplish with the design parameters of a function. The factor chosen depends on designer and prevail over others SF in research to achieve expected performance.
3. The life cycle relationship establishes link between SF and life cycle phase (LCP) (3). Each factor corresponds to one or more life cycle phase that will be affected.
4. Tracking of eco-design guidance (4). Now each function is in relation with one or more LCP and the designer has a whole view of the all life cycle phases that will be affected. To obtain an adapted solution for each function and its corresponding LCP a guideline is being developed.
5. Proposition of a global solution that takes into account technical and environmental recommendations of functions (5).

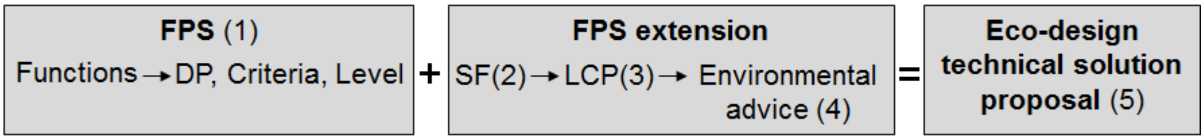

Figure 4. FPS extension

3.1.1 Solution factor

The second step of the FPS extension proposal is the assignment of a solution factor, which prevails over the others to satisfy expected performance of each function. The assignment of a solution factor involve three essential object classes that were chosen to form part of the future solution. They are inspired from "Core Model for Product Data" model (CPM) (Fenves et al., 2008). CPM is an abstract model of a generic semantic to support a wide range of relevant management life cycle information.

The selected object classes, called in this research "solution factor", are:

- Material factor: is the component or constituent matter that will compose the product. The assignment of this solution factor is when the design parameters can be satisfied in terms of the material that will form the product.
- Geometry factor: the chosen geometry factor can be global or specific. Global in terms of the total volume of the product and specific in terms of constituents or product parts. The second choice has no continuity in the FPS as it will be discussed later in detailed design. Global geometry gives a spatial description of the product (Fenves et al., 2008). The assignment of this solution factor is when the design parameters can be fulfilled with respect to the overall geometry driven by the functions, i.e. in terms of product volume.

- Energy factor: The achievement of design parameters depends on the energy, which produces the effect of operation. The energy in CPM is defined like a medium, which serves as the output and the input of one or more transfer functions (Fenves et al., 2008).

To assign a SF, the designer has to carefully review the function, criterion and level to estimate the factor that could satisfy it. For example, criterion and level for a function is weight below 1.5 kg, design parameters can be fulfilled by taking into account the material and its properties. In the same case, to satisfy supply air flow higher than 120 l/min, may be is required an amount of energy to produce this flow. Anyway, this choice depend on designer and can be adapted to the design goal. If the goal is to achieve a low energetic consumption product, the designer will be focused in functions where predominates the energy consumption. Then, designer could assign the energy solution factor to concerned functions.

3.1.2 Life cycle relationship

The next step in the FPS extension process is to link a SF with a life cycle phase (LCP). . A theoretical relationship between solution factors and life cycle phases has been built to be able to assign LCP to SF.

Solution factors material, geometry, and energy, have a broad impact on environmental impacts of product life cycle. Eco-design qualitative tools that address environmental issues to help designers often include recommendations for best eco-design practices related to materials, geometry and energy. Thus, issues such as minimizing resource consumption, reducing energy consumption in the use phase and reducing the weight and volume of products are common recommendations in several qualitative methods. They can be found in tools proposed by Akermark (1999), European Commission (2009), Luttropp and Lagerstedt (2006), Maxwell and van der Vorst (2003), Masui et al. (2001) and Keoleian et al. (1995).

The analysis of previous qualitative tools allowed to observe that eco-design recommendations are generally focused for each phase of the product life cycle. Table 3 shows the choices that have been privileged to realize a theoretical relation between SF and LCP, they are based in recommendations of qualitative tools for each life cycle phase.

The designer will be guide in the Table 3 to link a SF with a LCP in FPS extension tool. Thus, material is related with raw material acquisition, manufacturing and end of life; geometry is related with trade and delivery; energy is related to the use phase. To complete the FPS extension is necessary to create then an eco-design guide that can be developed according to the needs of the designer or company.

The life phase affected should be taken into account to find an adapted solution from an environmental point of view. Consequently, if solution factor is "material" the phases of the life cycle that are considered from an environmental point of view are: raw materials acquisition (RM), manufacturing (M) and end of life (EOL).

Table 3. Theoretical relationships between solution factors and life cycle phases

Theoretical SF - LCP relationship		
SF	**LCP**	**Justification of relationship between SF and LCP**
Material	Raw materials acquisition (RM)	The focus is on the acquisition of raw materials, manufacturing and end of life. The material chosen will affect the acquisition of raw materials, which can cause major environmental impacts. Product manufacture can produce more or less impact depending upon the setting form of the chosen materials. In addition, the end of life of a product depends largely on the type of materials.
	Manufacturing (M)	
	End of life (EOL)	
Geometry	Trade & delivery (TD)	This factor includes comprehensive measures in terms of product volume. Although it can influence several phases of life, the choice of this proposal is the packaging and transportation of the finished product. This will provide an effective size that optimizes transport and packaging of the product in environmental terms.

Energy	Use (U)	A key factor that causes environmental impacts during the use phase is the power consumption. Environmental damage are incurred during the period of use primarily by user behaviour that are influenced by the product design (Oberender et al., 2001).

3.1.3 Eco-design guide

After to assign one or more LCP to each function, the designer need to be guided to obtain an adapted solution. A guideline is being developed that takes into consideration the eco-design main points that allow to respond to different life cycle phases affected by the same function. Thus, the designer will be guided in taking better technical and environmental decision.

3.1.4 Solution proposal

In this point each function has a solution that takes into account not only the environmental impacts of the use phase, but also the life cycle phases that could be affected. The designer working in iterative way could propose a global technical solution. An example of the complete process of the life cycle concept integration is shown in Table 4.

Table 4. Extended FPS example

FPS				Extension of FPS			
Use life cycle phase	**Functions**	**Criteria**	**Level**	**SF**	**LCP**	**Eco-design guide**	**Solution proposal**
	Supply air	Air flow	> 120 l/min	Energy	U	*Under construction*	...
	Filter particles of the air	Degree of filtration, micrometre	≥ 0,0006 µm	Material	RM, M, EOL	*Under construction*	...
	Storing energy	Hours of energy	≥ 8 h	Energy	U	*Under construction*	...

4 DISCUSSION AND PERSPECTIVES

The objective in this paper was briefly present the proposal of collaborative process between FA and LCA and show a part of this process: the integration of life cycle concept.
Find compatibility between FA and LCA methods has enabled the development of a reciprocal strategy, where both methods will be mutually enhanced to generate environmental information early in the design process.
"FPS extension" is a proposition aiming to help the designer in integrating the "life cycle" concept in FA to obtain eco-friendly products. The advantage of this proposal is the expansion of technical solutions toward the environmental dimension. The development of FPS extension, seeks to fulfil use phase functions and take into account environmental constraints of other life phases in order to propose solutions to will have a balanced environmental performance throughout the life cycle. Anyway, the concept of function is difficult to define and multiple approaches are available for working with them. This research is based on value analysis (EN 12973), where functional analysis allows to create functions that can be integrated directly in the "functional performance specification" tool. Although the definition of functions in FA is based on a verb-object format, it was chosen to leave the freedom to the designer to determine the functions and the level of functional decomposition. The concept of solution factor is then proposed. The identification of the solution factors consists in choosing among three categories: material, geometry, energy. They are considered as the most interesting factors that will influence the environmental profile of a product. In addition to these categories other factors of interest may be integrated. Thus, further investigations will be conducted in this way. For the moment the current procedure to go from the function to solution factor is qualitative as well as to go from solution factor to life cycle. Despite the definition of rules for assigning solution factor, it will be considered the creation of a contradiction matrix to check the right choice of this factor. This approach can also be considered for the passage from solution factor to life cycle relation.

The validation method of the integration of "life cycle concept" will be realized with a series of tests to validate or invalidate assumptions by designs teams. They will use the proposal to design in parallel to observe the robustness of the proposal, but also to see if designers are able to better visualize the environmental influence with FPS extension.
At this stage of the research, the collaborative process is only beginning to develop. Although the life cycle model for FA was defined, a long way of construction and validation of all the propositions are needed before collaborative process could be practicable.

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