UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

FACULTAD DE INGENIERÍA
DIVISIÓN DE ESTUDIOS DE POSGRADO

T E S I S

A PROPOSAL OF CRITERIA TO EVALUATE AND RE-DESIGN SUSTAINABLE PRODUCTS

PRESENTADA POR:

ALEJANDRO FLORES CALDERÓN

PARA OBTENER EL GRADO DE:

DOCTOR EN INGENIERÍA MECÁNICA

TESIS DIRIGIDA POR:

DR. VICENTE BORJA RAMÍREZ

CIUDAD UNIVERSITARIA DICIEMBRE, 2011

JURADO ASIGNADO:

Presidente:	Dr. López Parra Marcelo
Secretario:	Dr. Dorador González Jesús Manuel
1er. Vocal:	Dr. Borja Ramírez Vicente
1er. Suplente:	Dr. Ramírez Reivich Alejandro Cuauhtémoc
2do. Suplente:	Dr. Ruiz Huerta Leopoldo

Lugar o lugares donde se realizó la tesis:

Ciudad Universitaria, Facultad de Ingeniería - UNAM

TUTOR DE TESIS:
NOMBRE

____
FIRMA

Abstract

The contradictory use of concepts, the way product sustainability is measured and the extensive offer of sustainability design criteria are some of the important issues concerning Sustainable Product Design (SPD). Two basic questions can be formulated: The first one, what are concerns to the principal elements that really contribute to product sustainability? And the second one, how can the product sustainability be measured? To answer these questions the present research thesis presents an analysis of the most representative Sustainable Product Approaches (SPA) frameworks, methods, and tools that in the specialized literature can be identified nowadays. The analysis is divided into two stages; (1) a 'conceptual taxonomy study' of three SPA (biomimicry, cradle-to-cradle and total beauty), and (2) a re-design case study that is used to assess each of the three approaches. The work carried out allowed the author to compare the design methods and the redesign solutions obtained from each different approach. An original cluster of ready-to-be-used sustainable design criteria is proposed as a result of the investigation of these accepted approaches.

Acknowledgements

The author wish to thank the support to:

- Universidad Nacional Autónoma de México that has supported this research work with its PhD scholarship program UNAM-DGEP.

- The support program 'Research and Innovation Projects' (Proyectos de Investigación e Innovación Tecnológica - PAPIIT), thought the project IN18810 "Metodologías de diseño de productos sustentable".

- The National Science and Technology Council of Mexico through its Basic Science Program CONACYT (México), project no. 83239.

TABLE OF CONTENTS

I n t r o d u c t i o n

C h a p t e r 1

Alejandro Flores Calderón

1.1. Background to research

The intensive production systems that only consider economic variables are remains in past. In contrast, organizations that have been considering environmental, economic and social variables are becoming more competitive (López 1996). The reasons to this model change have different guidelines motives, two of them are: 1) The companies have to fulfill more strict environmental norms (OTA 1995). 2) The companies have to recognize and integrate the cultural changes to the company policies (Alting et. al. 1998, Hemel et. al. 2002).

In this context of paradigms change, the evolution of the organizations can be described in four stages, see figure 1.1

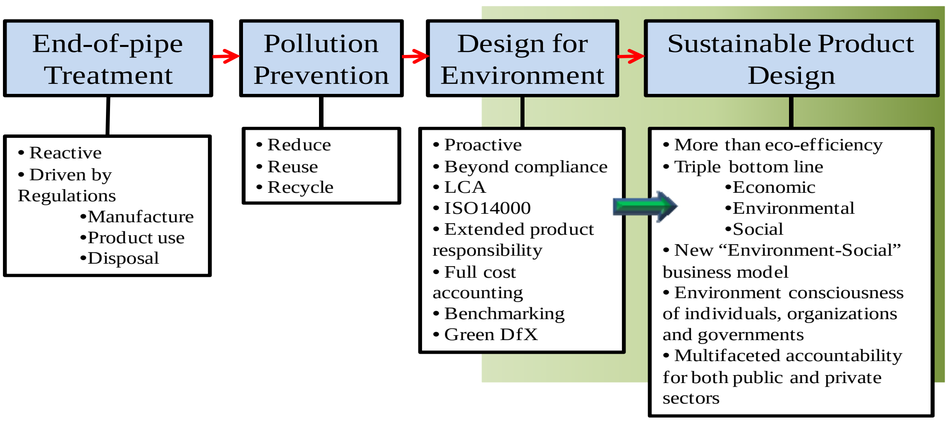


Figure 1.1. Evolution of environment issues to sustainable science and engineering (modified from Mihelcic et. al. 2003)

In the first stage, the design efforts are characterized by its orientation to improve the manufacturing consequences in the environment and regulations developed to control the toxic emissions in different elements such as water, air, and soil (UNU-IDRC 2007). The "reactive attitude" is caused by environment regulations that improve the specifications related to environment protection (OTA-E-541 1992, OTA-ITC-155 1995, OTA-ENV-634 1995). The common concept used by organizations at this stage is to reduce pollution with a minimum cost and without losing competitiveness.

In the second stage, the efforts on design are characterized by its orientation to improve the environmental impact of products particularly at their end of life. At this stage, specialized techniques are implemented, for example: material selection for low environmental impact, the use of minimum amount of different materials, etc. (Hemel et. al. 2002). In addition, specific design methods are implemented targeting on the improvement of particular product life cycle stages; one of such methods is Design for Disassembly that is required to ease and reduce the disassembly and maintenance cost and support the reuse of parts, components and materials (Mien et. al. 2006, Lee et. al. 2001, Flores-Calderón et. al. 2000). The common concept used by organizations at this stage is to reduce waste by recycling parts, materials, and substances discarded as rubbish (UNU-IDRC 2007). Besides, an approach to waste management can be observed.

In the third stage, the design efforts are oriented to integrate the product's life cycle stages with the characteristic of an efficient use of materials and energy (Lin et. al. 2003, Bryant et. al. 2004). At this stage, specific methods and tools are developed and implemented; some of them are (Hundal 2000):

- Raw materials: Strategy- Material use optimization. Design for resource conservation
- Manufacturing: Strategy- Clean manufacturing. Design for cleaner production
- Distribution: Strategy- Efficient in distribution. Design for efficient distribution
- Product use: Strategy- Clean use/operation. Design for energy efficiency
- End of life: Strategy- End of life optimization. Design for Disassembly

The "Proactive attitude" at this third stage establishes a competitive difference in the product life cycle, its benefits can be noticed by consumers and society, e.g.: less energy consumption during operation for the benefits of the end-user, reduction of cost for the society through recycling materials, etc. (Dogan 2003). The common concept used by organizations at this stage is to increase the competitiveness making a positive environmental impact with low cost for the users in each life cycle stage.

In the fourth stage, design efforts are oriented to integrate the sustainability triple bottom line society, economic and environment (Charter 2007). At this stage, frameworks, methods and tools are developed to consider the '*lessons*' from the Nature (McDonough et. al. 2002, Datschefski 2002, Benyus 1997). The sustainability issues observed in the product's lifecycle stages look for increasing the 'capital' in its different forms. The types of 'capital' are (Hawken 1994):

- Human capital: labor and intelligence, culture and organization
- Financial capital: cash, investments and monetary instrument
- Manufactured capital: infrastructure, machines, tools and factories
- Natural capital: resources, living systems and ecosystem services

At this fourth stage, some business models consider the service provided by products as the relevant issue and not necessarily the product by itself (Choi et. al. 2008). The common concept used by organizations at this stage is to improve the quality of life of those related with the product during its lifecycle.

The current research is placed in the fourth stage of the evolution of environmental issues to sustainable science and engineering (see figure 1.1). In this stage, the product design considers the triple bottom line (economic, environment, and social). This kind of design in which are considered these three variables is called Sustainable Product Design (SPD) (Mihelcic et. al. 2003, Charter et. al. 2007, SPC 2011).

1.2 Thesis structure

The present thesis is organized in sections. The *first section* contains chapters 2 and 3; these chapters help to introduce the problematic in the Sustainable Product DEvelopment (SPDE) issues furthermore, in Chapter 3, the contribution to the knowledge is established. The *second section* refers to chapter 4, in this chapter, representative SPA from the specialized literature are described (the selection of these SPA is according to a process defined in section 4.2). The *third section* presents the kernel chapters (chapters 5 and 6), because in these chapters are analyzed the SPA selected in the second stage. The analysis is in two ways, the first in a taxonomic study (chapter 5) and the second one is through the redesign of a common study case (chapter 6). The outcome of this analysis is the identification of the SPD criteria used by the SPA analyzed. The *fourth section* is presented in chapters 7 and 8. Chapter 7 refers to the results and conclusions (obtained in the third section) integration. Also in this chapter, the criteria proposed are defined and described. In Chapter 8, the criteria proved their usefulness in the assessment of the sustainability level of a product.

A detailed description of the content in each Chapter is described below.

Chapter 2 presents a description of the specialized literature, specifically the three kernel issues in Sustainable Product Development (SPDE) are presented, i.e.: SPDE-Framework, SPDE-Models, and Sustainable Product Design. These are the foundations for the analysis done in the current research. The context presented in Chapter 2 supports the aims and objectives defined for the present doctoral research, these objectives and aims are defined in Chapter 3. In addition, in Chapter

3, it is defined the research process and a description of how this process ease the fulfillment of the targets presented.

In Chapter 4, and as part of the research process (Chapter 3), the most referenced sustainable Product Design are identified and described. For the description (Chapter 4) and analysis (Chapter 5) were considered only the references emitted from the original sources, this was done to ensure the correct use of concepts, methods and tools. In Chapter 5, an analysis of the approaches is done in two levels: 1) in a conceptual taxonomic study and 2) through each of the approaches, re-designing a common study case.

In Chapter 6 the criteria, target of the present research, furthermore, the processes to apply in each criterion to evaluate the product sustainability are presented. The previously defined criteria are used in Chapter 7 to evaluate the sustainability of the study case after being re-designed (Chapter 5) through the SPDE approaches.

Chapter 8 presents a synthesis of the work done, highlighting the core points identified during the research development. In addition the results in terms of the criteria implementation are presented, i.e. the sustainability evaluation of the study case re-designed through the SPDE approaches. Finally, some relevant conclusions are set, these in function of the hypothesis and aims defined for the present doctoral research.

Sustainable product approaches –a literature review

C h a p t e r 1

Alejandro Flores Calderón

2.1 Introduction

The Sustainable Development (SD) concept was defined in 1983; however, this is still cited in current technical publications. The SD can be defined (Gilpin 1998, DSM 2008) as "a development that considers the needs of today without compromising the resources of future generations". It refers to three essential components, which are the society, environment, and economy (Charter et. al. 2007, Parris et. al. 2003).

The SD also refers to a development in the triple bottom lines and hence the issues arising in each of them (see figure 1). For example, the issue that refers to the "technology growth" is contextualized in the 'economy' component, but this implies that since the sustainability point of view, the technology growth must incorporate environmental and social issues and not only the economic interests. For other issues in the SD occur similar situations.

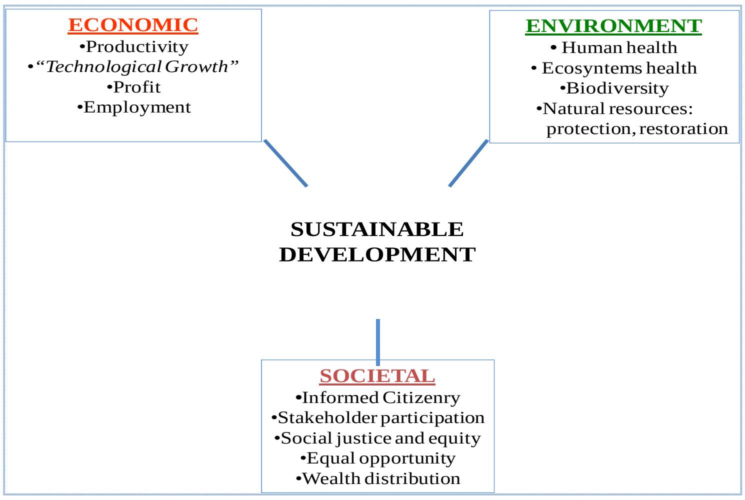


Figure1. Some issues in SD (Michelcic et. al. 2003).

The Sustainable Product Approaches (SPA) are considered as issues of *technology growth* (OTA 1992 y 1994, Michelcic, et. al. 2003, Petrick, et. al. 2004). In this context, the product design deals with more complexity because in the stages of the design is necessary to deal with more variables i.e. with the social and environmental, besides to the economical one.

In this chapter it is analyzed the SPA literature with the target of identifying its principal issues and to describe the theoretical knowledge which supports the present research.

In section 2.2., the SPA principal issues are described and some core concepts are introduced. Finally, in section 2.3 some conclusions are presented. These conclusions support the research problem statement.

2.2 Sustainable product approaches --*a literature review*

For the SPA literature review technical publications were considered books, conferences, journal papers, and public information of easy access[1] (e.g. internet pages, podcasts); in addition the class notes and the suggested readings in the course of SPD given for master students at California University, Berkeley USA were considered (Agogino et. al. 2007).

The analysis of these technical references identifies the principal topics, as well as its targets and aims. This activity had the objective of identifying the most frequent issues used by the authors to present their proposals. The conducted analysis helped to identify three generic groups (Flores-Calderón et. al. 2008): documents related to sustainable product development –Frameworks, documents related to sustainable product development --Methods, and those related with specific sustainable product design –Process.

These three generic groups are described below.

2.2.1 Sustainable product development -Frameworks

In this group, most of the authors use the concept of ‘SPDE-Framework’ to describe how a company gets benefits through the implementation of specific tools. Some benefits of these proposals are for example a better image in the society, a better return investment, competitive advantages, and less pollution emissions (Alting et. al. 1998, Kara et. al. 2005, Hawken et. al. 2005, Choi 2008). After the analysis of this group of references and for the purposes of the present research it is defined the ‘Framework’ for the Sustainable Product DEvelopment (SPDE) implementation as (Flores-Calderón et. al. 2008): *the set of procedures that a company defines to*

1 Easy access in this case means that it is not necessary to be part of any organization or make any payment.

organize processes of decision-making in the economical, social and environmental planes for the development of a product, process, or service.

The features highlighted in this definition such as … '*set of procedures that*'… '*decision-making in economic, social and environment*'*…;* can be observed in the examples presented below. The author considers these examples as representatives of SPDE-Frameworks because it is relatively easy to identify the framework characteristics expressed in the definition.

Fargnoli et. al. (2007)

Fargnoli (et. al.) presents a framework divided in to two decisions making stages; these are: 1) the strategical (*what*?), and 2) the tactical (*how*?).

In the first stage (the "*what*?") the core activities are identified are:

- The analysis of consumers need and the market
- The assessment of performance of the product throughout the product life cycle
- The definition of a design strategy
- The generation of quality information of the product development

In the second level (the *how?*), the product development team will need to define a decision-making process and to select the tools to use and decide "*how*" to apply them (the second level). To do this, some requirements have to be considered:

1. The ability to correctly define the product requirements
2. The skills in the method to be used
3. The effectiveness in the method for assessing the environmental performance throughout the product life cycle
4. The ability to provide new solutions
5. The possibility to improve design activities in the technical, legal and administrative issues
6. The ability to link tools in order to generate information about the product

Regarding to the point 6, Fargnoli et. al. identifies three general tools to generate information:

- Tools based on QFD
- Tools based on LCA (Life Cycle Assessment)
- Tools based on Checklist-based

Burke et. al. (2007)

Burke (et. al.) begin their framework proposal making four basic assumptions, these are:

1. Sustainability is composed of society, environment, and economy
2. ISO 14001 is the base and key step towards sustainability
3. ISO9000/OHSAS 18001/SA 8000 are advantages, but not requirements for the framework
4. Management of sustainability is an incremental process

Burke (et. al.) proposes a process that involves completely the company including technical and administrative processes. This proposal is composed of two stages:

The first stage is concerned to the ISO14001 structure. This stage refers to a procedure of eight steps, i.e.:

1. The definition of a continuous improvement plan
2. The initial environmental review
3. The definition of a strategy
4. The definition of an environmental policy
5. Updating legal and environmental aspects
6. The objectives, goals and programs definition
7. The implementation and the operation
8. The monitoring, auditing and review

In the second level Burke (et. al.) proposes a similar structure to the one in level 1. To do this a tool called ‘management of the sustainability’ is used and the steps are as follows:

1. The definition of a sustainability program improvement
2. The review and the sign the sustainability factors
3. Modify the policy of ISO 14001 to the sustainability management process
4. Define the objectives and indicators of performance definition
5. The implementation and operation of sustainability programs
6. The review of monitoring and audit.
7. The sustainability reports publish.

The process presented by Burke (et. al.) can be adapted to the technical or administrative process of the SPDE.

Kara et. al. (2005)

Kara (et. al.) points out three levels in the framework implementation, these are:

1. Applicability of operational concepts
2. The development of strategic concepts in the SPDE
3. The interaction between the operational and strategical concepts

This framework defines concepts to support the company environmental strategy (level 1), then concepts for making decisions considering the product life cycle and concepts for an efficient internal communication (level 2), and finally operational concepts (level 3) to integrate the environment as a target in the traditional process of product development.

In addition, Kara (et. al.) indicates five basic criteria for a successful implementation.

1. Environmental objectives: the strategy of the SPDE defines the business objectives towards the environmental sustainability.
2. Environmental performance: the effectiveness of the SPDE is achieved by considering the evaluation of the product life cycle.
3. First stages: with an emphasis in the early product development stages to implement best innovations and less expensive solutions.
4. Implementation: The SPDE is based on the strategic direction and the operational tasks of the designers.
5. Simplicity: term applied by designers which is directed to managers. This concept has as meaning "easy to handle and applicable".

2.2.2 Sustainable product development -methods

Currently there is no agreement in the definition of a Sustainable Product (SP). At the beginning of this research the definition proposed by Belz (2006) is considered: SP are those that "*satisfy customer needs and that significantly improve the social and environmental performance along the whole life cycle in comparison to conventional or competing offers*. In chapter 9 it will be proposed a new definition of SP based on the results obtained of the current research.

In addition, Beltz highlight some core product attributes from the sustainability perspective.

- *Customer satisfaction:* If sustainable products do not satisfy customer needs, they will neither survive nor thrive in the market economy.
- *Dual focus:* Unlike “green” products, sustainable products have a dual focus on social and/or environmental performance.
- *Life cycle orientation:* Sustainable products have to take the whole life cycle from cradle to grave into account, i.e. extraction of raw materials, transportation, manufacturing, distribution, use, and disposal.
- *Significant improvements:* Sustainable products have to make significant contribution to the main environmental and social problems analyzed and identified with appropriate protocols and instruments of the life cycle assessment.
- *Continuous improvement:* Sustainable products are not absolute measures, but relative in dependence of the status of knowledge, latest technologies and societal aspirations, which change over time. A product that meets customer needs and that has an extraordinary social and environmental performance today may be considered standard tomorrow. Thus, sustainable products have to be continuously improved regarding customer, social and environmental performances.
- *Competing offers:* A product that satisfies customer needs and that proposes environmental and social improvements may still lag behind competing offers. Thus, the offerings by competitors are yardsticks for improvements with regard to customer, social and environmental performances.

Regarding to the SPDE methods, like in the SP concept, there is not one widely cited definition by those who work in the SPDE field. There are definitions that respond to particular targets, e.g., some of them are methods proposed from the academic perspective (Vogtländer 2001, Howard et. al. 2006, Agogino et. al. 2007, Byggeth et. al. 2007); others from industrial concern (Petrick et. al. 2004, Maxwell et. al. 2006, Woy et. al. 2007, Tsai et. al. 2009); and some of them are proposed by not profit organizations (e.g. PNUMA 2007). After the analysis of this group of references, and for the purposes of this research, it is defined ‘SPDE-Method’ as: “*A way to link the company´s Sustainable Development policies with the sustainable product targets”*. The features highlighted in this definition are common in most of the before references. These features are described below.

- *A way to link:* The SPDE is a complex issue that demands strong and multidisciplinary work in the company departments. Therefore, the way(s) in ‘how a company coordinates its efforts in sustainability' refers to integrate the economical, social and environmental variables to the multidisciplinary SPDE teams.

- *Sustainable development Policies*: The set of these policies can have different origins, some of these can be environmental regulations, government taxes incentives, competitive advantages, etc. Independently of their origins, they define a framework for the decision makers.
- *Sustainable product targets*: They refer to satisfy customer needs and propose environmental and social improvements.

The author considers to the SPDE-Method proposed by Woy et. al., as a good representative of this group because in it, is relatively easy to identify the features expressed in the definition (see Figure 2).

Woy et. al. (2007)

In this method it is presented a generic product development process in which the inclusion of the sustainability variables to the process stages (*pre*, *during*, and *post*) are described.

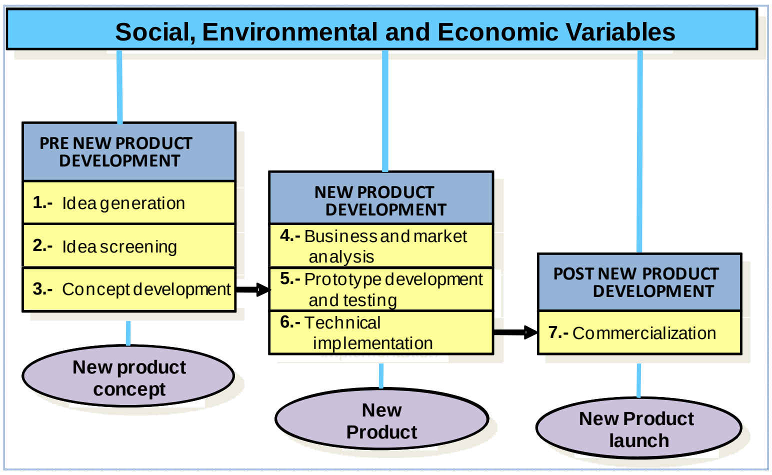


Figure 2. Stages in the SPDe; adapted from Woy, et. al. (2007)

Woy et. al., describes a generic approach to the SP through the sustainability variables inclusion in the design and development process. This inclusion is supported in two forms: *The first one* refers to the company's directives decision to declare an environmental policy and ensure that this is clearly understood by the product development team. *The second one* refers to the use in the product development process technology that manages environmental variables, e.g. (see figure 2): In stage 3 can be the use of 'life cycle analysis' tools to generate and develop product concepts. In stage 5, the CAD-CAM systems that incorporate environmental modules can be useful. In stage 7 tools of 'distribution analysis channels' can be convenient.

2.2.3 Sustainable product design -processes

Summers (2005) identified three elements that engineers use during product design. In the sustainability context, these elements can be described as follows (see also figure 3):

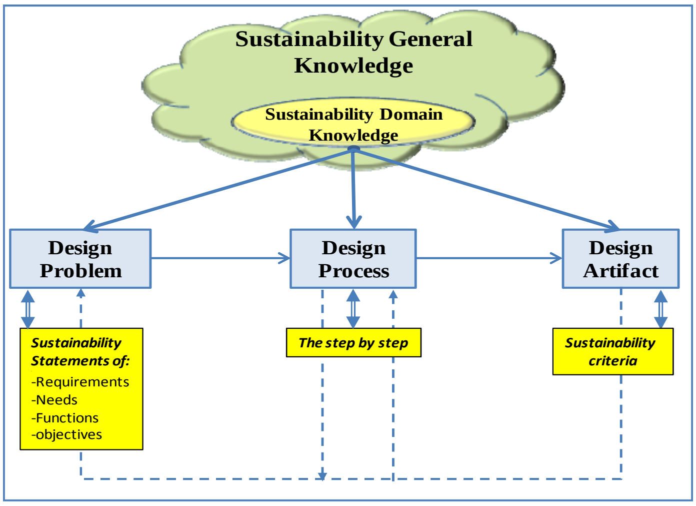


Figure 3 Relations among Design *Problem*, *Process*, and *Artifact* (adapted from Summers 2005)

1) *The Sustainability Design Problem (SDP):* The SDP is a statement of requirements, needs, functions, and objectives of design in terms of sustainable attributes to be solved for the product. The design problem is the purpose or the catalyst for executing the design process in search of a suitable design artifact. As the design problem describes the sustainability goals of the design, it is associated with the design specifications or the conclusions of reasoning (design problem ~ conclusions).
2) *The Sustainability Design Process (SDPR):* The SDPR includes the steps that are undertaken to find satisfactory solutions to the stated SDP. The warrants of the design process may include the experience of the designer, design rules, design procedures, sustainable domain knowledge used (or available), and sustainable design methods. The possible set of knowledge that may be

included in the design process is extremely large, yet still not complete (design process ~ warrants).

3) *The Sustainability Design Artifact (SDA):* The SDA is the SDPR result that is developed to meet the needs described in the SDP. In addition, the SDA is a model of the design variables and therefore is associated with the grounds or minor premises of reasoning (design artifact ~grounds).

Figure 3 presents a generic relationship among SDP, SDPR, and SDA. The solid lines connecting the elements present the typical flow or primary relationships among them. The dashed lines show secondary relationships in the cyclic model of design. The design artifact feeds back into the SDPR and may be included in the redefinition of the SDP. This means that the SDP knowledge (warrants) is used to analyze whether specific values of the SDA (grounds) achieve the SDPR (conclusions) desired goals.

SPD approaches reported in the specialized literature presents product improvement examples in the following issues:

- Least amount of materials and energy in the creation and use of the product (Kara et.al. 2003)
- Limited emission and use of dangerous substances (Greenwood 2004)
- Fewer parts and components (Bryant et. al. 2004)
- Increased recycling of parts, components and materials of the product (Ljungberg 2007)
- Use renewable resources (Thinkcycle 2009)
- Longer life of the product (Mien et. al. 2005)
- Ease of disassembly (Lee et. al. 2001)

The literature analysis shows that in the SPD the objectives are defined according to particular intentions of those that propose them, e.g., objectives to make improvements in product competitiveness, demonstrate academic proposals, fulfillment of environment regulations, etc. The analysis of several of these SPD objectives shows that most of them have at least one of the next three characteristics:

I. *Increase the Organization (company) value:* This feature result refers to fostering loyalty by investing in customer relationship management and product and service innovation that focuses on technologies and systems, which use financial, natural and social resources in an efficient, effective and economic manner over the long-term. The tendency is to invest in companies that are worried in their environment and social context (DJSI 2011).

II. *Reduce the costs to society throughout the product life cycle:* This feature result refers to the government's regulations. These regulations extend the company's responsibility to the complete product life cycle. The society does not have to pay the economic costs derived from the products in along of its life cycle. The tendency is to increase the regulations and taxes by the 'bad practices' (e.g. use of toxic materials, not consider efficient use of energy, toxic emissions during the product manufacture etc.) (Hemel et. al. 2002).

III. *Reduce the toxicity level for the human and environment:* Like in the previous point, this features result refers to the increment of government's regulations and by the society conscious. The tendency is to increase the regulations and taxes (national and internationally) in all the stages of the product life cycle, these can be (local, regional or global) (Michelcic et. al. 2003), and the social tendency of preferring 'eco-products' (Beltz 2006).

2.3 Conclusions

The literature review reported in this chapter performed a survey on the main issues related to the SPDE. Recent research reported in the specialized literature, exposed in this chapter, shows that most of them can be grouped in one of the next issues: SPDE Frameworks, SPDE Methods, and SPD Processes. These issues were described in this chapter. The survey on these main issues also helps to introduce some core concepts.

The issues identified in the literature, in addition permits to distinguish three implementation levels of the sustainability bottom lines, (environment, economic, and social). The last statement means that it is possible to distinguish how the environmental, economic, and social variables are used and implemented in the SPDE Frameworks, SPDE Methods, and SPD Process. This also shows a structure among the issues identified, this means that in the SPDE --Frameworks are defined the main sustainability policies that a company defines for the SPDE. These policies are considered in the SPDE --Methods to define a decision-making process in the product design. The SPDE Methods has SPD processes in which are defined the targets for the product improvements in terms of economic, environment and social capitals. In opinion of the author, the companies should have at least one simple structure as the one described before.

Considering an overview of the present literature review it can be conclude that, the SPA have been acquiring a high level of maturity. This can be observed by the increasing number of publications related to these issues and because of the level of specialization, particularly over the past 10 years (Stroble et. al. 2008). In addition, recent research on ‘engineering design’ has shown the inclusion of other areas of knowledge as for example biology, chemistry and human-environment health (Liu et.al. 2009).

However, there are still some challenges to overcome in the SPD research-field as for example, the misleading and sometimes contradictory use of concepts (Boks, et. al. 2007), and the lack of ready-to-use sustainability criteria and guidance tools for the design of products (García-Serna, et. al., 2007).

In the SPA it is desired to identify which are the attributes that distinguish the sustainability of a product i.e., for the designer it is fundamental to know the sustainability *criteria* consider for the product design; and for customers it is important to know which are the sustainability *features* to consider before buying a product. The considerations of these (*criteria* and *features*) leads to a multi-attribute decision making situation with regards to the selection of the most appropriate product.

Contribution to knowledge

C h a p t e r 3

Alejandro Flores Calderón

3.1 Introduction

This Chapter aims to define the objectives and contributions of the research conducted. It is described as well the research process applied. Finally, the contributions to knowledge of the present dissertation are stated.

3.2 Research problem and research questions

In Chapter 2, the main research lines in which most of the technical publications can be classified were identified and described. The research lines identified were SPDE Frameworks, SPDE Methods, and SPD Processes. In the description of these lines, it was possible to distinguish how some sustainability concepts are applied.

In this scenario, different authors had identified some barriers and contradictions in the use of concepts, methods, tools and criteria in the SPA (Boks, et. al. 2007). At the end of Chapter 2 some conclusions about the SPA were presented. In particular, three main conclusions can be done: 1) The rapid evolution of the issues related to the SPA and 2) The misleading and sometimes contradictory use of concepts related to SPA, and 3) The lack of ready-to-use sustainability criteria for the SPD.

The present research deals with the second and third points enounced in the previous paragraph. The author states three fundamental questions in the current research.

- *What are the design criteria that really contribute to the product sustainability?*
- *How these criteria are defined?*
- *And, how can the sustainability of a product be measured?*

3.3 Research Hypothesis

The hypothesis stated for the current research is:

Through a detailed analysis of representative SPA identified in the specialized literature it is possible to distinguish the essential criteria (common to the technical proposals analyzed) to re-design more sustainable products and evaluate their sustainability.

According to this hypothesis, a kernel concept for this research can be defined: "sustainable design criteria". Two common, definitions for the "criteria" concept are: According to EB (2008) 'criteria' refers to: 1) A standard on which a judgment or decision may be based. 2) A characterizing mark or trait standard. The OXED (2011) reefers to "criteria" as: a principle or standard by which something may be judged or decided.

In the present research, the author defines *sustainable design criteria* as the judgments done or considered (explicitly or implicitly) in the SPD decision-taking process.

This definition is intentionally wide with the target of considering the greater number of meanings of this concept.

3.4 Thesis objective

The present thesis has as objective:

- *To propose a criteria cluster to evaluate the product sustainability*

These criteria can be useful:

1. To evaluate the product sustainability i.e. measures quantitatively the product sustainability. The criteria has the characteristic of being ready-to-use

2. To generate specific information for the product re-design i.e. sustainability attributes to be considered by the decision maker in the product re-design process.

3.5 Research process

According to the hypothesis defined in section 3.3, a valid approach to identify the 'essential criteria' can be supported through a comparative analysis of the most successful SPA that can be identified in the specialized literature. This comparative analysis has three kernel points:

- The first one refers to a 'conceptual taxonomical study': the target of this study is to analyze and compare the core concepts among the most referenced SPA.

- The following refers to 're-design methods': the target is to explore the methods and tools proposed by the SPA for the product *re*-design.

- The third one refers to the re-design of a 'unique study case': the objective of this study case is to compare the re-design results in terms of its sustainability criteria.

With the results and conclusions of these three kernel points, the common criteria to the SPA analyzed (the hypothesis defined, see section 3.3) could be identified.

A detailed description of this research process is presented below:

1. *Literature Review:* The aim of this stage is to present and describe the principal issues related to the SPA. This description was reported in Chapter 2; some examples of the SPA references were cited and described. This states the bases on which the research problem for the present thesis is defined.

2. *Identification of representative SPA:* The aim of this stage is to identify the most complete SPA; to do this a process of selection was defined. A description of this process and its results are presented in Chapter 4.

3. *Core concepts study:* The aims in this stage refer to highlight the conceptual coincidences and differences among the SPA analyzed. To do this, it is necessary to integrate all the information from the original sources i.e. from the organizations that propose the sustainability approach or from the original authors. The study is based on information from

original authors to ensure the correct interpretation of concepts and their use. This study is carried out in a conceptual taxonomic study that is presented in Chapter 5.

4. *Analysis of the re-design process:* The aim of this stage is to describe the activities, methods and tools carried out in each SPA analyzed. This study is presented in Section 6.3 and Appendix B.

5. *Re-designs of the study case:* The aim of this stage refers to apply the SPA re-design processes. Through the re-design a common study case and the comparison of the results in terms of product sustainability attributes. The complete study is divided and presented in three sections (i.e. 6.3.1, 6.3.2, and 6.3.3).

6. *Comparison and results analysis*: The aim in this stage refers to summarize the comparative results and conclusions (stages 4, 5 and 6) and then synthesize them in terms of sustainability criteria (section 6.4).

7. *Define criteria definition:* The sustainability re-design criteria identified in stage 7 are the basis of the current proposal. The aim of this stage is to make a SPD criteria structure (ready-to-use) for product evaluation in terms of sustainability attributes. This information, in addition, is used to generate information in the product re-design. These sustainability re-design criteria in Chapter 7 are presented.

8. *Sustainability criteria application:* The aim of this stage is to apply the sustainability criteria by assessing the re-designs obtained in each SPA (sections 6.3.1, 6.3.2, and 6.3.3); this is presented in section 8.1. The results of this evaluation represent a quantitative value of the product sustainability level; this sustainability level is identified (section 8.2) as a sustainability indicator.

3.6 Contribution to knowledge

Current research (Chapter 2) shows different forms to consider the sustainability variables in the SPA. But, Boks, et. al., (2007) and García-Serna, et. al., (2007) identified some problematical situations in e.g. the use of concepts, methods, tools, and design criteria. This situation stated in

Boks (et. al. 2007) and García–Serna (et. al 2007) can be seen in the comparative analysis carried-out in the current research.

Besides to the diversity of sustainable design variables identified in Chapter 2 and the problematical situations pointed out by Boks and García-Serna; the author conclude that in the specialized literature there are not general sustainability product design criteria widely accepted, but it is possible to identify some coincidences, i.e., mimic the Natural processes. The current research analyzes the specialized literature in SPD and identifies the coincidences among them. In specific the present research is about sustainability design criteria considered in the product re-design processes. The contribution to the state of the art relies in the presentation of criteria for the sustainability product re-design. The criteria proposed should be ready-to-use to evaluate the sustainability of a product and they have to be useful in order to generate specific information for the product re-design.

This proposal of sustainability criteria is original due to the fact that in it the experiences of representative and successful SPA approaches are integrated.

Description of the sustainable product approaches

C h a p t e r 4

Alejandro Flores Calderón

4.1 Introduction

In this chapter it is defined and applied the process in which are identified the most successful SPA that can be distinguished in the specialized literature; this is presented in section 4.2. In section 4.3 are described these SPA, in addition, relevant concepts are introduced. Finally, in section 4.4 some conclusions are presented.

4.2 Representative sustainable product approaches

In the research process (section 3.5), the second stage refers to identify representative SPAs from the specialized literature. To identify these SPAs it was considered the literature survey presented in chapter 2 and in addition, it is defined a process to select the most successful SPA. The author considers 'representative SPAs' as those that fulfill the requirements described in the process defined below:

1. Identify all the documents which principal topics are:
    a. Sustainable product development frameworks
    b. Sustainable product development methods
    c. Sustainable product design processes
2. Select documents between 1995 *(to ensure a minimum standard of recent information and because of the possible necessity of have a evolution perspective in the candidates)* and 2009 *(year in which was done the study)*
3. Select documents aimed to show or demonstrate the application of methods, models, processes, or frameworks related to the SPA.

In this part were identified 28 documents (some of them were cited in the literature review, section 2.2). Continuing in the process, two more stages are defined:

4. Select the author(s) that has published at least two of the next options: journals, conference proceedings, books, theses, research reports, web pages, etc.
5. Authors with at least three study cases in which their methods, models, process, or frameworks are referenced.

At the end, three SPA were identified. :

- *Cradle to Cradle (C2C); William McDonough & Michael Braungart*
- *Biomimicry (BIO); Janine Benyus*

- *Total Beauty (TB); Edwin Datschefski*

In section 4.3, a description of these SPAs is presented.

In the selection process of the SPA can be observed that the author intention was to look for references that represent a minimum index of formalism in their proposals (see stage 4 in the process) and with proved examples in the market (stage 5 in the process). In addition; in proposals of other authors can be observed references from these SPA selected. Contributing to confirm the present SPA selection, these appear as important references analyzed in the sustainable product design course for graduate students at Berkeley (Agogino et. al. 2007) and they are point-out in AIGA (2009) because of their contributions in the Evolution of Visions, Principles, Frameworks and Tools for Sustainability.

The next step in the research process (see third stage in the section 3.5) is to integrate the information (all as possible) is emitted from the original authors or from the same organizations in which they participate. This is defined with the target of ensure that the definitions, concepts, methods and tools are from the original proposes and do not from interpretations of others.

4.3 Description of the representative sustainable product approaches

In the below sections the SPA C2C, BIO, and TB are described. In Appendix A it is presented SPA extra information that supports the descriptions exposed in the following sections. Appendix A refers to a complete list of concepts, its definition, and it is expressed in most of them a context description.

4.3.1 Cradle to Cradle (C2C)

C2C is a design framework developed by MBDC (McDonough Braungart Design Chemistry) which is a consultancy firm founded in 1995 by William McDonough and Michael Braungart (MBDC 2008). They proposed the philosophy, principles and concepts of C2C used to improve companies´ practices to make them more sustainable (McDonough 2002).

MBDC has defined three basic principles (also the authors refer to these principles as "tenets") based on the observation of the natural systems. These principles are:

- *Waste equals food:* It refers to the processes on which each organism engaged in a living system contributes to the health of the whole. The concept of waste virtually does not exist in nature because each organism's processes contribute to the health of the whole ecosystem. Designers can recognize that all materials can be designed as nutrients that flow through natural or designed metabolisms.
- *Use current solar income:* It refers to the use of sunlight to "manufacture food". Designers can use this principle to ensure that energy is renewable rather than depleting.
- *Celebrate diversity:* Healthy ecosystems are complex communities of living things. Designers might profit from this principle by considering the maximization "all sustainability is local". It means optimal sustainable design solutions draw information from and ultimately "fit" within local natural systems.

Others two relevant concepts related to the first principle are:

- *Biological Metabolism:* It refers to the natural processes of the ecosystems. This metabolism needs biological nutrients that consist in biodegradable material posing no immediate or eventual hazard to living systems that can be used for human purposes and can be safely return to the environment to feed environmental processes.

- *Technical Metabolism:* It is modeled on natural systems. It is a term used for the processes of human industry that maintain and perpetually reuse valuable synthetic and mineral materials in closed loops. This metabolism needs materials that remain in a closed-loop system of manufacture, reuse, and recovery, maintaining its value through many product life cycles.

C2C makes a difference between two concepts, 'Eco-efficiency and Eco-effectiveness'. The difference is explained in the context of the sustainability of a product (see figure 4.1).

- *Eco-efficiency:* Refers to the strategies for "sustainability" of minimizing harm to natural systems by reducing the amount of waste and pollution that human activities generate. In this context, sustainable design is the process that defines objectives that pretend to increase the economic value of a product, and simultaneously decrease the negative effects to the environment and to the society.

- *Eco-effectiveness:* Refers to the strategy of designing a human industry that is safe, profitable, and regenerative; producing economic, ecological, and social value. To achieve this kind of industry, C2C proposes to keep the quality and the productivity of materials through subsequent life cycles. The philosophy of C2C design can be expressed saying that in an ideal design a 100% of the materials are nourishment into a biological metabolism or a technical metabolism.

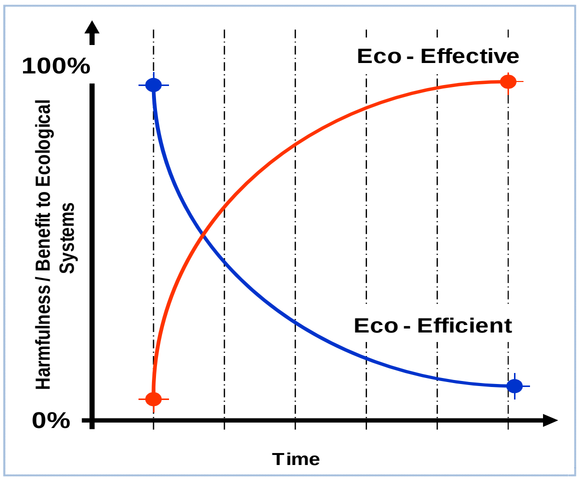


Figure 4.1 Eco-effective vs. Eco-efficient (McDonough, et al. 2002)

In order to achieve an ideal design McDonough, et al., defined a strategy for an eco-effective product (re)-design. This can be summarized as:

1. *Get "free of" known culprits.* It refers to turn away the substances that are widely recognized as harmful. These harmful substances are called as "X" substances. The decision to create products that are "free of" forms a kind of "design filter" that is in the designer's head instead of on the ends of pipes.
2. *Follow informed personal preferences.* In any design process decisions are taken under the best available information, but currently there is a lack of data and experience on sustainable issues. In this context the designer should choice or prefer one of the next possibilities:
   a. *Prefer ecological intelligence:* Choose products that do not contain substances or support practices that are clearly harmful to human or environment.
   b. *Prefer respect:* Respect to those who make the product, for the communities close to where it is made, for those who handle it, and ultimately for the customers.
   c. *Prefer delight, celebration, and fun:* For ecological products to be at the forefront, they should express the best of design creativity, adding pleasure and delight to life.

3. *Create a "passive positive" list (P).* The list is made by systematically evaluating the materials of a product and classifying them according to its toxicity to human and ecosystems. The "P" list includes substances defined as healthy and safe for use. This aspect refers to rethink how the product is made of, not what it fundamentally is--or how it is marketed and used.
4. *Activate the positive list.* It refers to optimize the "P" list until the point of each material is truly defined as biological or technical nutrient. It is necessary to encode information about all of the ingredients in the materials themselves, in a kind of "upcycling passport" that can be read and used productively by the future generations.
5. *Reinvent.* This concept gives to designer to reinvent the relationship with the end user, for example to create business models based on the service of the product and not necessary on the product itself.

In Appendix 'A' it is presented a complete list of concepts regarding to this SPA. This list of concepts and their description is helpful to complement the description of C2C presented in this section.

4.3.2 Biomimicry (BIO)

The "Biomimetic" concept has its origins in 1957 when Otto Schmitt, in the biophysics field, described biomimetic as an approach to problems of biological science using the theory and technology of the physical sciences (Vincent et. al. 2006). In the early 60's, the term "Bionics" was introduced in the US Air Force by Jack Steele. He defined Bionics as the science of systems that have a function copied from nature, or which represent features of natural systems or their analogues (Hsiao 2007).

However, it was until 1974 when the word Biomimetics made its first public appearance in the Webster's Dictionary. The Webster's Dictionary identifies as synonymous of Biomimetic the words 'biomimesis', 'biomimicry', 'bionics', 'biognosis', 'biologically inspired design' and similar words and phrases implying, copying or adapting or deriving from biology. In this research, it will be used the term 'Biomimicry' (BIO).

The literature review shows that between Biomimicry and Product Development, there are four basic issues commonly discussed:

1. The development of new materials that incorporate “nature friendly” properties e.g. Casis et. al. (2007).

2. The application of particular models taken from nature to aid in the solution of specific technical problems e.g. Kim et. al. (2008)

3. The application of generic design methods for a broader type of products e.g. Mansoorian, et. al. (2004)

4. The development of data structures to share information between biology and technology e.g. Cheong, et. al. (2008)

The Biomimicry concepts, design method, and tools analyzed in this research are the ones proposed by The Biomimicry Institute (BI) (BI 2011). This is the proposal resulted in the process defined in section 4.2. The BI promotes the use of BIO in many different ways; it encourages the emulation of natural forms and processes to create more sustainable and healthier technologies (BIO 2011). Benyus (1997) defines Biomimicry as a design and leadership discipline that seeks for sustainable solutions emulating Nature’s time-tested ideas. The vision is to create products, processes, organizations, and policies—new ways of living— that are well adapted to life on Earth over the long haul. Benyus identified three core concepts (Benyus 1997):

- *Nature as model:* BIO is a new science that studies Nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.
- *Nature as measure:* BIO uses an ecological standard to judge the "rightness" of our innovations. After 3.8 billion year of evolution, Nature has learned: What works. What is appropriate. What lasts.
- *Nature as mentor:* BIO is a new way of viewing and valuing Nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it. Once we see Nature as a mentor, our relationship with the living world changes.

In Appendix ‘A’ it is presented a complete list of concepts regarding to this SPA. This list of concepts and their description is helpful to complement the description of BIO presented in this section.

4.3.3 Total Beauty 'BioThinking' (TB)

The "Total Beauty" (TB) concept has its origin in 1998 when Edwin Datschefski used it to characterized products by means of sustainability criteria (Datschefski 2002). The criteria are aimed at identifying if products are fully compatible with Nature throughout their entire lifecycle (BioThinking 2011).

Datschefski synthesizes in five core concepts the experience of 500 green products. The study also identified 24 techniques (*the manner in which the issues dealt with* (EB 2008), *as in sustainability e.g.*) for green innovation (see table 4.1) (BioThinking 2011).

Table 4.1 Techniques for green innovation

✓ Recycled materials	✓ Extremely long view
✓ Components	✓ Re-use
✓ Increased efficiency	✓ Complementary
✓ Organic Mat. and composting	✓ Increased utility
✓ Dematerialize	✓ Upgradability
✓ Multifuntionality	✓ Photons
✓ Substitute Materials	✓ Stewardship sourcing
✓ Fine control	✓ Work with the seasons
✓ Biomimicry	✓ Be more local
✓ Bio-everything	✓ Hydrogen and electricity
✓ Every little count	✓ Muscle power
✓ Durability	✓ Takeback and remanufacture

The core concepts proposed by Datschefski are classified in three groups (BioThinking 2011):

1. The first three, which derived from the Bio-everything technique, refer to *'mimic'* the protocols used by plants, animals and ecosystems:
    - *Cyclic*: The product is made from organic materials, and is recyclable or compostable, or is made from minerals that are continuously cycled in a closed loop.
    - *Solar*: The product uses solar energy or other forms of renewable energy that are cyclic and safe, both during use and manufacture.
    - *Safe*: The product is non-toxic in use and disposal, and its manufacture does not involve toxic releases or the disruption of ecosystems.

2. The fourth one refers to the maximization of the utility of resources in a finite world:
   - *Efficient*: The product requires 90% less materials, energy and water in manufacture and use, than products providing equivalent usefulness in the year 1990.
3. The fifth refers to the maximization of human happiness and potential:
   - *Social*: The product's manufacture and use supports basic human rights and natural justice.

In TB, the goal for sustainable products is to be 100% *cyclic*, *solar* and *safe*. In addition, they use materials and energy *efficiently*, and they are made in companies that actively look for employees and suppliers equity, *social* (Datschefski 2002).

The TB sustainability approach introduces the concept of “BioThinking” which meaning refers to as *looking at the world as a single system, and developing new ecology-derived techniques for industrial, organizational and sustainable design*, (Datschefski 1999).

In Appendix ‘A’ is presented a complete list of concepts regarding to this SPA. This list of concepts and their description is helpful to complement the description of TB presented in this section.

4.4 Conclusions

At the beginning of the present Chapter, a procedure to select representative SPAs was defined and as result of this process were identified C2C, BIO and TB. Then it is concluded that these approaches are the SPA to be considered in the present research and the first step in this way is a description of them; this was done in section 4.3.

In Chapter 5 and 6 these SPA will be analyzed in detail.

Conceptual taxonomy study

Chapter 5

Alejandro Flores Calderón

5.1 Introduction

In chapter 4 the SPA on which is based the present research were identified and described. This chapter refers to the stage 4 defined in the research process (section 3.5). This Chapter presents a taxonomy study that synthesizes and compares the SPD approaches mentioned above.

The taxonomy study (section 5.2) includes three levels: Sustainable Development, Sustainable Product Development and Sustainable Product Design Task. In section 5.3 the SPAs visions, focus points and key concepts are pointing-out furthermore some comparative comments are presented.

5.2 Taxonomy study

The study began with an analysis of the publications written by the identified authors (see Chapter 4). This was to ensure that the definitions, development and concepts used are obtained from their original sources.

With this analysis, core concepts of each author(s) were identified as well as a description of the context for their use. This information was summarized in tables; an example of them is presented in table 5.1. The complete tables are presented in Appendix ‘A’.

For C2C 44 core concepts were identified. For example, table 1 is presents the concept of ‘C2C’. This concept lets us to conclude that C2C makes emphasis in a long term vision, where the design is fundamental for the elimination of conflicts between the three bottom lines for the sustainability.

For Biomimicry 14 core concepts were identified one of them is for example ‘Biomimicry Revolution’ (table 1). This concept refers to the Nature as a source of knowledge, to the biology as a science that helps to understand how Nature function and whit the design, mimic the Nature using the biological knowledge.

Table 5.1 Example of core concepts tables (Flores-Calderón et. al. 2009).

	CRADLE TO CRADLE		
	CONCEPT	DEFINITION	DESCRIPTION
1	C2C	It is a science--and values based vision of sustainability successfully that enunciates a positive, long-term goal for engineers.	C2C designs industrial systems to be commercially productive, socially beneficial, and ecologically intelligent. C2C is a framework that posits a new way of designing human systems to eliminate conflicts between economic growth and environmental health resulting from poor design and market structure. It is based on the manifested rules of nature and redefines at hand, eco-efficient strategies can serve a large purpose.

	BIOMIMICRY		
	CONCEPT	DEFINITION	DESCRIPTION
1	Biomimicry Revolution	It introduce an era based not on what we can extract from nature, but on what we can learn from her.	In a biomimicry word we would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibers, ceramics, plastics and chemicals

	TOTAL BEAUTY				
	CONCEPT	DEFINITION	DESCRIPTION		
1	Techniques for innovation	Having analyzed over 500 products, the author found that all the innovations were base on just 24 techniques.	Recycled materials Re-use Organic Materials and composting Takeback and remanufacture Muscle power Hydrogen and electricity Photons Substitute Materials	Extremely long view Increased efficiency Increased utility Dematerialize Every little counts Be more local Multifuntionality Fine control	Components Complementary Upgradability Durability Bio-everything Biomimicry Stewardship sourcing Work whit the seasons

For Total Beauty 18 core concepts were identified. A representative one is 'Technique for Innovation' (table 5.1). This concept refers to the job made up over 500 products and the identifications of innovation techniques applied on them.

All these concepts were analyzed with the target of understand how they are defined, how they are related and how they are used. To make it possible was applied a taxonomical study. The taxonomic studies (Gershenson, et. al. 1999) are commonly used to add order and clarity to large bodies of information. In addition, Gershenson (et. al.) indicates three interrelated issues that characterize a taxonomy study: parallel structure, completeness and perceptual orthogonality.

Parallel structure

This characteristic in the taxonomy helps us to define the frontiers and gives structure to the study.

A taxonomic study of C2C, BIO, TB, was carried out at three levels of abstraction. These levels of abstraction allowed a better appreciation of the author's intention, in how they use the concepts, their justification and the application of the methods. Also this characteristic in the taxonomy lets a better appreciation of the concepts for a sustainable product design.

The first level of the taxonomy was defined as 'Sustainable Development' (SD) (see table 5.2). There are concepts with a high level of abstraction or too generic, but they justify the conceptual frameworks for the SPDE methods. The relevant concepts were classified according to its sustainability focus (economy, environment or social, [Parris 2003]).

The second level of the taxonomy was defined as 'Sustainable Product DEvelopment' (SPDE) (table 5.2). A product development process typically can be divided into three generic phases [Woy, et. al. 2001] (in this case sub-topics in table 5.2): 'pre-product development' (also divided in idea generation and concept development); 'product development' (also divided in prototype, development and testing); and 'post-product development' (commercialization).

Identified the subtopics in the SPDE the next step is to identify the methods and tools according to its purpose within the SPDE process. It also allows a better understanding of the interactions that take place among them.

The third level of the taxonomy was defined as 'Sustainable Product Design Task' (SPDT). It refers to the lowest level of abstraction and includes very specific concepts in terms of design activities. This level of abstraction is divided into four classifications of design tasks (sub-topics in table 5.2) (Wenzel, et. al. 2000): Focusing (referring to point out the most significant), Specification (referring to characterize the purpose of the product), Synthesis (referring to integrate the systems in a functional product) and Verification (referring to compliance with the product objectives).

Completeness

This feature of the taxonomy aids to allocate any concept of its domain and identify each part of the taxonomy as a complete unit and, at the same time, as a part of a bigger unit.

The completeness of the taxonomy is reflected in two complementary ways: the taxonomy integrates the three abstraction levels (i.e. SD contains SPDE and SPDE contains SPDT); and each abstraction level includes its own sub-topics forming a complete unit too. For example the environment, economic and social aspects form a complete unit for SD (Parris 2003). The SPDE completeness has its origin in the sub-classification (*pre*, *during* and *post*) that can divide whichever product development process (Woy 2007). For SPDT, its completeness is given by the generic sub-classification that groups any task of the sustainable product design process (Wenzel, et. al. 2000).

Table 5.2 Taxonomy study of the SPAs (Flores-Calderón et. al. 2009)

ABSTRACTION LEVELS (Topics)		CONCEPTUAL FACTOR		CRADLE TO CRADLE Dominant concepts	BIOMIMICRY Dominant concepts	TOTAL BEAUTY Dominant concepts
		Sub-Topics	Complementary information			
SUSTAINABLE DEVELOPMENT	1	Environment	Biotic factors Abiotic factors	* Waste does not exist in nature * All the organisms sustain the system. * Sun light to manufacture food	* Nature as model * Nature as measure * Nature as mentor	* Cyclic * Solar * Safe Mimic the protocols used by plants and animal ecosystems.
	2	Social	Relationships between individuals and groups	* Improve the quality of life	* What is good for life first, and trust that it will also be good for us	* Support of basic human rights and natural justice. People are living a decent life and are treated fairly. It is necessary to know where materials and components are coming from and how they are being made.
	3	Economy	Efficient use of resources	* Use and create industrial systems into regenerative forces	* Economies are like ecosystems; both systems take in energy and materials and transform them into products. The problem is that our economy performs a linear transformation, whereas nature's is cyclic.	* Eco-efficient is just the begining, because cost reductions has its limits.
SUSTAINABLE PRODUCT DEVELOPMENT	4	Pre-Product Development	Idea generation	* Product of consumption: It is safe and complete return to the environment, * Product of service: It is used by the customer, but owned by the manufacturer	* Create new ways of interact whit product—that are well-adapted to life on earth	* Products that are part of the living ecosystems * Those that are part of the "technosphere"
			Concept development	* Eco-effectiveness	* Compare ideas (concepts) whit the Life's Principles	Considering *cyclic *solar *safe *efficient *social
	5	Product Development	Prototype, development and testing	* Assess materials for human and ecological health	* Creating conductive ways to life (see Life's Principles)	* Considering the entire product lifecycle
	6	Post-Product Development	Commercialization	* Reinvent the relationship between product and customer	* Closing the loops in commercial possibilities	* Showing comercial advantage of products that are cyclic, solar, safe and efficient.
THE TASK OF THE DESIGNER	7	Focusing	The most significant	* Avoid the use of toxic materials	* Biologize the human needs (the design problem)	* Ensure that products are fully compatible with nature throughout their entire lifecycle
	8	Specification	The target for the new product	* 100% biological and/or technical nutrient	* Find the best Natural Models to answer your questions.	* 100% cyclic / solar / safe / efficient / social
	9	Synthesis	The product and its systems	* The materials are part of a closed-loop	* Mimicking Form * Mimicking Function * Mimicking Ecosystem	* Efficiency in energy and materials in the product life cycle
	10	Verification	Compliance with the objectives	* Create value throughout the economy, ecology and equity (social)	* The Life's Principles	A product ca be scored in two main ways -- * Relative to a baseline * Absolute term

Perceptual Orthogonality

This characteristic in the taxonomy helps us to ensure that each taxon can be classified in one and just one option.

This is observed in the taxonomy study by the definition or by the complementary information (see table 5.2), e.g.: For ‘environment’, the concepts that are part of the environment are the ‘biotic or abiotic’ factors (EB 2008). For ‘Pre-product development’, the concepts in which can be divided this SPDE sub-topic are (Woy, et. at. 2007): idea generation and concept development. For the sub-topic ‘focusing’ we refer to the concepts that mark the most significant.

This allows us to be very specific and to provide a better judgment for the classification of the concepts. A complete view of the taxonomic study can be seen in table 5.2.

5.3 Results in the taxonomic study

The results in taxonomic study are summarized in table 5.3.

Table 5.3 Comparative comments for the SPA analyzed (Flores-Calderón et. al. 2009)

	CRADLE TO CRADLE C2C	BIOMIMICRY BIO	TOTAL BEAUTY TB	COMPARATIVE COMMENTS
VISION	Design products that completely can be integrated to a biological or in a technical metabolism.	Create products that are well-adapted to life on earth over the long haul.	Products which are fully compatible whit nature throughout their entire lifecycle.	A coincidence can be observed in the three proposals in their vision of being close to the natural process. For example C2C refers to ‘bio or techno metabolisms’. BIO talks about being -‘well adapted to life’. TB talks of ‘compatible with nature’. The approaches focus and emphasize points which are different in every particular design procedure. C2C focuses on materials; for BIO, the focus point is the interaction between the human needs and the nature or the biology; and TB presents a synthesis of 500 green products and is defined the targets. Regarding the design process, some differences are observed as well. C2C, for example, is not a design process is a framework, but it can be adapted to establish material requirements in any particular design process. In the case of BIO, a design process is defined which is structured on the base of ‘life’s Principles’. Finally, TB develops tools that permit to maximize the focus points.
FOCUS POINT(S)	Materials and its chemical	Biologize the human needs	100% cyclic / solar / safe / efficient / social	
PRODUCT DESIGN PROCESS	It is not a design process, it is framework that can be adapted to any design process	Structured to interact and find the best solution in nature and translate it in a technical solution.	Oriented to maximize the ‘biocompatibility’ of the product throughout be cyclic, solar, safe and efficient	

Other results from the taxonomic study are:

<u>Cradle to Cradle (C2C)</u>

C2C defines the approach to sustainability as a dynamic interaction between the environment, the society and the economy. ‘Environment’ is the dominant sub-topic, because it defines the relations with the ‘social’ (improving the quality of life) and with the ‘economy’ (creating new forms of businesses).

In the SPDE topic there is a core concept, ‘eco-effectiveness’ that was classified in the sub-topic pre-product development. This concept is relevant because it helps to defines a solution to the supposed antagonism between the environment and economy; making an economic suitable proposal, but also socially and environmentally convenient.

In the task of the designer, the consideration of materials in the designer tasks is notorious. Essentially, the tasks are oriented to: 1) Use of materials that are not toxics for humans or the environment; 2) Use of materials that are bio or techno nutrient of another process.

Biomimicry (BIO)

In this approach to sustainability as a model that imitates the health of natural systems is presented. And for the economy, ecosystems can be good represents of development in harmony.

The sub-topic ‘environment’ is fundamental because it drives most of the SPD decisions and the designer tasks, also because ‘nature’ is considered as a model, measure and mentor.

The SPD is also close to a natural process, but in this case some ‘Life’s Principles’ have been defined to assists in the decision making process.

In the designer task (table 2), the concept of ‘biologize’ the human needs is included. It refers to a transformation of humans needs in terms of biological solutions, and a return from biology to human needs to give a technical solution.

Total Beauty (TB)

The approach to sustainability is presented as a search to the equilibrium of human rights, `biothinking’ for a convenient economic benefit and `biothinking’ for environment protection.

With regards to SPD, a group of concepts that assists the decision making process was defined. These concepts were synthesized from a study of 500 green products, so the decisions taken considering this innovation technique help to develop sustainable products.

The activities in the designer task are oriented to fulfill the target of 100% of the cyclic, solar, safe, efficient and social.

In addition to the previous points, a description of the sustainable product design processes for the three approaches can be done from the conceptual taxonomic study. This description is summarized in table 5.2.

5.4 Conclusions

Some relevant conclusions from this taxonomic study are described below:

- *The strongest conceptual coincidence* among the studied approaches is their intent to be close to Nature or to have similar processes to it, e.g. C2C refers to 'bio and techno metabolisms', BIO talks about being 'well adapted to life' and TB talks about 'compatibility with Nature'. The conceptual divergences of the approaches are reflected on the views they use to be "compatible with Nature", e.g. C2C uses nontoxic materials (based on chemical information), BIO mimics Natural systems (based on models taken from biology) and TB applies probed solutions (based on 500 green products).

- *At the Sustainable Development level* of the analysis it was found that, the concepts used by the studied approaches are too generic, but they support the concepts applied in the SPD processes. For the three approaches, the 'environment' is the kernel concept, but they use it in particular ways: for C2C 'in Nature, waste does not exist'; for BIO Nature is 'a model, a measure and a mentor'; and for TB 'it is the source to mimic the Natural protocols in terms of cyclic (materials), solar (renewable energy), safe (nontoxic substances)'.

- *At the Sustainable Product Development level,* specific concepts were identified for each approach, i.e. the 'product development' concept is guided in C2C by 'eco-effectiveness', in

BIO by ‘the life principles’ and in TB by ‘the approximation to a product 100% cyclic, solar, safe, efficient and social’.

- *At the Task of the Designer level*, specific concepts were identified and related to design activities. Each activity was linked to one of four groups, depending on the design activity’s ‘intention’. The groups are listed in the first column of figure 1, under the heading ´task of the designer’. This means that the activity fits in-group one if it is oriented to identify the sustainability most significant features or parameters therein mentioned. The activity fits in-group two if it is oriented to define the sustainability targets for the new product. The activity fits in-group three if it is oriented to integrate or abstract the product or its sub-systems. The activity fits the last group if it is oriented to compare or evaluate compliance with the sustainability objectives.

It is important to mention that; originally, C2C and TB are defined as frameworks not as product design or re-design processes. On the other hand, BIO is defined as a design process. However, this taxonomic study helps to place the three SPA in the same abstraction levels and compare them, at least, in a conceptual level as is presented in this chapter.

The study case and its re-design

C h a p t e r 6

Alejandro Flores Calderón

6.1 Introduction

In Chapter 5 a taxonomic study of the most mature SPA identified in the specialized literature was presented. In this Chapter, the analysis of these approaches continues through the redesign of a study case in common for the three approaches. This part of the analysis corresponds to the stage five defined in the research process stated in section 3.5.

In this Chapter, section 6.2, the study case is described. In section 6.3, it is re-designed the study case through the activities, methods and tools of the SPAs analyzed. In addition, a detailed description of the activities for each approach is presented. Finally, in section 6.4 some conclusions are given.

6.2 The study case

The study case refers to a Motorized Lens (ML), this is shown in Figure 6.1. The ML is a versatile artifact that embodies mechanical, electrical, and electronic components, making use of steel, aluminum and plastic materials for its construction. The ML is an appropriate study case because it illustrate basic concepts and functions that can be transformed from the pure “cost to manufacture” to the sustainable product domain. This ML is typically fitted to photographic cameras in vision workstations. In bioscience laboratories, these devices are programmed to automatically capture images from experiments during predetermined periods. The ML has therefore to be able to accurately focus, control aperture and zoom according to the demands of dynamic biotech processes.

The ML consists of a camera lens that is driven by three electric motors coupled to spur gear mechanical transmissions. The motor controller is enclosed in the printed circuit board (PCB) that handles the ML´s basic actions: automatic aperture, focus and zoom. The PCB is also wired to a DC power connector and a DB9 RS232 pinout. The camera lens and all the electric and mechanical components are mounted onto an aluminum plate. This subassembly is encased and protected by a one-piece ABS housing. Table 6.1 and figure 6.2 present a detailed description of the ML.

Table 6.1 List of ML parts

Part #	Qty	Description	Part #	Qty	Description
1	1	Connector of voltage DC	**16**	2	Brass bar (75.8 mm)
2	1	DB9 Connector	**17**	1	Assembly of PCB control
3	1	O-ring parker 2-339	**18**	1	Assembly of PCB feeding
4	1	O-ring parker 2-337	**19**	1	Gear of zoom for the lens
5	2	Lateral fasteners	**20**	1	Lenses of 28mm
6	3	Gear	**21**	1	Housing
7	3	Spring	**22**	1	Glasses´ adaptor
8	3	Bushing	**23**	1	Plaque of fastening
9	3	Motor	**24**	1	Gear of focus for the lens
10	6	Screw of button heat	**25**	1	Plaque for housing
11	1	Flat head screw (assembly plaque of connecters)	**26**	1	Gear of opening for the lens
12	3	Flat head screw (lenses´ adaptor)	**27**	1	Adjust ring glass-plaque
13	3	Head flat screw (Housing and “Al” plaque)	**28**	1	Screw Prisoner kind
14	2	Button head screw	**29**	1	Energy cables
15	4	Brass bar (23.2 mm)	**30**	1	Plaque for assembly of connectors

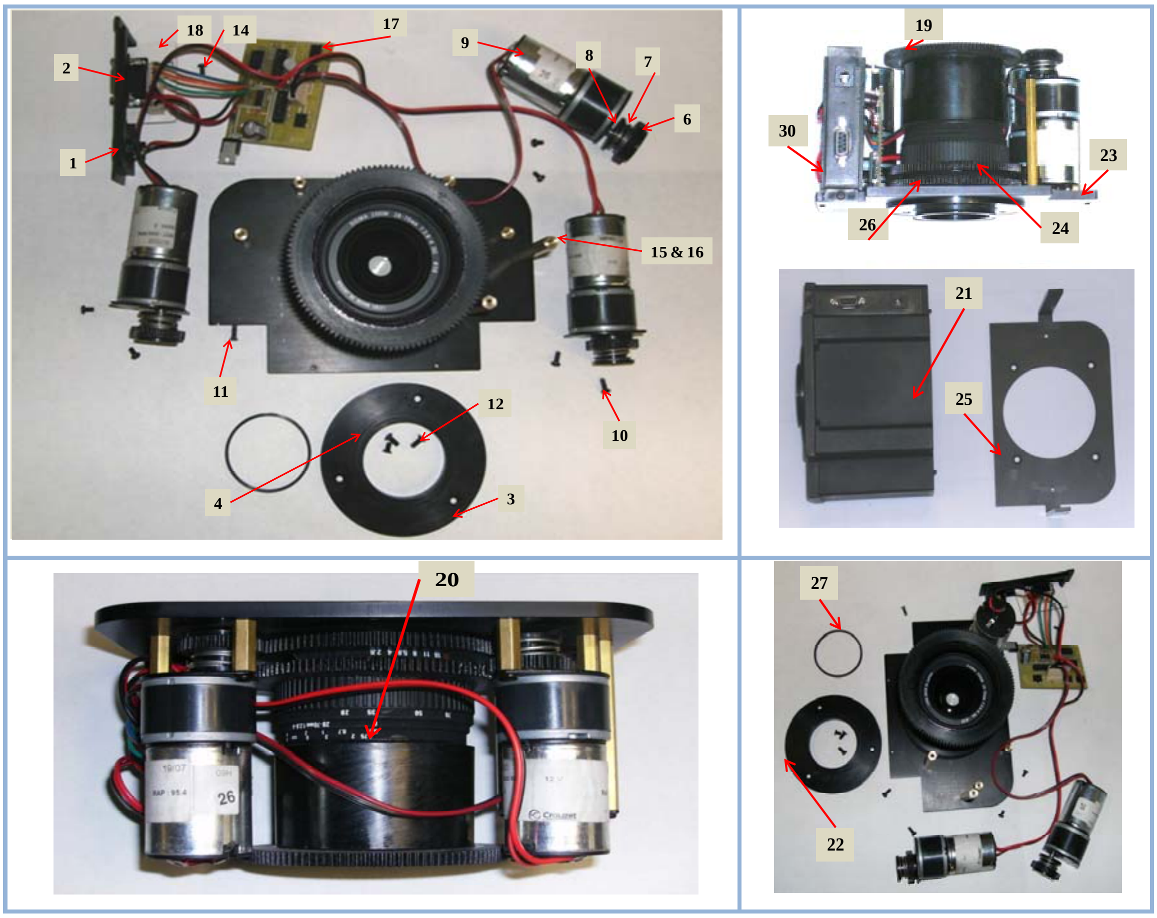


Figure 6.1 The Motorized Lens (ML)

6.3 The re-design of the study case

In chapter 5 a conceptual taxonomic study of the three SPA in three abstraction levels was presented. In this section the three SPA in the context of the third abstraction level are explored, i.e., at the level of *task of the designer*.

By a taxonomical analysis (Flores-Calderón et. al. 2009A) and by the analysis of others re-design study cases reported in the literature it was possible to synthesize the re-design processes, see figure 6.2. These processes, in addition, were explored and reported in Flores-Calderón et. al. (2009B, 2010, 2011).

The designer tasks are divided in four categories (see figure 6.2). In each category are grouped the activities and tools that correspond to the category (see section 5.2 for the meaning of each category), some examples of activities are showed in figure 6.2. A detailed description of the re-design activities, methods and tools for each SPA are summarized in Appendix 'B'.

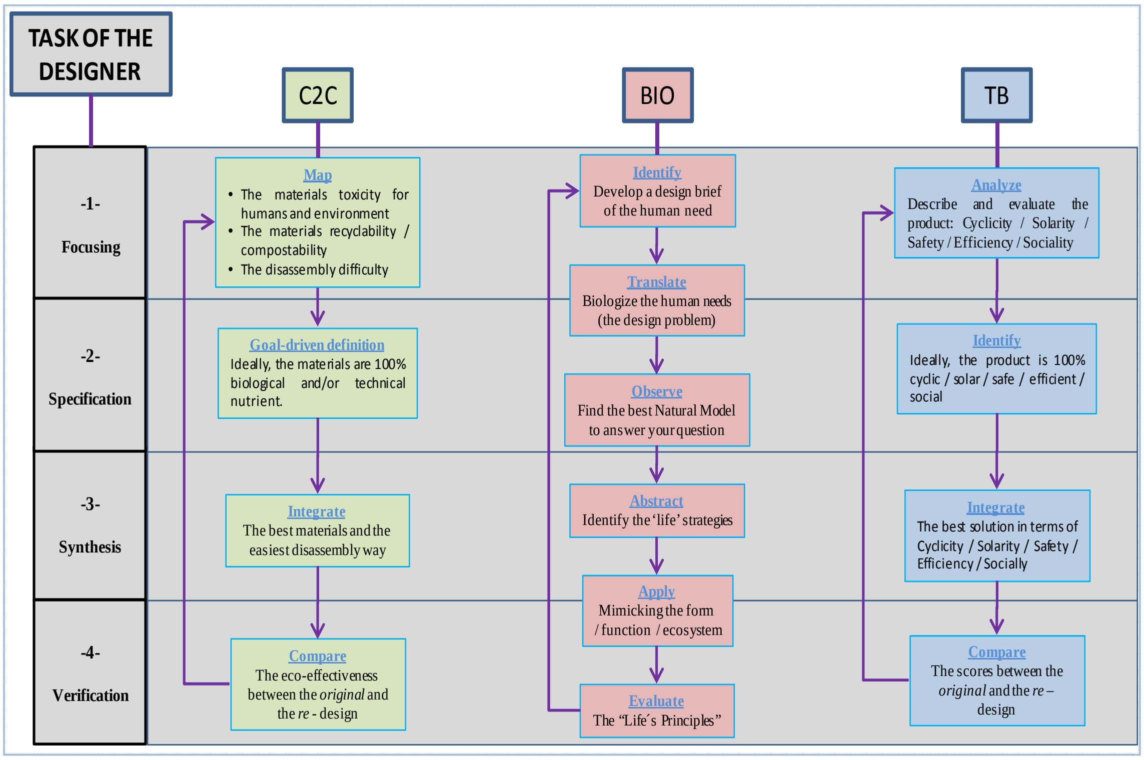


Figure 6.2 SPAs re-design processes

In the following sections, the re-design processes (figure 6.2) are applied to re-design the ML. The description of the re-design processes are divided in the four categories (*Tasks Of the Designer TOD*) before described; this is with the target of making a comparative analysis of the activities in each category. The analysis in the conclusions of the current chapter is presented, section 6.5.

6.3.1 Cradle to cradle (C2C)

In a strict sense, C2C is not a design process is a framework that can be used or adapted in specific product design or re-design process. An example of this is the 'product design process' defined and implemented by Herman Miller, Inc. (HM) for its Mirra Chair (Rossi, et. al. 2006). For the present research, it was considered the design process defined in Rossi, et. al. (2006) because it uses, specifically, the C2C framework and because one of the authors is a Senior Project Manager at MBDC (MBDC 2008), the company founded by the authors of C2C authors.

C2C has established a "goal-driven" that states that products have to be made entirely 100% biological and/or technical nutrients. For this, HM defines a Design For Environment (DfE) product assessment tool that make possible to assess the progress towards C2C goal. This process is used for the redesign of the study case, the ML.

The activities in the redesign process are grouped according to the categories of the designer tasks (see figure 6.2). A detailed description of these activities is presented in the following sections:

C2C – 'FOCUSING' ACTIVITIES

Collect chemical constituent data:

The ML is disassembled and its parts were analyzed obtaining the following: 30 Components. 9 Different materials. 51 Different chemicals. Table 6.1, presents the materials proportions of its total weight.

Table 6.1 Materials proportions of the ML

Materials by weight	
Metal Alloys	6.8 %
Plastics	19 %
Aluminum	27.6 %

The difference to complete the 100% of the weight corresponds to the lenses and to the motors, which material characterization was not documented and they were not considered for the redesign.

Color code material based upon MBDC Protocol:

MBDC defines a material assessment protocol (Mcdonough 2003) based upon a hazard assessment of each of the chemical constituents to manufacture material and it rates them as follow:

- *A green rating* indicates that a chemical presents little or no risk and is acceptable for the desired application.
- *A yellow rating* indicates low to moderate risk, and this chemical can be used acceptably until a green alternative is found.
- *An orange rating* means that the chemical is not necessarily high risk, but a lack of information prevents a complete assessment.
- *A red rating* means high risk. Chemicals with a red rating include all known or suspected carcinogens, endocrine disrupters, mutagens, reproductive toxins, teratogens, and chemicals that do not meet other human health or environmental relevance criteria.

The classification system for the chemicals is based on the human and ecological health ends points listed in table 6.2.

Table 6.2 Human and ecological health included in MBDC's materials assessment protocol (McDonough 2003)

Human health endpoints	Ecological health endpoints
Carcinogenetic	Algae toxicity
Teratogenicity	Bioaccumulation
Reproductive toxicity	Climatic relevance
Mutagenicity	Content of halogenated organic compounds
Endocrine disruption	Daphnia toxicity
Acute toxicity	Fish toxicity
Chronic toxicity	Heavy metal content
Irritation of skin / mucous membranes	Persistence / biodegradation
Sensitization	Other (water danger list, toxicity to soil organism, etc.)
Other relevant data (e.g., skin penetration potential, flammability, etc.)	

HM consulted the MBDC specialist to define the level of toxicity of each material. According to the MBDC process, the chemicals that constitute the material is assigned a color according to the rating above described for the material. The process defined by MBDC can be described as follows:

1. If the material is clearly classified as red, orange, yellow or green, according to the color criteria and the protocol of table 4; then the material adopts that color of classification.
2. If the material cannot be classified then a search for the materials is carried out, but this time at a level of chemicals of the material. The material adopts the color of its chemical classified as the most toxic.

The techniques, methods, studies and results in chemical analysis of materials carryied out by MBDC are not available to the public. That is why in the study case of the ML the materials were classified according to different information sources such as the Agency for Toxic Substances and Disease Registry (ATSDR 2010).

“Contextual filter” adjust color code based upon how chemicals are used:

It refers to the criteria definition that a company adopts and decides whether adjust the rating downward, for example from red to yellow because of minimal exposure concerns. Each case is different and is necessary to know the context.

C2C – ‘SPECIFICATION’ ACTIVITIES

The search for a safer alternative: At this stage, alternative materials to those rated as red or orange are looking for.

In the Mirra Chair case (Rossi et. al. 2006) it was defined as a goal that the use of materials that rank yellow or better. The same goal was set for the redesign of the ML. Will be used materials that are ranked yellow or better.

Table 6.3 shows the materials toxicity for some components. In Appendix C it is presented the complete list.

In the original ML it was identified (e.g.) the use of ‘Polycarbonate’. This is a material frequently used in the electronic industry, but the ATSDR identifies it as dangerous for the human health because in its manufacture it is used the BPA (Bisphenol-A) a chemist associated to human reproductive diseases. Also the ATSDR indicates the need of new research of this material to identify other consequences against the human health. This material was ranked as red.

In the re-design, the component has a rank of green because in the context of 'green chemistry' is possible to find new materials that are environmental convenient. These materials are known as 'organic' electronics materials because the polymers and molecules are carbon-based, like the molecules of living things (Mohanty et. al. 2002). In specific the component made of polycarbonate was changed by one made of cellulosic plastic, a bio-composite (Mohanty et. al.).

With regard to other components, which function implies structural resistant as in the housing can be used Biofiber composite (PB 2009).

Weight the component:

- Measure the weight of each component (see the 'Wt (g)' column on table 6.3).

Calculate "material chemistry weight" for each component:

- Multiply the component's weight by its material chemistry assessment color code, which is translated into a percentage: Green=100%, Yellow=50%, Orange=25% and Red=0%. See column Wt Credit (%) in table 6.3.

Calculate "material chemistry score" for entire product.

- Add up the material chemistry weights of all of the components (see column 'Wt Credit (g)') and divide by the total weight of the product to calculate a material chemistry score for the entire product (see column 'Final Score').

The HM Design For Environment (DFE) method consider other aspects such as:

C2C – 'SYNTHESIS' ACTIVITIES

<u>Disassembly:</u> The ease of disassembling products is based upon four questions (Rossi 2006):

1. Can the component be separated as a homogeneous material (no other material attached)? The goal for the disassembly is to create individual components that may have value when recycled.
2. Can the component be disassembled using common tools? The goal is to be easily disassembled anywhere in the world.
3. Does it take less than 30 seconds for one person to disassemble the component? Experts concluded that 30 seconds is too long for any component to be removed (Rossi et.al. 2006).

4. Is the material identifiable and marked? If parts are not marked, then disassemblers will not know which recycling bin to place them in.

Each component receives a disassembly score of either 100%—if all four answers are "yes"—or 0%—if one or more answers are "no." The disassembly score for each component is multiplied by the weight of the component to achieve a disassembly weight for each component. The final disassembly score is the ratio of the total disassembly weight to the total weight of the product. Table 6.4 shows the disassembly score for the ML.

Recyclability + (Recycled / Renewable Content):

The recyclability / compostability of a component can be defined by three criteria:

1. Is the material a technical or biological nutrient and can it be recycled (or composted) within an existing commercial collection and recycling infrastructure? If yes, the component receives a score of 100%.
2. Can the component be down-recycled (recycled but into a lesser value product) and does a commercial recycling infrastructure exist to collect and recycle it? If yes, the component receives a score of 50%.
3. Is there no recycling potential or infrastructure for the product? If yes, the component receives a score of 0%.

The recyclability (see recyclability column in table 6.5) score for each component is calculated by multiplying the recyclability percentage by the weight of the component. The final recyclability score is the ratio of the total recyclability weight to the total weight of the chair (see table 6.5).

The goal for the ML was a recyclability ranking, of 75%.

The method for scoring recycled/renewable content is (see 'Recycled/renewable content' column in table 6.5): the percent weight of a component made from recycled or renewable content equals the recycled/renewable content score for that component.

The recycled/renewable content score is multiplied by the weight of the component to achieve a recycled/renewable weight for each component. The final recycled/renewable score is the ratio of the total recycled/renewable weight to the total weight of the ML.

Table 6.5 shows how both the recycled/renewable content score and the combined score for recyclability and recycled/renewable content are calculated. The combined "recyclability and recycled/renewable content score" is a weighted average of recyclability (75% of the recyclability weight credit) and recycled/renewable content (25% of the recycled/renewable weight credit).

The DFE product assessment tool calculates a single DfE score for each product. See table 6.6.

- Calculates a final DFE score for each part in the product. The DFE score for each part is determined by the scores received in each of the three assessment categories: material chemistry (column 'Wt Credit (g)' in table 6.3), disassembly (column 'Wt (g)' in table 6.4), and recyclability– recycled/renewable content (column 'Wt'd ave. (g)'in table 6.5). These scores are summed and divided by the total potential DFE weight of the part to create a final DFE score.
- Weights each of the three assessment categories equally: material chemistry, disassembly, and recyclability–recycled/ renewable content. Within the last category, recyclability of materials carries a higher weight than recycled/renewable content (to promote the development of materials that can be closed-loop recycled). See column Potential DFE wt in table 6.6.
- Adds the DFE weights for all the parts divided by the "total potential DfE weight" of the parts, to calculate the final DFE score. See column 'Final score' in table 6.6.

In appendix 'C' are exhibited tables 6.3 to 6.6 showing the complete calculus for the ML re-design under the C2C sustainability approach.

Table 6.3 MATERIAL CHEMESTRY CALCULATION FOR THE MOTORIZED LENSES RE-DESIGN

MOTORIZED LENSES REDESIGN									
Bill of Material						Material Chemistry			
Part #	Qty	Description	Material—Print	Supplier	Wt (g)	Rating	Wt Credit (%)	Wt Credit (g)	Final Score
1	1	Connector of voltage	Bioplastics (cellulosic plastic)		4	*Green*	100	4	
2	1	DB9 Connector	Bioplastics (cellulosic plastic)		6	*Green*	100	6	
3	1	O-ring parker 2-339	Biofiber composite		0.8	*Green*	100	0.8	
4	1	O-ring parker 2-337	Biofiber composite		2.4	*Green*	100	2.4	
5	2	Lateral fasteners	Steel--SAE 1010		30	*Yellow*	50	15	
6	3	Gear	Bioplastics (Poliesteramidas)		8.25	*Green*	100	8.25	
7	3	Spring	Steel--SAE 1010		9	*Yellow*	50	4.5	
8	3	Bushing	Bioplastics (Poliesteramidas)		11.14	*Green*	100	11.14	
			Weight of all the components		***1572.9***			***1337***	***85***

Table 6.4 DISASSEMBLY ASSESSMENT FOR THE MOTORIZED LENSESS RE-DESIGN

MOTORIZED LENSES REDESIGN												
Bill of material						Disassembly assessment				Disassembly score		
Part #	Qty.	Description	Material—Print	Supplier	Wt (g)	#1	#2	#3	#4	Wt credit (%)	Wt (g)	Final score
1	1	Connector of voltage DC	Bioplastics (cellulosic plastic)		4	**No**	Yes	**No**	Yes	0	0	
2	1	DB9 Connector	Bioplastics (cellulosic plastic)		6	**No**	Yes	**No**	Yes	0	0	
3	1	O-ring parker 2-339	Biofiber composite		0.8	Yes	Yes	Yes	**No**	0	0	
4	1	O-ring parker 2-337	Biofiber composite		2.4	Yes	Yes	Yes	**No**	0	0	
5	2	Lateral fasteners	Steel--SAE 1010		30	Yes	Yes	Yes	Yes	100	30	
6	3	Gear	Bioplastics (Poliesteramidas)		8.25	Yes	Yes	Yes	Yes	100	8.25	
7	3	Spring	Steel--SAE 1010		9	Yes	Yes	Yes	**No**	0	0	
8	3	Bushing	Bioplastics (Poliesteramidas)		11.14	Yes	Yes	Yes	Yes	100	11.14	
			Weight of all the components		***1573***						***1258***	***80***

Table 6.5 Recyclability + recycled/renewable content ASSESSMENT FOR THE ML RE-DESIGN

MOTORIZED LENSES REDESIGN													
	Bill of material					Recyclability			Recycled/renewable content			Recyclability + rec./ren.	
Part #	Qty	Description	Material—print	Supplier	Wt (g)	Wt credit (%)	Wt (g)	Final score	Wt credit (%)	Wt (g)	Final score	Wt'd ave. (g)	Final score
1	1	Connector of voltage DC	Bioplastics (cellulosic plastic)		4	100	4		40	1.6		3.4	
2	1	DB9 Connector	Bioplastics (cellulosic plastic)		6	100	6		40	2.4		5.1	
3	1	O-ring parker 2-339	Biofiber composite		0.8	100	0.4		50	0.2		0.35	
4	1	O-ring parker 2-337	Biofiber composite		2.4	100	2.4		50	1.2		2.1	
5	2	Lateral fasteners	Steel--SAE 1010		30	50	15		28	4.2		12.3	
6	3	Gear	Bioplastics (Poliesteramidas)		8.25	100	8.25		40	3.3		7.0125	
7	3	Spring	Steel--SAE 1010		9	50	4.5		28	1.26		3.69	
8	3	Bushing	Bioplastics (Poliesteramidas)		11.14	100	11.14		40	4.456		9.469	
			Weight of all the components		***1573***		***1179.75***	***75***		***339.32***	***22***	***863.2***	***55%***

Table 6.6 CALCULATING THE FINAL DFE SCORE FOR THE ML RE-DESIGN

MOTORIZED LENSES REDESIGN								
	Bill of material					DfE score		
Part #	Qty	Description	Material	Supplier	Wt (g)	**DfE Weight:** Mat. chem. + disassembly + recyclability (g)	Potential DfE wt	Final score
1	1	Connector of voltage	Bioplastics (cellulosic plastic)		4	2.467	4	61.667
2	1	DB9 Connector	Bioplastics (cellulosic plastic)		6	3.700	6	61.667
3	1	O-ring parker 2-339	Biofiber composite		0.8	0.367	0.8	45.833
4	1	O-ring parker 2-337	Biofiber composite		2.4	1.100	2.4	45.833
5	2	Lateral fasteners	Steel--SAE 1010		30	19.100	30	63.667
6	3	Gear	Bioplastics (Poliesteramidas)		8.25	6.670	8.25	80.848
7	3	Spring	Steel--SAE 1010		9	2.730	9	30.333
8	3	Bushing	Bioplastics (Poliesteramidas)		11.14	9.003	11.14	80.820
			Weight of all the components		***1572.93***	***1179.7***	***1572.93***	***75.00%***

$$DFE\ sco.for\ each\ part = \frac{\frac{1}{3}\left[mat.chem.sco + Disass.sco + \left(Recyclability + \frac{rec.}{ren.content\ score}\right)\right]}{Total\ potencial\ weight}$$

C2C – 'VERIFICATION' ACTIVITIES

The process described from table 6.3 to 6.6 was applied to the original design and was compared with the redesign as result we have the follow:

	ML Original Design	ML Redesign
Material chemistry score	40%	85%
Disassembly score	40%	80%
Final DFE score	The final DFE score for the redesign is 75%, which represent a 35% improvement in environmental design from the initial design score of 40%. The result also means that the redesign is closer (75% of a possible 100%) of having all its components with the characteristic of being incorporated to a *bio-* or *techno-* cycle (this refers to the ML eco-effectiveness).	

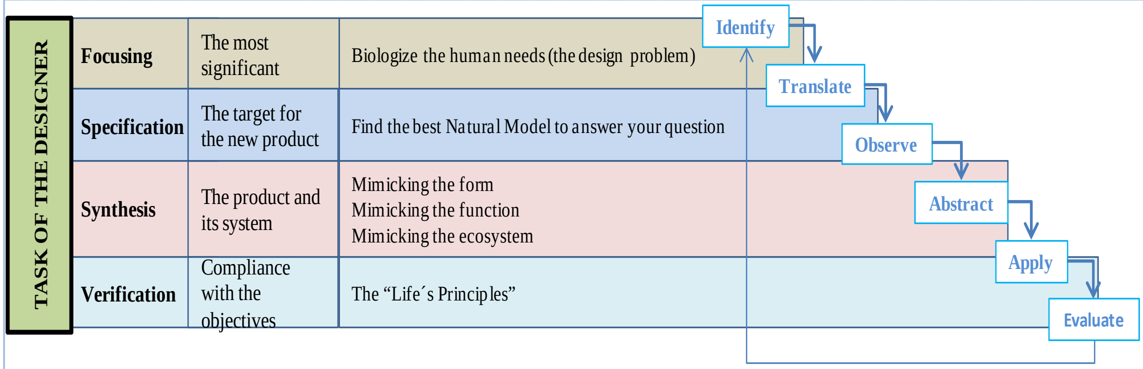
6.3.2 Biomimicry (BIO)

Hastrich (2011) propose a methodology to design products that follows the Biomimicry sustainability approach. In order to apply and to keep the analysis structure proposed in this research, it is presented a correlation between the 'designers tasks' obtained from Biomimicry taxonomical study (fig. 6.3-a) and the design process proposed by Hastrich (fig. 6.3-b).

The design stages proposed by Hastrich are:

- *Identify*. Develop a Design Brief with specifications about the problem to be solved. At this stage, the functional characteristics and the technical specifications of the product are defined. The task of the designer is to identify the technical requirements and the functional parameters, or functions that must be satisfied. This information is used to search in the Natural models in the next stage.
- *Translate*. Biologize the question; ask the Design Brief from Nature's perspective. In order to "Biologize" the functions that the product carries out, questions are asked from the natural perspective at this stage, e.g., how does Nature do this function? The task of the designer is to establish a relationship between functional characteristics and biological models.
- *Observe*. Look for the champions in Nature who answer/solve your challenges. At this stage, the best models in Nature that carry out the same functions required from the product are identified. The task of the designer is to cluster the Natural solutions undertaken by these functions.

- *Abstract*. Find the repeating patterns and processes within Nature that achieve success. This stage refers to characterize the natural model that best answers the design problem. The task of the designer is to analyze the functional parameters defined in the stage "Identify", but in the natural model. This shows the successful patterns and processes in the natural model.
- *Apply*. Develop ideas and solutions based on the natural models. Based on the results of the previous stage, solutions are proposed and one idea is selected. The idea based on the natural model and conditions in which Nature solves the product´s function, is implemented at this stage, i.e. it is "mimicked". The task of the designer is to integrate Nature's successful patterns and processes into alternative technical solutions.
- *Evaluate*. How your ideas are compared to the "Life's Principles", the successful principles of Nature? Biomimicry Institute (BI) (2011). At this stage, comparison criteria to evaluate the alternative solutions are defined. The task of the designer is to compare the solutions identified in the previous stage against the models in Nature. In addition, the solutions are compared with the "Life´s Principles". From these, the best solution is selected and implemented.



a) Designers tasks in the Biomimicry process [Flores-Calderón , et. al. 2009]

b) Biomimicry design process [Hastrich 2011]

Figure 6.3. Designers task in the biomimicry design process

This process is taken as reference to define the re-design process used for the ML re-design.

The activities in the re-design process are grouped according to the categories of the designer tasks (see figures 6.2 and 6.3).

A detailed description of these activities is presented in the following sections:

BIO – 'FOCUSING' ACTIVITIES

A product can be represented in functional labels associated with their physical embodiments (Hirtz, et. al. 2002). This type of representation provides an abstraction to conceptualize, evolve designs and apply it to many stages of the product design process: product architecture, concept generation, and physical modeling as examples.

In the original design were considered some restrictions, two of them are:

- The 'accurately focus' function has to be done by the camera lenses because there is an external element to be considered; the camera.
- The function of convert electric energy (e. e.) to mechanical energy (m. e.) has to be carried up by elements that are controller by the PCB, because there is an external element to be considered; the software and the PC.

For the ML re-design, the restrictions before described are still considered. These restrictions in the re-design constrain the proposal of the 'housing' because the motors and the camera lenses (the yellow square in figure 6.4) need to keep their functions and their performance. Due to this fact, the feeding and control PCBs have to be presented to manage the motors actions.

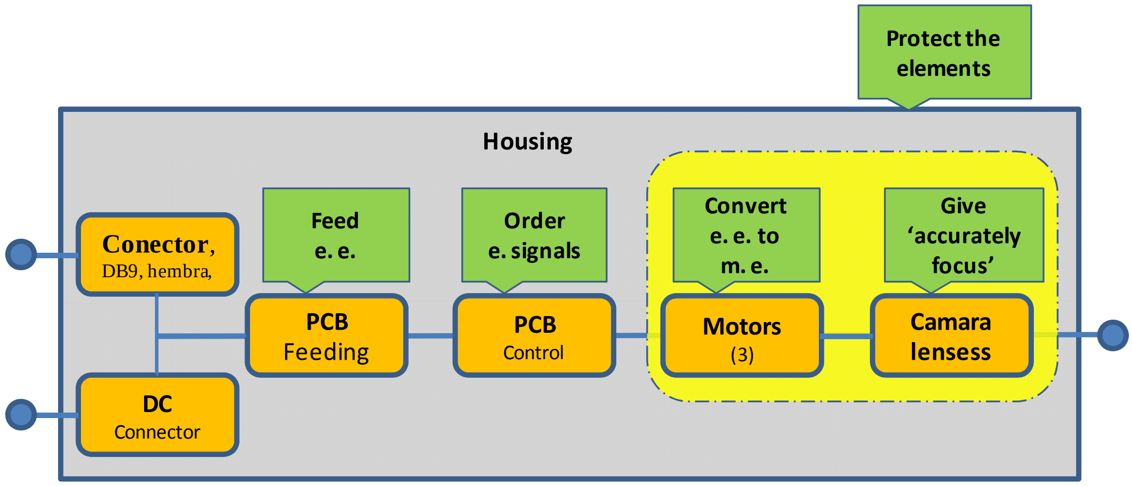


Figure 6.4. The ML 'functional representation'

Figure 6.4 represents the ML in a functional representation level. Through the observation, the functions identified by the housing are: *protect*, *locate* and *insulate* ML's components.

The redesign of the housing is presented stage by stage applying the process proposed by Hastrich (2011):

- *Identify*: As mentioned before, the functions of the housing are to protect, locate and insulate. The functional parameters of the housing can be defined as those referring to material resistance in specific conditions, e.g. load and temperature. The technical specifications of the housing are: maximum working temperature 79.44°C, maximum load resistance 50N, maximum defluxion 9.453E-03 mm.

BIO – 'SPECIFICATION' ACTIVITIES

- *Translate*: The BI has developed a 'biological concepts' taxonomy (BI 2011) to help designers in the construction of ideas and in the generation of solutions to the functional requirements. This taxonomy was used to establish a relationship between the functions performed by the housing and those found in biological models. The following functions were identified for the housing when using the information above mentioned taxonomy: maintain physical integrity, manage structural forces, impact, structures that minimize materials and maximize strength. These functions can be found in natural models and are analyzed below to characterize its performance.
- *Observe*: The *natural* solutions that undertake the functions identified in the taxonomy are: the human skull, the turtle's shell and the coconut. The human skulls are nearly spherical domes--and the light and thin bone needs only minimal internal bracing. Similarly, a turtle's shell is a light, strong dome, as are the shells of many bivalve and gastropod mollusks; the thoraces of many insects, spiders, and crustaceans; the eggs of birds; and nutshells. Smashing the wall of a coconut takes quite an effort, and the resulting pieces do not weigh a lot. Still, domes have several disabilities. Localized loads can be coconut, and resistance to local penetration may demand enough material to offset most of their cheap resistance to uniform transmutably pressure differences.

BIO – 'SYNTHESIS' ACTIVITIES

- *Abstract*: In this stage, the designers analyzed why the human skull, the turtle's shell and the coconut, are successfully performing their functions. It was concluded that an important factor is the spherical type shape, such as domes. These shapes are the predominant geometry used to protect sensible organs like the brain, and biological processes like the development of a chick in an egg. An study of the 'Physical properties of egg shells' (Voisey, et. al. 1967), demonstrate that structures under eggs shells are some of the best structures to respond to external loads and protect internal elements.

- *Apply*: In order to integrate the Nature's successful pattern described before, dome shapes were designed for the housing. This was based on a mathematical model developed by Voisey (et. al. 1967). Additionally, the geometric restrictions of the ML and the capabilities and limitations of manufacturing processes were also considered. The alternatives generated for the housing forced changes in the architecture of the rest of the ML's components.

BIO – 'VERIFICATION' ACTIVITIES

- *Evaluate:* To evaluate the different housing shapes proposed in the application stage, two comparisons were used:
  - ✓ The first one was the mechanical performance of the shapes. The alternatives were analyzed using a FEA software tool (see figure 6.5).

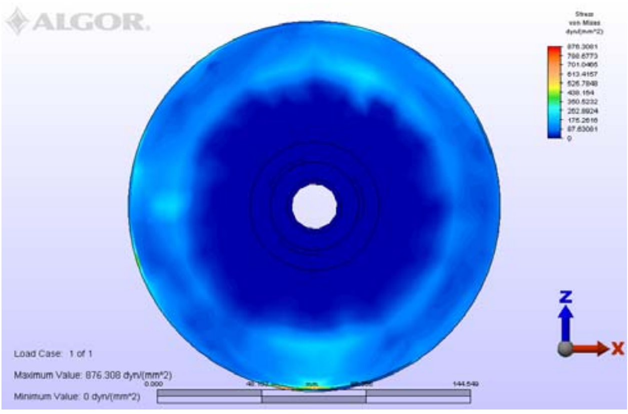
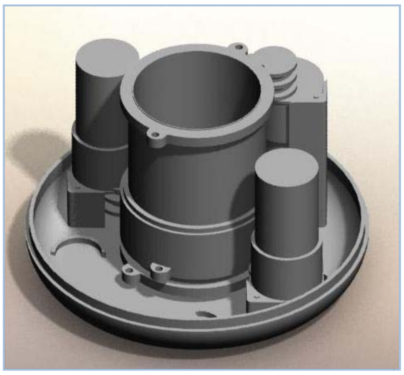


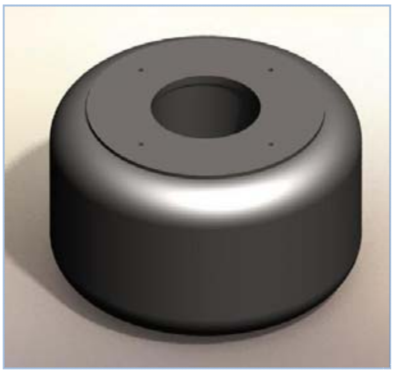
Figure 6.5 FEA analysis for the ML housing

  - ✓ The second comparison was made answering the questions proposed in Biomimicry Newsletters (2006) that refers to the fulfillment of the ´Life´s Principles´. In this case the relevant questions were:
    - *Are the materials used in the recyclables solutions?* Several materials were considered. The material selected for manufacturing the housing is a Bioplastic which mechanical properties satisfy the design requirements.
    - *Is the form of the solution associated to the function?* The alternative shapes were compared and the one with the best mechanical performance, with enough internal space to house the internal ML's components and minimum material content was selected.

The proposed solution for the housing is presented in table 6.7 and the resulting architecture of the internal components is presented in figure 6.6.



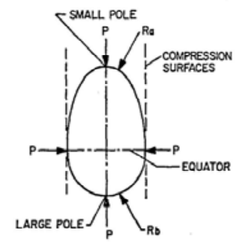
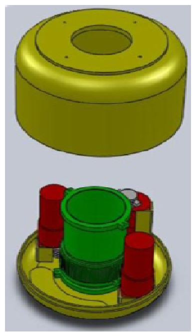
a) The ML inner



b) The ML housing

Figure 6.6 The ML BIO Re-design

Table 6.7 ML redesign trough BIO

		Nature constant	Mechanical Requirements	Design Functions	
Results in BIO redesign		Shell forms  P = force applied R = radius of spherical shell	Model at 79.44°C APPLIED LOAD 50N 9.453E-03 mm	Protect the internal elements. Give structure to the ML. Contain the internal elements.	
	Original design	**NO**	**YES** ABS material (It is a toxic material)	**YES**	
	Redesign proposal	**YES**	**YES** PHA copolymer (It is a linear polyesters produced in nature). But also, it is needed 20% less mass for the same functions	**YES**	

6.3.3. Total Beauty 'BioThinking'

Datschefski from a study of 500 green products makes a proposal of five sustainability criteria. The criteria are cyclicity, solarity, safety, efficiency and social. The goal for the sustainable products under this SPA is to be 100% cyclic, solar and safe; in addition, sustainable products use materials and energy efficiently, it means 100% efficiency, and they are made in companies that actively look for employees and suppliers equity, social (Datschefski 2002).

In Flores-Calderón, et. al. (2010) it was reported that there is not a single document in which Datschefski's approach shows specific activities and tools to design or re-design a product. Then based on the analysis of Datschefski's documents such as (Datschefski; 2002 and 2010, BioThinking 1999) and other publications taking as references Datschefski proposals such as in Puma Steve (2008) and Hautanen(et. al. 2009); a redesign process to develop sustainable products based on the TB BioThinking is introduced in Flores-Calderón (el. al. 2010). The process includes activities and tools grouped into the task of the designer, see table 6.8. below, each one of the designer tasks is described to re-design the ML.

TB – 'FOCUSING' ACTIVITIES

The activities to evaluate the criteria proposed by Datschefski for each TOD category are described below.

<u>*Cyclicity:*</u> the *cyclicity* of the product is calculated by using.

$$\boldsymbol{Cyclicity} = \frac{(\mathbf{a}+\mathbf{b})}{\mathbf{2}} \qquad \text{(eq. 1)}$$

Where:
- **a** = % of recycled material mass used during product's manufacture.
- **b** = % of product´s material mass that is recycled at the end of life.

Table 6.8 Activities, methods and tools of the TB re-design process

TOD	ACTIVITIES	METHODS AND TOOLS
Focusing	**Cyclicity:** • Identify and classify product’s materials in plastics, metals, etc. • Calculate: % of recycled material mass used in manufacture. And % of product´s material mass that is recycled at the end of life • Determine the Cyclicity %	• Materials proportion table (e.g. table 6.9). • Equation to calculate the cyclicity • If it is the case, consider the criteria of classify product’s materials.
	Solarity • Identify the product´s parts that need energy to function. • Calculate the *KWh* of solar energy needed for the product (consider all the life cycle stages).	
	Safety** • Identify the toxic materials used in the product. • Calculate the % of toxic material contained in the product.	• Material/disruption table (e.g. table 6.10).
	Efficiency** • Identify the number of functions carried out by each part of the product. • Determine the mass of each part. • For the parts that need energy to function, determine its energy use efficiency. • Calculate the average material and energy efficiency.	• Relation between component mass and the numbers of functions carried out by the part. • Efficiency formula
	Social • Identify if there is a policy of human development implemented. • Identify if there are dangerous materials in use or if the labor conditions represent a risk for the workers.	• Norm SA8000
Specifi-cation	• Identify the lowest scores obtained in the category focusing. • Establish as a priority of the redesign process to address the lowest scores and define as target values of the requirements for the redesigned product: Cyclicity = 100%, Solarity = 100%, Safety = 100%, Efficiency = 100%, Social = 100%	
Synthesis	**Cyclicity:** • Identify the materials and motives for the score obtained for cyclicity in the category focusing. • Search and define new materials with high % of recyclability in bio or techno cycles. • Re-evaluate the product with the selected materials.	• Materials proportion table (e.g. table 6.12). • Equation to calculate the cyclicity
	Solarity: • Considering the results from solarity in the category focusing, design parts and relations amongst them, that required only renewable energy to function. • Re-calculate the *KWh* of solar energy needed for the product (consider all the life cycle stages).	
	Safety** • Considering the results from cyclicity in category synthesis, ensure that the selected materials are not toxic for humans and Nature. • Re-calculate the % of toxic material contained in the product.	• Material/disruption table (e.g. table 6.13).
	Efficiency** • Identify the number of functions carried out by each part of the product, paying particular attention to the parts redesigned or with new materials. • Determine the mass of each part. • Determine the energy use efficiency of the product. • Calculate the average material and energy efficiency.	• Relation between component mass and the numbers of functions carried out by the component. • Efficiency formula.
	Social • Establish targets based on the Norm SA8000. • Identify if there are dangerous materials in use or if the labor conditions represent a risk for the workers.	• Norm SA8000
Verificat ion	• For each sustainable criteria (cyclicity, solarity, safety, efficiency, social) show the results of both the original and the redesigned product.	• Comparative results table (e.g. table 6.14).

TOD *Task Of the Designer*.
**** **** *Datschefski defined a formula to calculate these criteria. Its calculus is difficult because refers to information of a similar product created in 1990. In Flores-Calderón (2010) is proposed a different way to calculate these concepts.*

Datschefski defines criteria to classify product´s materials (BioThinking 2010):

- All organic materials are considered as being from recycled source, as they are made with recycled Carbon, Hydrogen and Oxygen.
- Most scrap metal recovery and composted organics count as end of life cycling.
- It is considered down-cycling as not counted as being recycled at end of life, so most paper and plastics recycling would have to be counted as materials life extension, perhaps under efficiency below.

The criteria defined by Datschefski in the previous paragraph were applied to the ML. The results together with the materials weight proportions are showed in table 6.9.

Table 6.9 Materials proportions of the ML

MATERIALS	% Of Total Weight	% Of recycled for Manufacture	% Of recycled	Weight recycled
Plastics	19%	0%	0%	0 gr.
Metals	34.40%	0%	100%	541.11 gr.
Others *(lenses, motors)*	46.60%	---	---	---
Total weight =1573 gr.	*100 %*			***541.11 gr. = 34.4%***

It is important to notice that parts, such as the lenses and motors, were not analyzed in the redesign of the ML because the material characterization was not available. For this reason, the materials of these parts were classified as "others" (most of the weight of motors is provided by metallic components and most of the weight in the lenses is provided by crystal parts). So, using Datschefski´s criteria and the values of Table 6.9:

a = % of recycled material mass used in manufacture = **0%**

b = % of product´s material mass that is recycled at the end of life= 34.40% + 46.60%= **81%**

By eq. 1, we have:

$$\boldsymbol{Cyclicity} = \frac{(\mathbf{0} + \mathbf{81}\%)}{\mathbf{2}} = \mathbf{40.5}\%$$

Therefore, the ML has a cyclicity of **40.5%**.

Solarity: It was not possible to find out if renewable energy was used at any stage of the life cycle of the ML, but probably this would represent a very little contribution. For this reason, a value of **0%** was assigned to this requirement.

Safety: To estimate the value of this requirement, the information presented in table 6.10 was used.

Table 6.10 Examples of disruption forms (BioThinking 2010)

	Chemical disruption	**Physical disruption**
People	Human toxicity	Physical injury, noise
Other life	Eco-toxicity	Land take, noise, enclosure, ecosystem unbalance

For the ML, the following data was identified: 30 components, 9 different materials and 51 different chemicals (see table 6.11).

Table 6.11 Materials used in the ML

#		**Material**	**Principal type of disruption**
			People (ATSDR 2010)*
Plastics	**1**	ABS	Carcinogenic
	2	BUNA "N"	”
	3	PVC	”
	4	Fiberglass	”
Metals	**5**	Cooper	Only with in high levels of concentration can be harmful (breathing or ingesting)
	6	Aluminum	”
	7	Brass	”
	8	Stainless Steel	”
	9	Zinc-coated steel sheet	” *(by zinc)*

**These disruptions are present in the manufacturing process of the materials of the components and not in the manufacturing of the ML.*

According to tables 6.9 and 6.11, the ML scores 40.5% in 'cyclicity' (see also the concept definition of 'safe'). This is due to the fact that metals used are considered safe. This means that they cause no damage to humans in their life cycle. In contrast, all of the components made by plastics are carcinogenic. Safety is estimated in 40.5%.

Efficiency: The *material* and *energy* efficiency of the ML is estimated considering, in particular, the housing and the transmission efficiencies.

The housing is the component that concentrates most of the mass in the ML with 392.76 gr., and it represents 25% of the total weight (components 21 and 23 see table 6.1). So, the housing has an efficiency of **75%** to carry out the functions of (1) protecting the internal elements, (2) giving structure to the ML, and (3) containing internal elements.

The transmission system consists of two parallel spur gears in. These types of systems have an efficiency of almost 95% (Budynas 2006).

So, by estimating an overall efficiency score for the ML, we have:

$$\boldsymbol{Efficiency} = \frac{\mathbf{75}\% + \mathbf{95}\%}{\mathbf{2}} = \mathbf{85}\%$$

<u>*Social:*</u> This requirement refers, in specific to the norm SA8000 fulfillment. There is not policy to use only sustainable or environmental friendly materials, manufacturing processes, distribution forms, etc., for the ML. Overall, the ML does not score high on social performance. It uses carcinogenic materials (see table 6.10) and the main design criteria used for the design of the ML was low cost. So, Social is 20 %.

Summarizing the results for the Focusing – task of the designer:

Cyclicity =	40.5%
Solarity =	0%
Safety =	40.5%
Efficiency =	85%
Social =	20%

This means a Total Score for the ML of *186* of a maximum of *500*, or **37.2%**

TB – 'SPECIFICATION' ACTIVITIES

The activities in the specification stage are described below (see also TOD – Specification in table 6.8).

The activities in the designer's task in this SPA refer to determine the sustainable targets for the new product. Datschefski defines a sustainable product as the one that is 100% *cyclic, solar, and safe*. In addition, the product has to be *efficient* in the use of materials and energy and the product has to be manufactured in a company that looks for the employees and suppliers´ equity (Datschefski 2002). For TB, the product redesign refers to ensuring the product´s compatibility with nature throughout its entire lifecycle.

TB – 'SYNTHESIS' ACTIVITIES

Datschefski indicates that the redesign of a product should be oriented to improve the lowest requirements scores estimated in the product evaluation using his proposal of five criteria (Datschefski 2002); in this case the present author refers to the TOD-focusing (see table 6.8).

Cyclicity: The ML scored 40.5% in cyclicity because: (1) the plastics used for the manufacture are <u>*not*</u> recycled, and (2) their properties are diminished and cannot be used in continues cycles, (3) in addition, the plastic parts do not have material identification codes to facilitate their recyclability.

The plastic selected for the product redesign has to increase its *cyclicity* score and, at the same time, at least fulfill the *safety* and *efficient* values obtained in the original design.

A substitute for the ABS used in the ML could be the PHA copolymer called PHBV (poly (3-hydroxybutyrate-co-3-hydroxyvalerate)). The Polyhydroxyalkanoates or PHAs are linear polyesters produced in nature by bacterial fermentation of sugar or lipids. The PHAs can be processed via injection molding, extrusion and extrusion bubbles into films and hollow bodies (Zhong, et. al. 2009).

Natural fibers and a bio-based Thermosetting Matrix (Zhong, et. al. 2009, John, et. al. 2007) can substitute the fiberglass, other of the carcinogenic materials, table 6.11, in the ML. An example of this could be the "epoxidized linseed and vegetable oils from biocomposites". Several companies provide this material. A similar situation occurs with the flame-retardants (Zhong, et. al. 2009). A substitute could be the Aluminum Trioxide.

As in cyclicity, regarding focusing category, the row of *others* in the materials column of table 6.12, is considered to determine the percentage calculus, but they were not considered for the redesign. So, that means that instead of having 52% we have 52% + 46.60% = 98.60%.

Table 6.12. Materials proportions of the ML

MATERIALS	% Of Total Weight	% Of recycled for Manufacture	% Of recycled	Weight recycled
Plastics	19%	0%	96.8%	289.54 gr.
Metals	34.40%	0%	100%	541.11 gr.
Others *(lenses, motors)*	46.60%	---	---	---
Total weight =1573 gr.	*100 %*			***830.65 gr. = 52%***

Evaluating the ML cyclicity, we have:

It was not possible to achieve 100% because it was not possible to identify commercial substitutes for the materials of components 3, 4 and 29 (table 6.1). These components represent less than 2% of the product. According to eq. 1, we have:

a = % of recycled material mass used in manufacture= **0%**

b = % of product´s material mass that is recycled at the end of life = **98.60%**. Substituting in eq. 1

$$\boldsymbol{Cyclicity} = \frac{\mathbf{(0 + 98.60)}}{\mathbf{2}} = \mathbf{49.3}\%$$

Therefore, the cyclicity value is **49 out of 100.**

Solarity: The score for the ML in the use of renewable energy is 0%. This score is due to the lack of information along the ML life cycle.

The stage of the product life cycle in which it is possible to improve the score, is in the *use* stage. A system that works with renewable energy, e.g. a kind of winding system, that transforms mechanical to electric energy, can drastically improve the final score. One more example is the use of solar energy. These two alternatives require modifications in the control system because there are new functions and components. In addition, the internal modifications have to be in coordination with external elements, e.g., the software that controls the complete system. These modifications cannot be implemented due to restrictions of the ML. So, the solarity score stay in its same value 0%.

Safety: The *safety* value of the ML is 40.5% because of the use of carcinogenic plastics. From tables 6.12 and 6.13, the ML has a *safety* score of 98%. This is because of the use of metals and new polymers.

Table 6.13 Materials in the ML

#		Material	Principal kind of disruption
			People
Plastics	**1**	PHA copolymer	Only in high levels of concentration is harmful (breathing or ingesting) (Zhong, et. al. 2009)
	2	BUNA "N"	Carcinogenic (ATSDR 2010)
	3	PVC	”
	4	Epoxidiz linseed	Not toxic (Ash, et. al. 2004)
Metals	**5**	Cooper	Only in high levels of concentration is harmful (breathing or ingesting) (ATSDR 2010)
	6	Aluminum	”
	7	Brass	”
	8	Stainless Steel	”
	9	Zinc-coated steel sheet	” *(by zinc)*

Efficiency: The ML’s efficiency score is 85%, due to the housing and transmission design.

In the original housing design, this component scores 75%. In the cyclicity requirement of these TOD-Synthesis category, the PHA copolymer P(3HB) was selected as the new material for the housing. This material has a Young’s modulus of 3.5 GPa, and a tensile strength of 43 MPa (Shimamura, et. al. 1994, Guo-Qiang, et. al. 2005). In figure 6.7 it is presented a CAD simulation of the housing made-of P(3HB). In addition, on this CAD was simulated the original conditions of mechanical requirements (see figure 6.7) i.e., temperature max of 79.44°C; applied load of 50N; and a max deformation of 9.453E-03 mm. The simulation shows that, the housing made of the P(3HB) fulfills the original mechanical requirements, but with less mass. This new housing has a mass of 235.66gr., this represents 15% of the total mass to carry out the same original three functions. In consequence, this represents an efficiency of 85%.

Regarding to the transmission efficiency it was established that this would not be considered for the redesign of the ML, the '*solarity*' criterion was discussed above. For this reason, the efficiency keeps its value, 95%.

Therefore, the efficiency score for the redesigned ML is:

$$\boldsymbol{Efficiency} = \frac{\mathbf{85\% + 95\%}}{\mathbf{2}} = \mathbf{90\%}$$

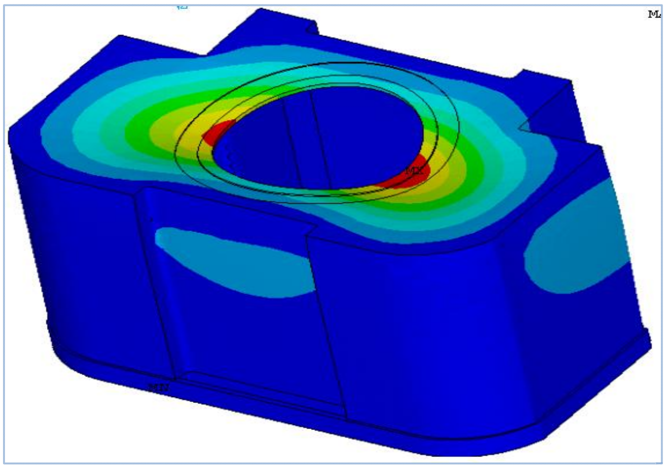


Figure 6.7 Maximum deflection for P(3HB)

Social: The redesign of the ML is the first attempt of the company to integrate sustainable criteria in a product. The company has not shown a formal policy in the use of sustainable criteria, but it has some interest on the use of environmental friendly materials (two topics in the Norm SA 8000). The company's interest on sustainability may increase if the ML redesign shows some other opportunities. Derived from the value of use of safety materials of 98%, the author estimates the value of the social requirement as 40%.

TB – 'VERIFICATION' ACTIVITIES

These activities refer to ensure the sustainable objectives fulfillment. In table 6.14, the scores obtained in the original ML and in the ML redesigned are presented.

Table 6.14 Comparative results for the ML (original vs. re-design)

Symbol	Original	Specification	Redesign
Cyclicity	40.5%	*100%*	**49.3%**
Solarity	0%	*100%*	**0%**
Safety	40.5%	*100%*	**98.60%**
Efficiency	85%	*100%*	**90%**
Social	20%	*100%*	**40%**
	186	***500***	***278***

Cyclicity: The results show a low score in both cases. This is because the *recycled material used in manufacture* is 0%, this represent almost the 50% of cyclicity in both cases (see eq. 1). However, the use of Bio-materials for the redesigned increases the suitability due to the incorporation of components to a bio-cycle or to a techno-cycle.

Solarity: This is the lowest score, 0%. It was not possible to increase this value in the redesign because the solarity reliable options require the modification of external elements, which are not possible. The solarity aspect along the product life cycle was difficult to determine because ofthe lack of supplier´s information.

Safety: This is the highest score obtained, 98.60%. This was possible because almost all of the toxic materials were eliminated. There were no commercial and economic convenient substitutes for the remaining toxic materials of the product.

Efficiency: The score obtained was 90%. The redesign of the housing improved its efficiency in a 15%. This means that with 15% less material it is possible to do the functions identified for the housing. The transmission was not modified.

Social: The score obtained was 40%. This is a 20% improvement. The increment in this score is due to the elimination of toxic materials, which reduces the health risk to people associated with the product in its life cycle.

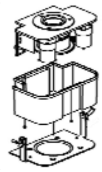
6.4 Comparative Analysis

Table 6.15 presents the results obtained in the SPA redesigns of the ML. Some of these results are highlighted below.

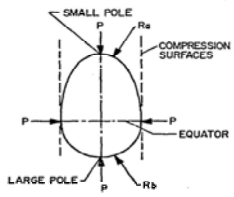
Table 6.15 Results of the study case re-designs

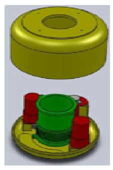
Results in C2C redesign

	ML Original Design	ML Redesign
Material chemistry score	**40%**	**85%**
Disassembly score	**40%**	**80%**
Final EFF score	**40%**	**75%** The result also means that the redesign is closer (75% of a possible 100%) of having all its components with the characteristic of be incorporated to a *bio-* or *techno-* cycle.



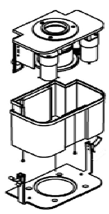
Results in BIO redesign

	Nature constant	Mechanical Requirements	Design Functions
	Shell forms  P = force applied R = radius of spherical shell	Model at 79.44°C APPLIED LOAD 50N 9.453E-03 mm	Protect the internal elements. Give structure to the ML. Contain the internal elements.
Original design	**NO**	**YES** ABS material (It is a toxic material)	**YES**
Redesign proposal	**YES**	**YES** PHA copolymer (It is a linear polyester produced in nature). But also, it is needed 20% less mass for the same functions	**YES**



Results in TB redesign

Symbol		Original %	Specification %	Redesign %
	Cyclicity	40.5	*100*	**49.3**
	Solarity	0	*100*	**0**
	Safety	40.5	*100*	**98.60**
	Efficiency	85	*100*	**90**
	Social	20	100	**40**
		186	**500**	**278**



Re-design based on C2C: The material toxicity mark was improved from 40% to 85% (Table 6.15 C2C section). The disassembly score was improved from 40% to 80% and the eco-effectiveness score was improved from 40% to 75%. The re-design experience proved that C2C had a vision of ‘sustainability’ in which the materials toxicity was fundamental. The focus point is to set the use of materials with high possibilities of being integrated to techno or bio cycles. In this way, C2C is aimed to develop products in which most of their components or materials are easily incorporated to bio or techno cycles.

Re-design based on BIO: The ML´s material efficiency was improved mimicking shell forms; this results in 20% less mass content, complying with the same original mechanical requirements and design functions.

In general, BIO is aimed at developing highly efficient products. The main hypothesis formulated in BIO is that ‘there is no system more efficient than the one found in Nature’.

Re-design based on TB: Improvement in SD attributes (cyclicity, solarity, safety, efficiency and socially) was from 186 to 278.

Some conclusions after the SPA exploration through the re-design of the ML, are presented below. These conclusions are given in order to highlight the activities in the TOD.

Focusing: C2C´s activities focus on the eco-effectiveness (i.e. the material´s quality; incorporation to close cycles). BIO´s activities focus on the definition of the technical problem and the ‘biologization’ of the needs. TB´s activities are dedicated to measure the product in terms of cyclicity (of materials), solarity (use of renewable energy), safety (use of non-toxic materials), efficiency (of energy), and socially (support of the human rights).

Specification: Activities in C2C emphasize materials toxicity, disassemblability difficulties, and recyclability characteristics. Based on this knowledge the product eco-effectiveness goal is defined. In BIO the activities are dedicated to determine the functional performance of the product´s sub-systems. The functional parameters (the specifications) are defined based on the biological model performance. In TB, the activities point out the components with the lowest scores in cyclicity, solarity, safety, efficiency, and sociality. Based on this information goals for improvement are defined.

Synthesis: In C2C, the activities are defined so as to select the materials with best scores for no toxicity, recyclability or compostability. In addition, better disassemblability characteristics have also to be considered. The activities in BIO are oriented to create and select the technical solution that best mimics the form, function, and ecosystem, all of them taken from biological models. The TB´s activities integrate the best technical solution in terms of cyclicity, solarity, efficiency, and sociality.

Verification: The activities in C2C are defined according to the percentage of materials incorporated to a bio or techno cycle. For BIO, the activities compare the performance differences between the biological model and the technical solution. In TB, the best solution is evaluated in terms of its cyclicity, solarity, efficiency, and sociality. This solution is also compared against the ideal (100% criteria compliance) ‘beauty’ product.

A proposal of criteria to evaluate and re-design sustainable products

C h a p t e r 7

Alejandro Flores Calderón

7.1 Introduction

The SPAs (C2C, BIO and TB) were analyzed by a two-stage comparison process: 1) In a conceptual taxonomic study (Chapter 5) and 2) Re-designing a common study case for the SPAs (Chapter 6). The results and conclusions of these comparative processes are the foundation for the sustainability product design criteria proposed in the present research.

A kernel conclusion is that the SPA analyzed are not antagonist but complementary. This is because in order to achieve a sustainable product, sustainability has to be considered in the complete product life cycle. This means: the use of the best material with the characteristics of being incorporated to techno or bio cycles (C2C), choice the best functional solution in Nature (BIO), and finally consider the experiences accumulated in innovations of other green products (TB).

Based on the analysis carried out above and the conclusions presented in section 5.4 and 6.5, in addition to the ML´s re-design effort summarized in section 6.4; a handful of criteria to evaluate the product sustainability is proposed. These criteria are presented in the following sections.

In section 7.2 are introduced the criteria proposed trough a definition of them. In section 7.3, the criteria and measurement procedures proposed are presented. Finally, in section 7.4 some conclusions are presented.

7.2 Definition of the sustainable product evaluation criteria

The criteria proposed herein attempts to integrate features of the three approaches analyzed above.

- *Materials toxicity (human / nature).* This criterion refers to any chemical or mixture emitted or contained in materials that may be harmful to the environment or to humans at any stage in the product life cycle.
    - Toxicity to humans refers to substances that produce: carcinogenicity, teratogenicity, reproductive toxicity, mutagenicity, endocrine disruption, acute toxicity, chronic toxicity, irritation of skin/mucous membranes, sensitization, and other harmful effects (e.g., potential skin penetration, flammability).

- Toxicity to Nature refers to substances that cause: algae toxicity, bioaccumulation, climatic relevance, content of halogenated organic compounds, daphnia toxicity, fish toxicity, heavy metal content, persistence/biodegradation, or another harmful effect (e.g., water danger list, toxicity to soil organisms).

- *Efficiency (Materials / Energy). This criterion includes materials and energy efficiency.*
  - Materials efficiency expresses the degree in which a material is used or carried in such a way that its consumption, incorporation, use or wastes are reduced. Material efficiency also refers to the degree in which a material handles a particular load, strain, or weight upon it.
  - Energy efficiency expresses the degree in which the energy is used or carried out in such a way that a product in its daily use or for its manufacture consumes or wastes less energy. Energy efficiency also refers to the degree in which a product or component can reduce the required energy to carry out a function.

- *Materials cyclicity:* This criterion refers to the material quantity that can be incorporated into a bio or a techno cycle.

- *Renewable energy.* This criterion refers to the energy used at any stage of the product's life cycle that comes from natural resources, e.g., wind power, solar power, thermal, photovoltaic, hydroelectric power, tidal power, geothermal energy, biomass, muscle power, hydrogen power.

- *Social benefit:* Refers to inform to the customers that the product manufacture is in conformity with the parameters concerning to work conditions and respect of the fundamental rights of man.

7.3 Criteria evaluation procedures

In this section, the evaluation procedures for each criterion defined in the above section are described. The required information to make the evaluation is commonly available for a design team and no complex operations are needed.

7.3.1 Criterion 1: Materials toxicity (humans / environment)

The evaluation of this criterion has a six stages process:

Table 7.1 Criterion 1: Materials toxicity (humans / environment)

CRITERIA	STAGES		ACTIVITIES DESCRIPTION
MATERIALS TOXICITY (HUMANS / ENVIRONMENT)	*1*	***Material Kind***	• Separate all the product components • Group all the components by material group
	2	***Weight***	• Add all the components weight [gr.] by group of material and express the result in a table • Add the before results and determine the Total Product Mass [TPM]
	3	***Toxicity level***	• Determine the toxicity level according to: green, yellow, orange, or red
	4	***Toxicity weight***	• Determine the toxicity weight multiplying the mass of each material group (stage 2) by its corresponding toxicity score (stage 3). • Add the before results and determine the Total Toxicity Weight [TTW]
	5	***Relative product material toxicity (RPT)***	• Determine the RPT dividing Is the result of $RPT = \frac{\sum TTW}{\sum TPW}$

The evaluation of this criterion has a six steps process and is similar to the one used by C2C (Flores et.al. 2009B, Rossi et.al. 2006). The process proposed is as follows:

Stage 1: Classify each one of the product materials within one of six groups (i.e. metals, ceramics, synthetic polymers, natural organic, natural inorganic and composites); which cover almost 99% of all of the materials used in mechanical, civil and electrical engineering [Ljungberg 2007].

Stage 2: Determine the mass of each material group and then adding the before results the Total Product's Mass is determined [TPM].

Stage 3: Select the toxicity score (i.e., 100%, 50%, 25% or 0%) of each material based on the toxicity of its chemical components. A score of 100% (green) indicates that the chemicals contained in the materials presents little or no risk and is acceptable for the desired application. A score of 50% (yellow) indicates low to moderate risk, and the chemical can be used acceptably until an alternative material with 100% score is found. A score of 25% (orange) indicates that the materials contain a chemical not declared as a high risk, but a lack of information prevents a complete assessment. A score of 0% (red) indicates high risk because of the presence of chemicals which are known or suspected to be carcinogens, endocrine disrupters, mutagens, reproductive toxins, teratogens, or substances that do not meet other human health or environmental relevance criteria.

Stage 4: For each product's material, calculate the 'toxicity weight' by multiplying the mass of the materials estimated in stage 2 by the toxicological score (stage 3), then the 'Total Toxicity Weight' (TTW) is obtained by adding the before results.

Stage 5: Determine the 'Relative Product material Toxicity' (RPT) by: $\text{RPT} = \frac{\sum \text{TTW}}{\sum \text{TPW}}$

7.3.2 Criterion 2: Efficiency

The evaluation of this criterion has a six stages process:

Table 7.2 Criterion 2: Efficiency

CRITERIA	STAGES		ACTIVITIES DESCRIPTION
EFFICIENCY ***(MATERIALS / ENERGY)***	*1*	***Sub-systems***	• Identify the subsystem
	2	***Identify the related items***	• For each sub-system, identify the components 'items' in the sub-system.
	3	***# of carried out functions***	• For each sub-system, identify the carryout functions
	4	***Biological systems***	• For each sub-system, answer the next two questions: How does Nature do these functions? And Whose survival depends on this? • Reframe the before questions additional keywords,
	5	***Mimicking*** ***Form*** ***Function*** ***Ecosystem***	• Compare the technical and biological solution in terms of 'Form', 'Function', and 'Ecosystem' assigning the mimic level: 100%, 75%, 50%, 25%, 0%
	6	***Total Mimicking Score***	• Determine the $SMS = \frac{MFO+MFU+MECO}{3}$ • Determine the $TMS = \frac{\sum SMS}{THE\ NUMBER\ OF\ SUBSISTEMS}$

Stage 1: Divide the product into sub-systems. A 'sub-system' can be a regularly interacting or an interdependent group of items forming a unified whole (EB 2008).

Stage 2: Identify the items contained in the sub-systems. An 'item' is an object of attention, or interest, and it is part of a whole (EB 2008).

Stage 3: For each sub-system, identify the carryout functions. In the context of the procedure proposed, a function is 'the job that a sub-system was designed to do'.

Stage 4: Identify the biological systems that best represent the functions carry out by the technical sub-system, by asking how does Nature do this function?, and whose survival depends on this? Then refine the answers adding new keywords. This depends on the specific cases, e.g. 'load', 'speed'.

Stage 5: Determine how much the technical system mimics the biological systems (these were identified in stage 4). For the comparison are considered three aspects: a) Mimicking Form (MFO) (i.e., compare the bio and techno systems in terms of their form and structure or 'morphology'). b) Mimicking Function (MFU), (i.e., finds out generic aspects of the biological process and compare against the process of the technical function). c) Mimicking Ecosystem (MECO), (i.e., find out details of the biological context, e.g. temperature, humidity, pressure, etc., and compare against the technical context). The imitation level is defined by a scale of 5 levels. The scores for these three aspects refer to: A 100% if there is a complete biological system imitation. A 75% if the principal characteristics of the biological system are imitated. A 50% if the imitation is acceptable, but clear evince of improvement are identified. A 25% if the principal characteristics in the biological system present some differences. A 0% if there is a complete difference between the biological and technical systems.

Stage 6. Determine the Subsystem Mimicking Score (SMS) and the Total Mimicking Score (TMS).

Determine the $SMS = \frac{MFO+MFU+MECO}{3}$

Determine the $TMS = \frac{\sum SMS}{THE\ NUMBER\ OF\ SUBSISTEMS}$

7.3.3 Criterion 3: Materials Cyclicity

The evaluation of this criterion has a process of five stages:

Table 7.3 Criterion 3: Materials Cyclicity

CRITERIA		STAGES	ACTIVITIES DESCRIPTION
MATERIALS CYCLICITY	***1***	***Material Kind***	• Like in material toxicity: o Separate all the components and determine its weight. o Classify the components by material kind in one of the next groups: Metals, Ceramics, Synthetic polymers, Natural organic, Natural inorganic, or Composites
	2	***Weight***	• Summarize all the components weight [gr.] by kind of material and express the result in a table.
	3	***FROM Recycled Materials***	• For each materials kind determine the percentage of materials that came from recycled sources (100%, X%, 0%) • Multiply the % by the weight of the material kind, this is the MFRS • Calculate: $A = \frac{\sum MFRS}{Total\ Product\ weight}$
	4	***TO Recycle Materials***	• For each materials kind determine the percentage of materials that can be used to recycle (100%, 50%, 0%) • Multiply the before % by the weight of the material kind, this is the MTBR • Calculate: $B = \frac{\sum MTBR}{Total\ Product\ weight}$
	5	***Product Cyclicity***	• Calculate the Total Product Cyclicity $Cyclicity = \frac{A\,\% + B\,\%}{2}$

Stages 1 and 2 are the same as stages 1 and 2 defined for criterion 1.

Stage 3. Assign the percentage of product's Materials that have came From Recycled Sources (MFRS) (i.e., 100% if the materials are made of Carbon, Hydrogen, and Oxygen; 'X'% if the value is known and 0% if there is no information. Then multiply the MFRS by its weight (second stage), and calculate the total product material recycled (called A).

Stage4. Determine the percentage of Materials that is going To Be Recycled or composted (MTBR) according to one of the next situations: 100% if the material is a technical or biological nutrient and can be recycled or composted within an existing commercial collection and recycling infrastructure. 50% if the material can be recycled, but into a lesser value product and if a commercial recycling infrastructure exists to collect and recycle it. And 0% if there is not recycling potential or infrastructure for the product. Then multiply the MTBR by its weight (second stage). Finally, the total product material recycled (called B) is calculated.

Stage 5. Calculate the Total Product Cyclicity using A (stage 3) and B (stage 4) by

7.3.4 Criterion 4: Use of renewable energy

The evaluation of this criterion has a process of four stages:

Table 7.4 Criterion 4: Use of renewable energy

CRITERIA		STAGES	ACTIVITIES DESCRIPTION
RENEWABLE ENERGY:	***1***	***Subsystems***	• Like criterion 2 stage 1, identify the subsystem
	2	***Energy consumed***	• For each subsystem determine the energy consumed • Determine the Total Energy Consumed (TEC) adding the energy quantities consumed by the subsystems.
	3	***Energy from Renewable Source***	• From the energy consumed in each subsystem, determine the quantity of renewable energy used. • Add the values and get the Total Energy from Renewable Energy (TRE)
	4	***Product % of Renewable Energy***	• Calculate the percentage of Renewable Energy (RE) $RE = \frac{TRE * 100}{TEC}$

Stage 1. The same as the one defined in stage 1 of criterion 2.

Stage 2. Determine the energy consumed for each sub-system by directly measuring in the subsystems or by theoretical calculation, expressing the quantities in Joules. Then add the before results and determine the Total Energy Consumed (TEC).

Stage 3. From the energy consumed in each sub-system determine the quantity of renewable energy used in the subsystems (see the definition and examples of renewable energy in section 7.2,) and add the before results to determine the Total Energy from Renewable Energy (TRE).

Stage 4. Calculate the Product percentage of Renewable Energy by.

$$RE = \frac{TRE * 100}{TEC}$$

7.3.5 Criterion 5: Social Benefit

The evaluation of this criterion has a process of three stages:

Table 7.5 Social Benefit

CRITERIA	STAGES		ACTIVITIES DESCRIPTION
SOCIAL BENEFIT	***1***	***Collect information***	• Collect information regarding to the issues: Minors' Labor, Forced Labor, Health and Safety, Freedom of Association and the Right to Collective Bargaining, Discrimination, Disciplinary Procedures, Work Schedules, and Salaries.
	2	***Score?***	• Determine the average % of fulfillment for each issue. • Add the values of % of fulfillment $A = \sum(\%\ of\ fulfillment)$
	3	***Fulfillment %***	• Determine the % of Social Benefits $SB = \frac{A}{The\ number\ of\ issues}$

Stage 1. Identity in the organization the information and people to answer some questions based on the NORMSA8000 issues.

Stage 2. Answer two questions for each issue of the Norm. Evaluate the answer according to the levels, which will be described below; then calculate the % average of fulfillment in each issue adding the scores obtained in the two questions and then divide by 2. The possibilities of score for each question are: 100% if the answer satisfies the question with clear evidence. 75% if there are some positive aspects, or there is doubt in the evidence. 50% if there are doubts or the evidence does not support the answer. 25% if there are no doubts about its no-satisfaction, or there is no evidence to support the answer. 0% if the answer or the evidence goes against the issues defined by the Norm.

Stage 3. Calculate the total score for the Social Benefit (SB). The two questions for each Norm SA8000 topic are:

- *Child Labor Issues:*
  1. Management is aware of and respects applicable law/regulation regarding minimum age?
  2. Practices comply with applicable laws/regulations?
- *Forced Labor Issues:*
  1. Management is aware of, and respects applicable laws/regulation governing the use of forced, prison and indentured labor?
  2. Practices comply with applicable laws/regulations?

- *Health & Safety Issues:*
    1. Management aware of and respects applicable laws/regulations governing health and safety in the workplace?
    2. Legal/Regulatory licenses/permits/certificates available and current?
- *Freedom of Association and Right to Collective Bargaining Issues:*
    1. Management aware of and respects applicable laws/ governing employees' rights to freedom of association and collective bargaining?
    2. Practices comply with applicable laws/regulations?
- *Non-Discrimination:*
    1. Management aware of and respect applicable laws/regulation governing discrimination in the workplace?
    2. Practices comply with applicable laws/regulations?
- *Disciplinary Practices:*
    1. Management aware of and respects applicable laws/regulation governing disciplinary practices and harassment in the workplace?
    2. Practices comply with applicable laws/regulations?
- *Working Hours:*
    1. Management aware of and respects applicable working hour laws and regulatory requirements?
    2. Practices comply with applicable laws/regulations?
- *Compensation:*
    1. Management aware of and respects applicable wage laws?
    2. Practices comply with applicable laws/regulations?

7.4 Conclusions

Taking as reference the representatives SPA, in this chapter the product sustainability criteria are introduced and defined. In addition, for each one of these criteria it is described the procedures to evaluate the sustainability level of a product.

In chapter 8, this criteria will prove their usefulness through the evaluation of the re-designs obtained in the SPAs explored (this was done in Chapter 6).

Sustainability evaluation of the re-designs

C h a p t e r 8

Alejandro Flores Calderón

8.1 Introduction

In Chapter 7 the sustainability design criteria were defined and a procedure to evaluate the product sustainability for each was described. In this Chapter, these criteria are applied to evaluate the re-designs obtained from the SPA analyzed. These evaluations have two objectives, the first refers to show the SPD criteria usefulness, and the second one refers to compare the re-designs in terms of a common sustainability criteria.

In section 8.2, it is presented the summary of the results obtained from the evaluation. In section 8.3, a scale to identify the product sustainability is proposed. Finally, in section 8.4 some conclusions are presented.

8.2 Sustainability evaluation of the re-designs

In order to show the SPD criteria usefulness, there were used to evaluate the re-designs obtained in the SPAs analyzed (see table 6.15).

The detailed calculations of the sustainability evaluation for each re-design are presented in Appendix C. Table 8.1 only shows a synthesis of the scores obtained.

Table 8.1 Sustainability criteria scores

SUSTAINABLE CRITERIA	Re-designed products		
	C2C %	BIO %	TB %
CRITERION 1. MATERIALS TOXICITY	81.41	76.20	80.54
CRITERION 2. EFFICIENCY	38.33	46.67	38.33
CRITERION 3. MATERIALS CYCLICITY	74.23	65.76	73.71
CRITERION 4. USE OF RENEWABLE ENERGIES	0.00	0.00	0.00
CRITERION 5. SOCIAL BENEFIT	88.75	88.75	88.75
TOTAL PRODUCT SCORE [%]	***56.54***	***55.48***	***56.27***

As it can be observed in table 8.1, for the '*materials toxicity*' criterion, the product designed using C2C obtained the highest score (81.41%); this is due to the fact that in the corresponding design process avoiding the use of toxic materials is one of the core aspects.

The highest score for the '*efficiency*' criterion (table 8.1), was obtained by BIO´s redesign (46.67%) because its process looks at and mimics the efficiency patterns that Nature provides. For C2C and TB the efficiency is not considered with the same emphasis. In C2C, efficiency is concerned with the ease of product´s disassembly process and for TB it is mentioned as a core attribute to consider for the product re-design, but the process proposed by Datschefski presents some difficulties (Flores-Calderón, et. al. 2009, Hautanen, et. al. 2009, Puma 2008).

The highest score for the '*materials cyclicity*' criterion (table 8.1), was obtained by the product designed using C2C (74.23%) and this is consistent with the importance that this approach gives to the material´s requirements. TB considers cyclicity as a kernel issue as well, but C2C also questions ecological health and the material´s economic possibilities; TB, on the other hand, just makes emphasis in the ecological aspects related to the material. For BIO the cyclicity is relevant, but does not propose ways to evaluate it.

The three approaches obtained a score of 0% in the '*renewable energy*' criterion (table 8.1). C2C and BIO recommend the use of renewable energy, but do not describe a method to do that or mention a procedure to evaluate it. For TB, the renewable energy use is relevant and it has to be considered when designing a product, but in the study case, the external conditions (the motor control system and the digital camera) limited the possibility to improve the score in TB.

Regarding the '*social benefit*' criterion, the score obtained by the three products designed with the SPD approaches is 88.75%. It was considered that the same manufacturing conditions would apply for the realization of the products, and therefore the answers to the questions formulated were the same.

8.3 Sustainability product indicator

In order to have the possibility to compare products in terms of sustainability scores or to have a unique score that represents the product sustainability level, in this chapter it is proposed an indicator scale based on the criteria proposed in this research thesis.

The indicator scale proposed take in to account the structure defined in the Norm VDI2225, Guideline (see table 8.2). This structure is convenient for the present sustainability criteria analysis, because it is commonly used in the evaluation criteria of approximately equal importance (Pahl, et. al. 2007), as is proposed at the end of the present research (see Chapter 9).

Table 8.2 Scale in the Guideline VDI2225

Pts.	Meaning
0	Unsatisfactory
1	Just tolerable
2	Adequate
3	Good
4	Very good (ideal)

The advantage of the small range is that, in dealing with what are so often no more than in adequately known characteristics of the variants, rough evaluations are sufficient and, indeed, may be the only meaningful approach. They involve the following assessments (Pahl, et. al. 2005):

- Far below average
- Below average
- Average
- Above average
- Far above average

The indicator scale proposed for the sustainability criteria is presented in table 8.3.

Table 8.3 Indicator of sustainability level

Pts.	From [%]	To [%]	Sustainability Indicator
0	0	19	**Unsatisfactory**
1	20	39	**Just tolerable**
2	40	59	**Adequate**
3	60	79	**Good**
4	80	100	**Very good (ideal)**

Table 8.4 shows that the sustainability level of the re-designs is the same for the three SPA and they have an ‘Adequate’ sustainability level.

Table 8.4 sustainability indicator level for the Re-Designs (RD)

Product	Total sustainable product score [%]	Sustainability indicator
RD (C2C)	*56.54*	Adequate
RD (BIO)	*55.48*	Adequate
RD (TB)	*56.27*	Adequate

8.4 Conclusions

In Chapter 7 the sustainability criteria and their evaluation procedures were defined. In this chapter, these criteria and their procedures are applied to evaluate the re-designs sustainability level. Table 8.1 presents a synthesis of the scores, but in Appendix C, the detailed calculations are presented.

In addition, it is proposed an indicator sustainability scale. The re-designs obtained the same level of sustainability, i.e. a level of ‘adequate’. The score obtained have the following interpretation: The sustainable approaches and the SPD methods are not antagonist but complementary. This is because in order to achieve a sustainable product, sustainability has to be considered in the complete product life cycle. This means: the use of the best material with the characteristics of being incorporated to techno or bio cycles (C2C), choice the best functional solution in nature (BIO), and finally consider the experiences accumulated in innovations of other green products (TB).

Conclusions

C h a p t e r 9

Alejandro Flores Calderón

CONCLUSIONS AND FURTHER WORK

9.1 CONCLUSIONS

The hypothesis stated in section 3.3 of the current work was '*Through a detailed analysis of representative SPA identified in the specialized literature it is possible to distinguish the essential criteria (common to the technical proposals analyzed) to re-design more sustainable products and evaluate their sustainability*'. This hypothesis is confirmed as valid. This can be asseverate due to the fact that after being identified C2C, BIO, and TB as representatives of the SPA (section 4.2), these were studied and was possible to identify, analyze, compare and synthesize the sustainable product re-design criteria used by these approaches (Chapters 5 and 6).

From the C2C, BIO, and TB study, it was possible to identify the criteria used by those approaches in the re-design of a product. Taking as reference the knowledge and experience acquired from this sustainability approaches the author propose a cluster of criteria (Chapter 7). This proposal fulfills the objective established in section 3.4; the objective refers to '*propose a criteria cluster to evaluate the product sustainability*'. Also, the sustainable product criteria proposed in the current research were test through the evaluation of the study case; this evaluation is reported in Chapter 8. The results obtained through the application of the sustainability criteria shows at least two characteristics: 1) The sustainability criteria evaluate quantitatively the product sustainability in percentage (see table 8.1) and the score obtained is associated to an indicator which refers to a scale of five sustainability levels (see table 8.3). 2) The evaluation scores provide the designer specific information on what can be done to improve the product sustainability level. The re-design target, now consist in generate the best solution based on the highest values in each of the criteria proposed in the current research. These two features also fulfill the requirements established for the thesis objective (section 3.4).

The author considers, based on the literature research (Chapter 2) and the analysis of the representative SPA (Chapter 5 and 6) that:

- This proposal of sustainability criteria is original because in it, there are integrated, in a single proposal, the experiences of the SPA analyzed.

And because of the criteria proposed were explored in the evaluation of the re-designs (Chapter 8) the author also conclude that:

- The criteria proposed are ready-to-use to evaluate the sustainability of a product and from this evaluation; it is possible to generate specific information for the re-design of a product.

The previous conclusions can be asseverated based on the results obtained in Chapter 8 in which the author refers to the scores obtained in the sustainability evaluation of the re-designs, table 8.1, are very close to each other. This is due to the fact that the criteria developed by the author somehow are considered in each analyzed approach. Essentially, they are differentiated only by the level of attention given by the approach to each criterion. The emphasis given by each approach is presented in table 9.1. The table 9.1 suggests that the three approaches can complement each other if new criteria are developed.

Table 9.1 presents the criteria proposed by the author; by identifying the emphasis that each of the three approaches gives to them. Table 9.1 shows that even when the criteria are considered by the three approaches, these are at different emphasis level.

Table 9.1 Emphasis of the sustainability approaches

SUSTAINABILITY PRODUCT EVALUATION	EMPHASIS		
	HIGH	MEDIUM	LOW
CRITERION 1 MATERIALS TOXICITY	C2C	TB	BIO
CRITERION 2 EFFICIENCY	BIO	C2C-TB	
CRITERION 3 MATERIALS CYCLICITY	C2C	TB	BIO
CRITERION 4 USE OF RENEWABLE ENERGIES			C2C-TB-BIO
CRITERION 5 SOCIAL BENEFIT	C2C-TB-BIO		

These new criteria proposed in the current thesis have therefore four relevant features:

1. The core features of C2C, BIO and TB are considered.
2. The evaluation processes proposed have the same complexity level for C2C, BIO or TB, because they essentially need the same kind of information and metrics.

3. The criteria proposed can be considered by the designer as a ‘handy unit of criteria’ ready to evaluate product´s sustainability therefore, ready to obtain valuable information for the following re-design process.
4. An hypothetic sustainability product re-design considering the present sustainability criteria will present an ‘*emphasis*’ level as the one presented in table 9.2.

Table 9.2 Emphasis level through the criteria proposed

SUSTAINABILITY PRODUCT EVALUATION	EMPHASIS		
	HIGH	MEDIUM	LOW
CRITERION 1 MATERIALS TOXICITY	√		
CRITERION 2 EFFICIENCY	√		
CRITERION 3 MATERIALS CYCLICITY	√		
CRITERION 4 USE OF RENEWABLE ENERGIES	√		
CRITERION 5 SOCIAL BENEFIT	√		

9.2 Further work

This thesis has presented a criteria cluster to evaluate the product sustainability. These criteria were used to evaluate the sustainability level of the redesigns obtained in the SPA analyzed….

REFERENCES

Agogino Alice M., Beckman Sara, Shedroff Nathan, (2007) “Notes and slides for the Design for Sustainability” class. Universidad de California, Berkeley.

AIGA (2009) (last income October 2009). Center for Sustainable Design http://www.livingprinciples.org/.

Alting L. Hauschild H. Wenzel H. (1998). “Elements in a new sustainable industrial culture environment assessment in product development”. Robotics and computer-integrated manufacturing 14 (1998) 429-439

Ash Michael, Ash Irene (2004). “Handbook of green chemicals”. Synapse Information Resources.

ATSDR, Agency for Toxic Substances and Disease Registry (2010). “Toxicological profile for different substances”. U. S. Department of Health and Human Services, Public Health Services. http://www.atsdr.cdc.gov/

BioThinking (Last income November 2011). http://www.biothinking.com/

Biomimicry Newsletter (2006). Volume No: 4 Issue No: 1 March 27, 2006

BI (2011). http://www.biomimicryinstitute.org/

Biomimicry (Last date of income, January 2009) http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html

Benyus Janine M. (1997). "Biomimicry: Innovation inspired by nature". Edit. Harper Perennial.

Belz Frank-Martin (2006). “Marketing in the Age of Sustainable Development”. Technical University of Munich (TUM) Business School. Proceedings: Changes to Sustainable Consumption, 20-21 - April, Copenhagen, Denmark. Workshop of the Sustainable Consumption Research Exchange (SCORE!) Network (www.score-network.org), supported by the EU’s 6th Framework Programme.

Boks C., Stevels A., 2007. “Essential perspective for design for environment. Experiences from the electronics industry” International Journal of Production Research, 45:18, 402 1-4039

Braungart Michael, McDonough William, Bollinger Andrew (2007). "Cradle-to-cradle design: creating healthy emissions - a strategy for eco-effective product and system design". Journal of Cleaner Production

Bryant Cari R., Sivaramakrishnan Karthik L., Wie Van Michael, Stone Robert B., Daniel A. McAdams (2004). “A modular design approach to support sustainable design”. Proceedings of DETC-04. DETC2004-57775

Burke, S., Gaughran W.F. (2007) “Developing a framework for sustainability management in engineering SME´s”. Robotics and Computer-Integrated Manufacturing. 696–703 Elsevier Ltd.

Byggeth Sophie, Broman Go¨ran, Robe`rt Karl-Henrik, (2007). “A method for sustainable product development based on a modular system of guiding questions”. Journal of Cleaner Production 15, page 1-11.

Casis N., Luciani C.V., Berlanga J. Vich, Estenoz D.A., Martino D. M. and Meira G.R. (2007). “Synthesis of ‘bioinspired’ copolymers: experimental and theoretical investigation on poly (vinyl benzyl thymineco-triethyl ammonium chloride". Green Chemistry Letters and Reviews Vol. 1, No. 1, March 2007, 65-72

Charter Martin & Clark Tom (2007) "Sustainable innovation key conclusions from sustainable innovation conferences 2003–2006". The Centre for Sustainable Design University.

Cheong Hyunmin, Shu L.H., Stone Robert B., McAdams Daniel A. (2008). "Translating terms of the functional basis into biologically meaningful keywords". ASME IDETC-CIE.

Choi, J. K., Nies, L. F. and Ramani, K. (2008) "A framework for the integration of environmental and business aspects toward sustainable product development". Journal of Engineering Design, Vol. 00, No. 0, January 2008, 1–16.

Datschefski Edwin (1999) "Cyclic, solar, safe – biodesign's solution requirements for sustainability". The Journal of Sustainable Product Design, January. ISSUE 10: July 1999

Datschefski Edwin (2002) "Productos sustentables, el regreso de los ciclos naturales". Edit. McGraw Hill International.

Datschefski Edwin (Last income 2010), Sustainable Products. http://www.biothinking.com/pubs.htm

DJSI. Dow Jones Sustainability Indexes (Last income, November 2011). http://www.sustainability-index.com/default.html

Dogan Cagla and Walker Stuart (2003). "The best of both: A study of the feasibility of integrating scales of design and production for sustainable products". The Journal of Sustainable Product Design 3:135–147.

DSM- The Dictionary of Sustainable Management. http://www.sustainabilitydictionary.com/s/sustainability_helix.php. Last income November 2011.

EB 2008. Encyclopedia Britannica Library. Ultimate Reference DVD-Suite (2008).

Fargnoli Mario, Kimura Fumihiko (2007) "Sustainable design of modern industrial products". The University of Tokyo, Department of Precision Engineering, Japan. 13° CIRP International Conference on Life Cycle Engineering 189-194.

Flores-Calderón Alejnadro, Vicente Borja Ramírez, Gustavo Valeriano Barrientos, Adrián Espinosa Bautista (2000). "Rediseño para desensamble de una bomba tipo estrella considerando su ciclo de vida". Memoria del VI congreso anual de la Sociedad Mexicana de Ingeniería Mecánica.

Flores-Calderón Alejandro, Borja Ramírez Vicente (2008). "Conceptos para la implementación del desarrollo sustentable del producto". XIV Congreso Internacional de la SOMIM. Pag. 95 – 103.

Flores-Calderón Alejandro, Vicente Borja, López Parra Marcelo, Alejandro C. Ramírez Reivich (2009). "A conceptual taxonomy study of sustainable product design processes". Proceedings of the ASME 2009, IMECE2009. IMECE2009-13088

Flores-Calderón Alejandro, Borja-Ramírez Vicente, López-Parra Marcelo, Ramírez-Reivich Alejandro C. (2009B). "Redesign of a motorized lenses using Cradle to Cradle design". XIV-International Annual Congress SOMIM 2009.

Flores-Calderón Alejandro, Borja Vicente, López-Parra Marcelo, Ramírez-Reivich Alejandro (2010). "A case study in "total beauty" design: an experience trough sustainable product design". Proceedings of the ASME2010 IMECE2010-39271.

Flores-Calderón Alejandro, Borja Vicente, López-Parra Marcelo, Ramírez-Reivich Alejandro (2011). "A study case in biomimicry redesign: an experience trough sustainable product design". Inner report. Centro de Diseño, Manufactura e Innovación Tecnológica (CDMIT). FI-UNAM

García-Serna J., Pérez-Barrigón L., Cocero M. J. (2007). "New trends for design towards sustainability in chemical engineering: green engineering". Chemical Engineering Journal 133 7–30

Gilpin Alan, (1998). "Dictionary of environment and sustainable development". Edit. Wiley.

Greenwood Tom (2004). "A Guide to Environmentally Sustainable Product Design". http://www.espdesign.org/

Gershenson John K., Stauffer Larry A. (1999). "A taxonomy for design requirements from Corporate Customers". Research in Engineering Design 11:103–115.

Guo-Qiang Chena, Qiong Wua (2005). "The application of polyhydroxyalkanoates as tissue engineering materials". Elsevier Ltd. Received 8 February 2005; accepted 12 April 2005.

Hautanen Kathryn, Jacobs Erin, Meade Erica and Ranson-Walsh Kate, (2009). "Publishing is a problem". Sustainability Studio Feb. 12, 2009. http://www.ericameade.com/publishing_is_a_problem_DMBA.pdf

Hastrich Carl (Last income 2011) http://www.biomimicryinstitute.org/about-us/biomimicryatool-for-innovation.html

Hawken Paul, Lovins B. Amory, Lovins L. Hunter (1994). "Natural capitalism: the next industrial revolution". http://www.natcap.org/

Hawken Paul, Lovins Amory and Lovins Hunter, (2005). "The natural capitalism". http://www.natcap.org/defaultHTM.php

Hemel C. Van, Cramer J. (2002). "Barriers and stimuli for ecodesign in SMEs". Journal of Cleaner Production. (10) 439–453

Hirtz Julie, Stone Robert B., McAdams Daniel A., Szykman Simon, and Wood Kristin L. (2002). "A functional basis for engineering design: reconciling and evolving previous efforts". NIST Technical Note 1447 U.S. Department of Commerce.

Howarth George, Hadfield Mark (2006). "A sustainable product design model". Materials and Design 27. Pag. 1128–1133 Elsevier Ltd.

Hsiao Hsi-Chi, Chou Wen-Chih (2007). "Using biomimetic design in a product design course". World Transactions on Engineering and Technology Education Vol.6, No.1.

Hundal Mahendra 2000. "Life cycle assessment and design for environment". International design conference - design Dubrovnik. University of Zagreb; Faculty of Mechanical Engineering and Naval Architecture

John D. Lincoln, James C. Earthman, Oladele A. Ogunseitan, Jean-Daniel M. Saphores, and Andrew A. Shapiro4 (2007). "Renewable-resource printed wiring board design using natural fibers and a bio-based thermosetting matrix". IEEE

Kara Sami, Honke Ina, Kaebernick Hartmut (2005) "An integrated framework for implementing sustainable product development". 1-4244-0081-3/05, IEEE

Kim Seok, Metin Sitti (2008). “Fabrication and characterization of biologically inspired mushroom-shaped elastomer microfiber arrays”. ASME 2008 IDETC/CIE.

Lee S. G., Lye S. W. and Khoo M. K. (2001). “A Multi-Objective Methodology for Evaluating Product End-of-Life Options and Disassembly”. International Journal of Advanced Manufacturing Technology 18:148–156. Springer-Verlag London Limited.

Lin Feng and Lin Li (2003). “A discussion of the state-of art research on environmentally conscious material selection methodologies for the reduction of products’ toxic impact”. The Journal of Sustainable Product Design 3:119–134.

Liu Shaofeng, Boyle Iain M., 2009. “Engineering design: perspectives, challenges, and recent advances”. Journal of Engineering Design. Vol.20 No. 1, February, 7-19

Ljungberg Lennart Y. (2007). “Materials selection and design for development of sustainable products”. Materials and Design 28. Peg. 466–479.

López Andrés (1996). “Competitividad, innovación y desarrollo sustentable” una discusión conceptual IDRC, el North South Center de la Universidad de Miami y la AVINA Foundation. http://www.fund-cenit.org.ar/investigaciones/publicaciones1.htm

Mansoorian Alireza Fatemeh Heidaryan Naeini (2004). “Integrating TRIZ and bionical engineering. http://www.trizjournal.com/archives/2005/03/07.pdf

Maxwell Dorothy, Sheate1William, and Vorst1 Rita van der (2006). “Functional and systems aspects of the sustainable product and service development approach for industry”. Journal of Cleaner Production Volume 14, Issue 17, Pages 1466-1479

MBDC (2008). Brochure (Last income September 2009) . www.mbdc.com/c2c_home.htm

McDonough William, Braungart Michael (2002). "Cradle to Cradle: Remaking the Way We Make Things". Edit North Point Press.

Mcdonough William, Braungart Michael, Anastas Paul T., Zimmerman Julie B. (2003). "Applying the Principles of Green Engineering to Cradle-to-Cradle Design". Environmental Science & Technology December - peg 434-441.

Mihelcic, J. R., Crittenden, J. C., Small, M. J., Shonnard, D. R., Hokanson, D. R., Zhang, Q., Chen, H., Sorby, S. A., James, V. U., Sutherland, J. W. and Schnoor, J. L., (2003), "Sustainability science and engineering: the emergence of a new metadiscipline," Environmental Science and Technology, 37 (23), pp. 5314-5324.

Mien Hui Lee, Feng Wen Lu, Leng Kheng Robert Gay (2005). “An Integrated Manufacturing and Product Services System (IMPSS) Concept for Sustainable Product Development”. IEEE. 3B-2-1F. Peg 656-662.

Mien Hui Lee, Gay Robert, Lu Wen Feng, Song Bin, (2006) “The Framework of Information Sharing in End-of-Life for Sustainable Product Development”. IEEE International Conference on Industrial Informatics.

Mohanty A. K., Misra M., and Drza L. T. (2002). “Bio-Composites from Renewable Resources: Opportunities and Challenges in the Green Materials World”. Journal of Polymers and the Environment, Vol. 10, Nos. 1 / 2.

OTA (1992) “Green products by design: choices for a cleaner environment” September 1992 OTA-E-541 NTIS order #PB93-101715 GPO stock #052-003-01303-7.

OTA (1994) “Industry, technology, and the environment: competitive challenges and business opportunities” January 1994 OTA-ITE-586 NTIS order #PB94-134616 GPO stock 052-003-01362-2.

OTA-ENV-634 (1995). “Environmental Policy Tools: A User's Guide”. http://www.princeton.edu/~ota/disk1/1995/9517/951701.PDF

OTA-ITC-155 (1995). “Environmental Technology: Analysis of Selected Federal R&D Programs”. http://www.fas.org/ota/reports/9515.pdf

OXED (Last income, November 2011). “The Oxford English Dictionary”. http://oxforddictionaries.com.

Pahl Gerhard, Beitz Wolfgang (2005). “Engineering Design: A Systematic Approach”. Edit. Springer-Verlag London Limited

Parris Thomas M., Kates Robert W. (2003). “Characterizing a sustainability transition: Goals, targets, trends, and driving forces”. Proceedings of the National Academy of Sciences of the United States of America, Vol. 100, No. 14. pp. 8068-8073.

PB (Polimeros Biodegradables, last incom Aug. 6, 2009) http://www.eis.uva.es/~macromol/curso05-06/medicina/polimeros_biodegradables.htm

PNUMA (2207) “Diseño para la sostenibilidad - un enfoque práctico para economías en desarrollo”. Programa de las Naciones Unidas para el Medio Ambiente. ISBN: 978-92-807-2915-3. http://www.unep.fr/shared/publications/pdf/DTIx1044xPA-D4SSPA.pdf

Petrick Irene J., Echolsb Ann E., (2004) “Technology roadmapping in review: a tool for making sustainable new product development decisions”. Technological Forecasting & Social Change 71 81–100. Elsevier Ltd.

Puma Steve (2008). “The TESLA roadster: an evaluation”. http://www.thepumablog.com/wpcontent/uploads/2009/05/tesla_puma_final.pdf

Rossi Mark, Charon Scott, Wing Gabe, and Ewell James (2006). “Design for the Next Generation Incorporating Cradle-to-Cradle Design into Herman Miller Products”. Journal of Industrial Ecology.

Song M. and Noh J. (2006) "Best new product development and management practices in the Korean high-tech industry", Industrial Marketing Management, 35, pp. 262-27 8

SPC (2011). Sustainable Product Corporation. http://www.sustainableproducts.com/susproddef.html. Last income November, 2011.

Stroble Jacquelyn K., Nagel Robert L., Poppa Kerry R., Bohm Matt R. and Stone Robert B., (2008). “A retrospective on twenty years of the design theory and methodology conference”. Proceedings of the ASME. DETC2008- 49373.

Shimamura Eihaku, Kasuya Ken-ichi, Takeshi Shiotani, Yu Shima, Miyamae, Takasago, Hyougo, Hirosawa, Wako-shi. (1994). “Physical properties and biodegradability of microbial poly(3-hydroxybutyrate-co-3-hydroxyhexanoate)”. American Chemical Society. Received December 10, 1993.

Sherwin Chris (2006) “design and sustainability a discussion paper based on personal experience and observations”. The Journal of Sustainable Product Design 4:21–31.

Summers Joshua D. (2005). “Reasoning in engineering design”. ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference DETC2005-85334 pp. 329-340.

Thinkcycle. (Last income, November 2009). http://thinkcycle.org/

Tsai Wen-Hsien, Chou Wen-Chin, (2009). "Selecting management systems for sustainable development in SMEs: A novel hybrid model based on DEMATEL, ANP, and ZOGP". Expert Systems with Applications 36. Page 1444–1458.

UNU-IDRC (2007). "Industrial innovation and environmental regulation: Developing workable solutions". Edited by Saeed Parto and Brent Herbert-Copley. United Nations University & International Development Research Centre.

Vincent F. V. Julian, Bogatyreva A. Olga, Bogatyrev R. Nikolaj, Bowyer Adrian and Pahl Anja-Karina (2006). "Biomimetics: its practice and theory". Journal of the Royal Society Interface 3. Peg. 471 – 482.

Voisey Peter W., Hunt J. R. a Voisey (1967) "Physical properties of egg shells". British Poultry Science, 8: 4, 263-271

Vogtländer Joost G., Hendriks Charles F., Brezet Han C., (2001). "The EVR model for sustainability: A tool to optimize product design and resolve strategic dilemmas". The Journal of Sustainable Product Design 1: peg. 103–116.

Wenzel Henrik, Hauschild Michael and Alting Leo (2000). "Environmental assessment of products" Volume 1 and 2". Edit. IBT Global, London.

Woy U., Wang Q. (2007) "New product development: implementing procedures for sustainable product development in SME´s utilizing available technologies". Agile Manufacturing, ICAM. IET International Conferences on Publication.

Zhong Z. W., Song B., and Huang C. X. (2009). "Environmental impacts of three polyhydroxyalkanoate (pha) manufacturing processes". Materials and Manufacturing Processes, 24: 519–523, 2009. Taylor & Francis Group.

A P P E N D I X

‘ A ’

Alejandro Flores Calderón

C2C **C0RE CONCEPTS**	**(1)** McDonough William, Braungart Michael (2002). "Cradle to Cradle: Remaking the Way We Make Things". Edit North Point Press. **(2)** Braungart Michael, McDonough William, Bollinger Andrew (2007). "Cradle-to-cradle design: creating healthy emissions - a strategy for eco-effective product and system design". Journal of Cleaner Production **(3)** Mcdonough William, Braungart Michael, Anastas Paul T., Zimmerman Julie B. (December, 2003). "Applying the Principles of Green Engineering to Cradle-to-Cradle Design". Environmental Science & Technology (peg 434-441). **(4)** Braungart Michael, Engelfried Justus (2008). "The intelligent products system (IPS)". http://www.epea.com/english/cradle_methodology/Intelligent%20Products%20System%20(IPS).pdf **(5)** Brochure. www.mbdc.com/c2c_home.htm **(6)** Key Concepts http://www.mbdc.com/c2c_gkc.htm

	CONCEPT	DEFINITION	DESCRIPTION
1	**C2C**	It is a science--and values based vision of sustainability successfully that enunciates a positive, long-term goal for engineers *[(3) peg 435]*.	C2C designs industrial systems to be commercially productive, socially beneficial, and ecologically intelligent. C2C is a framework that posits a new way of designing human systems to eliminate conflicts between economic growth and environmental health resulting from poor design and market structure. It is based on the manifested rules of nature and redefines at hand, eco-efficient strategies can serve a large purpose *[(3) peg 436]*.
2	**C2C DESIGN**	Is an innovative approach to sustainability that models human industry on the integrated processes of nature's biological metabolism—its productive ecosystems—by developing an equally effective technical metabolism, in which the materials of human industry safely and productively flow *[(5) peg 3]*.	Cradle to Cradle Design is MBDC's design paradigm, based on principles and an understanding of the pursuit of value, as well as MBDC's processes for product and material research and development, and for educating and training. At a fundamental level, the new paradigm proposes that human design can learn from nature to be effective, safe, enriching, and delightful. Cradle to Cradle Design models human industry on nature's processes, in which materials are viewed as nutrients circulating in healthy, safe metabolisms. Industry must protect and enrich ecosystems—nature's biological metabolism—while also maintaining safe, productive technical metabolism for the high-quality use and circulation of mineral, synthetic, and other materials [6].
3	**Tenants of C2C design**	C2C identifies three key tenants in the intelligence of natural systems that can inform human design *[(3) peg 436] :*	*1.- Waste equals food:* Waste virtually does not exist in nature because each organism's process contribute to the health of the whole ecosystem (think biological metabolism). The technical metabolism is designed to mirror the biological metabolism; it is a closed loop system in which benign, valuable, high-tech synthetics and mineral resources circulate in cycles of production, use, recovery and remanufacture. 2.- *Use current solar income:* trees and plants use sun light to manufacture food. Human energy systems can be nearly as effective. 3- *Celebrate diversity:* Healthy ecosystems are complex communities of living things, each of which has developed a unique response to its surroundings that works in concert with those of other organisms to sustain the system. When designer celebrate diversity, they tailor designs to maximize their positive effects on the particular niche in which they will be implemented--all sustainability is local.

4	**Principles of green engineering**	C2C vision sets a course for "What do I do?". The 12 Principles of Green Engineering answer, "How do I do it?" They can be used systematically to optimize a system or its components *[(3) peg 437]*.	*Principle 1* Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible. *Principle 2* It is better to prevent waste than to treat or clean up waste after it is formed. *Principle 3* Separation and purification operations should be designed to minimize energy consumption and materials use. *Principle 4* Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency. *Principle 5* Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials. *Principle 6* Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition. *Principle 7* Targeted durability, not immortality, should be a design goal. *Principle 8* Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw. *Principle 9* Material diversity in multicomponent products should be minimized to promote disassembly and value retention. *Principle 10* Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows. *Principle 11* PPS should be designed for performance in a commercial afterlife". *Principle 12* Material and energy inputs should be renewable rather than depleting.
5	**C2C Design Protocol**	A scientifically based, peer-reviewed process used to assess and optimize materials used in products and production processes in order to maximize health, safety, effectiveness, and high quality reutilization over many product life cycles *[6]*.	
6	**Design**	Is a signal of intention	The ides was manifested saying "I was tired of working hard to be less bad *[(1) peg 9]*.
7	**Chemical substances**		There are approximately 80 000 defined chemicals substances and technical mixes that are product and used by industries today (each of which has five or more by-products), only 3 000 so far have been studied for their effects on living systems *[(1) peg 42]*.
8	**Design Chemistry**	The incorporation of scientific and ecological knowledge into product and process design [6].	
9	**Downcycling**	The practice of recycling a material in such a way that much of its inherent value is lost (for example, recycling plastic into park benches) [6].	
10	**Recycling**		Is an aspirin, alleviating a rather large collective hangover … overconsumption. The best way to reduce any environmental impact is not to recycle more, but to produce and disposal lees *[(1) peg 50]*

11	**Eco-efficiency**	The strategy for "sustainability" of minimizing harm to natural systems by reducing the amount of waste and pollution human activities generate *[6]*.	Primarily the term means "doing more whit less", a precept that has its roots in early industrialization. It is an outwardly admirable, even noble concept, but it is not a strategy for success over the long term because it does not reach deep enough. At the 1992 Rio Earth Summit. 167 countries were represented. One major strategy emerged from the industrial participants. The machines of industry would be refitted with cleaner, faster, quieter engines. Industry would redeem its reputation without significantly changing its structures or compromising its drive for profit. It was officially coined by the Council for Sustainable Development, a group of forty-eight industrial sponsors had been asked to bring a business perspective to the Earth Summit [*1) peg 51]*. Eco-efficiency strategies focus on the maintaining or increasing the value of economic output while simultaneously decreasing the impact of economic activity upon ecological systems. Zero emissions, as the ultimate extension of eco-efficiency, aims to provide maximal economic value whit zero adverse ecological impact--a true decoupling of the relationship between economy and ecology *[(2) Introduction]*.
12	**Reduction (4R)**	Is a central tenet of Eco-efficiency. Reduction in any case not halt depletion and destruction it only slows them down, allowing them to take place in smaller incremental over a longer period of time *[(1) peg 54]*.	
13	**Reuse (4R)**		Wastes can also make industries and customers feel that something good is being done fore the environment, because piles of waste appear to go "away". But in many cases these wastes-and any toxins and contaminants they contain-are simply being transferred to another place *[(1) peg. 55]*.
14	**Recycle (4R)**	Most recycling is actually downcycling	It reduce the quality of a material over time *[(1) peg. 56]*.
15	**Regulate (4R)**	Is a signal of design failure	In fact, it is what we call a license to harm: a permit issued by a government to an industry so that it may dispense sickness, destruction, and death at an "acceptable" rate. Good design can require no regulations at all *[(1) peg. 61]*.
16	**Eco-effectiveness**	MBDC's strategy for designing human industry that is safe, profitable, and regenerative, producing economic, ecological, and social value *[6]*.	Once you are doing the right things, then doing them "right", whit help of efficiency among other tools, make perfect sense. It means working on the right things-on the right products and services and systems-instead of making the wrong things less bad.*[(1) peg. 76]*.
17	**Right things**	Are those that lead to good growth--more niches, health, nourishment, diversity, intelligence, and abundance--for this generation of inhabitants on the planet and for generations to come *[(1) Peg 78]*	

18	**New design assignment**	Instead of fine-turning the existing destructive framework, why don't people and industries set out to create the following:	Instead of fine-turning the existing destructive framework, why don't people and industries set out to create the following *[(1) Peg 90]:* * Buildings that, like trees, produce more energy than they consume and purify their own water * Factories that produce effluents that are drinking water * Products that, where their useful life is over, do not become useless waste but can be tossed onto the ground to decompose and become food for plants and animals and nutrients for soil; or alternately, that can return to industrial cycles to supply high-quality raw materials for new products * Billions of dollars worth of material accrued for human and natural purposes each year * Transportation that improves the quality of life while delivering goods and services * A world of abundance, not one of limits, pollution, and water
19	**Materials Flows**	Can be divided into two categories: * Biological mass * Technical mass	Biological Nutrients are useful for the biosphere, while technical nutrients are useful for the technosphere, the systems of industrial processes *[(1) peg 93]*.
20	**Waste equals food**	It is a principle of natural systems and that eliminates the concept of waste. In this design strategy, all materials are viewed as continuously valuable, circulating in closed loops of production, use, and recycling *[6]*.	To eliminate the concept of water means to design things--products, packaging, and systems--form the very beginning on the understanding that waste does not exist. Waste equals food *[(1) peg 104]*.
21	**Products**		Can be composed either of materials that biodegrade and become food for biological cycles, or of technical materials that stay in closed-loop technical cycles, in which they continually circulate as valuable nutrients for industry *[(1) peg 104]*.
22	**Intelligent Products System (IPS)**	It is a system that can reduce dramatically the cost of waste management. Looking at products available today from a life-cycle approach, it is apparent that all products could be assigned to three categories *[(4) peg 1-3]:*	Consumption Products, Service Products, Unmarketable Products.
23	**Product of consumption**	A product designed for safe and complete return to the environment, which becomes nutrients for living systems. The product of consumption design strategy allows products to offer effectiveness without the liability of materials that must be recycled or "managed" after use *[6]*.	These are usually used only once, then these products and/or their by-products become waste. They are normally put out into the natural environment after one use. Among other basic requirements, in a system of "intelligent products", these have to be: * biodegradable and / or biotically degradable * non-bioaccumulative * non-carcinogenic, non-teratogenic, non-mutagenic and - in applied concentrations - non-toxic to human beings. * analyzed on a picogram level *[(4) peg 1-3]*.

24	**Product of service**	A product that is used by the customer, formally or in effect, but owned by the manufacturer. The manufacturer maintains ownership of valuable material assets for continual reuse while the customer receives the service of the product without assuming its material liability. Products that can utilize valuable but potentially hazardous materials can be optimized as Products of Service *[6]*.	The producer basically provides consumers with products on a service basis. After the product has served its function and has to be renewed, the consumer returns it to the producer who is responsible for disassembly and recycling *[(4) peg 1-3]*.
25	**Products of unmarketable**	Products or materials to be eliminated from human use because they cannot be maintained safely in either biological or technical metabolisms *[6]*.	Unmarketable products cannot be consumed or used in an environmentally sound *[(4) peg 1-3]*.
26	**Biological Metabolism**	The natural processes of ecosystems are a biological metabolism, making safe and healthy use of materials in cycles of abundance *[(6)]*.	
27	**Biological Nutrient**	A biodegradable material posing no immediate or eventual hazard to living systems that can be used for human purposes and can safely return to the environment to feed environmental processes *[6]*.	The idea is to compose these products of materials that can be tossed on the ground or compost heap to safely biodegrade after use--literally to be consumed. Is a material or product that is designed to return to the biological cycle--it is literally consumed by microorganisms in the soil and by other animals. *[(1) peg 105]*.
28	**Technical metabolism**	Modeled on natural systems, the technical metabolism is MBDC's term for the processes of human industry that maintain and perpetually reuse valuable synthetic and mineral materials in closed loops *[6]*.	
29	**Technical Nutrient**	A material that remains in a closed-loop system of manufacture, reuse, and recovery (the technical metabolism), maintaining its value through many product life cycles *[6]*.	Is a material or product that is designed to go back into the technical cycle, into the industrial metabolism from which it came. Isolating them from biological nutrients allows them to be upcycled rather than recycled--to retain their high quality in a closed-loop industrial cycled. Industrial mass can be specifically designed to retain its high quality for multiple uses *[(1) peg 109]*.

30	**Materials assessment (protocol)**	McDonough Braungart Design Chemistry's (MBDC (CM) -- Is an organization associated to C2C (SM)) which target is to propose sustainable design solutions. Its core procedure is based on a material assessment protocol of all the materials associated to the product and classifies them in 4 categories *[(3) peg 438]:*	*A green rating indicates* that a chemical presents little or no risk and is acceptable for the desired application. *A yellow rating indicates* low to moderate risk, and this chemical can be used acceptably until a green alternative is found. *An orange rating means* that the chemical is not necessarily high risk, but a lack of information prevents a complete assessment. *A red rating means* high risk. The criteria for the materials assessment are, for example: *Human health criteria:* Carcinogenicity, Teratogenicity, Reproductive toxicity, Mutagenicity, Endocrine disruption, Acute Toxicity, Chronic toxicity, Irritation of skin/mucous membranes, Sensitization, Other relevant data (e.g., skin penetration potential, flammability, etc.) *Ecological health criteria:* Algae toxicity, Bioaccumulation, Climatic relevance, Content of halogenated organic compounds, Daphnia toxicity, Fish toxicity, Heavy metal content, Persistence/biodegradation, Other (water, danger list, toxicity to soil organisms, etc.).
31	**Diversity in design**	Means considering not only how a product is made but how it is used, and by whom.	In a cradle to cradle conception. It may have many uses, and many users, over time and space *[(1) peg 139]*
32	**Diversity**		enriches the quality of life in another way: the furious clash of cultural diversity can broaden perspective and inspire creative change. What can we do now to begin the process of industrial re--evolution? *[(1) peg 144]*
33	**Commerce**		IS the engine of change, and honors its need to function quickly and productively. But it also recognizes that if commerce shuns environmental, social, and cultural concerns, it will produce a large-scale tragedy of the commons, destroying valuable natural and human resources for generations to come *[(1) peg 150]*.
34	**Conventional Design**	Its criteria are a tripod. Cost, aesthetics, and performance *[(1) peg 153]*.	
35	**Sustainable Design**	Its criteria used are the "triple bottom line" approach based on tripod of Ecology, Equity, and Economy	See the fractal tile *[(1) peg 153]*
36	**Health of the site**	It is measured whit respect to things like the number of earth-worms per cubic foot of soil, the diversity of birds and insects on the land and of aquatic species in a nearby river, and the attractiveness of the site to local residents *[(1) peg 162]*.	
37	**Eco-effectiveness**	It is a positive agenda for the conception and production of goods and services that incorporate social, economic, and environment benefit, enabling triple line growth	Eco-effectiveness concept moves beyond zero emission approaches by focusing on the development of products and industrial systems that maintain or enhance the quality and productivity of materials through subsequent life cycles *[(2) Abstract]*.

38	**5 steps to Eco-effectiveness (Is a stepwise strategy for business to realize the transition from eco-efficiency to eco-effectivenesses on the level of product design *[(2) point #4)]*) / (The result of the 5 steps will be the evolution of the product, and the application of the active positive list give us to radical new possibilities *[(1) peg 180]*.**	Step 1. Get "free of" know culprits	The first step to move toward eco-effectiveness, is to turn away the substances that are widely recognized as harmful. These harmful substances are called as "X" substances. The decision to create products that are "free of", form the rudiments of what is called a "design filter": a filter that is in designer's head instead of on the ends of pipes. Bear in mind that positively selecting the ingredients of which a product is made, and how they are combined, is the goal *[(1) peg 166]*.
		Step 2. Follow informed personal preferences	It is know little about what they are made of, and how; that is way most of the products do not meet truly eco-effectiveness design criteria. For these and other design decisions, the team made choices based on the best information available to them and on their judgment. That is way designers most decide based on his personal preferences and at least has to be considered the follow: *Prefer ecological intelligence:* be sure as possible that a product or substance does not contain or support substances and practices that are blatantly harmful to human and environmental health. Keep in mind the technical and biological metabolism. *Prefer respect:* this is the heart of eco-effective design, although it is a difficult quality to quantify, it is manifested on a number of different levels, some of which may be readily apparent to the designer in search of material: respect for those who make the product, for the communities near where it is made, for those who handle and transport it, and ultimately for the customer. *Prefer delight, celebration, and fun:* it is important for ecologically intelligent products to be at the forefront of human expression. They can express the best of design creativity, adding pleasure and delight to life *[(1) peg 168]*.
		Step 3. Creating a "passive positive list"	This is the point where the design begin to become truly eco-effective. In relations to materials different questions are established as for example: are they toxics? Carcinogenic? How is the product used, and what is its end state? What are the effects and possible effect s on the local and global communities? After that the substances are placed on the following lists in a kind of technical triage that assigns greater and less urgency to problematic substances: T*he "X" list:* this substances list includes the most problematic ones--those that are teratogenic, mutagenic, carcinogenic, or otherwise harmful in direct and obvious ways to human and ecological health. *The gray list:* this list contains problematic substances that are not quite so urgently in need of phase out. The list include problematic substances that are essential for manufacture and for which, currently, doesn't exist viable substitutes. *The "P" list:* this is the "positive list", the "preferred list". It includes substances actively defined as healthy and safe for use. It is rethinking what the product is made of, not what it fundamentally is--or how it is marketed and used *[(1) peg 173]*.
		Step 4 . Active the positive list	Here is stopped the way of trying to be less bad and start figuring out how to be good. The product is designed from beginning to end to become food for either biological or technical metabolism safely and prosperously. It is necessary to encode information about all of the ingredients in the materials themselves, in a kind of "upcycling passport" that can be read by scanners and used productively be future generations *[(1) peg 177]*.
		Step 5. Reinvent.	Here it is doing more than designing for biological and technical cycles. It is recasting the design assignment: not "design a car" but "design a nutrivehicle". Instead of aiming to create cars whit minimal or zero negative emissions, "cars designed to release positive emissions and generate other nutritious effects on the environment" *[(1) peg 178]*.

39	**Five guiding principles**	Signal your intention	It refer to commit to a new paradigm, rather than to an incremental improvement of the old *[(1) peg 182]*.
		Restore	It refer to strive for "good growth", not just economic growth. Design products that are restorative, as biological and technical nutrients *[(1) peg 183]*.
		Be ready to innovate further	No matter how good your product is, remember that perfection of an existing product is not necessarily the best investment one can make *[(1) peg 184]*.
		Understand and prepare for the learning curve	It refer to recognize that change is difficult, messy, and takes extra materials and time *[(1) peg 184]*.
		Exert intergenerational responsibility	It refer to ask questions as for example: How can we support and perpetuate the rights of all living things to share in a world of abundance? How can we love the children of all species--not just our own--for all time? Imagine a world of prosperity and health in the future will look like, and begin designing for it right now *[(1) peg 185]*.
40	**Ecological Intelligence**	A product or process designed to embody the intelligence of natural systems (such as nutrient cycling, interdependence, abundance, diversity, solar power, regeneration) *[6]*.	
41	**Eco-effective nutrient management**	That is a structure that its central role is to optimize or ensure the integrity of cyclical nutrient flow metabolisms and maintenance of the status of materials as resources *[(2) point #5)]*.	The effective management of nutrient flow associated whit the biological and technical metabolism necessitates the formation of collaborative business structures whit the role of coordinating the flow of materials and information throughout the product life cycle.
42	**Intelligent materials pooling**	Is a framework for the collaboration of economics actors within the technical metabolism which allows companies to pool materials resources, specialized knowledge and purchasing power relating to the acquisition, transformation and sale of technical nutrients and their associated products. The formation of an intelligent materials pooling community is a four steps process *[(2) point #6)]:*	*Phase 1. Creating Community:* Identification of industrial partners whit a common interest in replacing hazardous chemicals whit technical nutrients.
			Phase 2. Utilizing market strength: Development of a positive purchasing and procurement list of preferred intelligent chemicals.
			Phase 3. Defining materials flows: Development of specification and design for preferred materials, creation of a common materials bank, design of a technical metabolism for preferred materials.
			Phase 4. Ongoing support: Preferred business partner agreements amongst community sharing's of information gained from research and materials use, cobranding strategies.

43	**Life Cycle Assessment**	A technique for assessing the potential environmental impacts of a product by examining all the material and energy inputs and outputs at each life cycle stage *[6]*.	
44	**The next industrial revolution**	This emerging movement of production and commerce eliminates the concept of waste, uses energy from renewable sources, and celebrates cultural and biological diversity. The promise of the Next Industrial Revolution is a system of production that fulfills desires for economic and ecological abundance and social equity in both the short and long terms-becoming sustaining (not just sustainable) for all generations *[6]*.	

BIOMIMICRY CORE CONCEPTS	**(1)** Benyus Janine M. (1997). "Biomimicry: Innovation inspired by nature". Edit. Harper Perennial. **(2)** http://www.biomimicryguild.com/guild_product_service_reference_09.pdf **(3)** http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html

	CONCEPT	DEFINITION	DESCRIPTION
1	**Bi-o-mim-ic-ry**	From the Greek Bios, life, and mimesis, imitation *([1] peg 0)*.	1.- *Nature as model:* Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e. g., a solar cell inspired by a leaf 2.- *Nature as measure:* Biomimicry uses an ecological standard to judge the "rightness" of our innovations. After 3.8 billion year of evolution, nature has learned: What works. What is appropriate. What lasts. 3.- *Nature as mentor:* Biomimicry is anew way of viewing and valuing nature. It introduces an era based not on what we can extract from the nature world, but on what we can learn from it.
2	**Biomimicry**	Is a design and leadership discipline that seeks sustainable solutions by emulating nature's time-tested ideas *([2] peg 1)]*.	The vision is to create products, processes, organizations, and policies—new ways of living—that are well-adapted to life on earth over the long haul.
3	**The Biomimicry Guild**	Is the first and only innovation consultancy in the world to use a deep knowledge of biological adaptations to help others implement sustainable practices that create conditions conducive to all life *([2] peg 2)]*. Janine Benyus and Dayna Baumeister, PhD, founded the Biomimicry Guild in 1998	The Guild's process of consulting life's genius utilizes a clear, proven design methodology, complete with effective implementation tools, developed over a decade of work with companies, entrepreneurial organizations, universities, governments, and non-profits. It refer to a systemic change that makes a real difference in the world translating nature's genius. Our tools—the Biomimicry Design Spirals, the Life's Principles Butterfly, our proprietary database, and Ask Nature: Biomimicry Design Portal—bridge the gaps of terminology and specialization that separate biologists, chemists, and other researchers from industrial designers, engineers and other developers and strategists in industry. Using these tools, we have discovered how to effectively translate the wisdom of our teachers—the organisms and ecosystems of the natural world—into designs and systems that become sustainable innovations and evolve into a bio-inspired ethos for our clients. As the industrial age moves into the biological age, modern scientific techniques are allowing us to gaze deeper into nature's secrets and helping us understand and learn from her elegant designs. Our in-house expertise allows us to access this constantly expanding knowledge base and to translate it for relevant application to our client's design challenges. After 3.85 billion years of R&D, nature has learned: What works, What is appropriate, What lasts.

4	**Biomimicry Revolution**	It introduce an era based not on what we can extract from nature, but on what we can learn from her *([1] peg 2)*.	In a biomimicry word we would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibers, ceramics, plastics and chemicals
5	**Some nature's laws, strategies, and principles**	*([1] peg 7)* Nature runs on sunlight Nature uses only the energy it needs Nature fits form to function Nature recycles everything Nature rewards cooperation Nature banks on diversity Nature demands local expertise Nature curbs excesses from within Nature taps the power of limits	Once we see nature as a mentor, our relationship with the living world changes
6	**How will we feed ourselves?**	Farming to fit the land: growing food like a prairie	When you look at a prairie, you don't see complete losses from anything--you don't see net soil erosion or devastating pest epidemics. You don't see the need for fertilizers or pesticides. You see a system that runs on sun and rain, year after year, with no one to cultivate the soil or plant the seeds. it drinks in no excess inputs and excretes no damaging wastes. It recycles all its nutrients, it conserves water, it produces abundantly, and because it's chock-full of genetic information and local know-how, it adapts (agriculture that hat same kind of self-sufficiency as a prairie) *([1] peg 12)*. The key is to mirror the natural tendency of succession which , over time, creates ecosystems the are effective and stable utilizes of spaces, energy, and biotic elements *([1] peg 40)*. If is it going to switch to a more natural agriculture, the systems must also pencil out in at least two ways: 1) Economically, they must sustain farmers and their communities, and 2) Ecologically, they must pay their own energy bills and not drawn the resources of local landscape or the planet *([1] peg 50)*.

7	**How will we harness energy?**	Light into life: gathering energy like a leaf	Duckweed (a small floating aquatic monocotyledonous plant) spreads an impressive solar array--one plant, a mere quarter of an inch across, can multiply through the sheer energy of sunlight to cover an area the size of a football field in a couple of months. This is a spasm of photosynthesis--sunlight transformed into acres of green tissue *([1] peg 60)*. Consider that everything we consume, from a carrot stick to a peppercorn filet, is the product of plants turning sunlight into chemical energy. The cars, the computers, the Christmas tree lights all feed on photosynthesis as well, because the fossil fuels they use are merely the compressed remains of 600 million years' worth of plants and animals that grew their bodies with sunlight. Plants gather our solar energy for us and store it as fuel *([1] peg 61)*.
8	**How will we make things?**	Fitting form to function: weaving fibers like a spider (An interdisciplinary team is where I see the future of biomimicry; engineers and materials scientists working alongside microbiologists, protein chemists, geneticists, and renaissance thinkers *([1] peg 106)*).	Just 4 primary materials industries-- paper, plastics, chemicals, and metals--account for 71 percent of the toxic emissions from manufacturing in the US. 5 materials --paper, steel, aluminum, plastics, and container glass-- account 31 percent of US manufacturing energy use ([1] peg 95). Nature has at least 4 tricks of the trade when it comes to manufacturing materials ([1] peg 95): 1.- Life-friendly manufacturing process: Life can't put its factory on the edge of the town, it has to live where it works. Nature's first trick of the trade is that nature manufacturers its materials under life/friendly conditions, in water, at room temperature, without harsh chemicals or high pressures ([1] peg 97). 2.- An ordered hierarchy of structures: the complexity of materials refer to an ordered hierarchical structure, from the atomic level all the way to the macroscopic, precision is built in, and strength flexibility follow. How does the nature manage to create microstructure? and how can we do the same? answering those questions is at the very heart of what biomimics are trying to do ([1] peg 100).

8			3.- Self-assembly: whereas it is spent a lot of energy building things from the top down--taking bulk materials and carving them into shape--nature does the opposite. It grows its materials from the ground up, not by building but by self --assembling rides the riot of forces ruled by classical and quantum physics. Like charges, but opposites attract. Weak electrostatic bonds hold molecules together gingerly, and as conditions change, they can easily correct and adapt. Stronger, more permanent bonds are consummated with the help of lock-and-key catalysts called enzymes ([1] peg 104). 4.- Tinplating of crystals with proteins: The final products that are a mish mash of polymer-chain sizes, whit the most to long or too short to be of ideal use, nature makes only what she wants, where she wants and when she wants. No waste on the cutting-room floor. It is the ability to customize materials through the use of templates. If we want to emulate nature's manufacturing, it is necessary to get backstage and interview the proteins, those templaters that make precision assembly possible at body temperatures. We have to learn their amino acid sequences and figure out how to produce them in commercial quantities. With the help of these invisible hands, the biomimics hope we may be able to sculpt with geometric precision, and do away with heat, beat, and treat ([1] peg 104).
9	**How will we heal ourselves?**	Experts in our midst: finding cures like a chimp	Wild things live in a chemically charged world, and their goal in life is to pick their way through the maze of poisons and find a packet of energy or perhaps a dose of curative. We humans were once as omnivorous as they, able to pick and choose between the good, the bad, and the bitter. Today, we are beginning to return to wild places to search for new drugs and new crops (or wild genes to add spunk to our old standbys) *([1] peg 147)* . In a country where millions are spend each year on diet and nutrition's advice, why haven't we consulted the mammals, birds, and insects that successfully act as their own nutritionists? Might their choices show us what we may have bee meat to eat, in a purely biological sense? *([1] peg 150)*. Different authors of articles in The Sciences, admitted that animal self-medication has not yet proven, nor has it been shown that animals have innate knowledge of medical plants. They know there is a lot more work to do. *([1] peg 182)*. In a storage repeat of history (referring to the Native Americans), we are once again watching what animals eat and what they avoid, what leaves they swallow whole or rub into their fur, and we are making notes to pass on to our tribe, the scientific community *([1] peg 183)*.

10	**How will we store what we learn?**	Dances with molecules: computing like a cell	The problem is, we don't always recognize nature's computing styles because they are so different from our own. A computer is not a giant brain: 1.- Brained being can walk and crew gun and learn at the same time; silicon digital computers can't (via thousands of processors (neurons) working in parallel) ([1] peg 189). 2.- Brains are unpredictable, but conventional computing is obsessed with control (computers can open and close gates to represent zeros or ones. In short, we can control them) ([1] peg 191). 3.- Brains are not structurally programmable the way computers are (The PC process information symbolically, whit zeros and ones; cells compute physically, working at a level of the molecule) ([1] peg 192). 4.- Brains compute physically, not logically or symbolically (instead of switches, nature computes whit submicroscopic molecules that jigsaw together, literally falling to a solution) ([1] peg 192). 5.- Brains are made of carbon, not silicon (is time to say good-bye to silicon and hello to carbon) ([1] peg 195). 6.- Brains compute in massive parallel; computers use linear processing (there is not central command) ([1] peg 196). 7.- Neurons are sophisticated computers, not simple switches ([1] peg 198). 8.- Brains are equipped to evolve by using side effects. Computers must freeze out all side effects ([1] peg 200).

11	**How will we conduct business?**	Closing the loops in commerce: running a business like a redwood forest	Economies are like ecosystems (Aleenby); both systems take in energy and materials and transform them into products. The problem is that our economy performs a linear transformation, whereas nature's is cyclic ([1] peg 242). The natural world is full of models for a more sustainable economic systems--prairies, coral reefs, oak-hickory forests, old -growth redwood and Douglas-fir forests, and more (Allemby [1] peg 248). (Allemby [1] peg 248): Type I systems: That is when communities take advantage of abundant resources and use them as quickly as they can. The Industrial Revolution is the equivalent of throwing a handful of flour beetles into a fresh bin of clean, sifted flour ([1] peg 249). Type II systems: consist of perennial berry bushes and woody seedlings that move into the field. This species won't spend their energy on making millions of seeds. Instead they'll make a few seeds and funnel the rest of the energy into hardy roots and sturdy stems that will see them through winter ([1] peg 250). Type III systems: species don't have to go looking for sunlight. They have larger and fewer offspring, which have longer and more complex lives. They live in elaborate synergy with the species around them, and put their energy into optimizing these relationships ([1] peg 250). We must replace portions of our type I economy with portions of a type III economy until the whole thing mirrors the natural world ([1] peg 251). The strategies in the following list are tried-and-true approaches to the mystery of surviving in place. Think of them as the ten commandments of the redwood clan. Organism in a mature ecosystem ([1] peg 253), if any company or national economy is successful in applying all ten lessons, it could master a trick that's as old as the first bacteria: life creating conditions conducive to life: 1.- Use waste as a result 2.- Diversify and cooperate to fully use the habitat 3.- Gather and use energy efficiently 4.- Optimize rather than maximize 5.- Use materials sparingly 6.- Don't foul their nest 7.- Don't draw down resources --Don't use nonrenewable resources faster than you can develop substitutes --Don't use renewable resources faster than they regenerate themselves. 8.- Remain in balance with the biosphere 9.- Run on information 10.- Shop locally

12	**Where will we go from here?**	May wonders never cease: toward a biomimetic future	Four steps to a biomimetic future 1.- Quieting: Immerse ourselves in nature: Reimmersing ourselves in the natural world. Wrapped tightly in our own version of knowledge, we have been unreceptive to the wisdom of the natural world ([1] peg 287). 2.- Listening: Interview the flora and fauna of our own planet: I say "interview" because it is not enough to simply name the species on Earth (though this in itself is a monumental task). We must also get to know these species as best we can and discover their talents and survival tips, their role in the great web of things ([1] peg 289). 3.- Echoing: Encourage biologist and engineers to collaborate, using nature as model and measure. The only way to ensure that nature's designs will be considered is to put biologists and engineers on the same working teams. We have to put what is good for life first, and trust that it will also be good for us. The new questions should be "will it fit in?", "will it last?", and "is there a precedent for this in the nature?" If so, the answers to the following questions will be yes ([1] peg 290): Does it run on sun light? Does it use only the energy it needs? Does it fit form to function? Does it recycle everything? Does it reward cooperation? Does it bank on diversity? Does it utilize local expertise? Does it curb excess from within? Does it tap the power of limits? Is it beautiful? Assuming our bio-inspired innovation passes those tests, our next design decision will have to do with scale. Since scale is one of the main things that separates our technologies from nature's, it's important to consider what is appropriate, that is, what is receptive to and acceptive of our habitat. 4.- Stewarding: Preserve life's diversity and genius. Our actions must be guided by humility that comes from the realization of how little we know. ([1] peg 292). WE CAN DECIDE AS A CULTURE TO LISTEN TO LIFE, TO ECHO WHAT WE HEAR, TO NOT BE A CANCER. HAVING THIS WILL AND THE INVENTIVE BRAIN TO BACK IT UP, WE CAN MAKE THE CONSCIOUS CHOICE TO FOLLOW NATURE'S LEAD IN LIVING OUR LIVES. THE GOOD NEWS IS THAT WE'LL HAVE PLENTY OF HELP; WE ARE SUROUNDED BY GENIUSES ([1] peg 297).

13	**Biomimicry: A Tool for Innovation**	Innovators from all walks of life--engineers, managers, designers, architects, business leaders, and more--can use biomimicry as a tool to create more sustainable designs. The Biomimicry process of consulting life's genius, described in the Design Spiral, can serve as a guide to help innovators use biomimicry to biologize a challenge, query the natural world for inspiration, then evaluate to ensure that the final design mimics nature at all levels—form, process, and ecosystem *[(3)]*	Our methodology brings nature's wisdom not just to the physical design, but also to the manufacturing process, the packaging, and all the way through to shipping, distribution, and take-back decisions.

14	**The Design Spiral**	[(3)]	Using these tools, we have discovered how to effectively translate the wisdom of our teachers—the organisms and ecosystems of the natural world—into designs and systems that become sustainable innovations and evolve into a bio-inspired ethos for our clients.
		Identify	Develop a Design Brief of the human need: * *Develop* a Design Brief with specifics about the problem to be resolved * *Break down* the Design Brief to identify the core of the problems and the design specifications * *Identify* the function you want your design to accomplish: What do you want your design to do? (not "what do you want to design?"). Continue to ask why until you get to the bottom of the problem. * *Define* the specifics of the problem: o Target Market: who is involved with the problem and who will be involved with the solution? o Location: where is the problem, where will the solution be applied?
		Translate	Biologize the question; ask the Design Brief from Nature's perspective: * *Translate* the design function into functions carried out in nature. Ask "How does Nature do this function?" "How does Nature NOT do this function?" * *Reframe* questions with additional key words. * *Define* the Habitat/Location o Climate conditions o Nutrient conditions o Social conditions o Temporal conditions
		Observe	Look for the champions in nature who answer/resolve your challenges * *Find* the best Natural Models to answer your questions. * *Consider* Literal and Metaphorical * *Find* champion adapters by asking "whose survival depends on this?" * *Find* organisms that are most challenged by the problem you are trying to solve, but are unfazed by it. * *Look* to the extremes of the habitat * *Turn* the problem inside out and on its head * *Open* discussions with Biologists and specialists in the field
		Abstract	Find the repeating patterns and processes within nature that achieve success * *Create* taxonomy of life's strategies * *Select* the champions with the most relevant strategies to your particular design challenge. * *Abstract* from this list the repeating successes and principles that achieve this success.

		Apply	Develop ideas and solutions based on the natural models * *Develop* concepts and ideas that apply the lessons from your Natural teachers. * *Look* into applying these lessons as deep as possible in your designs: o Mimicking Form: - Find out details of the morphology - Understand scale effects - Consider influencing factors on the effectiveness of the form for the organism - Consider ways in which you might deepen the conversation to also mimic process and/or ecosystem o Mimicking Function: - find out details of the biological process - Understand scale effects - Consider influencing factors on the effectiveness of the process for the organism - Consider ways in which you might deepen the conversation to also mimic the ecosystem o Mimicking Ecosystem: - Find out details of the biological process - Understand scale effects - Consider influencing factors on the effectiveness of the process for the organism
		Evaluate	How do your ideas compare to Life's Principles, the successful principles of nature? * *Evaluate* your design solution against Life's Principles * *Develop* appropriate questions from Life's Principles and continue to question your solution * *Identify* further ways to improve your design and develop new questions to explore. Questions may now be about the refinement of the concept: o Packaging, Manufacture, Marketing, Transport o New Products - additions, refinement o etc...
		Identify	Develop and refine design briefs based on lessons learnt from evaluation of life's principles Nature works with small feedback loops, constantly learning, adapting and evolving. We can also benefit from this thinking, evolving our designs in repeated steps of observation and development, unearthing new lessons and applying these constantly throughout our own design exploration.

TOTAL BEAUTY CORE CONCEPS	**(1)** Edwin Datschefki (2002), Sustainable Products. http://www.biothinking.com/pubs.htm **(2)** Datschefski Edwin (2002) "Productos sustentables, el regreso de los ciclos naturales". Edit. McGraw Hill International **(3)** BioThinking (2010). http://www.biothinking.com/ **(4)** Edwin Datschefski (1999) "Cyclic, solar, safe – biodesign's solution requirements for sustainability". The Journal of Sustainable Product Design, January. ISSUE 10: July 1999

	CONCEPT	DEFINITION	DESCRIPTION
1	**cyclic/solar/safe**	Is a protocol for understanding products and how they can become more environmentally sustainable *([1] peg 3)*.	Most environmental problems are caused by unintentional side-effects of the manufacture, use and disposal of products. Products are the source of all environmental problems. Design is the key intervention point for making radical improvements in the environmental performance of products and all their byproducts as well. Man is the only species capable of generating waste--things that no other life on earth wants to have
2	**Sustainable products**	They are products which are fully compatible with nature throughout their entire lifecycle. *([1-peg 3, 3])*.	He distinguish two kinds of sustainable products: * Those that are part of the living ecosystems, such as plant fibres which are grown and then turned into board packaging. At the end of its life it is composted and returned to the soil once again. Such a product would be deemed to be mostly within the "ecosphere"-the living ecosystem * Those that are part of the "technosphere", but follow similar protocols as those in the "ecosphere", for example aluminum sourced from recycling collection.

3	**Design requirements for sustainable products**	The basic protocol needed are very simple: use materials in cycles, and instead of emitting poisons, only emit materials that can be "food" for others. Over 500 environmentally-innovative products were analyzed (1999), and they all feel into 24 categories of innovation. These 24 inventive principles could themselves be placed into four groups: recycled and recyclable "cyclic", using renewable energy "solar", low or zero toxicity "safe", and improved eco-efficiency "efficient" The first three (cyclic, solar, safe) mimick the protocols used by plan and animal ecosystems. The goal of sustainable design is simple-to make all products 100% cyclic, solar, safe, efficient. The fourth requirement is based on the need to maximize the utility of resources in a finite world. And the fifth is about maximizing human happiness and potential.	Cyclic: The product is made from organic materials, and is recycled or compostable, or is made from minerals that are continuously cycled in a closed loop ([1] peg 4). The goal is to be fully cyclic, so that materials are used again at the same level ([1] peg 23). The basic measure of cyclicity is ([1] peg 24): [(the % of recycled material used + the % that is recycled at end of life) / 2] What percentage of the materials flow is cyclic (cradle to cradle) and what percentage is linear (going to landfill or being put into a different type of ecosystem or a similar one but far away)? Include byproducts as well. Solar: The product uses solar energy or other forms of renewable energy that are cyclic and safe, during the life cycle ([1] peg 4).Te he goal is to be cyclic and safe as well as solar ([1] peg 26). Safe: The product is non-toxic in use and disposal, and its manufacture does not involve toxic releases or the disruption of ecosystems ([1] peg 4). To be safe, products and process have to be free from toxic compounds and releases at all stages. The definition at "safe" includes both chemical and physical disruption to people as well as to other forms of life ([1] peg 29). Efficient: the product in manufacture and use requires 90% less materials, energy and water than products providing equivalent utility did in 1990 ([1] peg 4). The ecology theory shows us that ecosystems strive to maximize throughput of energy and materials for an individual organism or organizations, efficiency is the key way in which to compete for a set of resources such as sunlight, water or minerals ([1] peg 35). Social: The product's manufacture and use supports basic human right sand natural justice ([1] peg 4). A totally-beautiful product will have been made by people who are living a decent life and are treated fairly. You have to know where materials and components are coming from and how they are being made ([1] peg 36).

4	**Techniques for innovation**	Having analyzed over 500 products, the author found that all the innovations were base on just 24 techniques *([1] peg 5)*.	Recycled materials Re-use Organic Materials and composting Takeback and remanufacture Muscle power Hydrogen and electricity Photons Substitute Materials Extremely long view Increased efficiency Increased utility Dematerialize Every little counts Be more local Multifuntionality Fine control Components Complementary Upgradability Durability Bio-everything Biomimicry Stewardship sourcing Work whit the seasons
5	**Environmental impact of any product**	To really do it properly, you need to do a life cycle assessment study that could take many months and high cost ([1] peg 15).	But to quickly get to grip the environment impact of any product, you just need to look at five factors: * Materials: the type of materials used * Energy: how much energy is used in manufacture and use. * Toxics: what toxic releases there are likely to be * Sheer volume of consumption: how much materials and energy is used * People: how workers and consumers are affected
6	**Semi-sustainable products**	There are no products on the market that are 100% sustainable as per the cyclic/solar/sale scoring system outlined below *([1] peg 37)*.	Most of the "greener" products available today exhibit improvements in one or two of the protocols.
7	**Sustainable products**	All aspects of the product's life must meet all three requirements at 100% *([1] peg 38)*.	If all an organization's activities are 100% cyclic, solar and safe, across the full lifecycle of all materials used, then that organization would be sustainable. This means that we can score any organization or product according to: * % cyclic -- % of total materials that are continuously cycled * % solar -- % of total energy and embodied energy that is form renewable sources * % safe -- % of lifetimes releases that are non-toxic

8	**Sustainable product techniques**	These techniques are based on an analysis of 500 products. The innovative principles behind all of them are rather similar ([1] peg 44). Like in TRIZ. One can infer from this that almost all the sustainable products of the future will be based on recombination of existing, proven approaches , and that very few will require the pioneering of substantially newer technologies	The basic techniques are: Cyclic: * Recycled materials ([1] peg 45): the goal of being cyclic is to have continuous cycles of material, and it is easy to see that once this state has been achieved there will be no underground mining, as all mineral materials will be sourced from the collection of end of life products and byproducts. This will be sourced from the collection of end of life products and byproducts. This will also require "closed loop" or true cycling, and not "dowcycling". Designing for recyclability involves: - making sure that the product can be disassembled easily - labeling of parts to indicate materials types uses - usually by embossing to avoid contamination - ensuring that surface finished and graphics or decoration do not irreversibly contaminate the materials * Re-use ([1] peg 47): this rely on the raw materials being crushed or melted down before they are reformed into a new product. But it is often easier to keep the form of the original product, and simply clean it or re-use it again * Organic materials and composting ([1] peg 47): a biodegradable product must be disposed of property for its components to decompose properly, (see definitions of biodegradability. One of them: ASTM--any product that claims to be biodegradable must completely decompose into CO_2 and water within 180 days). * Takeback, refurbish and remanufacture ([1] peg 49): When manufacturers collect their own products once the consumer has finished whit them, it is known as product takeback. The manufacturer then has a choice of melting down the materials and reforming them, or keeping the components and refurbishing (remanufacture) them to go into new products. Solar: (the solar definition include any renewable energy that is also cyclic and safe) * Muscle power ([1] peg 50): It is a form of solar energy as for example the movement into electricity. * Hydrogen and electricity ([1] peg 51): electric vehicles, both battery and fuel cell driven are included because their power will eventually all be provided by non-fossil and no-nuclear sources * Photons ([1] peg 50): Photon is the secret to life on Earth. Photosynthesis can be a key energy provider via biofuels and biomass, and plants are being used for a wide variety of industrial purposes such as oils, fibres and plastics. Embedded photovoltaic is a solar solution, but can also be described as a safe efficient improvement, because over their lifetime, these devices are typically replacing battery-power versions which would otherwise consume ten or twenty times their own weight in disposable batteries, or perhaps twice their own weight in rechargeables.

8	**Sustainable product techniques**		Safe: * Substitute materials ([1] peg 52): for every product, there is always a safer material or compound that can be used, but the challenge is to match or exceed the performance of the original toxic solution. * Stewardship sourcing ([1] peg 55): the maintenance of ecosystems integrity requires that biomes such as forest and seas are not over-harvested. * Bio-everything ([1] peg 56): products and processes are being transformed as plastics, fuels, and drugs are being mass produced from plants. Traditional minerals based industries are becoming more organic by reusing materials and reducing toxicity. Efficient: (it can be grouped in two main types) (Life extension) * Durability ([1] peg 60): In general durability equates whit the high end of the price spectrum, and is a characteristic of luxury goods. However, there are engineering solutions that do allow for high durability at low manufacturing cost. * Upgradability ([1] peg 60): Another aspect of durability, but distinct from it, is the tendency of consumers to want the latest model of a product. This usually requires the replacement of a product, but if it can be engineered to be upgradable, the life of the original product can be extended. * Repairability ([1] peg 61): Consumer products may have environmentally sub-optimal life spans for many reasons. Several types of product obsolescence have been identified. (1) Technical: the product is irreparable. (2) Economic: the cost of repairing the product is uneconomic. (3) Functional: new products have improved features. (4) Psychological: the desire for new and fashionable products * Complementary components ([1] peg 61): It is important to design parts for equal lifetimes since failure of a single component often means the whole part or product will be discarded.

8	**Sustainable product techniques**		* Think ahead a long time ([1] peg 61): All the products are disposable in the end, so firms should always plan for end of life or takeback even if it will happen in 20 or 50 years. (Using less materials and energy) * Increased efficiency ([1] peg 62): improving efficiency reduces materials or energy costs and is always a good idea * Increased utility ([1] peg 62): it is not just about delivering to customer a chunk of materials in a certain form. What consumers want is light, heat, warmth, entertainment and so on. This utility is the thing to focus on and improve. * Dematerialise ([1] peg 63): An elegant technique is to simply remove a part of a product. * Every little counts ([1] peg 64): even if something seems small, it may be worth spending time on if large numbers of units are involved. * Be more local ([1] peg 65): Local sourcing reduces transport impacts and cost. It also stimulate the local economy, helping local sales of your own products. * Multifuntionality ([1] peg 65): Multifuntionality also ensure maximum utility. * Fine control ([1] peg 65): exquisitely fine control is found in the metabolism of living systems, and is something which maximizes the use of materials. Make systems respond on demand, use senses and feedback loops, and make use of everything. * Work whit the seasons ([1] peg 66): seasonal variations are inevitable, so work whit them. Natural systems are tolerant of flux and have strategies for feast and famine, winter and summer, and so should new products. * Biomimicry ([1] peg 66): also known as biomimetic is the fusion of the knowledge of engineers and biologists. It has created a wide range of innovations, particularly in the field of materials science.
9	**Environment criteria not mentioned**	Those criteria that are not essential to sustainability	Criteria such as noise and smell
10	**The goal of sustainable design**	To make all products 100% cyclic, solar and safe *([1] peg 74).*	If you are manufacturer, this means looking at each one of your product lines and making a long-term plan to bring them all up to speed. It you are a service organization. It means looking at all the things you buy, and making a plan to change their specification and seek out products that are nearer to being 100% environmentally sustainable.

11	**Ecological space**	Is the amount of air, land, water and energy taken up by the entire lifecycle of a product. *([1] peg 45).*	
12	**Product score**	A product ca be scored in two main ways -- relative to a baseline, or in absolute term	* The relative score is easier, and the hardest part is choosing a baseline product. Normally the market leading brand is the best choice for best line, but it could also be your the brand you currently and are wishing to replace. Or your existing product line if you are a manufacturer ([1-*peg 7*, 5, 2, 3, 4]). *The absolute score is harder to do, but is more useful to see if we are getting near the goal of being 100/100/100/100. The scores are calculated as follow ([1] peg 76): **Cyclic**: All organic material are counted as being fro a recycled source, as they are made with recycled carbon, hydrogen and oxygen. [(% materials from recycled sourced + % materials cycled sourced at end of life) / 2] **Solarity:** Not all the forms of renewable energy are classed as "solar" as they also have to be cyclic and safe [%KWh of energy that is solar, wind, muscle, photosynthetic, geothermal, hydro, or wave power] **Safety:** "Today" and "1990" are "release mass per product unit" for each type of release, including X-chemicals (black and grey list) and NOx and SOx but not including CO2 and not counting water, but only the mass of materials dissolved or suspended in it. [(Suma 100 (1-(today/1990) / n)] **Efficiency:** is the mean efficiency percentage for energy, water and materials usage. the efficiency percentage is based on 100% being a 90% reduction from 1990 levels. [score = 111 - (111(present level / 1990 level))]
13	**Product sustainability plan**	One a product has been assessed, the direction for improvement is usually obvious. However, the challenge usually requires a two-pronged approach: an immediate, "low-hanging fruit" approach and a transition plan.	As the fundamentals of products development are well known ad in widespread use, they are beyond the scope of this report - so suffice to say that the development of sustainable products is no different from any other type of product, and that the "8 Ps" apply ([1] peg 80): --Planning, Prototypes, Patents, Persistence, Production, Promotion, Patience, Payoff--

APPENDIX

'B'

Alejandro Flores Calderón

DESIGN PRO.		RE-DESIGN ACTIVITIES	METHODS AND TOOLS
FOCUSING	C2C	• Collect by each components its weight and chemical constituent.	• In a table A, declare each components weight, materials, and their chemicals.
		• Classify each component by toxicity level.	• Use the MBDC material assessment protocol. In table A, expose the results.
		• Evaluate the ease of disassembling.	• For each component answer the questions (*): o Can the component be separated as a homogeneous material? o Can the component be disassembled using common tools? o Does it take less than 30 seconds for one person to disassemble the component? Then, estimate the disassembly score with the radio of the total disassembly weight to the total weight of the product. In a table B, expose the results.
		• Measure the eco-effectiveness (EFF)	• $\text{EFF} = \frac{\frac{1}{3}\left[\text{Mat.chem.score+Disass.score+}\left(\frac{\text{Recycled}}{\text{Renewable Content socre}}\right)\right]}{\text{Total Potencial Weight}}$
	BIO	• Describe the functional characteristics of each component.	• In a figure AA, make a functional representation of each component and in a table AA, make a design brief of the technical necessity that it solve.
		• Determine the efficiency of each component according to its functional performance.	• Each component has its own units, for example: of speed, load, weigh, etc. Express the results in table AA.
	TB	• Measure the product in terms of: o Cyclicity o Solarity o Safety**	• Use the next formulas and concepts (^): o $\text{Cyclicity} = \frac{(\text{\%recy.mat.used.during.manu.+\%mat.recycled.at.endoflife})}{2}$ o Solarity: For each product life cycle stage, calculate the % of renewable energy. o Safety: Estimate the materials disruption. In a table AAA.

		o Efficiency** o Sociality • Express the evaluation scores.	- Determine the # of components, kind of materials and chemicals contained. - Determine the % of materials that cause damage and in what stage of the product life cycle. o Efficiency: determine the material efficiency (the number of functions carried out by mass unit), and the energy efficiency in each life cycle stage. o Sociality: fulfillment of the Norm SA8000 in each life cycle stage • In a table BBB.
SPECIFICATION	**C2C**	• Identify the components with highest level of toxicity (the red and orange ones). • For the highest toxic components, define the use of materials that rank yellow or green. • Identify the components with major difficulty for the disassembly. • For the components with highest difficulty, define as target answer YES to all questions. • Define an EFF goal for the product.	• From table A. • Use the MBDC material assessment protocol. In table A, expose the results. • From table B. • See the 4 questions in '*' (C2C-focusing). • Ideally, the product materials have to be 100% biological and/or technical nutrient.
	BIO	• Identify the components with lowest functional efficiency. • For the components with lowest functional efficiency, make a relationship between functional characteristics and biological models. • Look for the champions in Nature who *solve/resolve* the challenge. • Determine the performance of the biological models.	• From table AA. • Answer the question: How does Nature do this function? In addition, it can be used the 'Biomimicry Taxonomy tool´ to develop concepts. • Ask, whose survival depends on this? • From the component functional characteristics, abstract the functional parameters in the biological model.

		• Define the goal of functional performance for the component	• Ideally, the components have to have a similar performance than the biological model.
	T B	• Identify the TB criteria with the lowest score. • Identify the more dangerous materials that cause that low score • Define the product targets for Cyclic, Solar, Safety, Efficient, and Social. •	• In Table BBB. • In table AAA. • Ideally, the product is 100% Cyclic, Solar, Safety, Efficient, and Social.
S Y N T H E S I S	**C 2 C**	• Use no toxic materials for humans and ecology. • Give design features to the product (for example, ease of disassembly, modularity by same type of materials). • Use materials with high level of recyclability or compostability.	• MBDC, material assessment protocol. • Design for Disassembly. • Full knowledge of the material recyclability or compostability.
	B I O	• Identify the repeating patterns in Nature who answer/solve the challenge. • Develop technical ideas and solutions based on the Natural models. • Compare and select the best solution	• In table BB, describe the core concepts associated to the solution. • Mimicking: *the form, the function and ecosystem* • Use the "Life's Principles"
	T B	• Generate solutions for each one of the sustainability criterion: • Integrate the best solution in terms of cyclicity, solarity, safety, efficiency, and sociality.	• Increase the % of renewable energy in each stage of the life cycle: o Cyclicity / Solarity / Safety / Efficiency / Sociality • Use the formulas and concepts presented in (^)

VERIFICATION	C2C	• Compare the toxicity level of the original design vs. the redesigned proposal. • Compare the facility of disassembly of the original design vs. the redesign proposal. • Compare the EFF of the original design vs. the redesign proposal.	• In a table C. • In a table C. • In table C.
	BIO	• Measure and compare the technical solution against the Natural solution elected.	• Use a table to compare the Natural model functional performance vs. the technical solution proposed and the functional of the original design.
	TB	• Compare the % of Cyclicity, Solarity, Safety, Efficiency and Sociality.	• In a table C shows both the %´s of the original design and the redesign proposal.

*(**The calculus way of this concepts were proposed and reported in (Flores-calderón 2010))*

APPENDIX

'C'

Alejandro Flores Calderón

Table 6.3 Material chemistry calculation for the Motorized Lenses Redesign

MOTORIZED LENSES REDESIGN											
Bill of Material							Material Chemistry				
Part #	Qty	Description	Material—Print	Supplier	Wt (g)		Rating	Wt Credit (%	Wt Credit (g	Final Score
1	1	Connector of voltage DC	Bioplastics - (cellulosic plastic)		4		Green	100	4	
2	1	DB9 Connector	Bioplastics - (cellulosic plastic)		6		Green	100	6	
3	1	O-ring parker 2-339	Biofiber composite		0.8		Green	100	0.8	
4	1	O-ring parker 2-337	Biofiber composite		2.4		Green	100	2.4	
5	2	Lateral fasteners	Steel--SAE 1010		30		Yellow	50	15	
6	3	Gear	Bioplastic (poliestamidas)		8.25		Green	100	8.25	
7	3	Spring	Steel--SAE 1010		9		Yellow	50	4.5	
8	3	Bushing	Bioplastic (poliestamidas)		11.14		Green	100	11.14	
9	3	Motor	Different parts and materials		184.5		Yellow	50	92.25	
10	6	Screw of button heat	Still 12L14		0.55		Green	100	0.55	
11	1	Flat head screw (assembly plaque of connecters)	Still 12L14		0.33		Green	100	0.33	
12	3	Flat head screw (lenses´ adaptor)	Still 12L14		0.46		Green	100	0.46	
13	3	Head flat screw (Housing and "Al" plaque)	Still 12L14		0.3		Green	100	0.3	
14	2	Button head screw	Stell12L14		0.3		Green	100	0.3	
15	4	Brass bar (23.2 mm)	Brass liga 12 alloy 0360		5		Green	100	5	
16	2	Brass bar (75.8 mm)	Brass liga 12 alloy 0360		20.7		Green	100	20.7	
17	1	Assembly of PCB control	Organic resin materials		16.6		Green	100	16.6	
18	1	Assembly of PCB feeding	Organic resin materials		20.5		Green	100	20.5	
19	1	Gear of zoom for the lens	New polymers - ECOGEHR (PLA-V polylactide)		30.64		Green	100	30.64	
20	1	Lenses of 28mm	Different parts and materials		550.8		Yellow	50	275.4	
21	1	Housing	Bioplastics - NEC (polylactic acid)		142.5		Green	100	142.5	
22	1	Glasses´ adaptor	Bioplastics - NEC (polylactic acid)		51		Green	100	51	
23	1	Plaque of fastening	Bioplastics - NEC (polylactic acid)		246		Green	100	246	
24	1	Gear of focus for the lens	Bioplastics - NEC (polylactic acid)		14.7		Green	100	14.7	
25	1	Plaque for housing	Bioplastics - NEC (polylactic acid)		146.7		Green	100	146.7	
26	1	Gear of opening for the lens	Bioplastics - NEC (polylactic acid)		12		Green	100	12	
27	1	Adjust ring glass-plaque	Bioplastics - NEC (polylactic acid)		0.4		Green	100	0.4	
28	1	Screw Prisoner kind	Still 12L14		0.16		Green	100	0.16	
29	1	Energy cables	Cooper / PVC		12		Orange	25	3	
30	1	Plaque for assembly of connectors	Bioplastics - NEC (polylactic acid)		45.2		Green	100	45.2	
					1572.93				**1337**	**85**

Table 6.4 Disassembly assessment for the Motorized Lensess Redesign

MOTORIZED LENSES REDESIGN													
Bill of material						Disassembly assessment				Disassembly score		
Part #	Qty.	Description	Material—Print	Supplier	Wt (g)	#1	#2	#3	#4	Wt credit (%	Wt (g)	Final sco.
1	1	Connector of voltage DC	Bioplastics - (cellulosic plastic)		4	**No**	Yes	**No**	Yes	0	0	
2	1	DB9 Connector	Bioplastics - (cellulosic plastic)		6	**No**	Yes	**No**	Yes	0	0	
3	1	O-ring parker 2-339	Biofiber composite		0.8	Yes	Yes	Yes	**No**	0	0	
4	1	O-ring parker 2-337	Biofiber composite		2.4	Yes	Yes	Yes	**No**	0	0	
5	2	Lateral fasteners	Steel--SAE 1010		30	Yes	Yes	Yes	Yes	100	30	
6	3	Gear	Bioplastic (poliestamidas)		8.25	Yes	Yes	Yes	Yes	100	8.25	
7	3	Spring	Steel--SAE 1010		9	Yes	Yes	Yes	**No**	0	0	
8	3	Bushing	Bioplastic (poliestamidas)		11.14	Yes	Yes	Yes	Yes	100	11.14	
9	3	Motor	Different parts and materials		184.5	**No**	Yes	Yes	Yes	0	0	
10	6	Screw of button heat	Still 12L14		0.55	Yes	Yes	Yes	Yes	100	0.55	
11	1	Flat head screw (assembly plaque of connecters)	Still 12L14		0.33	Yes	Yes	Yes	Yes	100	0.33	
12	3	Flat head screw (lenses´ adaptor)	Still 12L14		0.46	Yes	Yes	Yes	Yes	100	0.46	
13	3	Head flat screw (Housing and "Al" plaque)	Still 12L14		0.3	Yes	Yes	Yes	Yes	100	0.3	
14	2	Button head screw	Stell12L14		0.3	Yes	Yes	Yes	Yes	100	0.3	
15	4	Brass bar (23.2 mm)	Brass liga 12 alloy 0360		5	Yes	Yes	Yes	Yes	100	5	
16	2	Brass bar (75.8 mm)	Brass liga 12 alloy 0360		20.7	Yes	Yes	Yes	Yes	100	20.7	
17	1	Assembly of PCB control	Organic resin materials		16.6	**No**	Yes	Yes	**No**	0	0	
18	1	Assembly of PCB feeding	Organic resin materials		20.5	**No**	Yes	Yes	**No**	0	0	
19	1	Gear of zoom for the lens	New polymers - ECOGEHR (PLA-V polylactide)		30.64	Yes	Yes	Yes	Yes	100	30.64	
20	1	Lenses of 28mm	Different parts and materials		550.8	Yes	Yes	Yes	Yes	100	550.8	
21	1	Housing	Bioplastics - NEC (polylactic acid)		142.5	Yes	Yes	Yes	Yes	100	142.5	
22	1	Glasses´ adaptor	Bioplastics - NEC (polylactic acid)		51	Yes	Yes	Yes	Yes	100	51	
23	1	Plaque of fastening	Bioplastics - NEC (polylactic acid)		246	Yes	Yes	Yes	Yes	100	246	
24	1	Gear of focus for the lens	Bioplastics - NEC (polylactic acid)		14.7	Yes	Yes	Yes	Yes	100	14.7	
25	1	Plaque for housing	Bioplastics - NEC (polylactic acid)		146.7	Yes	Yes	**No**	Yes	0	0	
26	1	Gear of opening for the lens	Bioplastics - NEC (polylactic acid)		12	Yes	Yes	Yes	Yes	100	12	
27	1	Adjust ring glass-plaque	Bioplastics - NEC (polylactic acid)		0.4	Yes	Yes	Yes	Yes	100	0.4	
28	1	Screw Prisoner kind	Still 12L14		0.16	Yes	Yes	Yes	Yes	100	0.16	
29	1	Energy cables	Cooper / PVC		12	Yes	Yes	Yes	Yes	100	12	
30	1	Plaque for assembly of connectors	Bioplastics - NEC (polylactic acid)		45.2	Yes	Yes	Yes	Yes	100	45.2	
					1573						**1258**	**80**

Table 6.5 Recyclability + recycled/renewable content assessment for the ML Redesign													
MOTORIZED LENSES REDESIGN													
	Bill of material					Recyclability			Recycled/renewable content			Recyclability + rec./ren.	
Part #	Qty	Description	Material—print	Supplier	Wt (g)	Wt credit	Wt (g)	Final score	Wt credit	Wt (g)	Final score	Wt'd ave. (g)	Final score
1	1	Connector of voltage DC	Bioplastics - (cellulosic plastic)		4	100	4		40	1.6		3.4	
2	1	DB9 Connector	Bioplastics - (cellulosic plastic)		6	100	6		40	2.4		5.1	
3	1	O-ring parker 2-339	Biofiber composite		0.8	100	0.8		0	0		0.6	
4	1	O-ring parker 2-337	Biofiber composite		2.4	100	2.4		0	0		1.8	
5	2	Lateral fasteners	Steel--SAE 1010		30	50	15		30	4.5		12.375	
6	3	Gear	Bioplastic (poliestamidas)		8.25	100	8.25		40	3.3		7.0125	
7	3	Spring	Steel--SAE 1010		9	50	4.5		30	1.35		3.7125	
8	3	Bushing	Bioplastic (poliestamidas)		11.14	100	11.14		40	4.456		9.469	
9	3	Motor	Different parts and materials		184.5	50	92.25		40	36.9		78.4125	
10	6	Screw of button heat	Steel 12L14		0.55	100	0.55		60	0.33		0.495	
11	1	Flat head screw (assembly plaque of	Steel 12L15		0.33	100	0.33		60	0.198		0.297	
12	3	Flat head screw (lenses´ adaptor)	Steel 12L16		0.46	100	0.46		60	0.276		0.414	
13	3	Head flat screw (Housing and "Al"	Steel 12L17		0.3	100	0.3		60	0.18		0.27	
14	2	Button head screw	Steel 12L18		0.3	100	0.3		60	0.18		0.27	
15	4	Brass bar (23.2 mm)	Brass liga 12 alloy 0360		5	100	5		70	3.5		4.625	
16	2	Brass bar (75.8 mm)	Brass liga 12 alloy 0360		20.7	100	20.7		70	14.49		19.1475	
17	1	Assembly of PCB control	Organic resin materials		16.6	100	16.6		30	4.98		13.695	
18	1	Assembly of PCB feeding	Organic resin materials		20.5	100	20.5		30	6.15		16.9125	
19	1	Gear of zoom for the lens	New polymers - ECOGEHR (PLA-V		30.64	100	30.64		20	6.128		24.512	
20	1	Lenses of 28mm	Different parts and materials		550.8	50	275.4		40	110.16		234.09	
21	1	Housing	Bioplastics - NEC (polylactic acid)		142.5	100	142.5		20	28.5		114	
22	1	Glasses´ adaptor	Bioplastics - NEC (polylactic acid)		51	100	51		20	10.2		40.8	
23	1	Plaque of fastening	Bioplastics - NEC (polylactic acid)		246	100	246		20	49.2		196.8	
24	1	Gear of focus for the lens	Bioplastics - NEC (polylactic acid)		14.7	100	14.7		20	2.94		11.76	
25	1	Plaque for housing	Bioplastics - NEC (polylactic acid)		146.7	100	146.7		20	29.34		117.36	
26	1	Gear of opening for the lens	Bioplastics - NEC (polylactic acid)		12	100	12		20	2.4		9.6	
27	1	Adjust ring glass-plaque	Bioplastics - NEC (polylactic acid)		0.4	100	0.4		20	0.08		0.32	
28	1	Screw Prisoner kind	Steel 12L14		0.16	100	0.16		50	0.08		0.14	
29	1	Energy cables	Cooper / PVC		12	25	3		50	1.5		2.625	
30	1	Plaque for assembly of connectors	Bioplastics - NEC (polylactic acid)		45.2	100	45.2		30	13.56		37.29	
					1572.9		**1176.8**	**75**		**339**	**22**	**863.2**	**55%**

Table 6.6 Calculating the final DfE score for for the ML Redesign									
MOTORIZED LENSES REDESIGN									
	Bill of material					DfE score			
Part #	Qty	Description	Material	Supplier	Wt (g)	**DfE Weight:** Mat. chem. + disassembly + recyclability (g)	Potential DfE wt	Final score
1	1	Connector of voltage DC	Bioplastics - (cellulosic plastic)		4	2.467	4	61.667
2	1	DB9 Connector	Bioplastics - (cellulosic plastic)		6	3.700	6	61.667
3	1	O-ring parker 2-339	Biofiber composite		0.8	0.367	0.8	45.875
4	1	O-ring parker 2-337	Biofiber composite		2.4	1.100	2.4	45.833
5	2	Lateral fasteners	Steel--SAE 1010		30	19.125	30	63.750
6	3	Gear	Bioplastic (poliestamidas)		8.25	6.670	8.25	80.848
7	3	Spring	Steel--SAE 1010		9	2.738	9	30.417
8	3	Bushing	Bioplastic (poliestamidas)		11.14	9.003	11.14	80.817
9	3	Motor	Different parts and materials		184.5	56.888	184.5	30.833
10	6	Screw of button heat	Still 12L14		0.55	0.532	0.55	96.667
11	1	Flat head screw (assembly plaque of connecters)	Still 12L14		0.33	0.319	0.33	96.667
12	3	Flat head screw (lenses´ adaptor)	Still 12L14		0.46	0.445	0.46	96.667
13	3	Head flat screw (Housing and "Al" plaque)	Still 12L14		0.3	0.290	0.3	96.667
14	2	Button head screw	Stell12L14		0.3	0.290	0.3	96.667
15	4	Brass bar (23.2 mm)	Brass liga 12 alloy 0360		5	4.875	5	97.500
16	2	Brass bar (75.8 mm)	Brass liga 12 alloy 0360		20.7	20.183	20.7	97.500
17	1	Assembly of PCB control	Organic resin materials		16.6	10.098	16.6	60.833
18	1	Assembly of PCB feeding	Organic resin materials		20.5	12.471	20.5	60.833
19	1	Gear of zoom for the lens	New polymers - ECOGEHR (PLA-V polylactide)		30.64	28.597	30.64	93.333
20	1	Lenses of 28mm	Different parts and materials		550.8	353.430	550.8	64.167
21	1	Housing	Bioplastics - NEC (polylactic acid)		142.5	133.000	142.5	93.333
22	1	Glasses´ adaptor	Bioplastics - NEC (polylactic acid)		51	47.600	51	93.333
23	1	Plaque of fastening	Bioplastics - NEC (polylactic acid)		246	229.600	246	93.333
24	1	Gear of focus for the lens	Bioplastics - NEC (polylactic acid)		14.7	13.720	14.7	93.333
25	1	Plaque for housing	Bioplastics - NEC (polylactic acid)		146.7	88.020	146.7	60.000
26	1	Gear of opening for the lens	Bioplastics - NEC (polylactic acid)		12	11.200	12	93.333
27	1	Adjust ring glass-plaque	Bioplastics - NEC (polylactic acid)		0.4	0.373	0.4	93.333
28	1	Screw Prisoner kind	Still 12L14		0.16	0.153	0.16	95.833
29	1	Energy cables	Cooper / PVC		12	5.875	12	48.958
30	1	Plaque for assembly of connectors	Bioplastics - NEC (polylactic acid)		45.2	42.563	45.2	94.167
					1573	***1179.700***	***1572.93***	***75.00%***

A P P E N D I X

‘ D ’

Alejandro Flores Calderón

C 2 C

CRITERION 1. MATERIALS TOXICITY / C2C RE-DESIGN				
1 Material Kind	2 Weight [gr]	3 Toxicity score [%]	4 Toxicity weight [%gr]	5 Relative product material toxicity [%]
Metals	570	50	28500	
Ceramics	220	100	22000	
Synthetic polymers	742.95	100	74295	
Natural organic materials	0	-	0	
Natural inorganic materials	0	-	0	
Composites	0	-	0	
TOTAL WEIGHT	**1532.95**		**124795**	**81.41**

CRITERION 2. EFFICIENCY / C2C RE-DESIGN							
1 Sub-systems	2 Identify the items related	3 # of functions carried out	4 Biological systems	5 Mimiking			
				Form	Funtion	Ecosystem	Score [%]
PCB feeding-elect. energy feed	1.- The cart made of organic resin 2.- electronic components 3.- Cables	1. Locate electronic components 2. Manage electric energy 3. Lead electric energy	* Sensing and sharing information: neurons	0	50	25	25.00
PCB control-electric signals	1.- The cart made of organic resin 2.- electronic components 3.- Cables	1. Locate electronic components 2. Manage electonic signals 3. Lead electric energy	* Sensing and sharing information: neurons	0	50	25	25.00
Transmition	1. Motors (3) 2. Spur gear	1. Convert EE to ME 2. Transmit circular movement	* Human Shoulder	25	50	25	33.33
Camera Lenses	1. Glass lenses 2. Focus mechanism	1. Give accurately focus 2. move the lenses to the correct position	* Eagle eyes * Owl eyes * Cat eyes	75	75	75	75.00
Housing	1. Housing 2. Brass bars and other comp.	1. To protect inner components 2. To insulate inner components 3.To locate inner components	* The human skull * The turtle's shell * The egg shell	0	75	25	33.33
						6 Total Mimicking Score	**38.33**

CRITERION 3. MATERIALS CYCLICITY / C2C RE-DESIGN				
1 **Material Kind**	**2** **Weight [gr]**	**3** **FROM Recycled Material [gr*%]**	**4** **TO Recycle Material [gr*%]**	**5** **Product Cyclicit y**
Metals	570	0	57000	
Ceramics	220	0	22000	
Synthetic polymers	742.95	74295	74295	
Natural organic materials	-	-	-	
Natural inorganic materials	-	-	-	
Composites	-	-	-	
TOTAL WEIGHT	**1532.95**	**74295**	**153295**	
				74.23

CRITERION 4. USE OF RENEWABLE ENERGIES / C2C RE-DESIGN			
1 **Subsystems**	**2** **Energy consumed [J]**	**3** **Energy from Renewable Source [J]**	**4** **Product % of Renewable Energy [J]**
PCB feeding-elect. energy feed	-	0	
PCB control- electric signals	-	0	
Motors (3)	540	0	
Camera Lenses	0	0	
Housing	0	0	
	540	**0**	**0.00**

CRITERION 5 SOCIAL BENEFIT / C2C RE-DESIGN			
1 Collect information	**2 Self evaluation?**	**3 Score? [%]**	**Fulfillment %**
Minors’ Labor	YES	100	
Forced Labor	YES	100	
Health and Safety	YES	80	
Freedom of Association and the Right to Collective Bargaining	YES	90	
Discrimination	YES	95	
Disciplinary Procedures	YES	95	
Work Schedules	YES	80	
Salaries	YES	70	
		710	**88.75**

B I O

CRITERION 1. MATERIALS TOXICITY / BIO RE-DESIGN				
1 Material Kind	2 Weight [gr]	4 Toxicity score [%]	5 Toxicity weight [%gr]	6 Relative product material toxicity
Metals	501.17	50	25058.5	
Ceramics	220	100	22000	
Synthetic polymers	331.82	100	33182	
Natural organic materials	0	-	0	
Natural inorganic materials	0	-	0	
Composites	0	-	0	
TOTAL WEIGHT	**1052.99**		**80240.5**	**76.20**

CRITERION 2. EFFICIENCY / BIO RE-DESIGN							
1 Sub-systems	2 Identify the componenets related	3 # of functions carried out	4 Biological systems	5 Mimiking			
				Form	Funtion	Ecosystem	Score [%]
PCB feeding-elect. energy feed	1.- The cart made of organic resin 2.- Electronic components 3.- Cables	1. Locate electronic components 2. Manage electric energy 3. Lead electric energy	* Sensing and sharing information: neurons	0	50	25	25.00
PCB control-electric signals	1.- The cart made of organic resin 2.- electronic components 3.- Cables	1. Locate electronic components 2. Manage electonic signals 3. Lead electric energy	* Sensing and sharing information: neurons	0	50	25	25.00
Transmition	1. Motors (3) 2. Spur gear	1. Convert EE to ME 2. Transmit circular movement	* Human Shoulder	25	50	25	33.33
Camera Lenses	1. Glass lenses 2. Focus mechanism	1. Give accurately focus 2. move the lenses to the correct position	* Eagle eyes * Owl eyes * Cat eyes	75	75	75	75.00
Housing	1. Housing	1. To protect inner components 2. To insulate inner components 3.To locate inner components	* The human skull * The turtle's shell * The egg shell	75	75	75	75.00
				6 Total Mimicking Score			46.67

CRITERION 3. MATERIALS CYCLICITY / BIO RE-DESIGN				
1 **Material Kind**	**2** **Weight [gr]**	**3** **FROM Recycled Material [gr*%]**	**4** **TO Recycle Material [gr*%]**	**5** **Product Cyclicity**
Metals	501.17	0	50117	
Ceramics	220	0	22000	
Synthetic polymers	331.82	33182	33182	
Natural organic materials	0	-	-	
Natural inorganic materials	0	-	-	
Composites	0	-	-	
TOTAL WEIGHT	**1052.99**	**33182**	**105299**	
				65.76

CRITERION 4. USE OF RENEWABLE ENERGIES / BIO RE-DESIGN			
1 **Subsystems**	**2** **Energy consumed [J]**	**3** **Energy from Renewable Source [J]**	**4** **Product % of Renewable Energy [J]**
PCB feeding-elect. energy feed	-	0	
PCB control- electric signals	-	0	
Motors (3)	540	0	
Camera Lenses	0	0	
Housing	0	0	
	540	**0**	**0.00**

CRITERION 5 SOCIAL BENEFIT / BIO RE-DESIGN			
1 **Collect information**	**2** **Self evaluation?**	3 **Score? [%]**	4 **Fulfillment %**
Minors' Labor	YES	100	
Forced Labor	YES	100	
Health and Safety	YES	80	
Freedom of Association and the Right to Collective Bargaining	YES	90	
Discrimination	YES	95	
Disciplinary Procedures	YES	95	
Work Schedules	YES	80	
Salaries	YES	70	
			88.75

T B

CRITERION 1. MATERIALS TOXICITY / TB RE-DESIGN				
1 Material Kind	2 Weight [gr]	3 Toxicity score [%]	4 Toxicity weight [%gr]	5 Relative product material toxicity
Metals	570	50	28500	
Ceramics	200	100	20000	
Synthetic polymers	694.44	100	69444	
Natural organic materials	0	-	0	
Natural inorganic materials	0	-	0	
Composites	0	-	0	
TOTAL WEIGHT	**1464.44**		**117944**	**80.54**

CRITERION 2. EFFICIENCY / TB RE-DESIGN							
1 Sub-systems	2 Identify the componenets related	3 # of functions carried out	4 Biological systems	5 Mimiking			
				Form	Funtion	Ecosystem	Score [%]
PCB feeding-elect. energy feed	1.- the cart made of organic resin	1. Locate electronic components	* Sensing and sharing information: neurons	0	50	25	25.00
	2.- electronic components	2. Manage electric energy					
	3.- Cables	3. Lead electric energy					
PCB control-electric signals	1.- the cart made of organic resin	1. Locate electronic components	* Sensing and sharing information: neurons	0	50	25	25.00
	2.- electronic components	2. Manage electonic signals					
	3.- Cables	3. Lead electric energy					
Transmition	1. Motors (3)	1. Convert EE to ME	* Human Shoulder	25	50	25	33.33
	2. Spur gear	2. Transmit circular movement					
Camera Lenses	1. Glass lenses	1. Give accurately focus	* Eagle eyes * Owl eyes * Cat eyes	75	75	75	75.00
	2. Focus mechanism	2. move the lenses to the correct position					
Housing	1. Housing	1. To protect inner components	* The human skull * The turtle's shell * The egg shell	0	75	25	33.33
		2. To insulate inner components					
		3.To locate inner components					
				6 Total Mimicking Score			**38.33**

CRITERION 3. MATERIALS CYCLICITY / TB RE-DESIGN				
1 **Material Kind**	**2** **Weight** **[gr]**	**3** **FROM** **Recycled Material** **[gr*%]**	**4** **TO** **Recycle Material** **[gr*%]**	**5** **Product** **Cyclicity**
Metals	570	0	57000	
Ceramics	200	0	20000	
Synthetic polymers	694.44	69444	69444	
Natural organic materials	0	-	-	
Natural inorganic materials	0	-	-	
Composites	0	-	-	
TOTAL WEIGHT	**1464.44**	**69444**	**146444**	
				73.71

CRITERION 4. USE OF RENEWABLE ENERGIES / TB RE-DESIGN			
1 **Subsystems**	**2** **Energy consumed [J]**	**3** **Energy from Renewable Source [J]**	**4** **Product % of Renewable Energy [J]**
PCB feeding-elect. energy feed	-	0	
PCB control- electric signals	-	0	
Motors (3)	540	0	
Camera Lenses	0	0	
Housing	0	0	
	540.00	**0.00**	**0.00**

CRITERION 5 TB / SOCIAL BENEFIT			
1 **Collect information**	**2** **Self evaluation?**	**3** **Score? [%]**	**4** **Fulfillment %**
Minors' Labor	YES	100	
Forced Labor	YES	100	
Health and Safety	YES	80	
Freedom of Association and the Right to Collective Bargaining	YES	90	
Discrimination	YES	95	
Disciplinary Procedures	YES	95	
Work Schedules	YES	80	
Salaries	YES	70	
			88.75