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Ecodesign Maturity Model: a framework to support companies in the selection and implementation of ecodesign practices

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ABSTRACT

Over the last few decades, ecodesign has emerged as a promising approach to integrate environmental concerns into the product development process in order to minimize environmental impacts throughout the product's material life cycle, without compromising other essential criteria such as performance and cost. Despite the recognition of the ecodesign potential benefits, its application has not reached companies worldwide mainly due to difficulties in the management of ecodesign, which include: lack of systematization of ecodesign practices; lack of integration into the product development process, management and corporate strategy; and lack of a method to support the selection of the most suitable ecodesign practices to be applied. This thesis introduces the Ecodesign Maturity Model (EcoM2), a framework aimed at supporting companies in the ecodesign implementation and management. The EcoM2 was developed in the context of the hypothetic-deductive approach combining the theoretical and empirical developments. Initially, a theoretical approach is adopted in order to have a deep knowledge and understanding about the issue, define the main elements of the model and elaborate the content of the theoretical version. The main research method adopted in this phase is the systematic literature review combined with experts' evaluation, in order to improve the theoretical version. Subsequently, the improved version of the EcoM2 is further developed following an empirical approach, with the application of the EcoM2 in an action research. Finally, in order test hypothesis of the research, i.e. that the EcoM2 can support companies in the selection of ecodesign practices to be applied into the product development process, two case studies for theory-testing are carried out. The results indicate that the EcoM2 can successfully support companies in the selection of the most suitable ecodesign practices to be applied, based on the current maturity profile of the company on ecodesign implementation and its strategic goals and drivers.

Keywords: ecodesign management; Ecodesign Maturity Model; ecodesign practices

RESUMO

Ao longo das últimas décadas, o ecodesign surgiu como uma abordagem promissora para integrar as questões ambientais ao processo de desenvolvimento de produtos de forma a minimizar os impactos ambientais ao longo de todo ciclo de vida material dos produtos, sem comprometer outros aspectos essenciais, tais como desempenho e custo. Apesar do reconhecimento dos benefícios potenciais do ecodesign, a sua aplicação ainda não é consolidada nas empresas em todo o mundo, principalmente devido às dificuldades na gestão do ecodesign, que incluem: falta de sistematização das práticas de ecodesign, falta de integração ao processo de desenvolvimento de produtos, gestão e estratégia empresariais; e falta de um método para apoiar a seleção das práticas de ecodesign a serem aplicadas. Esta tese apresenta o Modelo de Maturidade em Ecodesign (EcoM2), uma estrutura conceitual destinada a apoiar as empresas na aplicação e gestão do ecodesign. O EcoM2 foi desenvolvido no contexto da abordagem hipotético-dedutiva combinando o desenvolvimento teórico e empírico. Inicialmente, adota-se uma abordagem teórica de forma a obter conhecimento e entendimento sobre o assunto, definir os principais elementos do modelo e elaborar a versão teórica. O principal método de pesquisa adotado nessa fase é a revisão sistemática da literatura combinada com avaliação de especialistas, a fim de melhorar a versão teórica. Em sequência, a nova versão teórica do EcoM2 é aperfeiçoada por meio de uma abordagem empírica, com a aplicação do EcoM2 em uma pesquisa-ação. Finalmente, a fim de executar o teste da hipótese de pesquisa, isto é, de que o EcoM2 pode apoiar as empresas na seleção das práticas de ecodesign a serem aplicadas ao processo de desenvolvimento de produtos, são realizados dois estudos de caso para teste da teoria. Os resultados indicam que o EcoM2 pode apoiar as empresas na seleção das práticas de ecodesign, com base no perfil de maturidade atual da empresa na implementação do ecodesign e seus direcionadores e objetivos estratégicos.

Palavras-chave: gestão do ecodesign, Modelo de Maturidade em Ecodesign, design para o ambiente.

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1 Introduction

This section describes the context and motivation (section 1.1), the research objectives (section 1.2) and the structure of the thesis (section 1.3).

1.1 Context and motivation

The growth of economic activity in the last decades has been followed by an increase of the environmental concerns (OECD, 2010). The general understanding that the environment and the economy are interdependent have aroused increasing attention amongst political powers and the society in general (CARRILLO-HERMOSILLA et al., 2009)

The business concern with environmental issues is directly related to the intensification of environmental awareness in the 1970s and 1980s. This was a consequence of the pollution caused by the passive attitude until then adopted by companies: no mechanism was applied to pollution control. The waste generated in the production processes was disposed directly in the environment without any kind of treatment. In recognition of the pollution effects on human health, governments launched a series of environmental legislation which aimed to regulate companies' activities concerning pollution control. Due to the development and strengthening of environmental legislation worldwide, the so-called "end-of-pipe" solutions started to be applied. The main objective was the reduction of the pollution potential through treatment of wastewater and gases generated in the production processes (JOHANSSON, 2002).

The preventive posture emerged in a context in which companies began to improve their manufacturing processes, with approaches such as Pollution Prevention and Cleaner Production. These approaches aim to reduce the waste generation directly at its source, i.e. at the production processes, thereby reducing treatment and final disposal costs. Besides legal aspects, this change in attitude is also due to the recognition of the real costs associated to the traditional "end-of-pipe" approaches. In addition to the usual costs accounted for treatment and disposal, there are costs which are usually not taken into account. These costs are related to, for example, loss of resources (raw materials, water, energy, etc.), legal and regulatory non-compliance and corporate image (BIERMA et al., 1998; KENGPOL; BOONKANIT, 2011). According to the United Nations Environment Program (UNEP, 2004), typically, for every dollar accounted for waste treatment or disposal, there are two to three dollars "hidden" or simply ignored, even in well managed and large companies (UNEP, 2004).

Recently, there has been observed a transition to a proactive attitude, focusing on the environmental performance of products[1] and characterized by a holistic view of environmental impacts associated with the product´s life cycle (VAN WEENEN, 1995; BHAMRA; EVANS; et al., 1999). Despite being fundamental for economic growth and quality of life, the production and consumption of products are identified as the source of most of the environmental impacts[2] caused by society (COMMISSION OF THE COMMUNITIES, 2001; 2003).

The environmental impacts occur throughout the entire material life cycle of a product, from raw material extraction and manufacturing to use and final disposal (Figure 1) (ISO, 2002; NIELSEN; WENZEL, 2002; BAUMANN et al., 2002; COMMISSION OF THE EUROPEAN COMMUNITIES, 2003). The primary flow (direct), represented in figure 1, comprises raw material extraction, primary industry processing, manufacturing of finished products, use, product´s discard at its end-of-life and transportation/distribution processes along the whole life cycle (Figure 1). In order to close the loop of materials, minimizing the environmental impacts related to resources consumption and final disposal, the secondary flow (reverse) is related to the application of end-of-life strategies (such as recycling, remanufacturing and reuse) and reverse logistics to take the products back (Figure 1). Each product life cycle phase implies in the consumption of resources (inputs) and generation of wastes, which must be properly treated and disposed. The flows of material and the waste generation across the product life cycle phases are directly related to the environmental impacts of a product. Moreover, energy use associated with the different life cycle stages can add substantially to the environmental impact of the product.

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[1] The environmental performance of a product is determined by the sum of all environmental impacts throughout its material life cycle (NIELSEN; WENZEL, 2002)

[2] According to ISO (1996), environmental impact is defined as “any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization´s activities, products or services”.

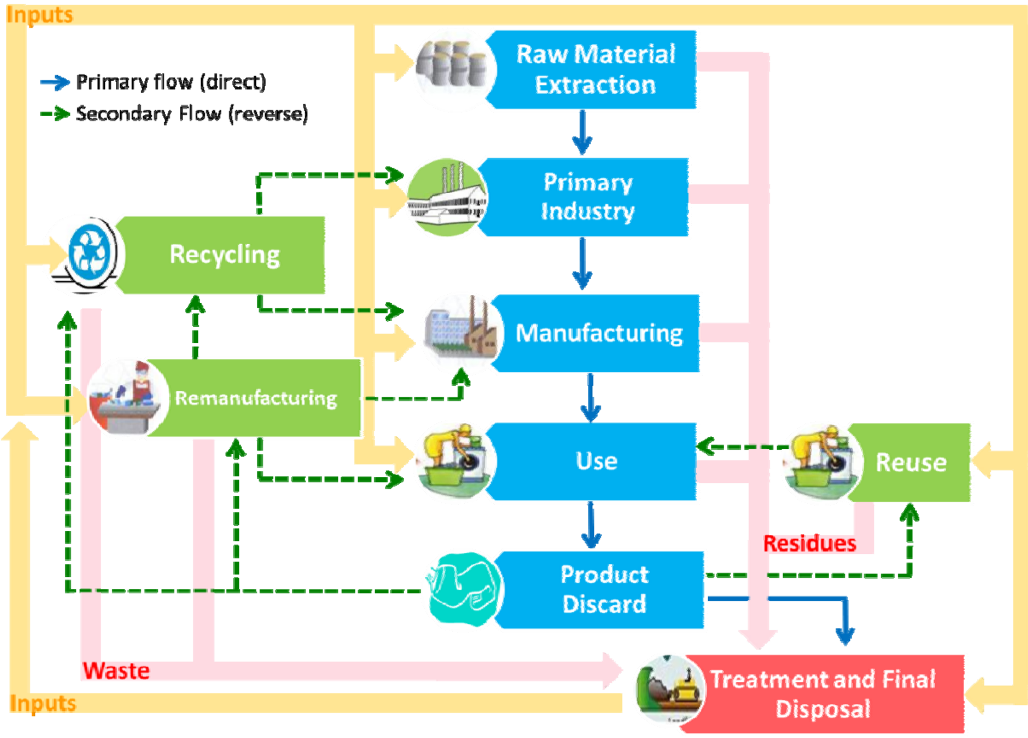

Figure 1: Scheme of a product's material life cycle

The environmental impacts caused by products throughout its material life cycle are, to a large extent, a result of interrelated decisions and definitions made in the early stages of the product development process (PDP) (POOLE et al., 1999; JOHANSSON, 2002; NIELSEN; WENZEL, 2002; HAUSCHILD et al., 2005; BYGGETH; HOCHSCHORNER, 2006; LUTTROPP; LAGERSTEDT, 2006). In order to reduce the environmental impact of products, the product development process must incorporate the environmental issues since the early stages (BAUMANN et al., 2002).

Ecodesign has emerged as a promising approach to integrate the environmental concerns into the product development process. Over the last decades, ecodesign evolved from an engineering perspective into an organizational, technical and design issue (CHARTER, 2001).

Ecodesign can be defined as a proactive environmental management approach that integrates environmental issues into the product development and related[3]

[3] Manufacturing, marketing, procurement, maintenance, quality, etc. are some examples of related processes. These processes are carried out together with the product development process and are essential to the ecodesign implementation into companies.

processes in order to minimize environmental impacts throughout the product's material life cycle (from raw material extraction and manufacturing to use and end-of-life - Figure 1), without compromising other essential criteria such as performance, functionality, quality and cost (VAN WEENEN, 1995; JOHANSSON, 2002).

The application of ecodesign is essential to companies that recognized that environmental performance is vital to sustain long term success. Ecodesign application has the potential to lead to legal compliance, image improvement, costs and risks reduction. It also promotes product innovation, new business opportunities, improved product quality and the development of new markets (ISO, 2002; HAUSCHILD et al., 2005; WIMMER et al., 2010).

Next moves on corporate environmental management are related to the concept of sustainable product development (or design for sustainability) (UNEP; DELFT UNIVERSITY OF TECHNOLOGY, 2009; SPANGENBERG et al., 2010), which addresses the consideration of environmental, social and economic issues into the product development in order to realize the overall objective of sustainable development[4] (VAN WEENEN, 1995). Concepts such as sustainable consumption, which highlights a need to reduce the volume of consumption and "desire", are also gaining momentum (KARLSSON; LUTTROPP, 2006).

Despite the recognized importance of these topics, they are out of the scope of this research, which focuses mainly on ecodesign (environmental consideration during the product development and related processes). Ecodesign can play a strategic role in a change towards more refined products that can also contribute to the societal shift towards sustainable consumption and production (KARLSSON; LUTTROPP, 2006). In the emerging agenda of integrated policies for innovation and sustainable development, building capacity and capabilities for ecodesign can play a key role (O´RAFFERTY, 2008).

The drivers often mentioned in literature for ecodesign adoption include: more severe environmental product-related legislations and standards which

[4]Sustainable development is defined by the World Commission on Environment and Development (WCED) as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(UN, 1987).

establish life cycle thinking; opportunities to enhance competitiveness by reducing costs and increasing the revenues; and increased stakeholders´ awareness about the environmental impact associated with products and services (DOWIE, 1994; BREZET; VAN HEMEL, 1997; BAKSHI; FIKSEL, 2003; HAUSCHILD et al., 2005; BYGGETH; HOCHSCHORNER, 2006; UNEP; DELFT UNIVERSITY OF TECHNOLOGY, 2009; DANGELICO; PUJARI, 2010; PLOUFFE et al., 2011).

Similarly, potential business benefits linked to the ecodesign application can be achieved by the organization, such as: stimulation of innovation and creativity; identification of new products and business models; ability to meet or surpass customer expectations[5]; enhancement of organizational image and/or brand; improvement of customer loyalty; attraction of financing and investments; enhancement of employee loyalty and motivation; increased knowledge about the product; reduction in liability through lessened environmental impacts; reduction of risks; improved relation with regulators; and improvement of internal and external communications (ISO, 2002, 2011; UNEP; DELFT UNIVERSITY OF TECHNOLOGY, 2009; DANGELICO; PUJARI, 2010; PLOUFFE et al., 2011; SANTOLARIA et al., 2011).

According to ISO (2011), organizations can obtain such benefits from ecodesign irrespective of size, geographical location, corporate culture and management system sophistication. Ecodesign application can enable companies to convert challenges into opportunities (RAMANI et al., 2010; WIMMER et al., 2010).

However, establishing ecodesign is a difficult and complex task (RAMANI et al., 2010). Successful implementation of ecodesign requires appropriate organizational and management structures based on solid internal and external information systems (CHARTER, 2001). The shape of ecodesign depends on the company, its culture, products and markets (CHARTER, 2001).

Currently, just few companies really know about ecodesign, its challenges, tools, implications and potentialities (NEY, 2008). The application of ecodesign has not reached companies worldwide over the last decades (PASCUAL;

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[5] Plouffe et al. (2011) affirms that corporate buyers seem to be more sensitive and receptive to ecodesigned products than individual consumers.

STEVELS; et al., 2003; BOKS, 2006; JOHANSSON, 2006; PLOUFFE et al., 2011), mainly due to:

I. There is no systematization of the existing ecodesign practices and an intense development of new ecodesign techniques and tools in detriment of the study and improvement of the existing ones (BREZET; ROCHA, 2001; BAUMANN et al., 2002; DEWULF; DUFLOU, 2004; HALLSTEDT et al., 2010; COLLADO-RUIZ; OSTAD-AHMAD-GHORABI, 2010b; BOVEA; PÉREZ-BELIS, 2012);

II. There is a lack of integration between ecodesign practices and the broad context of the product development process (POOLE et al., 1999; BAKSHI; FIKSEL, 2003; JOHANSSON, 2006; LUTTROPP; LAGERSTEDT, 2006; POCHAT et al., 2007; DANGELICO; PUJARI, 2010);

III. Ecodesign is poorly integrated into management and corporate strategy. Companies do not know how to address ecodesign during the strategic decision-making process, incorporating it into their corporate, business and functional level strategies (BHAMRA; EVANS; et al., 1999; BREZET; ROCHA, 2001; CHARTER, 2001; ISO, 2002; BAUMANN et al., 2002; PASCUAL; STEVELS, 2004; BONN; FISHER, 2011);

IV. Ecodesign implementation in companies is not supported by a roadmap for continuous improvement (BREZET; ROCHA, 2001; BOKS; STEVELS, 2007);

V. The selection of ecodesign practices is not performed in accordance with company´s characteristics and needs (MCALOONE, 2001; BOKS; STEVELS, 2007).

In order to carry out ecodesign in a systematic and manageable way, organizations need to implement appropriate activities and then have necessary levels of competence to effectively carry out and manage these activities (ISO, 2011). It is still not clear to companies which ecodesign strategies, guidelines and techniques/tools should be selected and how to manage the process of ecodesign integration into the product development process in a continuous improvement context (JESTON; NELIS, 2006).

In practice, organizations need guidance on how to apply their efforts in a systematic manner in order to achieve environmental goals and maintain continual improvements in the environmental performance of products and processes (ISO, 2011). Consequently there is a need to propose models that can support companies in the effective implementation of ecodesign into the product development, considering the different competence levels in ecodesign.

The hypothesis advocated in this research is that the selection and application of ecodesign practices may be supported by the use of a maturity model, which indicates the most suitable practices to be implemented into the product development and related processes according to the company current maturity profile on ecodesign, strategic drivers and goals. The maturity approach, as seen in other knowledge areas (such as project management and software development (see section 3.2)), can provide a systematization of the existing knowledge and provide guidance in the implementation of new concepts, such as ecodesign, which are still not internalized by companies.

1.2 Research objectives

The main objective of the research is to develop an Ecodesign Maturity Model (EcoM2) that can support companies in the selection of the most suitable ecodesign practices to be implemented into the product development and related processes, according to companies´ strategic objectives and drivers. The following specific objectives can be deployed from the main objective:

- Systematize the ecodesign practices;
- Develop and characterize the ecodesign maturity levels;
- Develop an application method to guide and support the application of the maturity model.

Ecodesign practice[6] is the term adopted in this research to define ecodesign activities that aims at integrating the environmental concerns into product

[6] According to PMI (2008), practice is defined as “a specific type of professional or management activity that contributes to the execution of a process and that employ one or more techniques and tools”. Technique is defined as “a defined systematic procedure employed by a human resource to perform an activity to produce a product or result or deliver a service, and that may employ one or more tools” (PMI, 2008) and tool is defined as “something tangible, such as a

development and related process and which application can be supported by techniques and tools.

Companies classified under the section C (Manufacturing) of the International Standard Industrial Classification of All Economic Activities[7] (ISIC) (UNITED NATIONS, 2008) following a structured product development process (PDP) for product development and aiming to apply ecodesign are, therefore, the target group for whom the research is being conducted[8].

Section C includes companies involved in the physical or chemical transformation of materials, substances, or components into new products (UNITED NATIONS, 2008). Section C comprises the following divisions: 10 - Manufacture of food products; 11 - Manufacture of beverages; 12 - Manufacture of tobacco products; 13 - Manufacture of textiles; 14 - Manufacture of wearing apparel; 15 - Manufacture of leather and related products; 16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; 17 - Manufacture of paper and paper products; 18 - Printing and reproduction of recorded media; 19 - Manufacture of coke and refined petroleum products; 20 - Manufacture of chemicals and chemical products; 21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations; 22 - Manufacture of rubber and plastics products; 23 - Manufacture of other non-metallic mineral products; 24 - Manufacture of basic metals; 25 - Manufacture of fabricated metal products, except machinery and equipment; 26 - Manufacture of computer, electronic and optical products; 27 - Manufacture of electrical equipment; 28 - Manufacture of machinery and equipment; 29 - Manufacture of motor vehicles, trailers and semi-trailers; 30 - Manufacture of other transport equipment; 31 - Manufacture of furniture; 32 - Other manufacturing; 33 - Repair and installation of machinery and equipment.

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template of software program, used in performing an activity to produce a product or result" (PMI, 2008).

[7] The International Standard Industrial Classification of All Economic Activities (ISIC) consists of a coherent and consistent classification structure of economic activities based on a set of internationally agreed concepts, definitions, principles and classification rules (UNITED NATIONS, 2008).

[8] Manufacturing companies that do not develop products (i.e. companies that manufactures the products developed by other companies, for example) are not included in the domain of this research.

The selection of companies of the Section C (Manufacturing) is justified due to the increase need for the consideration of environmental aspects of products, driven mainly by legislation and market requirements. The environmental impacts of products developed by these companies are of higher importance and need considerably improvements. The companies should benefit from the results of the application of the Ecodesign Maturity Model (EcoM2) to perform the selection of ecodesign practices in accordance with their strategic objectives and drivers, developing products with improved environmental performance and contributing to their long-term competitiveness.

1.3 Document structure

The document is structured into 8 sections and 7 appendixes, according to the scheme presented in Figure 2.

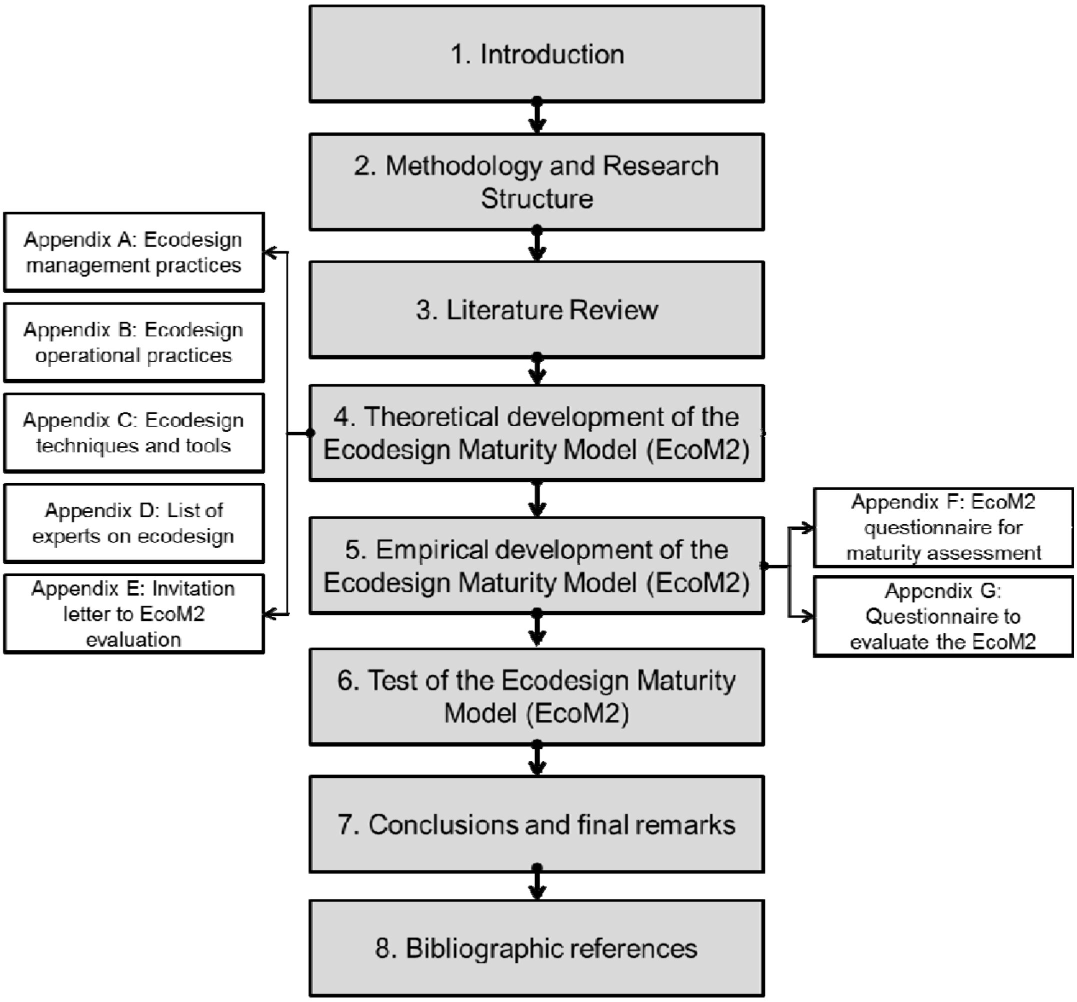

Figure 2: Structure of the document

The next section discusses the methodological aspects and the phases carried out in the research in order to develop the Ecodesign Maturity Model (EcoM2). Section 4 describes the theoretical development of the EcoM2 and is followed by section 5, which presents the empirical development of the model based on an action research in a large manufacturing company. Section 6 presents the results of the application of the Ecodesign Maturity Model in two case studies for theory testing. The conclusions and final remarks of the thesis are presented in section 7. To conclude, section 8 presents the bibliographic references.

2 Methodology and research structure

In this section, the methodological aspects (section 2.1) and the phases carried out in the research (section 2.2) are discussed.

2.1 Methodological aspects

The nature of a research usually varies according to the evolution of the knowledge area under analysis. Karlsson (2009) states that "research should typically explore before being able to describe, know the components before understanding the relations, and know the relations before foreseeing the effects". The initial development phase of a knowledge area is characterized by exploratory researches that will result in concepts, classifications and definitions. Descriptions of the phenomena with overviews of patterns and structures are then observed, characterizing the descriptive phase. Analytical models that relate components together will then be developed, also allowing the development of models for managing the studied process. This level of evolution is termed prescriptive, as it prescribes new models to explain a phenomenon. The next level is related to the development of normative studies to understand causal relationships, making possible to predict the effects of different actions/measures and to develop manuals with checklists and other tools in order to implement the concept in practice (KARLSSON, 2009).

In this context, this research can be classified according to its nature as prescriptive, since it proposes the creation and application of a new analytical management model that relates the ecodesign components together in order to support companies in the selection of the ecodesign practices. Moreover, since the research strives to solve a problem faced in the real world, generating knowledge for academic and business areas, it can be characterized as an applied research (KARLSSON, 2009).

Research can also be classified according to the broad approach taken to solve the problem into deductive or inductive approaches. Those approaches are related to the starting point assumed by the researcher (the theory or the empirical world) and the logical thinking adopted. A deductive research approach entails the development of a conceptual and theoretical structure prior to its testing through empirical observation - it begins with abstract conceptualization and then moves on to testing through the application of the theory so as to create new experiences or observations until it is corroborated. Often, within the deductive approach, the theory is assumed to be established as a valid explanation after tested and corroborated (GILL; JOHNSON, 2002). However, Popper (1967; 1972a; 1972b)[9] apud Gill and Johnson (2002) affirms that a theory can never be proved to be true by a finite number of observations, no matter how many confirmatory instances has being carried out. The logical thinking of the hypothetic-deductive approach, proposed by Popper, is that, while theories can never be proved to be true, they can be falsified, since only one contradictory observation is required (GILL; JOHNSON, 2002). The logical ordering of induction is the reverse of deduction as it involves moving from the observation of the empirical world to the construction of explanations and theories about what has been observed (GILL; JOHNSON, 2002).

In this research, the hypothetic-deductive approach, as defined by Lancaster (2005), is adopted. The hypothesis advocated is that the selection of ecodesign practices may be supported by the use of the Ecodesign Maturity Model (EcoM2), which is the theory[10] developed in the research.

In order to select the research methods to be adopted, a continuum in terms of the relative emphasis upon deduction or induction can be distinguished (GILL; JOHNSON, 2002). True experiments can be identified at the deductive extreme, while ethnography research can be found in the inductive extreme. In the middle term, quasi-experiments, surveys and action research can be cited.

Since the hypothetic-deductive approach is adopted, the research methods related to deduction will be further studied in order to select the most suitable to the development of the Ecodesign Maturity Model (EcoM2).

In management research, the application of a true experiment is relatively rare. The subject under investigation in the management research area is usually

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[9] POPPER, K. R. **Conjectures and Refutations**. Routledge, London, 1967.
POPPER, K.R. **Objective Knowledge**. Clarendon Press, Oxford, 1972a.
POPPER, K.R. **The Logic of Scientific discovery**. Hutchinson, London, 1972b.

[10] According to Dul and Hak (2008), a theory is defined as a set of propositions about an object of study. Each proposition in the theory consists of concepts and specifications of relations between concepts. Such relations are assumed to be true for the object of study defined in the theory and they can, therefore, be seen as predictions of what will happen in instances of the object of study under certain circumstances. The set of instances to which the predictions apply is called the domain (i.e. the field to which the predictions can be “generalized”).

observed in its natural everyday setting, rather than in laboratory conditions (where the researcher can exercise a great deal of control and manipulate the relevant variables) (GILL; JOHNSON, 2002). In order to enable the investigation of the subjects in their normal everyday environments and preserve aspects of the true experiment logic, alternative research methods such as quasi-experimentation and action research were developed (GILL; JOHNSON, 2002).

The quasi-experiments are often adopted to investigate causal relationships in situations where manipulation of the independent variable and/or the systematic assignation of subjects to control and experimental groups are not ethically or practically feasible (i.e. in cases where the true experiments are not possible). Given these characteristics, quasi-experimentation is a particularly useful approach to research designs aimed at evaluating various types of social policy innovations or reforms (GILL; JOHNSON, 2002).

Particularly in management research, what is often seen as a valuable variant of the quasi-experiment is action research, or, to be more precise, certain forms of action research which entail the hypothetic-deductive approach. In the action research, the researcher acts upon beliefs or theories in order to change the organization and contribute to existing knowledge (GILL; JOHNSON, 2002). According to Rapoport (1970, p. 499)[11] apud Gill and Johnson (2002), 'Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework.' According to Stringer (2007), within business and industry it is now widely recognized that participatory approaches, such as action research, are much more effective ways of accomplishing productive and effective outcomes.

Comparing the nature and the content of the problem to be solved in this research (as well as the extent of the available resources) and the characteristics of the methods previously mentioned, the research method selected to be used in this research is the action research, in the context of the hypothetic-deductive approach. This methodological choice is compatible with the applied and prescriptive characteristics of the research. In this sense, the theory (or the Ecodesign Maturity Model – EcoM2) is initially developed based

[11] RAPOPORT, R.N. Three dilemmas in action research. **Human Relations**, Vol. 23, no. 6, pp. 299-513. 1970.

on a theoretical analysis (which includes a systematic literature review[12] and an evaluation of the first version of the EcoM2 by ecodesign experts) and further improved based on a subsequently action research, in order to incorporate the practical perspective and to improve the EcoM2 based on practice.

The action research is characterized by a problem solving focus and is applicable to understand, plan and implement changes in organizations (COUGHLAN; COGHLAN, 2009). The central idea of the action research methodology is to use a scientific approach to study the resolution of key organizational issues together and with the participation of the people involved with these issues. The main goal of the action research is to make more effective action at the same time that scientific knowledge is created. There are key characteristics that directly influence the development of the action research (COUGHLAN; COGHLAN, 2009):

- Direct action of researchers besides observation;
- Solve a problem and contribute to science;
- Interaction between the researcher and the researched company;
- Development of a holistic knowledge during the project, recognizing its complexity;
- Focus on understanding, planning and implementing organizational changes;
- Understanding the ethical framework, values and norms in the relationship between the company and the researcher;
- Possibility to use several methods to obtain data;
- Prior knowledge of the organizational environment and knowledge on the studied field area as a prerequisite;
- Conduction of the research in real-time;

The desired outcome of an action research goes beyond immediate problems and solutions to include important learning for participants and a contribution to scientific and theoretical knowledge (COUGHLAN; COGHLAN, 2009).

[12] The systematic review is the way by which the researcher can map existing and previous developed knowledge and initiatives in a specific research area. Besides the analysis of previous discovery, techniques, ideas and ways to explore topics, the systematic review also allows the evaluation of the information relevance to the issue, its synthesis and summarization (BIOLCHINI et al., 2005; BRERETON et al., 2007).

According to the ‘pragmatist’ position adopted, the ‘truthfulness’ of any methodologically theory would be ultimately available, or testable, only through practice. Research should proceed at least to identify the practical ramifications of the theory and, ideally, should also proceed to test through practical interventions so to get feedback from the external reality (GILL; JOHNSON, 2002). So, all these considerations regarding the ‘truth’ imply that research should not stop at the presentation of a theory that has been produced and corroborated by the methodologies used to develop it, such as the action research. Although important to the development and further improvement of a theory, the action research cannot be used to theory testing.

In order to test the hypothesis advocated in this research, which can be stated as “the selection of ecodesign practices can be supported by the application of the Ecodesign Maturity Model (EcoM2)”, the “case study for theory-testing” method was selected. According to Einsenhardt (1989), case studies may be used to develop or test a theory. Dul and Hak (2008) argue that case study is actually the preferred research strategy for testing specific types of proposition, if an experiment (i.e. manipulation of aspects of the object of study) is not possible (which is often true in business research).

Defining A as “the application of the EcoM2” and B as “support the selection of ecodesign practices”, the proposition of this research expresses that A is a sufficient condition for B – “If there is A, there must be B” - or “If the EcoM2 is applied, it must support the selection of ecodesign practices to be implemented by the company”. This proposition, that express a sufficient condition, is classified as a deterministic proposition (DUL; HAK, 2008). It means that the application of the EcoM2 at a company will certainly support the selection of ecodesign practices to be applied.

According to Dul and Hak (2008), in cases in which the proposition of a sufficient condition is to be tested (or to be refuted in the case of hypothetic-deductive approach), the preferred research strategy for testing is an experiment and the second best is a single case study. Since it is not possible to test the proposition in a controlled environment for an experiment, the relevance of the development of a single case study as methodology for theory testing was reinforced (DUL; HAK, 2008). In this research, the EcoM2 must be applied in a case and, if it supports the selection of the ecodesign practices, then the hypothesis is not refuted. If not, then the hypothesis is rejected.

However, by means of a single case study a theory cannot be “proven” to be correct. A single study cannot be conclusive neither provide generalization. Nevertheless, it can enhance the validity of the theory (DUL; HAK, 2008).

The degree of confidence that the theory is correct for a specified domain (or its generalizability) can be enhanced by repeated tests of the propositions in different parts of its domain (DUL; HAK, 2008). A failure to find rejections of the hypotheses in many different attempts (replications) provides confidence that the proposition might be generalizable to the theoretical domain, particularly if “least likely” instances are selected for the test (DUL; HAK, 2008). In order to improve the confidence of the generalization of the proposition in the theoretical domain of the research, the EcoM2 will be applied in two case studies for theory-testing.

2.2 Research structure

The research was developed in the context of the hypothetic-deductive approach and divided into four phases (Figure 3). Initially, a literature review was carried out (phase 1) in order to analyze previous knowledge and existing theories on ecodesign and maturity models. The theory formulation, i.e. the development of the Ecodesign Maturity Model (EcoM2), was performed combining the theoretical and empirical approaches in an iterative way. The theoretical approach was adopted (phase 2) to acquire a deep knowledge and understanding about the issue, define the main elements of the model and elaborate the content of the theoretical version of the EcoM2. The main research method adopted in this phase was the systematic literature review combined with the evaluation by a set of experts on ecodesign. In sequence, the improved version of the EcoM2 was further developed following an empirical approach, with the application of the EcoM2 in an action research (phase 3). Finally, in order to perform the test of the hypothesis of the research, i.e. that the EcoM2 could support companies in the selection of ecodesign practices to be applied into the product development and related processes, two case studies for theory-testing (phase 4) were carried out.

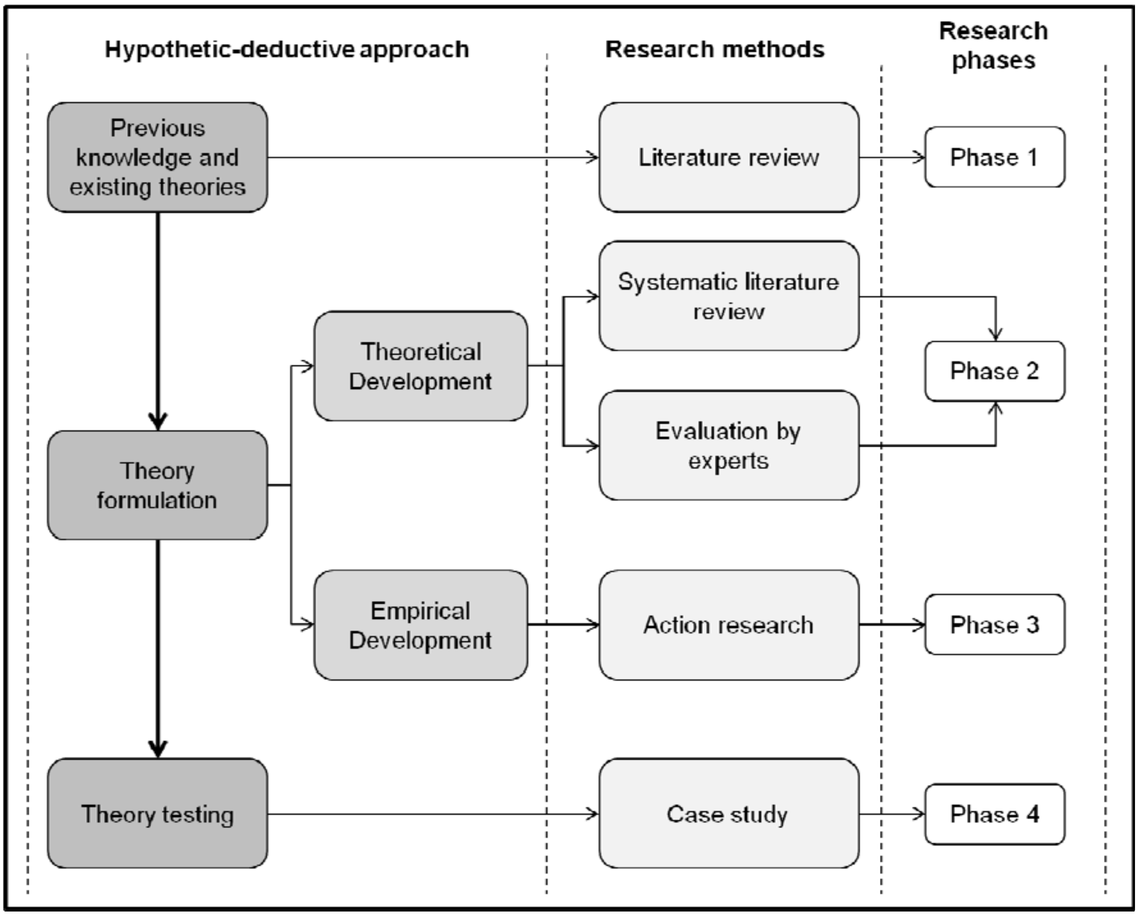

Figure 3: Methodological aspects and phases of the research

The four research phases carried out for the development of the Ecodesign Maturity Model (EcoM2) are presented in the sections 2.2.1 (phase 1), 2.2.2 (phase 2), 2.2.3 (phase 3) and 2.2.4 (phase 4).

2.2.1 Phase 1: Literature review on previous knowledge and existing theories

The first phase of the research aims to provide a theoretical basis for conducting the study and for the development of the Ecodesign Maturity Model (EcoM2). The identification, organization and analysis[13] of the main concepts in the literature related to the research topics are performed. The main activities carried out in this phase are:

[13] According to Lancaster (2005), analyzing data is the process of turning data into information (data which is in a form which can be used for explanation and/or for decision making) that in turn can serve to develop concepts, theories, explanations or understanding.

Activity 1.1: Review the literature on ecodesign

In order to gather knowledge on the ecodesign area, a literature review is carried out on the main topics related to the ecodesign implementation into companies, which includes the relationship between ecodesign and the product development process, the success factors and barriers for ecodesign adoption, the stages for ecodesign implementation and the innovation levels on ecodesign[14]. The results of this activity are presented in section 3.1.

Activity 1.2: Review the literature on maturity models

This activity aims to review the maturity models developed in other knowledge areas, in order to acquire knowledge about the main elements of a maturity model and the way in which they are organized. Additionally, it is explored how these models build up the maturity levels, how they are applied by companies and in which way the process improvement is carried out. In this activity, the most representative maturity models are selected and further studied. The results of this activity are presented in section 3.2.

2.2.2 Phase 2: Theoretical development of the Ecodesign Maturity Model (EcoM2)

The goal of the second phase of the research is to establish the theoretical version of the Ecodesign Maturity Model (EcoM2), based on a systematic literature review and on the evaluation by a set of experts on ecodesign. This section describes the five activities carried out in the second phase of the research in order to theoretically develop the EcoM2.

Activity 2.1: Systematize ecodesign practices

This activity is related to the specific objective of the research stated as "Systematize the ecodesign practices" (see section 1.2). In this activity, the identification, systematization and classification of the ecodesign practices are carried out following the systematic literature review methodology (BIOLCHINI et al., 2005).

[14] Despite the existence of other topics relevant for ecodesign, the scope of the literature review was focused on the ecodesign implementation into companies.

The systematic literature review is the way by which the researcher can map existing and previous developed knowledge and initiatives in a specific research domain. Besides the analysis of previous discovery, techniques, ideas and ways to explore topics, the systematic review also allows the evaluation of the relevance of the information to the issue, its synthesis and summarization (BIOLCHINI et al., 2005; BRERETON et al., 2007). The review is constructed around a central issue that represents the purpose of the investigation, and is expressed by means of specific concepts and terms.

The systematic review model adopted in this research is presented by Biolchini et al. (2005) and comprises three phases, namely: (1) planning, (2) execution, and (3) analysis of the results, as following described:

- (1) planning step: consists of defining the review protocol, which contains the formulation of the problem and the determination of the way in which the data is going to be collected, evaluated, analyzed and interpreted. The review protocol includes also the definition of how the conclusions should be drawn and how the results will be presented. The definition of the review protocol is fundamental to guide the execution and analysis of the systematic literature review (BIOLCHINI et al., 2005).
- (2) execution step: involves the application of the concepts defined in the review protocol, including the initial identification, selection and evaluation of studies according to the inclusion and exclusion criteria previously defined. This step involves the search for studies in databases using the pre-established keywords, as well as the selection of valid studies through the application of the inclusion and exclusion criteria (BIOLCHINI et al., 2005).
- (3) analysis of the results: once the studies have been selected, step (3) involves extracting data from the relevant studies that are pertinent to the objective of the systematic review, using the data representation standards defined in the review protocol and the criteria defined for the classification (BIOLCHINI et al., 2005).

The results of this activity are presented in section 4.2. The section 4.2.1 describes the outcome of the planning step (1), i.e., the review protocol, and is followed by section 4.2.2, that presents the execution step (2). The analysis of the results (3) is discussed in section 4.2.3, which presents the ecodesign practices identified in the review.

Activity 2.2: Develop and characterize the ecodesign maturity levels

This activity is related to the specific objective of the research stated as "Develop and characterize ecodesign maturity levels" (see section 1.2). In this activity, the ways in which companies evolve in ecodesign implementation and the dimensions involved in this process are further explored.

The main research method employed in this activity is the literature review focused on studies that explores cases of ecodesign implementation into companies. The tasks carried out in this activity are:

- Identify the dimensions that influences the ecodesign implementation and select the dimensions to be used to define the ecodesign maturity levels;
- Define and describe the maturity levels of the Ecodesign Maturity Model (EcoM2) based on the selected dimensions.

The results of the activity 2.2 are presented in section 4.3, which is divided in dimensions for ecodesign implementation (section 4.3.1) and description of the ecodesign maturity levels (section 4.3.2).

Activity 2.3: Develop an application method to support EcoM2 application

The activity 2.3 is related to the specific objective of the research stated as "Develop an application method to guide and support the application of the maturity model" (see section 1.2). The goal of this activity is to develop a method for continuous process improvement that can support the application of the Ecodesign Maturity Model (EcoM2) at companies. The main tasks carried out in this activity are:

- Perform a literature review on existing approaches for product development process improvement;
- Select an existing approach for process improvement which can be used to the application of the Ecodesign Maturity Model;
- Define and describe the application method for the EcoM2.

The section 4.4 presents the results of this activity, describing the theoretical version of the EcoM2 application method.

Activity 2.4: Consolidate the theoretical version of the EcoM2

In this activity, the results from all the previous activities of this phase are consolidated. The first theoretical version of the Ecodesign Maturity Model (EcoM2) is developed by establishing a relationship among the ecodesign practices, the maturity levels and the application method.

The main tasks carried out in this activity are:

- Perform a relationship analysis between the ecodesign practices and the ecodesign maturity levels (i.e. classify the ecodesign practices according to the maturity levels defined in the previous task);
- Perform relationship analysis among the application method in relation to the maturity levels and to the ecodesign practices;
- Develop a consolidated description of the theoretical version of the Ecodesign Maturity Model (EcoM2).

The consolidated description of the EcoM2 is presented in section 4.1, which provides an overview of the Ecodesign Maturity Model. In order to avoid repetitions, the description of the ecodesign practices, maturity models and application method are presented in the sections 4.2, 4.3 and 4.4, as previously mentioned.

Activity 2.5: Improvement of the EcoM2 based on the evaluation by experts on ecodesign

In this activity, the first theoretical version of the Ecodesign Maturity Model (EcoM2), obtained as a result of the activity 2.4, is evaluated by a group of experts on ecodesign. The objective is to gather impressions and suggestions for improvements, with emphasis on increasing the validity and the reliability of the Ecodesign Maturity Model (EcoM2) thereby adding to its credibility and acceptability.

The main outcome of this activity is the new version of the Ecodesign Maturity Model (EcoM2), which incorporates the suggestions and feedbacks from the ecodesign experts. In order to carry out the evaluation of the EcoM2 by experts on ecodesign, face-to-face interviews technique supported by semi-structured questionnaires was selected as the research method for collecting data.

Face-to-face interview is recognized as a particularly useful way of collecting data which has the potential for substantial depth and detail, and where the data encompasses complex issues. Additionally, it allows the researcher to provide feedback to respondents immediately upon collecting data. This, in turn, enables the researcher to check the validity and relevance of data as they are collected. Also, the face-to-face interview can enable the researcher to interrogate potentially large numbers of respondents and achieve, if required, a wide coverage (LANCASTER, 2005).

The main tasks carried out in this activity are:

- Planning and conduction of the interviews
    - Determine the data objectives and topics for discussion;
    - Select the ecodesign experts to be consulted by means of a recurrence analysis of the authors with more publications and citations in the ecodesign studies obtained during the systematic literature review (activity 2.1);
    - Contact the experts to be invited to participate on the evaluation of the EcoM2;
    - Perform evaluation with the experts and gather suggestions for improvement of the EcoM2;
- Data analysis and improvement of the EcoM2
    - Systematize the suggestions for improvements;
    - Select the improvements to be incorporated into the EcoM2;
    - Develop the consolidated theoretical version of the EcoM2 based on the incorporation of the selected suggestions for improvement.

The results of the activity 2.5 are presented in section 4.5, which also includes the transcripts of the interviews with the experts and the indication of the points to be improved in the second version. The improved version of the Ecodesign Maturity Model (EcoM2) is presented in section 4.6.

2.2.3 Phase 3: Empirical development of the Ecodesign Maturity Model (EcoM2)

The third phase of the research is chiefly empirical, with the application of the second version of the Ecodesign Maturity Model in an action research. The goal of this phase is to further improve the Ecodesign Maturity Model (EcoM2) based on the practical experience through the real application of the model into a company. As a result of the action research, a third version of the EcoM2 is developed (final version).

The action research methodology employed in this research follows the framework for designing an action research presented by Coughlan and Coghlan (2009) and the framework for carrying out the action research proposed by Coghlan and Brannick (2005)[15] apud Coughlan and Coghlan (2009). The framework is composed by a pre-step (context and purpose) and four basic steps – diagnosing, planning action, taking action and evaluating action. The activities to be carried out in this phase are described as following:

Activity 3.1: Pre-Step – Context and purpose

The pre-step of the action research (context and purpose) involves the following tasks:

- Obtain knowledge about the organization: in order to understand the context in which the company is inserted, general data about the organization and its business are gathered;
- Determine the scope of the action research: it includes definitions on how the action research is going to be carried out and on the main outcomes that the company and the researcher can expect from the action research;
- Gain access at the company: in this task, it is ensured access for the researcher at the company (including access to documents and relevant employees) in order to perform the steps of the action research.

The results of this activity are presented in section 5.1.

Activity 3.2: Perform the action research

The EcoM2 is employed at the company according to the EcoM2 application method, theoretically developed in the phase 2. At each cycle of the action

[15] COGHLAN, D.; BRANNICK, T. **Doing action research in your own organization**. Sage publications, 2005, 157p.

research, the behavior of the model is verified and opportunities for improvements are identified jointly with the company. The action research involves the application of the following steps:

- Diagnosing: is related to the articulation of the theoretical foundations of action and includes data gathering from the organization with a view to making them available for analysis;
- Planning action: in this step, the way in which the action is going to be executed is planned – it includes providing answer to questions such as: "what needs to change?" and "in what parts of the organization?"
- Taking action: involves the implementation of the action in collaboration with relevant key members of the organization – it can extend over one or more design iterations;
- Evaluating action: evaluation involves reflecting on the outcomes of the action and a review of the process. In order to evaluate action, an evaluation questionnaire must be developed, which evaluates the model in its dimensions in a holistic manner.

In order to improve the Ecodesign Maturity Model, the action research is performed in subsequent cycles. Section 5.2 presents the results of the first action research cycle (perform the diagnosis of the current maturity profile). The results of the second action research cycle (define the ecodesign maturity profile) are presented in section 5.3 and is followed by the presentation of the results of the third action research cycle (section 5.4). Section 5.5 presents the improvements performed in the EcoM2 application method during the action research. Finally, the new consolidated version of the Ecodesign Maturity Model (EcoM2) (final version) is presented in section 5.6.

2.2.4 Phase 4: Test of the Ecodesign Maturity Model (EcoM2)

In order to perform the test of the final version of the Ecodesign Maturity Model (EcoM2), the model was applied in two case studies for theory testing in the fourth phase of this research.

As described in section 2.1, the proposition[16] of the research expresses a sufficient condition. It is defined as “If the EcoM2 is applied, it must support the selection of the ecodesign practices to be implemented by the company”. It means that the application of the EcoM2 at a company will certainly support the selection of the most suitable ecodesign practices to be applied.

In this sense, the hypothesis[17] to be tested in the case studies states that, if the Ecodesign Maturity Model (EcoM2) is applied at a company, then it will support the selection of the most suitable ecodesign practices to be applied. In order to compare the prediction expressed in the hypothesis with the facts of the case, they must be measured.

The methodology employed for carrying out the case studies is defined by Dul and Hak (2008). The following activities are involved in this phase:

<u>Activity 4.1: Define candidate cases and case selection</u>

In this activity, the definition of candidate cases is carried out. A candidate case is a member of the domain in which the research is considered applicable (DUL; HAK, 2008).

As presented in section 1.2, the domain in which the Ecodesign Maturity Model (EcoM2) is applicable includes companies that develop products in a structure way, are classified under the Sector C (Manufacturing) of the International Standard Industrial Classification of All Economic Activities (ISIC) (UNITED NATIONS, 2008) and aim to incorporate and/or improve the implementation of ecodesign.

In this activity, two companies are selected for applying the EcoM2 in a case study for theory testing. The description of the companies selected for carrying out the case studies for theory testing is presented in sections 6.1 and 6.2.

<u>Activity 4.2: Conduct the case study</u>

This activity comprises the application of the final version of the Ecodesign Maturity Model (EcoM2) (output of phase 3, after the action research) at the selected case studies for theory testing.

[16] A proposition is defined as a statement about a relation between concepts (DUL; HAK, 2008).

[17] A hypothesis is a statement about a relation between variables in which the variable is a measurable indicator of the concept (DUL; HAK, 2008).

In order to ensure proper application of the EcoM2 at the companies, access and commitment of the company's areas which are essential to the development of the research must be ensured. Additionally, the role that the researcher should play during the development of research must be clearly defined.
The case studies are conducted following the steps, the methodology and the instruments for data gathering defined by the application method of the EcoM2, in order to test it. The results of the case studies are presented in sections 6.1 and 6.2.

<u>Activity 4.3: Analysis of the results</u>

In order to assess if the hypothesis of the research is confirmed or rejected in each case study, the companies should evaluate the model and the relevance of the results obtained with its application, according to the questionnaire developed for the EcoM2 evaluation during the action research.
The results of the case study together with the analysis performed by the companies enable the verification of the confirmation or rejection of the hypothesis advocated in this research in relation to the Ecodesign Maturity Model (EcoM2). The data analysis in the case study research is qualitative, i.e. a non-statistical test of the correctness of the hypothesis is carried out.
The results of this activity are presented in sections 6.1.3 and 6.2.3.

This section described the methodological aspects and the four research phases carried out in the development of the Ecodesign Maturity Model (EcoM2) (Figure 3). In the following sections, the results of each research phase are presented in detail. Section 3 presents the results of the literature review on previous knowledge and existing theories carried out in phase 1. The theoretical development of the EcoM2 (phase 2) is presented in section 4 and is followed by the description of the empirical development of the model (phase 3) in section 5. Section 6 presents the application of the EcoM2 in two case-studies for theory testing. Finally, section 7 presents the conclusions and final remarks.

3 Literature Review

In this section the general literature review carried out in the research phase 1 is presented. The review aims to provide an overview of the main concepts in the literature related to the research topics[18]. This section is divided into two main topics: Ecodesign (section 3.1) and Maturity Models (section 3.2), central themes to this research.

3.1 Ecodesign

The terminology for the concept related to the integration of environmental issues into the product development process considering the whole life cycle of a product has changed over the last decades. The original term, green design was replaced by ecological design, environmentally sensitive design or ecodesign (BREZET; HEMEL, 1997), design for (the) environment (EHRENFELD; HOFFMAN, 1993), life cycle design and environmentally responsible design (DERMODY; HANMER-LLOYD, 1998). Recently, the term Sustainable Design is gaining increasingly importance (PLOUFFE et al., 2011).

Despite slightly differences on the definition of the terms in their origin, today they are recognized as synonymous (POOLE et al., 1999; ISO, 2011). Nearly all processes and approaches related to the integration of environmental considerations into the product development are grouped under the term ecodesign (PLOUFFE et al., 2011)[19].

Ecodesign approaches also changed over the last years in several different ways: “from responding to outside drivers to well understood self-interest”; “from design issues only to design/managerial/stakeholder issues and management in a business context”; “from design rules to contributions to functionality through considering enablers, markets, value chains and system management”; “from

[18]The results of the systematic literature review on the ecodesign practices are presented in section 4, which describes the theoretical development of the Ecodesign Maturity Model (EcoM2) (phase 2 of the research).

[19] Remarkably, the use of the terminology also varies from continent to continent. While the term "design for environment" (DfE) is most used in the United States of America, the term “ecodesign” is most widely adopted in Europe. Differences on the terminology adopted according to the industry sector can also be observed. For example, ecodesign is more used in the electronics industry while DfE is frequent in the aerospace industry.

being environmentally right to getting it environmentally right" (STEVELS, 2007). In this research, the way in which companies evolve in ecodesign implementation and the main influent factors in this evolution are further explored. The next sections presents the relationship among ecodesign and the product development process (section 3.1.1), the success factors and barriers for ecodesign implementation (section 3.1.2), the stages for ecodesign implementation (section 3.1.3) and the innovation level on ecodesign (section 3.1.4).

3.1.1 Ecodesign and the product development process

The product development process[20] is considered a critical business process to increase the competitiveness of companies (ROZENFELD, 2007). Similarly, it is critical for the improvement of the environmental performance of products.

The biggest opportunities for improving the environmental performance of a product (i.e. for ecodesign implementation) are in the early stages of the product development process (PDP), in which the degrees of freedom in the establishment of product characteristics are higher. Estimations indicate that 60 to 80% of the total environmental impact of a product is established in these initial phases (BENEDETTI et al., 2010; RAMANI et al., 2010; KENGPOL; BOONKANIT, 2011). As the features and product details are being determined, the degrees of freedom decrease gradually. In the final stages of the process, the design possibilities for change are minor due to the large number of decisions that were made previously in the process. At this point, the options are limited to environmental improvement of production processes, logistics, recycling, etc. (BHAMRA; EVANS; et al., 1999; JOHANSSON, 2002; NIELSEN WENZEL, 2002; JESWIET; HAUSCHILD, 2005; BYGGETH; HOCHSCHORNER, 2006; LUTTROPP; LAGERSTEDT, 2006; VEZZOLI; MANZINI, 2008).

Eppinger (2011) affirms that the development of products with a higher environmental performance is one of the most fundamental challenges of

[20] Product development is the process of taking a product idea from planning to market launch and review of the product, in which business strategies, marketing considerations, research methods and design aspects are used to take a product to a point of practical use. It includes improvements or modifications to existing products or processes (ISO, 2011).

product design to be overcome in the next years - the imperative of ecodesign must be embraced and design practices must evolve in order to address this challenge.

A company that manages the product development properly and in a structured manner has a greater probability of being successful when integrating ecodesign in product development: most of the factors that foster the successful integration of ecodesign in product development process are the same factors that are recognized as essential to the success of the product development itself (JOHANSSON, 2002).

Moreover, the success of integrating environmental aspects into product design and development in an organization is enhanced by the involvement of relevant disciplines and organizational functions such as design, engineering, marketing, environment, quality, purchasing, service delivery, etc. (ISO, 2002). These disciplines are essential for ecodesign implementation and management and are mentioned in this research as related processes.

Tingstrom and Karlsson (2006) argue that there are two ways to incorporate sustainability[21] in product development:

- Product diversification: development of a line of products with lower environmental impacts, which are provided with conventional products and targeted to consumers with greater environmental awareness;
- Promoting changes in the standard product development process: the company promotes widespread changes in the process by which develops its products such that all products become more sustainable.

As previously mentioned, the focus of this research is on supporting companies in the incorporation of ecodesign into the product development and related processes by supporting the selection of the most suitable ecodesign practices to be implemented. In this sense, the theme “product diversification” is not included in the scope of this research.

The process of ecodesign implementation into the product development process can be initiated either by management (top-down) or by designers and product developers (bottom-up). In practice, both approaches can take place

[21] Although the term sustainability is used by the author, only the environmental aspects are addressed. In this sense, the author is dealing with ways to introduce ecodesign to the PDP.

simultaneously. In any case, the ecodesign implementation must involve the consideration of (ISO, 2002):

- Strategy: the goal of the ecodesign implementation must be addressed within the context of the organization´s existing policies, strategies and structure. It can provide valuable direction to integrate environmental aspects into product design[22] and implementation;
- Communication: internal and external communication is an integral part of ecodesign implementation. Internal communication may include: a) the organization´s policy; b) product related environmental impacts; c) training courses on environmental issues, programs and tools; d) successful projects or products; and e) site specific impacts on the environment. External communication to stakeholders can enhance the value and benefits of ecodesign, including information on product environmental performance and proper use/end-of-life of products;
- Management issues: establishment and maintenance of a basic framework within which the organization operates including the: a) definition of the environmental vision and policy; b) definition of objectives and targets to ensure legal compliance and improve the environmental performance of products; c) allocation of resources; d) assignment of responsibilities, tasks and accountabilities; e) definition, support and monitor of product design and development programs; f) definition and institutionalization of programs for reviewing the product design and development process; g) organization/systematization of environmental functions and processes for product design and development; h) identification of recruitment and training needs for implementing the programs; i) definition of measurement and performance indicators; and j) provision of feedback on environmental performance.
- Product considerations: in order to improve the environmental performance and functionality of products, the following concepts are applied: a) life cycle thinking (consider the environmental impacts

[22] The terms product design and product development are considered synonymous in this thesis and can be used interchangeable.

throughout the product life cycle (Figure 1); b) functionality analysis (thinking in terms of functionality rather than in terms of a specific technical solution); c) multi-criteria concept (in addition to traditional design criteria, the environmental criteria is taken into account); and d) priority setting in order to deal with trade-off decisions. Moreover, it also involves setting strategic product related objectives.

- Product development and design process: introduction of environmental aspects as early as possible in the product design and development process and definition of activities to be included in order to consider the environmental issues:

The integration of environmental aspects into product design and development can be supported by existing management systems, such as ISO 9001, ISO 14001 and ISO 14004 (ISO, 2002). Moreover, ecodesign can provide the link among those management systems (QUELLA; SCHMIDT, 2003). ISO (2011) provides guidelines for addressing ecodesign as part of an environmental management system such as ISO 14001:2004.

Ecodesign integration is achieved in a company when it has developed its own approach to ecodesign, i.e. when the company has modified not only its development process to integrate environmental constraints but also its management processes of decision-making (POCHAT, LE et al., 2007).

3.1.2 Success factors and barriers for ecodesign implementation

In the literature, a set of studies that focus on the identification of success factors and barriers for ecodesign implementation into the product development process can be found. In this section, an overview of these factors and barriers is provided.

Shelton (1995) perfomed four case studies at Xerox, AT&T, IBM and HP and identified four success factors for the implementation of ecodesign:

- it should be organized as a business management issue and be aligned with company culture and organization;
- it should produce more competitive products and be owned by the product management team in each business unit;

- ecodesign programs should start small and expand incrementally (start as a pilot project to generate critical learning about what works and what does not work in the organization);
- the development, integration, and growth of ecodesign varies in the different business units of a company.

According to McAloone (1998), ecodesign should be made into a business issue to ensure its successful integration – the change must happen incrementally and steadily.

Bhamra et al. (1999) and Poole et al. (1999) performed a survey of the Electric and Electronic Industry across Europe and North America and identified a set of success factors that enabled companies to successfully integrate environmental decisions into their product development process:

- Integration of ecodesign into the early stages of the product development process;
- Consideration of ecodesign on an equal balance with all other criteria at all stages of development;
- Inclusion of marketing and development jointly in early design so they understand the need for ecodesign;
- Simply having ecodesign tools available for designers is not sufficient to ensure effective implementation - management procedures are more crucial and tools should be regarded as an aid to management.

Cramer and Stevels (2001) described conditions for ecodesign implementation based on eco-efficiency success cases. These include: 1) organization's culture; 2) profitability and market share; 3) degree of environmental influence exerted by external stakeholders; 4) degrees of freedom for (re)design; and 5) degree to which environmental issues can be used to gain a competitive advantage (CRAMER; STEVELS, 2001).

By means of a literature review, Johansson (2002) identified 20 success factors for the integration of ecodesign into product development. The success factors were classified in six areas:

- 1) Management: the success factors of management are described as a) provision of commitment and support; b) establishment of clear environmental goals; c) consideration of the environmental concerns as business issues (balance environmental considerations and commercial aspects); d) consideration of the operational and strategic dimensions of ecodesign; and e) inclusion of the environmental issues in the company´s technology strategy;

- 2) Customer relationships: it includes the a) adoption of a strong customer focus; and b) provision of training to customers in order to enable understanding about the environmental issues;
- 3) Suppliers relationships: the success factor is related to the establishment of close supplier relationships;
- 4) Development process: it includes the a) consideration of the environmental issues at the very beginning of the product development process; b) integration of the environmental issues into the conventional product development process; c) introduction of environmental checkpoints, reviews and milestone questions into the product development process; d) development and use of company-specific environmental design principles, rules and standards; e) performance of ecodesign in cross-functional teams; and f) use of ecodesign support tools;
- 5) Competence: the success factors embraced in the competence area are a) provision of education and training on ecodesign to the product development personnel; b) provision of support by an environmental specialist on the development activities; and c) utilization of examples of good design solutions;
- 6) Motivation: includes a) establishment of a new mindset emphasizing the importance of the environmental considerations; b) existence of an environmental champion; and c) encouragement of individuals to take an active part in the integration of ecodesign.

Johansson (2002) states that the specific success factors for ecodesign integration into PDP are related to competence and motivation. In this sense, professionals (particularly senior management) need to be aware of the relationship between the company's operation and the associated environmental impacts. More specifically, the professionals directly involved with product development have to be trained in the methods and tools for ecodesign (JOHANSSON, 2002).

Maxwell and Vorst (2003) developed a Sustainable Product and Service Development (SPSD)[23] method to support the development of sustainable products and/or services. Key features as essential framework conditions for ensuring effective SPSD implementation in industry are provided:

- Use of a strategy level approach, which is integrated into existing corporate business, sustainability/environmental systems and product development systems;
- Use of a simple, flexible and non-resource intensive approach that is designed to mesh with the business reality;
- Integration and optimization of Triple Bottom Line (TBL) criteria with traditional product and service specifications over the entire product life cycle;
- Determination of the requirement for a product based on the functionality and consideration of the options for PSS (Product-Service System);
- Focus on the supply chain.

In order to identify which are the social, psychological and intangible processes related to ecodesign implementation, Boks (2006) performed a literature review on ecodesign success factors (Table 1) and barriers for ecodesign implementation (Table 2). The success factors and barriers are classified in two areas:

- Relevance for dissemination of ecodesign information to appropriate people in appropriate departments; and
- Relevance for ecodesign principles materializing in products brought on market.

The success factors and barriers were submitted to a survey on Asian electronics multinationals, in order to obtain a ranking on the most important success factors and barriers for these companies. The paper concludes that the highest importance in relation to success factors is attributed to more

[23] The key features identified are also applicable to the implementation of ecodesign, since the experiences adopted by the paper came from the ecodesign field itself.

conventional business aspects (such as customized ecodesign tailor made for companies´ needs and good management commitment and support). Regarding barriers, however, the most important ones appear to reflect more social issues (such as lack of cooperation between departments and non-demand from the market) (BOKS, 2006).

Table 1: Ecodesign success factors (BOKS, 2006)

	Success factors
Relevance for dissemination of ecodesign information to appropriate people in appropriate departments	Customized ecodesign tools tailored for company's needs
	Good contacts between departments about environmental issues
	Good international network
	Good management commitment and support
	Clear environmental goals and vision
	Alignment of operational and strategic dimensions
	Presence of a so-called 'environmental champion'
	Use of environmental checkpoints, reviews, milestones and roadmaps
	Cross-functional teamwork
	Environmental design guidelines, rules and standards that are very specific to a company
Relevance for ecodesign principles materializing in products brought on market	Market research
	Ecodesign considerations early in the PDP
	Inclusion of environmental issues in our company's technology strategy
	Adopting a strong consumer focus, good market research
	Goals & targets at managerial level
	Training consumers and customers in environmental issues
	Good involvement of supplier expertise in PDP
	Environmental issues play a role in all business activities
	Good environmental education and training programs for all product development personnel
	Make good use of examples of good design solutions, also from other companies
	Use of environmental checkpoints, reviews, milestones and roadmaps
	Presence of a so-called 'environmental champion'
	Cross-functional teamwork
	Environmental design guidelines, rules and standards that are very specific to the company
	Follow up studies; learn from previous experiences on a systematic way

Table 2: Ecodesign barriers (BOKS, 2006)

	Barriers
Relevance for dissemination of ecodesign information to appropriate people in appropriate departments	Lack of industrial context in general/not connecting environmental with business considerations
	Organizational complexities, lack of appropriate infrastructure
	Lack of cooperation between departments
	Too big a ‘gap’ between ecodesign proponents and those that have to execute it
	Lack of management commitment and support
	Lack of environmental goals and vision for the development organization as a whole
	Available tools are too complex
Relevance for ecodesign principles materializing in products brought on market	A lack of life-cycle thinking
	Organizational complexities
	Lack of innovative thinking
	Lack of testing
	Lack of experience
	Lack of appropriate marketing studies
	Issues too much material-related
	Issues too much addressed in terms of end-of-life or recyclability
	Too little involvement of sales and marketing departments
	Supply chain problems
	Not enough legislative incentives
	No demand from the market
	Lack of time/too time-consuming
	Lack of environmental goals and vision for individual development project
	Lack of follow-up of projects
	Lack of (quality of) data

Communication is also recognized as an important issue to be considered for ecodesign implementation. Boks and Stevels (2007) performed a literature research on criteria and enablers for improving the implementation of ecodesign through improving communication. The results indicate a) an excessive focus on complex tools and methods and lack of testing in practice; b) a lack of life-cycle thinking; c) a weak cooperation between actors and a lack of communication, exchange of experience and mutual knowledge sharing; d) lack of clear target groups and the (industrial) context in which ecodesign activities are or should be embedded (BOKS; STEVELS, 2007).

Murillo-Luna et al. (2011) executed a comprehensive study with 240 Spanish companies to identify the barriers to environmental adaptation in organizations. They are divided in internal and external barriers:

Internal barriers

- Budgetary and organizational limitations;
- Limited environmental motivation and preparation of the employees;
- Aversion to innovation and technological change;
- Operational inertia.

External barriers

- Scarcity of information and lack of clarity on environmental legislation;
- Rigidity of legislation and bureaucratic complexity;
- Limited development of the environmental supply sector;
- High cost of environmental services/technologies;
- Difficulties derived from competitive pressure.

The study concludes that although external barriers make environmental process difficult, internal barriers are what basically prevent the application of advanced measures to protect the environment (MURILLO-LUNA et al., 2011).

3.1.3 Stages for ecodesign implementation

In this section, the evolutionary stages described in the literature for ecodesign implementation into the organizational and business processes are presented.

Someren (1995) presents a staged model for the integration of ecological aspects (or ecodesign) into business strategy. In each stage a higher level of ecological management is achieved. It is composed by 3 successive stages:

- Defensive: ecological management is ad hoc and not an important issue in the company´s strategy, dealing only with legal compliance. Environmental issues are considered as an external factor. Technical measures are dominant;
- Offensive: environmental issues are more integrated into the business practice, but cost considerations are still regarded as most important. Knowledge is systematically gathered and diffused within the firm.

Organizational measures gains importance, but the existing organizational corporate structures are maintained;

- Innovative: environment becomes a part of the company´s strategy.

The author emphasizes the limitations of the model regarding the lack of a consistent explanation for the changes in each phase, the possibility of a company being classified in more than one stage at the same time and the lack of an economic explanation (SOMEREN, 1995).

Shelton (1995) defines 5 stages for the implementation of ecodesign, with differing organizational characteristics and location requirements:

- Corporate-oriented
    - 1. Getting a "big picture" perspective: it includes the assessment of the potential threats and opportunities and the definition of the scope needed to meet the company´s requirements for the ecodesign initiative. Moreover, it involves a cross-functional team and all relevant business units inside an organization;
    - 2. Devising corporate guidelines: it requires a focus on developing policy and organizational options for the whole company, including compliance issues. The guidelines require implementation at the operational levels and must be developed by cross-functional teams.
- Product-oriented: focus on a selected product or a set of products. It must deal with the technical and market specifics:
    - 3. Protecting mature products: make low-cost mitigation efforts such as minor tweaks to construction materials, manufacturing processes, and product specifications aimed at protecting market share;
    - 4. Rejuvenating existing products with growth potential: perform incremental changes in the product by multi-functional teams;
    - 5. Commercializing new products: the potential to innovate is maximized and the team must work in detail in the process, product, customer and competitors.

McAloone (1998) proposed a three stage model to represent the complex organizational changes that companies go through when integrating environmental criteria into their designs (Figure 4). According to the author, the model can be used by organizations to map their own ecodesign maturity and to get suggestions in regards to directions for improvement. The following stages can be distinguished:

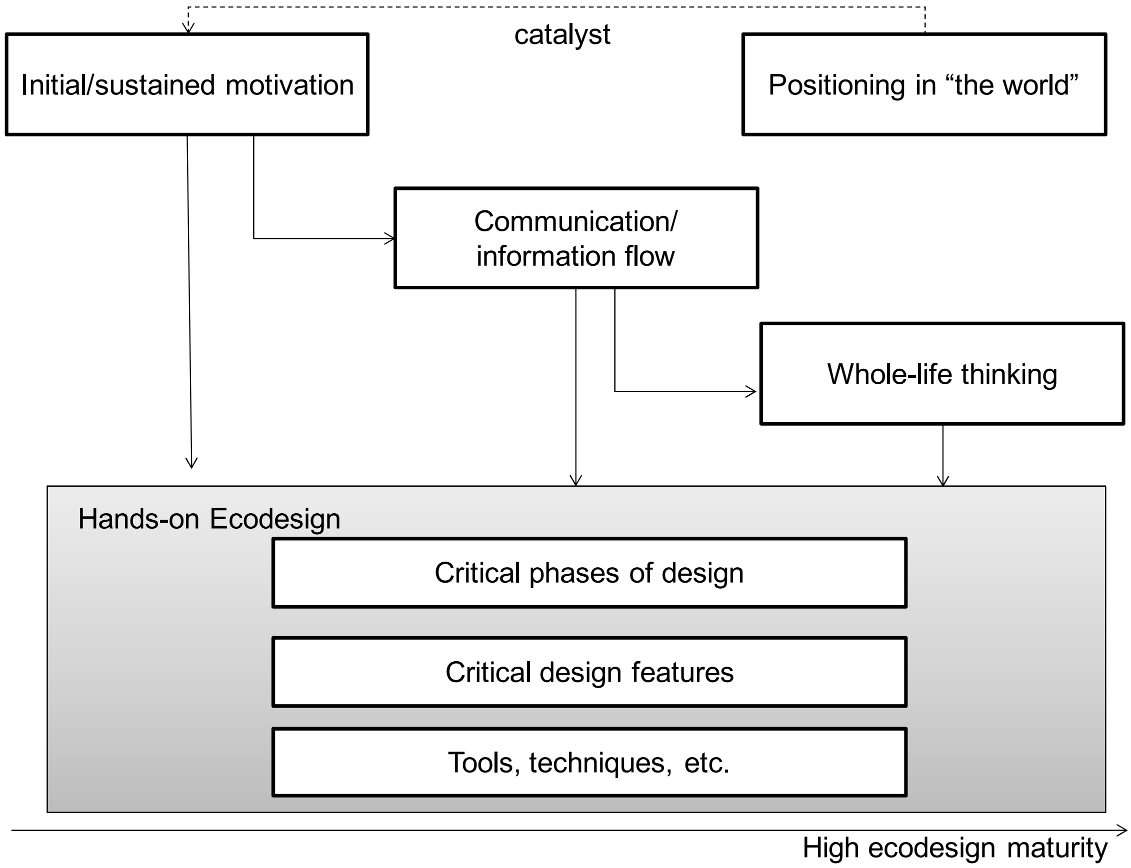

Figure 4: Model of ecodesign integration (adapted from McAloone (1998))

- "Initial/sustained motivation": this stage is often related to a single external demand, such as legislation or competitor product (reactive posture). The "Positioning in the world" acts as a catalyst for initial/sustained motivation. Progress to sustained motivation requires significant top management understanding and commitment;
- "Communication/ information flow", the second stage is characterized by increasingly wider involvement of departments into the ecodesign process. The company is improving its knowledge of ecodesign by means of training, provision of specific information, communication of the environmental goals to the stakeholders, etc. During the second stage, sufficient knowledge and experience to achieve the third stage, "Whole-life thinking", is built up;

- “Whole-life thinking”: in this stage, the motivation towards ecodesign at the company is high and widespread. Increasing understanding of the trade-offs between different product life-cycles phases can be observed and confidence on how to deliver is improved. Whole-life thinking requires high levels of communication and information flow between the various parts of the company and also commitment from the management chain.

The latter stage (“Whole-life thinking), however, is not static. The company needs to continually improve its environmental performance based on “Hands-on Ecodesign”, which comprehends three factors (MCALOONE, 1998):

(1) Critical phases of design (related to timing and scheduling of ecodesign decisions and actions into the PDP – the earlier, the better);
(2) Critical design features (includes desired environmental features of the product, such as easy identification of different materials); and
(3) Tools and techniques (in order to support the integration of environmental considerations during the PDP).

The model proposed by McAloone (1998) proposes a relationship between the elements of a physical design process (“hands-on ecodesign”) and the elements of a change process. The author reinforces, however, that the change process is of greater concern to industry.

McAloone (1998) claims that the ecodesign maturity can be improved as a company moves from simply designing considering single issue activities by improving certain aspects of their products (such as energy efficiency), to:

(1) being motivated to develop products with significantly increased environmental performance;
(2) realizing the opportunities of ecodesign implementation;
(3) learning how to develop and communicate environmentally conscious design ideas; and
(4) taking a whole-life view of its products.

Companies typically start ecodesign implementation by making single issue improvements to their designs. Slowly, the companies develop more sophisticated tools and techniques for integrating environmental criteria into their designs (MCALOONE, 1998).

Charter (2001) proposed a seven-stage model for the organizational implementation of ecodesign. The stages proposed by the author are:

- Ignorance in ecodesign: the company is not familiar with ecodesign issues;
- Starter in ecodesign: the environmental manager is in the process of selling the internal business benefits and opportunities with the adoption of ecodesign in the company;
- Project research and development (R&D) green: a "green" pilot project is being developed in R&D;
- Technical integration: the environmental criteria is being incorporated into engineering procedures;
- Semi-integration of ecodesign: the company has integrated environmental issues from idea generation and throughout the product development process in a business unit or for a family of products;
- Full integration of ecodesign: the company has integrated environmental issues from idea generation and throughout the development process of all products and services developed by the organization;
- Green strategy: the business has incorporated environmental research opportunities in corporate strategies and business.

In order to analyze which are the levels of performance of the ecodesign application in companies, Pascual et al. (2003) performed a study on the environmental reports and corporate websites of electronics companies. The following criteria were explored: clamming to use ecodesign, examples of ecodesigned products and managerial elements of the ecodesign process. Based on the assessment, 6 groups of companies were identified:

- *Group 1 – Relatively mature organizations*: the company is known as pioneer on ecodesign implementation, usually working closely with universities in the development of methodologies and tools. The company claims to use ecodesign in their product development process and shows examples of ecodesigned products launched to the market. A managerial system that helps them to define their environmental strategy (set-up quantitative targets related to ecodesign of products) is in place;

- *Group 2 – On their way to maturity*: Companies that claim to use ecodesign in their product development process, show examples and set up qualitative targets related to ecodesign products. This gives an indication that the organization is proactive on the ecodesign field, and that ecodesign is relevant on the overall strategy of the organization. Nevertheless, the qualitative targets give an indication of intentions, without compromising themselves to achieve a quantitative goal.
- *Group 3 – First movements*: Companies that claim to use ecodesign in their product development process, show examples of ecodesigned products, but do not publish/claim to set up targets (of any kind). There are not evidences of self-compromising themselves to a continual improvement of their product´s environmental performance, neither to increase the rate of ecodesigned products. It seems that ecodesign is not included on the overall strategy of the organization, due to the lack of targets and goals related to ecodesign of products;
- *Group 4 – Starters with good intent*: Companies that claim to use ecodesign in their product development process and set up qualitative targets, but do not publish examples. The company is starting the ecodesign adoption, there is not enough expertise on the organization to launch or demonstrate that they applied ecodesign and as starting point, they define qualitative targets.
- *Group 5 – Basically publicity driven*: Companies that claim to use ecodesign in their product development process, but do not publish examples or set up targets. The advantage for organizations under this cluster is to use environment as a marketing strategy in order to appeal customer´s sensitivity towards issues like environment, but it is doubtful that the organization spends resources on ecodesign.
- *Group 6 – Not published/not interested*: Companies that do not publish/claim to use ecodesign.

Based on the analysis obtained in the aforementioned study, Pascual et al. (2003) propose two levels of implementation (or maturity) of ecodesign in the product development process in respect to managerial aspects:

- Ecodesign Rules Level: in this level, the most popular elements of ecodesign (such as manuals, tools, methods and training programs to understand the benefits of ecodesign) can be observed. Pilot projects are developed by the organization to consider whether ecodesign really works and to understand the advantages that its application can bring. Most organizations are in this category;
- Ecodesign Management and Integration Level: the application of ecodesign is performed in a daily basis. Personal knowledge about ecodesign, the use of more sophisticated tools (such as software), and environmental programs are established. Subsequently, quantitative and qualitative goals are defined. Ecodesign is considered together with other areas of the company and is integrated in the daily activities.

Alakeson and Sherwin (2004) define four stages for integrating sustainable development into innovation:

- Single issue: addresses specific sustainability issues, but no systematic way of addressing the full range of economic, environmental and social impacts can be observed;
- Ad hoc: takes sustainable development into consideration, but no formal tools or processes to ensure the consistency of the approach are in place;
- Sustainability tools: develops tools to integrate social, environmental and economic issues in a consistent manner;
- Strategic consideration: sustainable development itself provides the framework for innovation.

Willard (2005) defines five stages of sustainability integration into an organization:

- Pre-compliance: the company ignores sustainability and is opposed to the related regulations;
- Compliance: the company obey laws and regulations on labor, environment, health and safety;
- Beyond compliance: the company recognizes the opportunity to cut costs mainly through higher resource efficiencies and reduction of waste,

leading to financial and ecological gains. Sustainability is still separated from the core business development;

- Integrated strategy: sustainability strategy is integrated in the company´s vision. The company informs key business strategies to be more successful than competitors through innovation, design, and improved financial risks assessment;
- Purpose and passion: it is a special kind of companies, being originally designed to “help saving the world”.

Philips developed an Ecodesign Maturity Grid to measure the performance on the implementation of an ecodesign procedure into the product creation process (Table 3) (DE CALUWE, 2004). The use of the Maturity Grids and the link to ecodesign procedures within the existing business processes aims to ensure that improving the environmental performance of products is part of the Philips way of working (DE CALUWE, 2004).

The Ecodesign Maturity Grid was used by Philips in the context of the environmental action program EcoVision II, from 2002 to 2005. The mandatory target to be achieved was level 6 on the maturity grid, while the recommended target was level 8 (PHILIPS, 2005). However, as published in the 2005 Sustainability Report, those targets were not realized, and the explanation is that “this parameter is not reported at Philips Group level” (PHILIPS, 2005). The EcoVision III (2006 – 2009) program did not consider the maturity grid anymore as a performance indicator, as it can be observed in the 2009 annual report (PHILIPS, 2009).

The reasons for the failure of the application of the Ecodesign Maturity Grid at Philips could not be identified in the literature, but the following aspects may have contributed to that: (1) existence of several different maturity levels without a clear distinction on how the assessment and classification into a given level should be performed; (2) the maturity evaluation is focused on departments rather than on organizational processes (such as the product development process); (3) there is a lack of a clear visualization of the current maturity level and what it means; (4) there are no background data in the maturity grid which could support the ecodesign application and the accomplishment of higher maturity levels; and (5) there is not a clear continuous improvement approach to

Table 3: Ecodesign Maturity Grid (DE CALUWE, 2004)

0	The development department delivers products without attention to their environmental consequences; no programs or tools exist to address this issue				
1	Environmental issues are taken into account only incidentally and mainly driven by individual initiatives. Environmental risks to the business are not identified or assessed. There are first signs of methods and tools; remedial features are introduced to correct unwanted environmental effects.				
2	An ecodesign procedure including mandatory environmental requirements is available in the development center. The development center's product creation process refers to this ecodesign procedure	Integrating ecodesign procedure and product creation process			
3	The available ecodesign procedure covers all elements of the framework for ecodesign procedures and is used in some projects. A management system (like ISO 14001/9001/other) is in place in the design center.		Secure procedure in systems		
4	The ecodesign procedure is used in many projects. The ecodesign procedure is integrated in the management system (like ISO 14001/9001/other). Environmental roadmaps (or environmental targets/improvement trends in technology roadmaps authorized by management of the design center) are available in the design center			Target setting in environmental roadmaps	
5	A mandatory ecodesign procedure is in place in the design center. The ecodesign procedure is used in most projects. An annual internal auditing process covers the ecodesign procedure. This maturity grid is off-line included as an extra element in the process survey tool of the design center.				Monitoring with performance indicators
6	The ecodesign procedure is used in all projects. Environmental roadmaps are used as input for target setting in the ecodesign procedure. Environmental roadmaps are update annually. This update process is integrated in the management system (like ISO 14001/9001/other). The maturity grid "ecodesign in the product creation process" is included as extra element in the process survey tool of the design center. The reached level of maturity grid element "ecodesign in product creation process" is part of annual Business Review.				
7	The development center's management system (like ISO 14001/9001) is certified externally. Targets/improvement trends in environmental roadmaps are based on environmental performance benchmarks with competitor or predecessor products/technologies				
8	An annual external auditing process covers the ecodesign procedure. Several objectives in environmental roadmaps are set to surpass environmental performance of competitor products. Development projects are started to reach those objectives. The grid level is reported in BEST Society Results.				
9	The position in the top 5 among competitors is confirmed by external reports, activities or prizes obtained for many key products that excel on environmental performance. The organization knows what steps have to be taken to reach the top position among competitors. Plans are ready and in place to reach that position.				
10	Recognition by competitors and other for best practices. Self-learning organization focused on sustained business excellence, fully integrated with partners.				

be followed towards higher maturity levels. Although, the Philips Ecodesign Maturity Grid brings some positive elements that can be incorporated into the Ecodesign Maturity Model (EcoM2), such as the definition of dimensions for ecodesign maturity and capability assessments.

Boks and Stevels (2007) present three maturity levels of environmental awareness:

- Level 1: relatively ignorant: the company need to be introduced and/or convinced, did perhaps some initial projects;
- Level 2: the company have been introduced, are moving forward with environmental issues, but still deal with some elementary problems;
- Level 3: the company has all procedures in place, has considerable experience, but has recurring problems with embedding environmental issues into the organization and its value chain.

According to the authors, the way any meaningful information (any type of consolidated information, i.e., principles, checklists, guidelines, examples of best practices, tools, databases and management systems) needs to be offered depends greatly on the level of sophistication - the higher the level of maturity in environmental awareness, the more customized consolidated information will have to be (Table 4) (BOKS; STEVELS, 2007).

Table 4: Maturity levels of environmental awareness (BOKS; STEVELS, 2007)

Maturity Level of Awareness	People involved	Level of generalness	Typically necessary communication tools
Level 1	Personal to department level	Generic solutions and understanding	General principles, slogans
Level 2	Department to company level	Solutions and understanding tailor-made to the industry	Checklists, guidelines, examples of best practices
Level 3	Company to chain level	Solutions and understanding tailor-made to products and processes	Customized tools, databases, including information of the company´s internal and external value chain, experience

Boks and Stevels (2007) also classify companies in five clusters according to the strategic ecodesign adoption:

1. 'Value' companies: companies interested in superior environmental performance as part of many aspects in which they want to be superior. It could be that their strategy is one of risk management, avoiding bad press, while at the same time trying to maintain a high level of environmental performance. Those companies are characterized by a pro-active behavior towards environmental legislation, teaming up in branch organizations and active lobbying;
2. Defensive strategies: companies with aggressive marketing and pricing strategies and less fundamental research. Those companies are less proactive towards cooperation, sign agreements late, etc;
3. Niche players: companies that operate in limited market segments, for example selling only high-end products. Those companies have a very strong value proposition to customers, and their strategy is likely to avoid interference between environmental issues and their main value propositions;
4. Manufacturers with little visibility in the international press: companies that address environmental issues only in terms of regulatory requirements. Price fighting rather than superior quality is the business they are in;
5. 'Low visibility giants': companies that extensively manufacture (and design) electronics products, mainly as outsourced manufacturing for value companies in particular. Their role is very interesting because it is potentially very powerful. A variation of this cluster includes companies that manufacture subassemblies and components for application in products for worldwide brands.

Murillo-Luna (2011) defines four proactivity levels of strategic environmental behaviors and provides a list of environmental practices associated with each level:

Level 1: Passive strategy

- The environmental objective is not currently pursued by the company;

- The company hardly dedicates any time/financial resources to environmental protection;
- The company does not adopt any kind of technical/organizational environmental protection measure;
- The company does not plan on obtaining environmental certifications;
- The company does not have a person responsible for dealing with environmental matters.

Level 2: Attention to legislation strategy

- The environmental objective of the company only consists of complying with legislation on environmental matters;
- The company only dedicates the time and financial resources necessary to environmental protection in order to comply with legislation;
- The environmental measures adopted by the company have not involved any significant change in production and work methods or in the organizational structure;
- The environmental measures adopted by the company are not certified;
- The environmental matters of the company are resolved by external professionals and/or by internal personnel who are not exclusively dedicated to the environment.

Level 3: Attention to stakeholder's strategy

- The environmental objective of the company is not just limited to complying with legislation on the environment, but rather attends to the environmental requirements of stakeholders (such as customers and suppliers);
- The company dedicates the necessary time and resources to environmental protection in order to comply with legislation and, furthermore, in order to attend to environmental pressures from other internal and external agents;
- The environmental measures adopted by the company have required modification of production and work methods and/or organizational structure;
- Some of the environmental measures adopted by the company are certified or are in the process of being certified;

- The company regularly requests the services of external professionals specialized in environmental matters and/or has qualified internal personnel to take care of these matters.

Level 4: Total environmental quality strategy

- The environmental objective is one of the priority objectives of the company;
- The company dedicates important budgets to environmental protection for reasons that go beyond complying with legislation and attending to pressures from other stakeholders;
- The environmental measures adopted by the company are highly relevant to conditioning both production processes and organizational structure and how work is performed at the company;
- The environmental measures adopted by the company are certified;
- The responsibility for environmental matters is clearly assigned to one or various persons of the company who are specialized in this matter and/or to a department.

According to Ramani et al. (2010), the environmental performance of products depends on the level of ecodesign implementation by the company - most of the levels of ecodesign have to be set up before companies start to implement their own ecodesign.

3.1.4 Innovation level on ecodesign

In this section, the different innovation levels that can be achieved when implementing ecodesign into the product development and related processes are presented. In ecodesign literature, innovations are often divided into categories referring to their potential for achieving environmental benefits (SANDSTRÖM; TINGSTRÖM, 2008).

Based on industry practice, Brezet and van Hemel (1997) presented a hierarchy to classify ecodesign innovations in the following four categories:

- Product improvement: small adjustments are made in the products and production techniques, such as replacement of existing materials or adoption of pollution control equipment;
- Product redesign: the general concept of the product remains the same, but parts of the product are better developed or replaced by others. The focus of innovation should be on increasing the use of non-toxic materials and on the minimization of energy consumption over the life cycle phases of the product;
- Function innovation: involves changes in how the product functions are obtained. New and different concepts with less environmental impact replace existing products;
- System innovation: refers to new products and services that require changes in infrastructure and other systems that are related to product use.

Charter and Chick (1997) propose a four-step model of ecodesign innovation with different types of innovation. As ecodesign practices move through the innovation steps, environmental improvement are increased along with the time and efforts needed to do so:

- Re-pair existing products: implies in minor alterations to existing products or substitution of components. This approach is reactive and deals with single environmental issues;
- Re-fine: comprehends the redesign of the product itself. Redesign may include the use of a more environmentally sensitive material or the extension of the product lifetime;
- Re-design: the lifecycle perspective is adopted, aiming to reduce the impacts across all the lifecycle stages (material extraction, production, use and disposal). Products may be significantly redesigned or new product concepts developed.
- Re-think: products and perhaps even the companies´ core business are reconsidered, exploring completely new ways to satisfy customer needs and design concepts such as services or dematerialization.

According to Stevels (1997), there are four levels for the integration of the environmental considerations into the product development process:

- Level 1: incremental improvement of the product;
- Level 2: redesign of existing products (the concepts are environmentally improved up to the limits which physics, chemistry and electronics allow);
- Level 3: functionality is fulfilled in an alternative manner (new concepts are created);
- Level 4: functionality concepts are conceived so as to fit completely into a sustainable society.

According to Vezzoli and Manzini (2008) there are four basic levels of environmental intervention in product design:

- Redesign of environmental systems (choosing materials and energy sources with low environmental impact);
- Design of new products and services (replacing the old systems for new ones with better environmental sustainability);
- Design of new production and consumption systems (offering intrinsically sustainable solutions);
- Creation of new scenarios for a sustainable lifestyle.

Leitner et al. (2010) defines 4 levels of ecodesign, from incremental to radical innovation processes:

- (L1) - Incremental improvements: comprehends incremental or small, progressive improvements to existing products that are mainly based on common sense or check lists;
- (L2) - Re-design or ‘‘Green-limits’’: consists of major re-design of existing products, limited by the level of improvement that is technically feasible;
- (L3a) - Functional or ‘‘Product’’ Alternatives that lead to ‘‘Green’’ Innovation: includes new product or service alternatives based on life cycle assessment (LCA) and life cycle cash flow analysis (LCFA) for alternative products systems, also identifying weaknesses in the infrastructure of society;

- (L3b) - Design for the sustainable society that leads to ‘‘Green-System’’ Innovation: functionality completely fitting into sustainable society based on LCA and scenarios of alternative infrastructures of the societies.

The ecodesign levels are furthermore compared against each other in a qualitative way according to 6 criteria (time horizon, degree of regulation, risk and uncertainty, return possibility and complexity) (Table 5).

Table 5: Characteristics of the levels of change (LEITNER et al., 2010)

	Time horizon	Degree of regulation	Risk and uncertainty	Investment	Return possibility	Complexity
L1	0-2 years	N/A	N/A	N/A	+	N/A
L2	0-5 years	+	N/A	+	++	+
L3	0-10 years	+++	+++	++	+++	+++
L4	0-30 years	++++	+++	++++	++++	++++

Ehrlenspiel (1995)[24] apud Ernzer et al. (2005) affirm that two thirds of product development activities undertaken by enterprises consist of improvements of existing products. Even companies that successfully introduce radical innovation may not do so very often. Furthermore, radical innovation is increasingly becoming a necessity for companies, not only from an environmental, but also from an economical point of view (UNEP; DELFT UNIVERSITY OF TECHNOLOGY, 2009).

The choices regarding the level of integration of environmental considerations should be made according to the level of environmental innovation (eco-innovation) required by the company (CHARTER; TISCHNER, 2001). According to Sandström and Tingström (2008), ecodesign maturity is one factor affecting a company´s ability to perform radical innovation while taking environmental consideration into account. Thus, according to Ernzer et al. (2005) startups in ecodesign focus their activities on the redesign of existing products.

3.2 Maturity Models

This section presents the conceptual description of maturity models (section 3.2.1) and describes the selected maturity models presented in the literature (section 3.2.2).

[24] EHRLENSPIEL K., **Integrierte Produktentwicklung: Methoden für Prozessorganisation, Produkterstellung und Konstruktion**, München, Wien, Hanser Verlag, 1995.

3.2.1 Conceptual description

A maturity model is a conceptual framework made up of parts that define maturity in a particular area of interest. In some cases, the maturity model can also describe a process in which the organization can develop or achieve something desirable, such as a set of capabilities or practices. This process can result in a more developed organizational state or, in other words, into a more mature organization (PMI, 2003).

Kohlegger et al. (2009) define maturity model as:

> *"A maturity model conceptually represents phases of increasing quantitative or qualitative capability changes of a maturing element in order to assess its advances with respect to defined focus areas"* - (KOHLEGGER et al., 2009)

The maturity models aim to support companies´ interventions into making changes in maturity of maturing elements in a more effective or efficient way (KOHLEGGER et al., 2009). A common principle of maturity models is to represent maturity as a number of cumulative stages, where higher stages build on the requirements of lower stages (MAIER et al., 2010).
Essentially, the maturity models describe the development of a particular area of interest (a human being, an organizational role, etc.) over time. The maturity models usually present the following properties (KLIMKO, 2001):

- The development path is simplified and described by a limited number of maturity levels (usually 4 to 6);
- The levels are characterized by certain requirements to be met;
- The levels are ordered sequentially from an initial to an end level (the latter is the level of perfection).

Maturity models can be used to evaluate specific business processes in relation to an evolving scale of less structured processes (lower level of maturity) to better managed processes (higher level of maturity) (ZANCUL, 2009).
The maturity models can be used for three main purposes (IVERSEN et al., 1999; JESTON; NELIS, 2006; PÖPPELBUS; RÖGLINGER, 2011):

- As a descriptive tool that allows an assessment of strengths and weaknesses of the company (“as-is” assessments);
- As a prescriptive tool that enables the development of a roadmap for improvement (“to-be” maturity);
- As a comparative tool that enables the evaluation of the company compared to standards and best practices of other organizations (or a benchmarking tool).

Ofner et al. (2009) recommend to divide maturity models into domain reference models (i.e., the domain or scope that is assessed) and assessment models (i.e., how maturity levels are assigned to particular elements of the domain reference model based on the diagnosis of the current situation). The result of the assessment models (or of the diagnosis of the current situation) may lead the organization to plan improvements, to repeat the evaluation or to complete the process (PMI, 2003). The main value of a maturity assessment is to capture a companies’ own perception of the current situation on a given area of analysis (MAIER et al., 2010).

The obvious advantage of the maturity models is the simplicity that enables ease of understanding and communication. On the other hand, simplicity can often lead to discussions about the validity of the models developed. The main criticisms regarding maturity models are:

- Lack of description of how to perform improvement projects, once identified the current maturity level and improvement opportunities (PFEFFER; SUTTON, 1999);
- Excessive emphasis on the process perspective rather than on people and capacities (BACH, 1994);
- Strong focus on the formalization of improvement activities accompanied by extensive bureaucracy that can prevent people from being innovative (HERBSLEB; GOLDENSON, 1996);
- Downgrading of the model due to new growth scenarios (KLIMKO, 2001);
- Poor theoretical basis: most models are based on "best practices" or "success factors" derived from projects that have shown favorable results to a specific organization or industry sector (BACH, 1994; BIBEROGLU; HADDAD, 2002)

- There is no agreement on a "one true way" to ensure a positive outcome (MONTOYA-WEISS; CALANTONE, 1994);
- The information produced by the assessment may be insufficient to plan and implement improvements (IVERSEN et al., 1999);
- Insufficient emphasis on tests of the models in terms of reliability, validity and generalization and little documentation on how to design and develop such a model (BRUIN; ROSEMANN, 2005).

The application areas of maturity models are wide spread and range from cognitive science to business applications and engineering (KOHLEGGER et al., 2009; PÖPPELBUS; RÖGLINGER, 2011). Tis probably rooted in the high importance of process orientation and continuous process improvements for organizational design (WOLF; HARMON, 2010).

3.2.2 Existing maturity models

This sub-section presents two maturity models described in the literature: Capability Maturity Model Integration for Development (CMMI-dev) (section 3.2.2.1) and Organization Project Management Maturity Model (OPM3) (section 3.2.2.2). These maturity models were selected based on the relevance to the field of this research; their international recognition and application in worldwide companies; and their level of consolidation and completeness.

The models were evaluated using the roadmap for maturity grid[25] development and evaluation proposed by Maier et al. (2010). The roadmap is composed by four phases: (1) Planning; (2) Development; (3) Evaluation; and (4) Maintenance (Figure 5). In order to provide a broader overview on the goal of the selected maturity models and how they are structured, organized and applied into companies; the evaluation will focus on the criteria defined in Phases 1 and 2 of the roadmap[26], as following described based on Maier et al., (2010).

[25] A set of similarities and differences can be distinguished between maturity grids and maturity models. The key distinctions can be made with respect to the work orientation, the mode of assessment and the intent of the model (MAIER et al., 2010).

[26] The primary sources and documents of the selected maturity models will be analyzed in order to have a complete understanding on how it is structured, organized and applied at organizations.

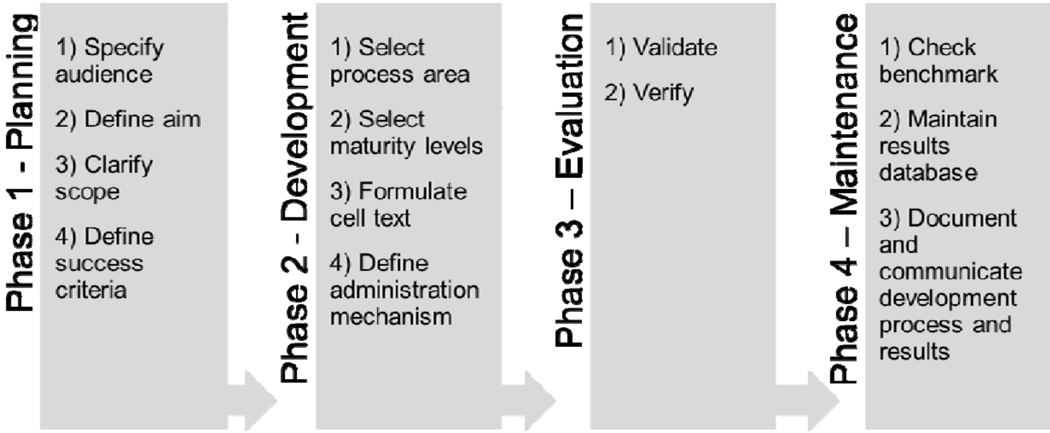

Figure 5: Phases and decision points of roadmap to develop new and evaluate existing maturity grids (MAIER et al., 2010)

Phase 1

1) Audience: definition of the expected users and stakeholders of the model;
2) Aim: definition of the aim of the model in relation to performance of assessments, implementation of improvements, benchmarking, etc.
3) Scope: definition of the domain in which the model is applicable;
4) Success criteria: definition of the criteria to be used to evaluate the model;

Phase 2:

1) Process areas: conceptualization, components and theoretical framework;
2) Maturity levels: definition of the maturity levels - different assessment frameworks use different ranking scales;
3) Relationships among the process areas and maturity levels: description of the process characteristics at each level of maturity;
4) Administration mechanism: definition on how the model is going to be applied into companies in order to reach its aims.

The structured analysis provides a summarization of the main characteristics of the maturity models, enables further comparison analyses among the models and the identification of patterns. These data will be used in the development of the Ecodesign Maturity Model (EcoM2) in the theoretical development phase.

3.2.2.1 Capability Maturity Model Integration for Development (CMMI-Dev)

The CMMI-Dev (CMMI for Development) consists of a set of best practices related to the development and maintenance activities applied to products and services that cover the entire product life cycle, from conception to delivery and maintenance (CHRISSIS et al., 2003). The classification of the CMMI-Dev in the criteria defined by Maier et al. (2010) was performed based on the information presented by Chrissis et al. (2003).

Phase 1

1) Audience:
    a. Users: the audience for the model includes people interested in process improvement, whether familiar with the concept of Capability Maturity Models or seeking information to get started on improvement efforts. The model is also intended for people who want to use an appraisal to see where they are, those who already know what they want to improve, and those who are just getting started and want to develop a general understanding of the CMMI-Dev constellation (CHRISSIS et al., 2003).
    b. Improvement entity: CMMI-Dev consists of best practices that address development and maintenance activities applied to products and services[27]. It addresses practices that cover the product's lifecycle from conception through delivery and maintenance (CHRISSIS et al., 2003).
2) Aim: the purpose of the CMMI-Dev is to help organizations to improve their development and maintenance processes for both products and services. CMMI-Dev is a collection of best practices that is generated from the CMMI Framework. The CMMI Framework supports the CMMI Product Suite by allowing multiple models, training courses, and appraisal methods to be generated that support specific areas of interest (CHRISSIS et al., 2003).
3) Scope: Organizations from many industries can use the CMMI-Dev, including aerospace, banking, computer hardware and software,

[27] The focus of CMMI is on hardware and software products.

defense, automobile manufacturing, and telecommunications, (CHRISSIS et al., 2003).

4) Success criteria: not defined

Phase 2:

1) Process areas (components and theoretical framework): in CMMI-DEV, a process area is a cluster of related practices in an area that, when implemented collectively, satisfy a set of goals considered important for making improvements in that area. There are 22 process areas, presented here in alphabetical order by acronym: Causal Analysis and Resolution (CAR); Configuration Management (CM); Decision Analysis and Resolution (DAR); Integrated Project Management +IPPD (IPM+IPPD); Measurement and Analysis (MA); Organizational Innovation and Deployment (OID); Organizational Process Definition +IPPD (OPD+IPPD); Organizational Process Focus (OPF); Organizational Process Performance (OPP); Organizational Training (OT); Product Integration (PI); Project Monitoring and Control (PMC); Project Planning (PP); Process and Product Quality Assurance (PPQA); Quantitative Project Management (QPM); Requirements Development (RD); Requirements Management (REQM); Risk Management (RSKM); Supplier Agreement Management (SAM); Technical Solution (TS); Validation (VAL); Verification (VER)[28]. Process areas can be grouped into four categories: (1) Process Management; (2) Project Management; (3) Engineering and (4) Support. Relationships among the process areas and among groups of process areas can be identified (CHRISSIS et al., 2003).
2) Maturity levels: in the CMMI-Dev, the maturity levels (or capability levels) are distinguished according to the process improvement approach adopted: the continuous or the staged representation.
   a. The continuous representation enables an organization to select a process area (or group of process areas) and improve processes related to it. This representation uses capability levels to

[28] Note that the CMMI-Dev process areas do not include the environmental considerations.

characterize improvement relative to an individual process area. These levels are a means for incrementally improving the processes corresponding to a given process area. There are six capability levels, numbered from 0 through 5 (CHRISSIS et al., 2003):

i. Level 0: Incomplete: An “incomplete process” is a process that either is not performed or is partially performed. One or more specific goals of the process area are not satisfied, and no generic goals exist for this level since there is no reason to institutionalize a partially performed process;
ii. Level 1: Performed: A capability level 1 process is characterized as a “performed process.” A performed process is a process that satisfies the specific goals of the process area. It supports and enables the work needed to produce work products;
iii. Level 2: Managed: A capability level 2 process is characterized as a “managed process.” A managed process is a performed (capability level 1) process that has the basic infrastructure in place to support the process;
iv. Level 3: Defined: A capability level 3 process is characterized as a “defined process.” A defined process is a managed (capability level 2) process that is tailored from the organization’s set of standard processes according to the organization’s tailoring guidelines, and contributes work products, measures, and other process improvement information to the organizational process assets;
v. Level 4: Quantitatively managed: A capability level 4 process is characterized as a “quantitatively managed process.” A quantitatively managed process is a defined (capability level 3) process that is controlled using statistical and other quantitative techniques.
vi. Level 5: Optimizing: A capability level 5 process is characterized as an “optimizing process.” An optimizing process is a quantitatively managed (capability level 4)

process that is improved based on an understanding of the common causes of variation inherent in the process. The focus of an optimizing process is on continually improving the range of process performance through both incremental and innovative improvements.

b. The staged representation uses predefined sets of process areas to define an improvement path for an organization. This improvement path is characterized by maturity levels. Each maturity level provides a set of process areas that characterize different organizational behaviors. These levels are a means of predicting the general outcomes of the next project undertaken. There are five maturity levels, numbered from 1 through 5 (CHRISSIS et al., 2003):

   i. Level 1: Initial: At maturity level 1, processes are usually ad hoc and chaotic.

   ii. Level 2: Managed: At maturity level 2, the projects of the organization have ensured that processes are planned and executed in accordance with policy; the projects employ skilled people who have adequate resources to produce controlled outputs; involve relevant stakeholders; are monitored, controlled, and reviewed; and are evaluated for adherence to their process descriptions;

   iii. Level 3: Defined: At maturity level 3, processes are well characterized and understood, and are described in standards, procedures, tools, and methods;

   iv. Level 4: Quantitatively managed: At maturity level 4, the organization and projects establish quantitative objectives for quality and process performance and use them as criteria in managing processes;

   v. Level 5: Optimizing: At maturity level 5, an organization continually improves its processes based on a quantitative understanding of the common causes of variation inherent in processes.

3) Relationships among the process areas and maturity levels
    a. Type of formulation: prescriptive - specific and detailed courses of action (practices) are suggested for each maturity level, with a technical subject;
    b. Information source: each process area is classified according to a maturity level.
4) Administration mechanism: once the organization has decided to adopt CMMI-Dev, an improvement approach such as the IDEAL SM (Initiating, Diagnosing, Establishing, Acting & Learning) model can be selected (CHRISSIS et al., 2003). Nevertheless, the CMMI-Dev does not define how it can be done.

3.2.2.2 Organizational Project Management Maturity Model (OPM3)

The Organization Project Management Maturity Model (OPM3) provides knowledge to understand organizational project management, tools to assess companies according to the standard, and the means to decide whether or not to pursue an improvement plan (PMI, 2003). The classification of the OPM3 in the criteria defined by Maier et al. (2010) was performed based on the information presented by the Project Management Institute (PMI, 2003).

Phase 1

1) Audience: project management professionals;
2) Aim: the purpose of OPM3 is to provide a way for organizations to understand organizational project management and to measure their maturity in comparison to a set of organizational project management best practices. The OPM3 also aims to support organizations wishing to increase their organizational project management maturity to plan for improvements. The OPM3 describes the incremental capabilities that aggregate into best practices, and which are prerequisite to effective organizational project management (PMI, 2003);
3) Scope: the scope of OPM3 is global. It has been developed through the participation and consensus of a diverse group of individuals in the project management profession, representing a cross-section of organizations from 35 countries. The OPM3 authors claim that the model

cuts across boundaries of organizational size and type, is applicable in cultures throughout the world, and in virtually any industry, from engineering and construction to information technology, financial services, government agencies, and manufacturers (PMI, 2003);

4) Success criteria: not specified;

Phase 2:

1) Process areas (components and theoretical framework): the organizational project management maturity is described in OPM3 through the existence of best practices[29]. The best practices are organized into three groups: high-level processes (Portfolio), multi-project processes (Program), and Project processes. The project management process groups (Initiating, Planning, Executing, Controlling, and Closing) of the PMBOK®[30] Guide are extended to the domains of Program Management and Portfolio Management. These process groups, within the three domains, along with the four stages of process improvement, are used to organize components within the OPM3 model (PMI, 2003);
2) Maturity levels: OPM3 was intentionally designed without an overall system of "levels" of maturity. There is a progression of four stages of process maturity from process standardization through continuous process improvement. OPM3 also categorizes the capabilities in terms of their association with the five project management process groups (Initiating, Planning, Executing, Controlling, and Closing), permitting evaluation of a fourth dimension of maturity. According to the authors, multiple perspectives for assessing maturity allow flexibility in applying the model to the unique needs of an organization. A capability is a specific competency that must exist in an organization in order to execute project management processes and deliver project management services and products. Capabilities are incremental steps, leading up to

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[29] A best practice is an optimal way currently recognized by industry to achieve a stated goal or objective. Best practices are best achieved by developing and consistently demonstrating their supporting capabilities, as observed through measurable outcomes (PMI, 2003).

[30] Project Management Body of Knowledge (PMBOK) is a guide that aims to document and standardize generally accepted project management information and practices.

one or more best practices. Each best practice is made up of two or more capabilities (PMI, 2003);

3) Relationships among the process areas and maturity levels: in order to ascertain the existence of a best practice — and, therefore, to assess the organization's maturity accurately — an organization must understand the dependencies among best practices and capabilities. The concept of dependencies is unique to OPM3. Breaking down each best practice into its constituent capabilities, and showing the dependencies among them, reveals a sequence that permits a detailed, orderly assessment, and provides a basis for later decisions related to improvement (PMI, 2003);
4) Administration mechanism: the OPM3 is applied in five steps (PMI, 2003):
    a. Step one: prepare for assessment. The first step is for the organization to prepare for the process of assessing its organizational project management maturity in relation to the model. This involves understanding the contents of the model as thoroughly as possible, becoming familiar with organizational project management and with the operation of OPM3. Contents of the standard include the narrative text, with appendices and glossary, the self-assessment tool, and three directories containing detailed data on the best practices of the model;
    b. Step two: perform assessment. The next step is to assess the organization's degree of maturity in organizational project management. To do this, an organization must be able to compare the characteristics of its current maturity state with those described by the model. The first phase of assessment is a review of which best practices in the standard are and are not currently demonstrated by the organization, and identifying the organization's general position on a continuum of organizational project management maturity. The self-assessment tool provided in OPM3 is one way to accomplish this, and organizations may develop others. Then, in a second phase of assessment, the organization proceeds to gather further information at a more detailed level to determine which specific capabilities, associated

with each best practice, the organization currently does and does not demonstrate — and what are the dependencies among them. The results of the assessment step may lead an organization to plan for improvements, repeat the assessment, or exit the process. If an organization elects to exit, a periodic revisiting of the assessment step is recommended, to monitor the effects of intervening changes;

c. Step three: plan for improvements. For those organizations choosing to pursue organizational improvements leading to increased maturity, the results of the previous step will form the basis for an improvement plan. The documentation of which capabilities the organization does and does not have — including the dependencies among them — permits a ranking of needed capabilities and outcomes according to their priority for the organization. This information opens the way to develop a specific plan to achieve the outcomes associated with the capabilities of the relevant best practices;

d. Step four: implement improvements. This step is where organizational change will take place. Once the plan has been established, the organization will have to implement it over time, i.e., execute requisite organizational development activities to attain the needed capabilities and advance on the path to increased organizational project management maturity;

e. Step five: repeat the process. Having completed some improvement activity, the organization will either return to the assessment step to reassess where it is currently on the continuum of organizational project management maturity (recommended) — or return to step three to begin addressing other best practices identified in an earlier assessment.

This section presented the literature review carried out in the first phase of the research, as described in section 2.2.1. The results presented in this section are going to provide the theoretical basis to support the theoretical development of the Ecodesign Maturity Model (EcoM2), presented in section 4.

4 Theoretical development of the Ecodesign Maturity Model (EcoM2)

This section presents the theoretical development of the Ecodesign Maturity Model (EcoM2), in accordance to the methodology and research structure presented in section 2.

Section 4.1 presents an overview of the theoretical version of the Ecodesign Maturity Model (EcoM2) and its three components: the Ecodesign Practices (section 4.2); the Ecodesign Maturity Levels (section 4.3); and the Application Method (section 4.4). Section 4.5 describes the evaluation of the EcoM2 by a set of ecodesign experts, which includes the selection of the experts, the execution of the interviews and the suggestions for improvements of the Ecodesign Maturity Model (EcoM2). The improvements performed in the EcoM2 after the experts evaluations are presented in section 4.6.

4.1 Ecodesign Maturity Model (EcoM2): overview

The Ecodesign Maturity Model (EcoM2) is a framework with an evolutionary (step-by-step) approach[31] that aims to support companies in the effective selection of ecodesign practices to be integrated into the product development and related processes (such as marketing, supply chain management, production, etc.), considering their strategic objectives and drives.

The application of the Ecodesign Maturity Model (EcoM2) aims to provide to companies:

(1) a benchmarking of ecodesign practices;
(2) an assessment of weaknesses and strengths concerning ecodesign practices application;
(3) a common language and a shared vision across the organization on ecodesign implementation; and
(4) a proposal for improvement of product development process towards environmental sustainability[32].

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[31] There is a learning process to be followed for ecodesign implementation – it is not possible to implement all of the practices at once.

[32] As previously mentioned, just the environmental aspects of sustainability are considered in this research.

The proposed Ecodesign Maturity Model (EcoM2) is composed by three main elements: Ecodesign Practices, Maturity Levels and Application Method[33] (Figure 6).

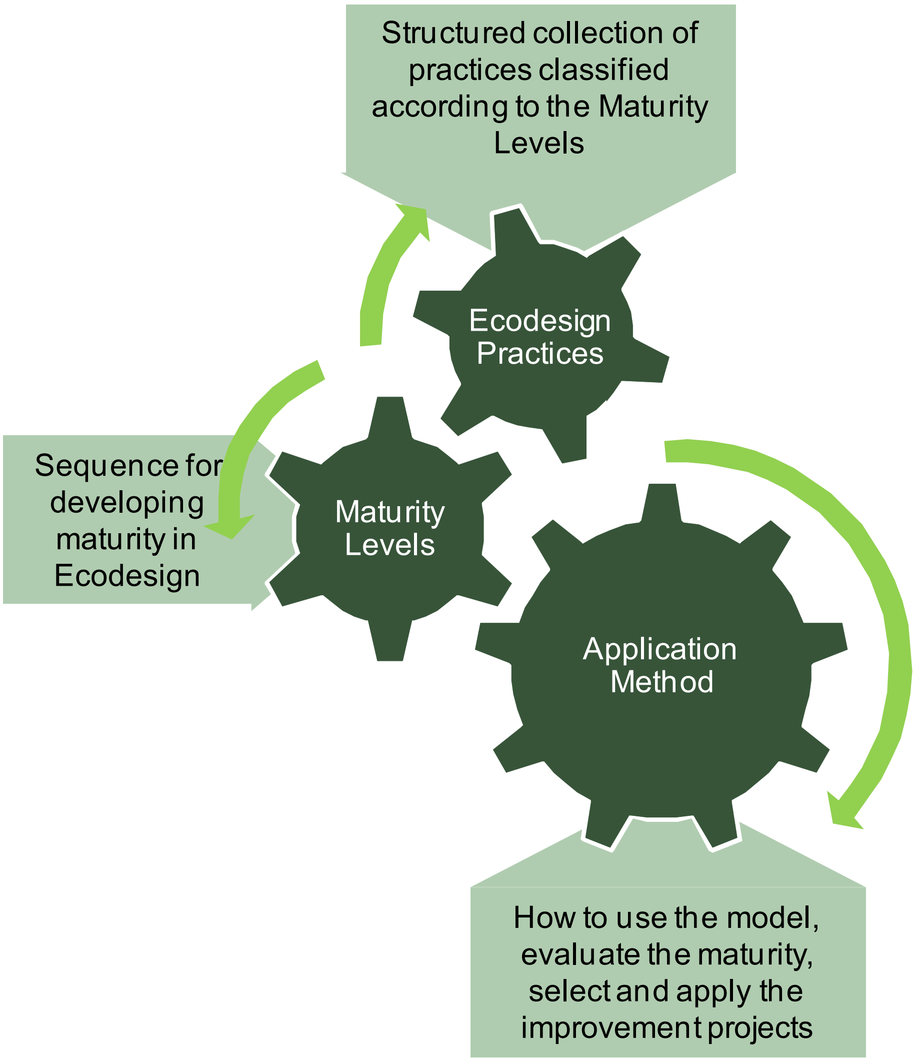

Figure 6: Elements of the Ecodesign Maturity Model (EcoM2)

The ecodesign practices correspond to the best practices for the integration of environmental concerns into the product development and related process – it is composed by ecodesign management practices and ecodesign operational practices associated to ecodesign techniques and tools (see section 4.2).

The maturity levels represent the evolutionary stages carried out by companies for the integration of environmental issues into their product development and related processes, i.e. for ecodesign implementation (see section 4.3).

[33] The definition of the three elements for the Ecodesign Maturity Model came from the literature review on maturity models and understanding of its mains functions and characteristics.

Finally, the EcoM2 application method presents the way in which companies can use the EcoM2 for process improvement. It contains a scheme for continuous improvement based on the PDCA (Plan, Do, Check and Act) and BPM (Business Process Management) approaches for process improvement (see section 4.4).

4.2 Ecodesign practices

This section presents the results of the activity 2.1: "Systematize the ecodesign practices". In this activity, the identification, systematization and classification of the ecodesign practices[34] are carried out employing the systematic literature review as research method (see section 2.2.2). In contrast to the previous section (literature review), the goal of the systematic literature review is to identify the existing ecodesign practices that can be applied by companies in order to support ecodesign implementation.

The framework adopted in this research to perform the systematic literature review is presented by Biolchini et al. (2005). It comprises three phases, namely: (1) planning, (2) execution, and (3) analysis of the results. The results of these three phases are presented in sections 4.2.1, 4.2.2 and 4.2.3, respectively.

4.2.1 Planning of the systematic literature review

The planning step (1) consists of defining the review protocol, which contains the formulation of the problem and the determination on how the data are to be collected, evaluated, analyzed and interpreted, including also the definition on how the conclusions should be drawn and how the results will be presented. The definition of the review protocol is fundamental to guide the execution and analysis of the results steps (BIOLCHINI et al., 2005).

This section presents the steps involved in the preparation of the systematic review protocol: problem formulation (section 4.2.1.1); data collection (section

[34] Ecodesign practice is the term adopted in this research to define ecodesign activities that aims at integrating the environmental concerns into product development and related process and which application can be supported by techniques and tools (section 1.2)

4.2.1.2); data evaluation (section 4.2.1.3); and data analysis and interpretation (section 4.2.1.4).

4.2.1.1 Problem Formulation

Problem formulation determines the type of evidence that should be included in the review, defining the objective, the benefited areas, and the expected results (BIOLCHINI et al., 2005). The focus of interest of the systematic review, i.e., the research objective, was the survey and classification of the state of the art of existing ecodesign practices. Thus, the question to be answered by the systematic review was: “What are the existing ecodesign practices and how they can be classified?”

It must be addressed that there is not a common term used to describe ecodesign practice in the literature: it can be stated as activity, strategy, task, routine, guideline, process, method, tool, technique, etc. In this research, the term ecodesign practice is applied according to the Project Management Body of Knowledge (PMBOK) general definition of practice[35] and defined as “ecodesign activities that aims at integrating the environmental issues into product development and related processes and which application can be supported by ecodesign techniques and tools”.

The area of product development, including academics and practitioners, and the area of environmental management, will be the main areas to benefit from the systematic review. The result expected from this activity is the identification, characterization and systematization of existing ecodesign practices.

4.2.1.2 Data Collection

Data collection focuses on the definition of the procedures that the researcher should adopt in order to find relevant evidence, according to the definitions established in the problem formulation. It includes determination of the data sources that may provide relevant studies, as well as keywords and logical research terms (BIOLCHINI et al., 2005).

[35] According to PMI (2008), practice is defined as “a specific type of professional or management activity that contributes to the execution of a process and that employ one or more techniques and tools”.

The databases, keywords and logical research terms to be used in the review were identified according to the study's objectives and focus. The criterion employed to evaluate the data sources was their international scope in the research area. The databases researched during the systematic review were Scirus; Compendex; ISI Web of Science; Research Communications for Scientists and Engineers; Scholar Google; Emerald; Find Articles; Science Direct, and IEEE Explore.

The selection of keywords and logical terms was performed iteratively. To begin with, there was a set of 21 articles from which the initial keywords were extracted. As the review proceeded, new keywords emerged and were added to the initial set, resulting in new searches in the databases using the newly included keywords. Additionally, cross searches on the relevant authors and journals were performed, in order to find papers not initially obtained.

The main terms or keywords that comprised the research question were: Eco-design; Ecodesign, Design for environment; Design for the environment; Sustainable product development; Sustainable product design, Life-cycle design; Life cycle design; Green product; Green design; Ecodesign strategies; Eco-design strategies; Design for life-cycle; Design for life cycle; Environmental product design; Sustainable design; Sustainable product development; Life cycle engineering; and Life-cycle engineering; Environmentally friendly design; Environmentally conscious design. The logical terms that combined the keywords and their synonyms, which were used to identify the largest number of relevant studies, were obtained by a combination of the terms and the words "practice, activity, strategy, task, routine, guideline, process, method, tool and technique".

4.2.1.3 Data Evaluation

In planning the data evaluation, the core issue is the type of evidence to be included in the review. This consists on devising definitions that allow the separation of relevant and non-relevant studies by determining inclusion and exclusion criteria. In addition, the standards for the way results are represented must also be defined (BIOLCHINI et al., 2005).

The studies to be included into the review were selected by applying the inclusion/exclusion criteria. Those criteria are related to the selection of studies that present ecodesign practices either in an explicit or implicit way (e.g. development and or/case studies of new tools, procedures, activities, industrial experience with ecodesign implementation, etc.). Studies out of this scope that could not contribute to achieve the goal of the research were excluded from the review. The procedure for selecting studies using the inclusion and exclusion criteria was a reading of their title and abstracts. Whenever this reading proved insufficient to include or exclude a study, the entire study has been considered.

In order to standardize the representation of the information, forms were created to collect and record the data of the study and the ecodesign practices (database). The studies were recorded in table format containing the following fields: title; author(s), type (article, thesis, dissertation or report); keywords; source; year of publication, and abstract. Filters were applied to the fields of this record to facilitate the identification of the studies according to the type of information required, such as author or keywords, for example. The ecodesign practices were recorded in database format due to the easy exportation of data in several formats. The database contains the ecodesign practices classification criteria, which are presented in section 4.2.3.

4.2.1.4 Data Analysis and Interpretation

The analysis and interpretation of data includes the preparation of a synthesis of the valid studies. It also involves the determination of information that should be extracted (e.g. criteria for the classification of ecodesign techniques and tools) in order to elaborate generalizations (BIOLCHINI et al., 2005). The studies were synthesized by extracting the relevant information from them, following the purpose of the review to identify and classify the ecodesign practices.

4.2.2 Execution of the systematic literature review

The execution step (2), which involves the application of the concepts defined in the review protocol, includes the initial identification, selection and evaluation of studies according to the inclusion and exclusion criteria defined in the review protocol (see section 4.2.1.3). This step involved searching for studies in databases using the pre-established keywords (see section 4.2.1.2), as well as the selection of valid studies through the application of the inclusion and exclusion criteria (BIOLCHINI et al., 2005).

As a result of the search process, a total amount of 5342 studies (including papers, books, thesis, dissertations and book reviews) was identified. After applying the inclusion/exclusion criteria, 2341 valid studies were further analyzed in order to extract the ecodesign practices.

4.2.3 Analysis of the results

Once the studies had been selected, step (3) – analysis of the results – involves extracting the data from the relevant studies that are pertinent to the objective of the systematic review, using the data representation standards defined in the review (BIOLCHINI et al., 2005).

The main tasks carried out in this activity were:

- Identification and categorization of ecodesign practices employing the systematic literature review and adopting the grounded theory technique[36] in order to identify key themes, patterns and categories from the data itself (LANCASTER, 2005);
- Establishment of relationships and dependences[37] among the ecodesign practices by analyzing the goals of each practice and comparing them to each other in order to identify possible relationships;

During the systematic literature review, the need for the distinction among the ecodesign practices in relation to the subject of interest (the product development process or the product itself) was observed.

[36] Distil potentially large amounts of data into forms that are more readily managed and absorbed, and also discard data that is not appropriate in the context of the research project (LANCASTER, 2005).

[37] Much data analysis is concerned with establishing causes and/or relationships between factors. Data analysis enables these relationships, and particularly causal relationships to be identified (LANCASTER, 2005).

Two main patterns from the ecodesign practices were identified: practices that are related to the product development process itself (or management practices, as defined in this research) and practices that are related to the technical issues of product design (or operational practices, as defined in this research). It was also identified ecodesign techniques and tools (or ecodesign methods and tools[38]), that can support the application of the ecodesign management and operational practices.

In summary, the Ecodesign Maturity Model (EcoM2) classifies the ecodesign practices into two main groups according to their characteristics in relation to the subject of interest of the practice:

- Ecodesign Management Practices (see section 4.2.3.1): practices that are related to the activities of the product development process (such as definition of the product requirements and idea generation);

- Ecodesign Operational Practices (see section 4.2.3.2): practices that are related to the technical issues of product design (such as selection of materials and connections between the parts);

The application of the ecodesign management and operational practices can be supported by ecodesign techniques and tools (or ecodesign methods and tools) (see section 4.2.3.3).

The aforementioned distinction among the ecodesign practices is supported by Pascual and Stevels (2004), which divides ecodesign into two dimensions:

(1) Managerial dimension: related to the business aspects of the discipline (including the alignment of ecodesign with traditional business perspectives, supply chain, green marketing, etc.); and

(2) Environmental dimension: related to the technicalities of the product (like physical units, materials, energy, efficiency, environmental load, etc.).

[38] In order to follow the nomenclature of PMBOK, the term “technique” is adopt, but it is considered in this research as a synonymous for “method”, which is the term usually adopted in the ecodesign literature.

As also observed in this research, the authors address that the focus of the literature is on the environmental dimension rather than on the managerial dimension (PASCUAL; STEVELS, 2004). Moreover, Pascual et al. (2003) also suggest the existence of product and process related activities to ecodesign.

Similarly, Fiksel and McDaniel (1998) establish differences among organizational and technical issues for ecodesign implementation:

- Organizational issues include the establishment of appropriate company policies and incentives, modification of existing business processes, capture and dissemination of sustainable design knowledge via training and information technology, and achievement of consistent practices across diverse business units;
- Technical issues include the implementation of various design strategies e.g., modifying the material composition of products so that they generate less pollution and waste, or changing the assembly requirements so that fewer material and energy resources are consumed per product unit as well as systematic adoption of sustainable design guidelines, metrics, and tools.

The organizational and technical issues are equally important, and must be addressed from the strategic, tactical and operational perspectives (FIKSEL; MCDANIEL, 1998). Successful ecodesign requires a double level activity: strategic, in order to define the problematic within the organization as a whole, and operational so as to be able to implement decisions concretely (NEY, 2008).

The ecodesign management practices defined in the EcoM2 are related to managerial (PASCUAL; STEVELS, 2004) and organizational (FIKSEL; MCDANIEL, 1998) dimensions while the ecodesign operational practices are related to the environmental (PASCUAL; STEVELS, 2004) and technical issues (FIKSEL; MCDANIEL, 1998).

The ecodesign management practices, ecodesign operational practices and ecodesign techniques/tools obtained during the systematic literature review are presented in the sections 4.2.3.1, 4.2.3.2 and 4.2.3.3, respectively. The relationships among the ecodesign practices are presented in section 4.2.3.4.

4.2.3.1 Ecodesign management practices

The ecodesign management practices are those that are related to the activities of the product development and related processes that address the environmental concerns. They are generic and can be applied by any company, regardless of the type of products developed.

In general, the ecodesign management practices are those related to the management of the product development process. In order to illustrate the ecodesign management practices, some examples are presented following:

- "10011: Ensure commitment, support and resources to conduct the activities related to ecodesign";
- "10015: Make ecodesign tasks a part of the daily routine for the relevant employees";
- "10019: Formulate and monitor mandatory rules concerning environmental issues for the enterprise to comply with law/regulations";
- "30002: Clearly define the environmental indicators and the methodology to be used during the gates (phase assessments)";
- "40013: Clearly define goals to improve products environmental performance (according to law, benchmarking, phases/aspects with higher improvement potential, etc.)", etc.

The Ecodesign Maturity Model (EcoM2) contains a set of 96 Ecodesign Management Practices (Appendix A[39]) obtained from studies that deals with ecodesign management, integration into the product development process and implementation into companies including studies on success factors and barriers for ecodesign implementation.

In order to locate the user whether the practice should be preferably applied in the context of the product development process, the ecodesign management practices were classified according to the group of activities of a reference model for the product development process. Although product development

[39] In order to avoid repetition of the content among the three versions of the Ecodesign Maturity Model (see section 2.2), the Appendix A presents the final consolidated version of the ecodesign management practices.

process significantly vary between different companies and product types, generic design process such as high-level reference models can be used to tailor the specific ecodesign procedures (DEWULF; DUFLOU, 2004).

The reference model used in this research as the basis for the Ecodesign Maturity Model (EcoM2) (Figure 7) is result of a collaborative research carried out among seven researchers and experts in the field of product development in a joint research group among the University of São Paulo (EESC-USP), the Federal University of São Carlos (UFSCar) and the Federal University of Santa Catarina (UFSC), coordinated by Professor Henrique Rozenfeld (ROZENFELD et al., 2006; ROZENFELD, 2007; AMARAL; ROZENFELD, 2007).

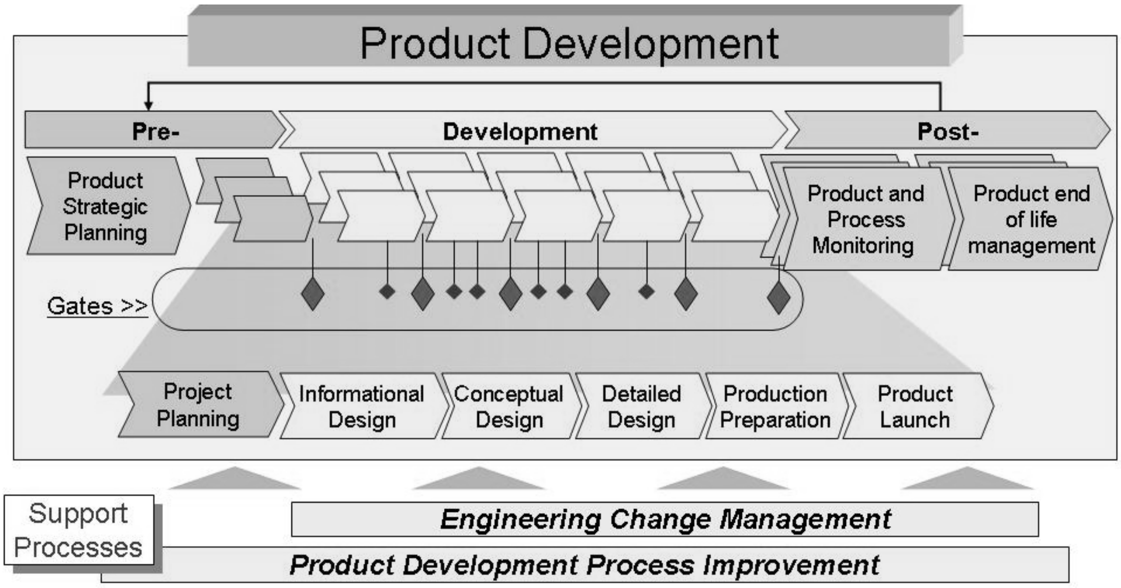

Figure 7: Reference model for product development (ROZENFELD et. al, 2006)

The reference model for product development process comprises three macro-phases: pre-development, development and post-development (ROZENFELD et al., 2006; ROZENFELD, 2007; AMARAL; ROZENFELD, 2007), sub-divided into nine phases. It encompasses also two support processes: engineering change management and product development process improvement. Each of these phases and support processes are sub-divided into activities and tasks, which can be linked to methods and tools to support their application.

The reference model for product development process (ROZENFELD et al., 2006; ROZENFELD, 2007; AMARAL; ROZENFELD, 2007) was selected considering the following reasons:

- it consolidates the best practices for product development, considering well-established models for product development and industrial experience on product development;
- it innovates in proposing the post-development phase, which support the monitoring of the product during the use phase and the consideration of end-of-life issues;
- it proposes a support process for improving the product development process that can be used for the integration of the environmental issues jointly with the traditional aspects considered during product development (such as quality, cost, risks and performance);
- It presents all of the phases, activities, tasks and tools that can be used during the product development process in a systematized way and describes how it can be used to develop standard development process at companies.

In the reference model for product development, three different groups of activities can be distinguished: (1) phases of the product development process; (2) support processes; and (3) "generic activities", which repeat across all the phases of the product development process. The ecodesign management practices were classified[40] according to the aforementioned group of activities of the reference model for the product development process.

It includes also two support processes: business process management for ecodesign (which application is essential to form the basis for ecodesign implementation) and environmental assessment of products. The reason for the creation of this last support process is the continuous need of information about the products environmental performance throughout the product development process, the need of high-skilled personal on environmental issues and the complexity, cost and time intensive activities involved in these studies, especially when quantitative and complex methods such as Life Cycle Assessment (LCA) are used.

The classification of the ecodesign management practices into these groups of activities of the reference model for product development was performed based

[40] Classification involves the grouping of data into categories that allow the researcher to quickly see what factors are involved and potentially what the data means (LANCASTER, 2005).

on a cross content analysis, were both the practices and the group of activities were analyzed against each other in order to identify similarities.

It must be stated, however, that depending on the specific product development process of the company, the practices can be applied in different phases. The proposed classification should be considered as an initial guidance and not as a fixed rule. The classification of the ecodesign management practices are presented in Appendix A.

In order to enable the easy update and addition of new practices, a code was assigned to each ecodesign management practice. The codification also enables the identification of the product development process phase (PPD), generic activities (GA) and/or support processes (SP) where the practices should be applied. The code scheme is presented in Table 6.

Table 6: Code scheme for ecodesign management practices classification

Code	Phases of the product development (PPD) and support processes (SP)
100xx	SP: Business process management for ecodesign
200xx	SP: Environmental impact assessment of products
300xx	GA: Generic activities
400xx	PPD: Product strategic planning
500xx	PPD: Project planning
600xx	PPD: Informational design
700xx	PPD: Concept design
800xx	PPD: Detailed design
900xx	PPD: Production preparation
1000xx	PPD: Product launch
1100xx	PPD: Product accompanying and monitoring

The ecodesign management practices are, moreover, further classified according to the ecodesign evolution levels defined by the EcoM2 (see section 4.3.2). This classification was accomplished by means of the development of a correlation matrix in which each management practice was compared to the characteristics of the established evolution levels (see section 4.3.2). The synthesis of the correlation matrix enabled the classification of the ecodesign management practices into the evolution levels, which were subsequently evaluated by a set of ecodesign experts and further improved (see section 4.5).

The ecodesign management practices are, moreover, used to assess the maturity profile of the companies in the ecodesign application (see section 4.4).

4.2.3.2 Ecodesign operational practices

The ecodesign operational practices deal with the technical issues of product design and are directly related to the material life cycle (Figure 1) of a product. They provide guidelines for the development of products with better environmental performance and can be linked to ecodesign techniques and tools (see section 4.2.3.3). In total, 468 operational practices were identified and systematized (Appendix B[41]) as a result of the systematic literature review.

The ecodesign operational practices were obtained by the consolidation of a set of ecodesign guidelines[42] and checklists[43] (tools identified during the review – see section 4.2.3.3) for product design into a unique list of operational practices. The unique list provides the advantage of eliminating redundancies and provides a complete and broad overview of the existing guidelines and checklists on ecodesign. Furthermore, it enables the establishment of relationships with ecodesign techniques/tools that can support their application.

The nomenclature proposed by Manzini and Vezolli (2008) for the classification of the ecodesign operational practices in strategies, guidelines and design options was adopted in this research. The guidelines provide a description on how the strategies can be achieved and the design options detail the guidelines.

The operational practices were grouped into six ecodesign strategies (adapted from Vezzoli and Manzini (2008))[44]:

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[41] In order to avoid repetition of the content among the three versions of the Ecodesign Maturity Model (see section 2.2), the Appendix B presents the final consolidated version of the ecodesign operational practices.

[42] Guideline is defined as a “tool that provides general guidelines to be followed during the product development process to improve the environmental performance of products”

[43] Checklist is defined as a “tool used to check if a determined parameter related to the product environmental performance was considered during the product development process”

[44] The classification structure proposed by Manzini and Vezolli (2008) was adopted due to its completeness. However, it was adapted in order to split the strategy “Minimize material and energy consumption” strategy into the following two strategies: “Minimize material consumption” and “Minimize energy consumption” in order to facilitate the identification of the most important strategies for a product, according to its characteristics.

1) Minimize Energy Consumption;
2) Minimize Material Consumption;
3) Extend Material Life Span;
4) Optimize Product Life Time;
5) Select Low Impact Resources and Processes; and
6) Facilitate Disassembly.

The strategies are detailed in guidelines, which provide alternative ways in which the strategy can be accomplished. The guidelines of the strategy “Minimize Material Consumption”, for example, are:

- “Minimize material content”;
- “Minimize scraps and discards”;
- “Minimize or avoid packaging”;
- “Minimize materials consumption during usage”; and
- “Minimize materials consumption during the product development process”.

In order to explicit the way in which the guidelines can be achieved during product design, the EcoM2 also presents the design options, which provide more detailed ideas of product design (adapted from Vezzoli and Manzini (2008)). For example, some of the design options of the guideline “Minimize material content” are:

- “Dematerialize the product or some of its components”;
- “Miniaturize”;
- “Digitalize the product or some of its components”;
- “Avoid over-sized dimensions”;
- “Reduce thickness”;
- “Apply ribbed structures to increase structural stiffness”;
- “Avoid extra components with little functionality”;
- “Reduce the material content by integrating functions”, etc.

A functional hierarchy among the ecodesign strategies can be identified (Figure 8). Facilitate disassembly, for example, is an effective strategy for the extension of material life span and to the optimization of product life time. It also implies in the minimization of material consumption and in the selection of processes and resources with low environmental impact (VEZZOLI; MANZINI, 2008).

Trade-off[45] situations among the strategies may happen; i.e. improving a concept in a strategy can have negative effects in another strategy (BYGGETH; HOCHSCHORNER, 2006). For example, the minimization of material consumption can compromise the product life time. Similarly, trade-offs among environmental issues and traditional requirements of a product such as cost, quality, aesthetics, etc. must be handled during a product development project.

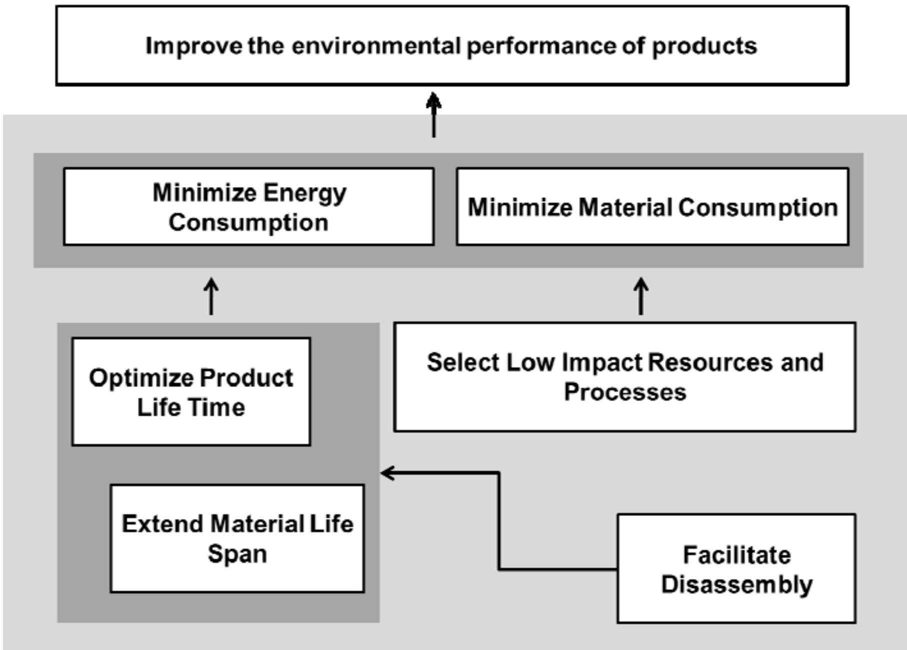

Figure 8: Functional hierarchy among the ecodesign strategies

The application of the ecodesign operational practices varies depending on the product characteristics (concerning life cycle phases/environmental aspects that present the greatest potential environmental impact) and/or on the priorities for minimizing impacts determined by the company (for example, if the focus is to minimize the global warming impact, the ecodesign operational practices to be prioritized should focus on the minimization of greenhouse gases emissions, such as carbon dioxide).

The ecodesign operational practices should be customized by a company, according to the characteristics of the developed products (for example, if the product is designed to have a long life span, it does not make sense to have a

[45] Trade-off situations in the product development process are often about choices among multiple factors that need to be weighed against each other in order to make a decision (BYGGETH; HOCHSCHORNER, 2006).

guideline for using biodegradable materials). Additionally, there may be specific and customized design options according to the product under development.

4.2.3.3 Ecodesign techniques and tools

The ecodesign techniques and tools can be defined as systematic means for the application of ecodesign (BAUMANN et al., 2002) that can support the application of both ecodesign management and operational practices.

The relationship of the ecodesign techniques and tools to ecodesign management and operational practices (section 4.2.3.4) proposed in this research can contribute to provide a link to the product development process, which could not be achieved just by incorporating the tools into the PDP since their functionalities do not include integration in the process of the enterprise (POCHAT, LE et al., 2007).

A total of 107 ecodesign techniques and tools were identified and classified by means of the systematic literature review (Appendix C[46]). The techniques and tools were codified using a classification code in the format (m00000x).

Some examples of ecodesign techniques and tools identified are:

- m00006 – Life Cycle Assessment (LCA): LCA has its basis in energy and material flow analysis for product systems across their whole life cycle. It is a quantitative method for the assessment of environmental impacts of products and services. LCA is carried out in four phases: (a) goal and scope definition, (b) inventory, (c) impact analysis and (d) improvement analysis. It is an important tool to support the decision making process and the external communication of the environmental performance of products. However, performing LCA studies has some disadvantages such as: it is costly and time consuming (difficult to perform during the product development process), data are often missing or have low quality, there is a large need for specialist knowledge and there is a lack of comparable and reliable LCA data (ANDERSSON et al., 1998; GRAEDEL, 1999; HUNKELER; VANAKARI, 2000; GUINÉE et al., 2001;

[46] In order to avoid repetition of the content among the three versions of the Ecodesign Maturity Model (see section 2.2), the Appendix C presents the final consolidated version of the ecodesign techniques and tools.

BALDO et al., 2002; LAGERSTEDT et al., 2003; BRAS-KLAPWIJK, 2003; HUR et al., 2005; DONNELLY; OLDS; et al., 2006; KNIGHT; JENKINS, 2009; COLLADO-RUIZ; OSTAD-AHMAD-GHORABI, 2010a; GONZÁLEZ-GARCÍA et al., 2011).

- m00015 - Design for Environment (DfE) Matrix: the goal of the tool is to determine the environmental impact of a product by asking a set of 100 pertinent questions about the effects of the product design throughout the product´s life cycle (from raw material extraction to end of life issues). The questions are designed to encourage the consideration by the design team of potential environmental impacts caused by the manufacture, use and disposal of the product. In addition, the matrix highlights areas of environmental concern and provides ideas and options for resolving those concerns. The intent of this toolkit is to raise questions regarding a product´s environmental impact that may not have been previously considered and to provide a semi-quantitative analysis of alternative product designs (JOHNSON; GAY, 1995; SANTOS-REYES; LAWLOR-WRIGHT, 2001; RAHIMI; WEIDNER, 2002; BAUMANN et al., 2002; YARWOOD; EAGAN, 2003; BOVEA; PÉREZ-BELIS, 2012);

- m00038 – Eco-roadmap: a concise graphical tool that captures short- and long-term environmental drivers (legislation [enacted and future] and customer requirements) in one document. The eco-roadmap contains the actual product-relevant legislation and customer requirements in the scope of sustainable and environmentally compliant product design. The eco-roadmap also highlights draft legislation, emerging customer requirements, and industry trends for future sustainable and environmentally compliant product features (DONNELLY; BECKETT-FURNELL; et al., 2006; DONNELLY; OLDS; et al., 2006);
- m00086 – QFDE (Quality Functional Deployment for Environment): the tool was developed by incorporating environmental aspects (environmental requirements and environmental engineering specifications) into traditional QFD to handle the environmental and traditional product quality requirements simultaneously. By carrying out

phases I and II, it is possible to identify which parts are the most important parts to enhance environmental consciousness of their products. In phases III and IV, the effects of design improvement concerning the parts on environmental quality requirements can be evaluated (MASUI et al., 2001; SAKAO et al., 2001; SAKAO, TOMOHIKO et al., 2002; MASUI, KEIJIRO et al., 2002, 2003; FARGNOLI, 2003; YIM; HERRMANN, 2003; SHIH; LIU, B.-SHUEN, 2005; SAKAO, 2007; FARGNOLI; SAKAO, 2008; YONGMING; BAIXIANG; MUZHI, 2009a, 2009b; GENEVOIS; BEREKETLI, 2009; WU; YANG, 2010; KENGPOL; BOONKANIT, 2011; ZHANG et al., 2011; BOVEA; PÉREZ-BELIS, 2012)..

Despite the existence of a large amount of ecodesign techniques and tools in literature, they are not organized and systematized and are still not being used in a systematic way by companies in the context of the product development process (BAUMANN et al., 2002). One of the most influencing factors is that companies do not have information to support the selection of the most suitable techniques and tools according to their needs (BAUMANN et al., 2002; KNIGHT; JENKINS, 2009). In this sense, a classification that aims to support companies in the selection of the most suitable ecodesign techniques/tools is proposed as part of the Ecodesign Maturity Model (EcoM2).

The criteria for the classification of ecodesign techniques/tools were selected by the understanding of their main functions, characteristics and application possibilities in the product development process. After the initial criteria selection, a consult with experts on ecodesign and product development areas was performed to evaluate the selected criteria. In this occasion, new criteria were suggested and added to the technique/tool registration form. These criteria represent important aspects that need to be considered by companies for the selection of the ecodesign techniques/tools. The classification of the ecodesign techniques/tools using the defined criteria was registered in an online database, which enables the filter according to the desired criteria.

The 13 criteria and their alternative values defined in this project to classify the ecodesign techniques and tools are[47]:

Nature of the main goal of the ecodesign technique/tool: describe the different types of techniques and tools according to their goals

- Prescriptive: techniques/tools that present generic guidelines (from a pre-established set of best practices for minimizing the environmental impacts) to increase the environmental performance of products considering environmental impacts that are recurrent for industrial products;
- Comparative: techniques/tools that aims to compare the environmental performance of different products, concepts or design alternatives for a given product.
- Analytic: techniques/tools that aims to identify improvement potentials in the product performance by means of the assessment of the most relevant environmental aspects. The impact categories can be pre-established according to the technique/tool.

Type of the tool used by the ecodesign technique/tool: presents the type of tool that is used by the technique/tool

- Checklist: tool used to check if a determined parameter related to the product environmental performance was considered during the product development process;
- Guideline: tool that provides general guidelines to be followed during the product development process to improve its environmental performance;
- Matrix: tool that contains a pre-defined scale used to assess the environmental performance of products by correlating two relevant aspects (e.g.: life cycle phase and environmental aspects).
- Software: computational tool used to support the application of an ecodesign method or tool.

[47] Due to the huge amount of data related to the classification of the ecodesign techniques and tools into those 13 criteria, they will not be presented in the thesis. However, it is presented in Appendix C the main conclusions obtained from the classification.

Nature of input data: identify the type of input data required by the ecodesign technique and tool

- Qualitative: the technique/tool requires qualitative data as input;
- Quantitative: the technique/tool requires quantitative and numerical data as input;

Nature of output data: identify the type of output data delivered by the ecodesign technique/tool

- Qualitative: can support subjective analysis, provide general guidance and do not generate numerical data;
- Quantitative: can support objective analysis, providing quantification and generating numerical data.

Origin knowledge area: describes the research area in which the technique/tool were developed

- Ecodesign/environmental management: technique/tool which origin is in the ecodesign and/or environmental management field, like techniques and tools to assess the environmental impact of products;
- Product development process: technique/tool which origin is in the product development field of research;

Lifecycle perspective: presents the phases of product lifecycle considered by the ecodesign technique/tool

- Raw material extraction: considers the scarcity of materials, provide guidelines and/or the impact related to the extraction of raw materials;
- Primary Industry: considers the environmental impact and/or provide guidelines related to the raw material processing;
- Manufacturing: considers the environmental impact and/or provide guidelines related to the manufacturing processes;
- Use: considers the environmental impact and/or provide guidelines related to the use phase;

- Reuse: considers the environmental impact and/or provide guidelines related to the reuse of the product, their parts and/or components;
- Recycling: considers the environmental impact and/or provide guidelines related to the recycling of the product, their parts and/or components;
- Remanufacturing: considers the environmental impact and/or provide guidelines related to the remanufacturing of the product, their parts and/or components;
- Treatment and final disposal; considers the environmental impact and/or provide guidelines related to the treatment and final disposal of products;

Environmental Aspect: presents the environmental aspects considered by the ecodesign technique/tool

- Energy use;
- Material intensity;
- Chemicals and toxics
- Waste residues;
- Water use;
- Waste water;
- Gas emissions;
- Others:

Current development level: This criterion assess the current development level of the technique/tool according to the actual application status

- Theoretical: there are just theoretical academic studies concerning the application of the ecodesign technique/tool;
- Experimental: the ecodesign technique/tool were already applied in case studies in pilot projects in order to validate them;
- Consolidated: the ecodesign technique/tool is already validated and applied regularly in the product development process of companies.

Environment assessment method: this criterion verifies if the ecodesign technique/tool presents the existence of an environmental impact assessment method

- Yes;
- No.

Demanded time for use: this criterion assess in a qualitative way the amount of time needed to the application of the technique/tool

- Low;
- High.

Application and acquisition cost: this criterion assess in a qualitative way the application and acquisition cost of the technique/tool

- Low;
- High.

User specialization level in environmental area: assess the knowledge level on environment required by the designer in the application of the technique/tool and interpretation of the results obtained

- Low;
- High.

Information obtained about the technique/tool: presents the detail level of the technique/tool obtained in the studies

- Superficial: the study presents just general information about the technique/tool;
- Succinct: the study presents specific information about the technique/tool, but in a succinct manner;
- Complete: the study presents complete information about the ecodesign technique/tool.

The overview of the classification of the Ecodesign techniques and tools into these criteria are presented in Appendix C.

It is important to notice that, once selected, the ecodesign techniques/tools must be adapted and customized by the company, according to its specific product development process and current tools in order to be more easily accepted and used by development engineers and designers (QUELLA; SCHMIDT, 2003).

According to Knight and Jenkins (2009), such tools and techniques are not necessarily generic and immediately applicable, but instead require some sort of process-specific customization prior to use, considering the common language, culture and current systems at a company. This can be addressed at two levels: firstly, choice of the tools which will ultimately support the ecodesign procedure that is to be implemented, and secondly, the detailed adaptation of those tools to the specific needs of the design process under consideration (KNIGHT; JENKINS, 2009).

In this context, Knight and Jenkins (2009) proposed a five-step applicability framework to support the selection and adaptation of the ecodesign tools/techniques:

1. Investigation into available tools and into the specific design process under consideration;
2. Compatibility analysis: initial assessment to develop a short-list of tools;
3. Compatibility peer review: discussion on the short-listed tools by a range of competent staff representing all levels of the organization;
4. Adaptation and refinement of the most promising tools identified by the peer review;
5. Validation through compatibility confirmation on a sample product, and subsequent incorporation into standard company processes.

In the EcoM2, the tools and techniques are selected based on the ecodesign management or operational practices to be adopted (this substitutes the step 1 of the aforementioned framework). Then, the classification of the ecodesign techniques and tools into the 13 criteria presented in the Ecodesign Maturity Model (EcoM2) support companies in the selection of the most suitable ecodesign techniques and tools to be used (this substitutes step 2 of the applicability framework, providing a short-list of tools). However, the company still needs to select the specific tool/technique to be used (step 3 of the applicability framework) and carry out customizations of these techniques and tools before their application (steps 4 and 5 of the applicability framework). Furthermore, the ecodesign tools and techniques need to be integrated to the traditional tools used during the product development process, i.e. it must be ensured the sharing of input data and integration of output data among traditional and ecodesign tools (DEWULF; DUFLOU, 2004).

The implementation of the tools in the product development process is a very important success factor that must be thoughtfully considered (PETALA et al., 2010) during the ecodesign implementation.

4.2.3.4 Relationship among ecodesign practices

The ecodesign management and operational practices are interrelated among them and can be supported by a set of ecodesign techniques/tools (Figure 9). In this activity, the relationships and dependences among the ecodesign practices of the EcoM2 were analyzed and established.

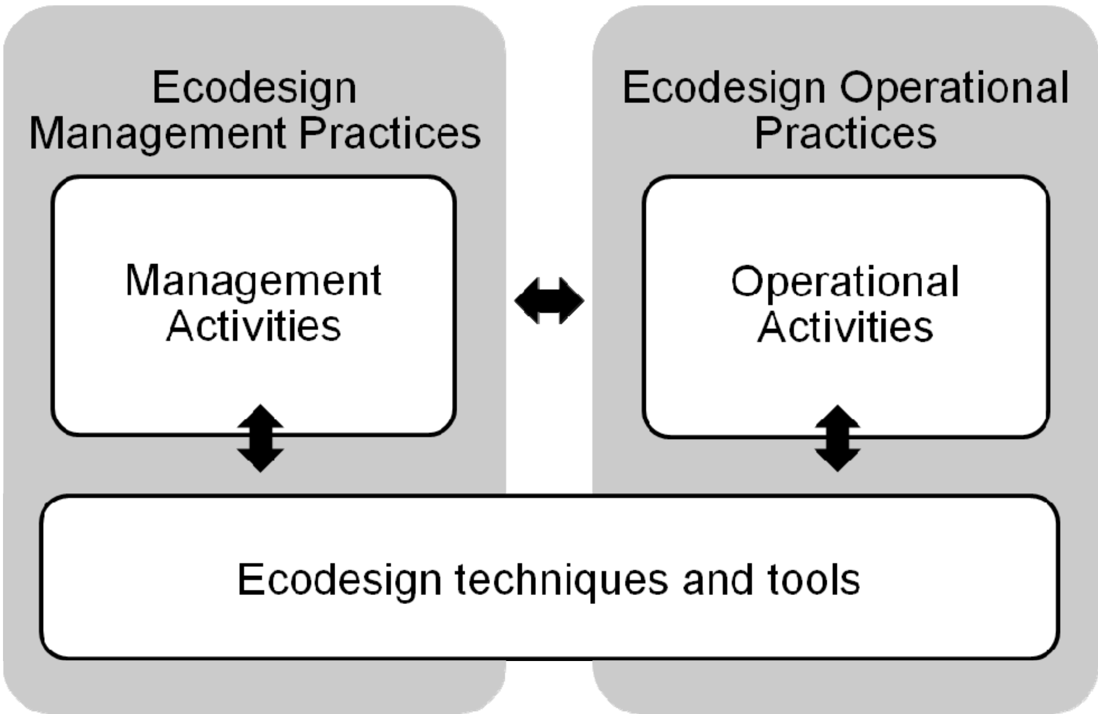

Figure 9: Relationships among the ecodesign practices

Considering "EMP" as ecodesign management practice, "EOP" as ecodesign operational practice and "ETT" as ecodesign techniques and tools, the following types of relationships and dependences can be defined:

Dependence relationships among the EMPs

Relations of dependence among the ecodesign management practices can be established, i.e., there can have pre-requisites for the application of certain ecodesign management practices (Appendix A). For example, in order to apply the practice “10002: Deploy and maintain an environmental policy/strategy for products” it is required to have previously applied the practice “10001: Formulate a company environmental policy/strategy”. The practice “20001: Evaluate the environmental performance of products” is also a pre-requirement for the application of the management practice “20004: Establish priorities on the environmental impacts to be minimized (invest time and effort in activities with significant contribution)”, since it supports the identification of the environmental hot spots[48] of the product under analysis.

The analysis of the dependence relationships among the ecodesign management practices is relevant for the definition of the improvement projects to be implemented by companies in order to achieve higher maturity levels on ecodesign implementation (see section 5.6), especially when the continuous approach for process improvement is selected. The relationships need to be analyzed in order to determine basic practices that need to be implemented before the selected ecodesign practice can be implemented. Additionally, the dependence relationships can guide the establishment of priorities and of a roadmap of the practices to be implemented by a company.

Relationship among the EMPs, ETTs and EOPs

An analysis was performed to identify which ecodesign techniques/tools (see section 4.2.3.3) could support the application of the ecodesign management practices (Appendix A). The analysis was performed based on the evaluation of the main goal of each technique/tool (for example, “deploy the environmental requirements of the customers” is the main goal of the tool “m00050 - Environmental Quality Function Deployment (EQFD)”) and subsequent correlation with the ecodesign management practices (in this example, the ecodesign management practice associated with EQFD is “60001: Identify the

[48] Environmental hotspots are stages in the life cycle, or environmental aspects, such as energy, that cause a high environmental impact of a product or service (UNGER et al., 2008)

customer and stakeholders requirements and priorities concerning the environmental issues”).

Another example of ecodesign management practice is “20001: Evaluate the environmental performance of products”. In order to support the application of this management practice, there are a set of ecodesign techniques and tools that can be used, ranging from complex methods such as m00006 - Life Cycle Assessment (LCA) (ANDERSSON et al., 1998; BREZET et al., 1999; GUINÉE et al., 2001; TINGSTROM; KARLSSON, 2006) to more simplified and abridged ones, such as m00070 - MET (Material, Energy and Toxics Matrix) (UENO et al., 2001; BYGGETH; HOCHSCHORNER, 2006) and m00069 - MECO (Material, Energy, Chemicals and Others Matrix) (HOCHSCHORNER; FINNVEDEN, 2003; HOCHSCHORNER, 2004).

The application of ecodesign management practices can also be linked to the ecodesign operational practices. For example, the ecodesign management practice “80004: Analyze and select the suitable ecodesign strategies/ guidelines/design options according to the environmental goals of the product” must be performed based on an analysis of the ecodesign operational practices (ecodesign strategies, guidelines and design options) – section 4.2.3.2.

The establishment of relationships among ecodesign management practices, tools/techniques and operational practices enables the deployment of strategic activities into tactical and operational ones – it allows the link between management and product specification, providing guidance on how the ecodesign management practices should be implemented and deployed into an organization.

Relationship among the EOPs and the ETTs

The ecodesign operational practices are also associated to ecodesign techniques and tools, which can support their application (Appendix B). The relationships among the ecodesign operational practices and the ecodesign techniques and tools were established based on a comparison among the main goals of the tools/techniques and each given guideline/design option. For example, to support the application of the guideline “c40007 - Facilitating Remanufacturing”, there are a set of ecodesign techniques and tools that can support its application such as m00044 - EDIT (Environmental Design Industrial Template) (SPICER; WANG, 1997) and m00043 - ELDA (End-of-Life Advisor) (SUN et al., 2003). The ecodesign operational practices and their association with ecodesign techniques/tools are presented in Appendix B.

The establishment of relationships among the ecodesign operational practices and the ecodesign techniques/tools can support companies in the implementation of the operational practices and in the selection of the most suitable tools/techniques to be implemented into the product development process.

<u>Final considerations about the relationships among the ecodesign practices</u>

Since there are several techniques and tools with similar goals (for example, evaluate the environmental performance of products or facilitating disassembly), the same ecodesign practice (EMP or EOP) may be associated with more than one technique/tool. On the other hand, there are some EMPs and EOPs that do not present any relationship/dependence and are, therefore, not supported by ETTs. In this case, the company must implement the practice considering its own culture, tools and processes for implementation[49].

Furthermore, it must be noted that there are some ecodesign techniques and tools that can be applied in more than one ecodesign management or operational practices. It usually happens when the ecodesign technique/tool has broader goals and applications.

The selection of the most suitable tool/technique to be used to the application of a specific practice can be supported by the classification criteria (see section 4.2.3.3) and must consider the current maturity level (see section 4.3.2) of the company (PIGOSSO et al., 2011). Moreover, the company has the freedom to develop an in-house tool or adopt other tools they find suitable as far as the ecodesign management practice are being applied.

[49] An analysis of the gaps in the existence of ecodesign techniques and tools for supporting the ecodesign management and operational practices can indicate future potential areas where ecodesign techniques/tools should be developed to further support the ecodesign implementation.

4.3 Ecodesign Maturity Levels

This section presents the ecodesign maturity levels defined in the theoretical version of the Ecodesign Maturity Model (EcoM2). In the first section (4.3.1), a consolidation of the literature review on the dimensions used to define the stages for ecodesign implementation (sections 3.1.3 and 3.1.4) is presented. Section 4.3.2 presents the description of the ecodesign maturity levels, as defined by the Ecodesign Maturity Model (EcoM2), by combining a selected set of dimensions.

4.3.1 Dimensions for ecodesign implementation

The deployment of the stages for ecodesign implementation into dimensions (recurrent criteria used by the authors to describe the stages for ecodesign implementation) was performed considering the main aspects taken into account in each definition (presented in section 3.1.3). As a result of the analysis process, six dimensions for ecodesign implementation could be distinguished, as following described:

- 1) Drivers for ecodesign implementation:
    - Someren (1995) distinguishes three levels for ecodesign implementation: (1) legislation compliance; (2) cost considerations; and (3) strategy consideration;
    - McAloone (1998) argues that the drivers definition is the first step for "initial/sustained motivation" and is based on the "positioning in the world";
    - Willard (2005) defines five levels, which includes (1) pre-compliance; (2) compliance; (3) beyond compliance; (4) integrated strategy; and (5) purpose and passion;
    - Boks and Stevels (2007) cluster companies into three levels: (1) regulatory requirements; (2) defensive strategies; and (3) pro-active behavior/active lobbying;

    - Murillo-Lina et al. (2011) defines four levels: (1) passive strategy; (2) attention to legislation strategy; (3) attention to stakeholders' strategy; and (4) total environmental quality strategy.

- 2) Implementation path for ecodesign:
    - Someren (1995) defines three levels for ecodesign implementation: (1) ad hoc management of environmental issues; (2) integration into business practice; and (3) integration into strategy;
    - Pascual et al. (2003) divides into two phases: (1) pilot projects; and (2) ecodesign applied in a daily basis;
    - Alakeson and Sherwin (2004) distinguish four stages: (1) single issue; (2) ad hoc; (3) tools; and (4) strategy;
    - De Caluwe (2004) defines the following eight levels: (1) first signs of methods and tools; (2) ecodesign procedure including mandatory environmental requirements; (3) ecodesign procedure integrated in the management system; (4) mandatory ecodesign procedure in place; (5) environmental roadmaps used as input for target setting in the ecodesign procedure; (6) targets/improvement trends in environmental roadmaps based on environmental performance benchmarks with competitor or predecessor products/ technologies; (7) annual external auditing process covers the ecodesign procedure; and (8) self-learning organization focused on sustained business excellence, fully integrated with partners;
    - Pascual et al. (2003) distinguish two levels: (1) ecodesign rules level; and (2) ecodesign management and integration;
    - Boks and Stevels (2007) define three main levels: (1) general principles and slogans; (2) checklists, guidelines and examples of best practices; and (3) customized tools, databases, including information of the company´s internal and external value chain;

- 3) Company widening for ecodesign implementation:
  - McAloone (1998) defines three levels: (1) departments; (2) the whole company; and (3) management chain;
  - Charter (2001) proposes six levels: (1) environmental manager; (2) Research & Development (R&D); (3) technical integration into the product development process (PDP); (4) semi-integration into the PDP; (5) full-integration into the PDP; and (6) strategically consideration;
  - De Caluwe (2004) defines four levels: (1) integrating ecodesign procedure and product creation process; (2) secure procedure in systems; (3) target setting and environmental roadmaps; and (4) monitoring with performance indicators;
  - Boks and Stevels (2007) define three levels: (1) personal to department level; (2) department to company level; and (3) company to chain level;
- 4) Knowledge level on ecodesign implementation
  - McAloone (1998) states that the company is improving its knowledge of ecodesign by means of training, provision of specific information, communication of the environmental goals to the stakeholders, etc.;
  - Charter (2001) defines four knowledge levels for ecodesign implementation: (1) ignorance; (2) starter; (3) integration into process and (4) strategically consideration;
  - Boks and Stevels (2007) define three stages: (1) relatively ignorant (generic solutions and understanding); (2) have been introduced (solutions and understanding tailor-made to the industry); and (3) have all procedures in place (solutions and understanding tailor-made to products and processes).
- 5) Existence of measures for ecodesign implementation:
  - Someren (1995) defines three levels: (1) technical measures; (2) organizational measures; and (3) strategic measures;

- Pascual et al. (2003) distinguish three levels: (1) do not set targets; (2) set up qualitative targets; and (3) set-up quantitative targets;
- Murillo-Luna et al. (2011) address four different levels: (1) does not adopt any kind of technical/organizational environmental protection measure; (2) environmental measures adopted by the company have not involved any significant change; (3) environmental measures adopted by company have required modification; and (4) environmental measures adopted by the company are highly relevant to conditioning the organizational structure and how work is performed at the company.

- 6) Innovation level of the product on ecodesign:
  - Shelton (1995) defined three levels: (1) protecting mature products; (2) rejuvenating existing products with growth potential; and (3) commercializing new products.
  - McAloone (1998) affirms that companies typically start by making single issue improvements to their designs and slowly develop more sophisticated tools and techniques for including environmental criteria;

This last dimension is aligned to the literature review on the innovation levels on ecodesign, presented in section 3.1.4. The different classifications for the ecodesign innovation levels are summarized in Table 7.

The classifications of the ecodesign innovation levels are very similar: all of them present four innovation levels with similar content and path for evolution. The classification proposed by Vezzoli and Manzini (2008), however, is slightly different and incorporates an innovation level related to the creation of new scenarios for a sustainable lifestyle. The classification proposed by Leitner et al. (2010) seems to consolidate and clarify the main concepts of the previous definitions, and was selected to be used in this research.

Table 7: Comparison of the classifications for the ecodesign innovation levels

(BREZET.; HEMEL, VAN, 1997)	(CHARTER; CHICK, 1997)	(STEVELS, 1997)	(VEZZOLI; MANZINI, 2008)	(LEITNER et al., 2010)
Product improvement: small adjustments are made in the products/production, such as change of existing materials or adoption of a pollution control equipment	Re-pair existing products: minor alterations/ substitution of existing products dealing with single environmental issues	Level 1: incremental improvement of the product	Redesign of environmental systems (choosing materials and energy sources with low environmental impact)	(L1) - Incremental improvements: small, progressive improvements to existing products - based on common sense or check lists
Product redesign: parts of the product are better developed or replaced by others.	Re-fine: product redesign, may use a more environmentally sensitive material or be produced to have an extended life	Level 2: redesign of existing products (the concepts are environmentally improved up to the limits)		(L2) - Re-design or ‘‘Green-limits’’: major re-design of existing products limited by the level of improvement that is technically feasible
Function innovation: involve changes in how the product functions are obtained. New and different concepts with less environmental impact replace existing products;	Re-design: adoption of lifecycle perspective to reduce the impact across all the lifecycle stages (significant redesigned or new product concepts)	Level 3: functionality is fulfilled in an alternative manner (new concepts are created)	Design of new products/services (new ones systems with better environmental sustainability)	(L3a) - Functional or ‘‘Product’’ Alternatives that lead to ‘‘Green’’ Innovation: new product or service alternatives
System innovation: refers to new products and services that require changes in infrastructure and other systems that are related to product use	Re-think: products and the companies´ core business, exploring completely new ways to satisfy customer needs and design concepts	Level 4: functionality concepts are conceived so as to fit completely into a sustainable society.	Design of new production/consumption systems (offering solutions intrinsically sustainable)	(L3b) - Design for the sustainable society that leads to ‘‘Green-System’’ Innovation: functionality completely fitting into sustainable society
			Creation of new scenarios for a sustainable lifestyle	

4.3.2 Description of the ecodesign maturity levels

As described in the previous section, the stages for ecodesign implementation can be defined according to the following dimensions:

- 1) Drivers for ecodesign implementation;
- 2) Implementation path for ecodesign;
- 3) Company widening for ecodesign implementation;
- 4) Knowledge level on ecodesign implementation;
- 5) Existence of measures for ecodesign implementation;
- 6) Innovation level of the product on ecodesign.

Based on the results of the systematic literature review carried out for the identification of the ecodesign practices (section 4.2), it can be argued that the dimensions:

- “1) Drivers for ecodesign implementation”; and
- “5) Existence of measures for ecodesign implementation”.

are already included in the ecodesign management practices addressed by the model. The ecodesign management practices are, for example, related to the identification of internal and external drivers for ecodesign implementation and to performance measurement. In this sense, these dimensions were not considered in the definition of the ecodesign maturity levels.

In this sense, the EcoM2 maturity levels were developed by the combination of the dimensions:

- “2) Implementation paths for ecodesign”;
- “3) Company widening for ecodesign implementation”;
- “4) Knowledge level on ecodesign”; and
- “6) Innovation level on ecodesign”.

In order to aggregate dimensions and simplify the model, the “evolution level on ecodesign” was defined as a combination of the dimensions:

- “2) Implementation paths for ecodesign”,
- “3) Company widening for ecodesign implementation”; and
- “4) Knowledge level on ecodesign”.

The variables of these dimensions (section 4.3.1) were analyzed and structured in order to build up a unique description of the “evolution level on ecodesign”. The dimension “6) Innovation level on ecodesign” was maintained as a single dimension, adopting the classification proposed by Leitner et al. (2008). Thus, the maturity levels for ecodesign implementation were defined based on the combination of the evolution and innovation levels on ecodesign implementation.

The Ecodesign Maturity Model (EcoM2) is composed by five maturity levels[50], which represents the evolution from the no consideration of environmental issues to the integration into the company strategic planning. It shows the path that a company should follow in order to improve the environmental performance of their product development and related processes. The ecodesign maturity levels of the theoretical version of the EcoM2 are:

Maturity Level 0

- Evolution Level: Company has no experience on ecodesign and does not yet apply practices to improve the environmental performance of the developed products. The environmental issues of products and the benefits of ecodesign adoption are not exploited yet.
- Innovation level on ecodesign: no project for improvement the environment performance of products is carried out.

Maturity Level 1

- Evolution level: The company does the first moves in the ecodesign application, is already familiar with some practices and with the potential benefits of ecodesign. Pilot projects with focus on specific phases of the product life cycle are carried out. Punctual and not consolidated approaches for the application of ecodesign practices are observed, with emphasis in the application of the practices related to product design

[50] Based on the maturity models assessed, on the general characteristics of the maturity models described in section 3.2 and on the dimensions for ecodesign implementation selected, 5 different ecodesign maturity levels are defined in the Ecodesign Maturity Model (EcoM2).

specification. In this level, company strives to create awareness and motivation on ecodesign.

- Innovation level on ecodesign: Incremental improvements - small, progressive improvements to existing products - based on common sense or checklists.

Maturity Level 2

- Evolution level: In this level, the company recognizes the importance and benefits of ecodesign implementation. Projects to improve the environmental performance of products (e.g. materials and energy intensity) considering all the life cycle phases, from raw material extraction to end-of-life, are developed. Technical integration into detailed design phase can be observed. The company starts the first insertions of ecodesign practices into the processes and the first steps to structure the environmental approach and common patterns.
- Innovation level on ecodesign: Re-design or ‘‘Green-limits’’ - major re-design of existing products limited by the level of improvement that is technically feasible.

Maturity Level 3

- Evolution level: The ecodesign practices are systematically incorporated into the product development process, since the initial phases (e.g. idea generation during conceptual design). Functionality analysis is now applied to conduct ecodesign.
- Innovation level on ecodesign: functional or ‘‘product’’ alternatives that lead to ‘‘green’’ innovation: new product or service alternatives.

Maturity Level 4

- Evolution level: the incorporation of environmental issues into company's corporate, business and product strategies take place. Environmental issues are considered jointly with technical and economic issues to support the decision making process.

- Innovation level on ecodesign: Design for the sustainable society that leads to ‘‘green-system’’ innovation: functionality completely fitting into sustainable society.

As presented in section 4.2.3.1, the ecodesign management practices are classified according to the ecodesign evolution levels defined by EcoM2 (Appendix A). A correlation matrix in which each management practice was compared to the characteristics of the evolution levels established was developed. The synthesis of the correlation matrix enabled the classification of the ecodesign management practices into the evolution levels, which were subsequently evaluated by a set of ecodesign experts (section 4.5) and further improved in the action research (section 5).

4.4 EcoM2 application method

The purpose of the EcoM2 application method is to guide the application of the Ecodesign Maturity Model (EcoM2) and establish a continuous improvement framework for the incorporation of ecodesign practices into the product development and related processes – i.e. to improve the processes of the organizations to incorporate the environmental issues.

McAloone (1998) claims that the change process for ecodesign implementation should be of greater concern to industry. According to Brezet and Rocha (2001), the effectiveness of ecodesign activities will be limited if they are not integrated into strategic management and daily operation of companies in a dynamic process of continuous improvement of the environmental performance. The ecodesign management must be established, documented, implemented, maintained and continuously improved (ISO, 2010).

Kotter (2007) affirms that change process goes through a series of phases that, in total, usually require a considerable length of time. The length of time necessary to adopt an ecodesign approach is likely to be several years (POCHAT, LE et al., 2007). Skipping steps creates only the illusion of speed and never produces a satisfying result (KOTTER, 2007).

In order to gather knowledge on how to perform process change for the incorporation of the environmental issues, a literature review on organizational changes[51] for process improvement was carried out. Two main approaches for process improvement were identified and incorporated into this research in order to build up the EcoM2 application method: the PDCA (Plan, Do, Check and Act) approach for process improvement and the Business Process Management (BPM) approach.

The PDCA cycle, also known as Deming cycle, contains a set of four basic steps to be followed in order to implement continuous improvement cycles (DEMING, 1986):

- Plan: study the current situation and develop changes for improvement;
- Do: pilot measures in a trial basis;
- Check: examine effect of changes to see if the desired results is achieved; and
- Action: standardize on a permanent basis.

The PDCA cycle evolved over time to the Business Process Management (BPM) approach. The traditional steps a business improvement project would complete in the BPM approach are: understand the business context and stakeholder vision; perform the diagnosis of the "as is" process; develop the "to be" process; develop and implement changes; and perform the continuous improvement (JESTON; NELIS, 2006).

Business Process Management (BPM) can be defined as a structured and systematic approach to analyze, improve, control and manage processes in order to improve product and/or service quality. From a holistic standpoint, BPM combines total quality management (TQM), which is incremental, evolutionary and continuous, and process reengineering, which is radical and revolutionary (JESTON; NELIS, 2006).

The Ecodesign Maturity Model (EcoM2) application method was developed based on the PDCA and BPM approaches for process improvement considering

[51] Organizational changes can be classified into four interconnected and interacting dimensions: (1) process change (process transforms inputs into outputs of value to customers), (2) functions and structure change (the way the people in a company are organized), (3) culture change (such as traditions, values and beliefs) and (4) politics change (power distribution for decision making) - change in one dimension will probably result in compensatory change in other dimensions (CAO; MCHUGH, 2005).

the specificities of ecodesign implementation, according to the literature review carried out. Moreover, the administration methods suggested in the maturity models analyzed in the literature review (see section 3.2.2.2) were used as inspiration to develop the EcoM2 application method.

The Ecodesign Maturity Model (EcoM2) application method comprises the following six steps:

1) <u>Diagnosis of the current maturity profile on ecodesign[52]</u>

The first step in the method is to assess the current situation of an organization concerning the consideration of environmental issues during the product development and related processes. It is done by performing a diagnosis of the current maturity level of the company by assessing which ecodesign management practices are currently applied by the company.

2) <u>Proposition of ecodesign management practices/improvement projects</u>

Once the current maturity level is obtained, the most suitable practices to be adopted are proposed, considering the maturity level of the company in ecodesign implementation (first filter of the practices) and also the strategic drivers for ecodesign adoption (that can include environmental laws/regulations, costs reduction, environmental customer awareness, new business opportunities, value creation and innovation opportunities). Once the company decides which practices must be applied, the future situation is designed in order to build a common future view of the desired process for the company.

3) <u>Portfolio management of the projects for ecodesign implementation;</u>

The next step involves the portfolio management of the projects for ecodesign implementation, defining when they are going to be developed at the company.

4) <u>Planning of the projects for ecodesign implementation</u>

In this step, the planning of the projects (including scope, resources, schedule, responsible, performance measurements, etc.) is carried out.

5) <u>Implementation of the projects for ecodesign implementation;</u>

The projects for process improvement are implemented, according to the plan developed in the previous stages;

[52] Ney (2008) argues that the ecodesign approach is indeed supposed to start with a diagnosis of the company´s activities and products

6) Assessment of the results.

Finally, the results obtained in the implementation of the ecodesign practices are measured by performance indicators

The improvement cycle can be repeated as many times as the company needs for maintain its continuous improvement towards higher maturity levels on ecodesign. It is expected that the action research, to be carried out in the third phase of the research, supports the improvement of the EcoM2 application method based on its use in a real company.

The sections 4.1, 4.2, 4.3 and 4.4 presented the theoretical version of the Ecodesign Maturity Model (EcoM2), composed by the ecodesign practices, the maturity levels and the application method. The next section (4.5) presents the evaluation of the EcoM2 by experts on ecodesign. The improvements carried out to develop the second version of the EcoM2 are presented in section 4.6.

4.5 Evaluation of Ecodesign Maturity Model by experts on ecodesign

The evaluation of the theoretical version of the Ecodesign Maturity Model (EcoM2) through consultation with ecodesign experts comprised the application of the face-to-face interviews technique (see section 2.2.1).

According to the interview dimensions defined by Lancaster (2005), the interview methodology adopted can be classified as formal, semi-structured, individual, qualitative and face-to-face. In the semi-structured interviews, there are predetermined issues and topics that must be discussed, but not in a rigid manner or necessarily in a rigid order. The interviews are designed to be focused in terms of topics covered and yet flexible in that it is possible (and often desirable) to steer questions into areas that appear promising from the view point of providing rich data and/or additional insights (LANCASTER, 2005). The methodology carried out to plan and conduct the interviews follows the following key steps proposed by Lancaster (2005):

- Determine data objectives and topics for discussion (section 4.5.1);
- Identify and approach the experts to be interviewed (section 4.5.2);
- Execute the evaluation meetings (section 4.5.3);
- Consolidate the expert´s comments (section 4.5.4);

After carrying out the interviews, the data gathered were analyzed in order to improve the theoretical version of the Ecodesign Maturity Model (EcoM2) (section 4.5.5).

4.5.1 Determine data objectives and topics for discussion

The goal of the interviews is to evaluate the theoretical version of the Ecodesign Maturity Model (EcoM2) in order to gather feedback and suggestions for improvement. The suggestions for improvement are based on the comments of a set of ecodesign experts, with different backgrounds and research focus on the ecodesign area.

The face-to-face interviews for the evaluation of the Ecodesign Maturity Model (EcoM2) by experts are divided into two parts. The first part of the interview intends to present to the expert the general concept of the Ecodesign Maturity Model, detailing its main elements: the Ecodesign Practices (section 4.2); the Ecodesign Maturity Levels (section 4.3) and the EcoM2 Application Method (section 4.4). During the presentation, the expert is welcome to clarify specific queries and/or to make comments about the model.

In the second part of the interview, the experts are invited to provide their feedback on the model and its elements, following a semi-structure questionnaire which addresses (1) the potential contribution of the EcoM2 to the academia and industry; (2) the strengths and weaknesses of the EcoM2 and its elements; (3) the evaluation of the ecodesign practices, maturity levels and application method; and (4) the provision of suggestions for improvement. The meeting is designed to have an average duration of 120 minutes: 60 minutes for the presentation of the EcoM2 and 60 minutes for discussion and feedback. Depending on the availability of the expert, the meeting can last longer.

Before proceeding to the performance of the evaluation meetings of the EcoM2, a pilot test of the methodology developed was carried out with an expert on sustainable design, Prof. Dr. Aguinaldo dos Santos, from the UFPR (Universidade Federal do Paraná), Brazil. In this opportunity, the methodology was adjusted in other to better cope with the challenges of performing the evaluation meetings with the experts.

4.5.2 Identify and approach the experts to be interviewed

In order to select the ecodesign experts to evaluate the Ecodesign Maturity Model (EcoM2), a recurrence analysis of the authors with more publications and citations in the ecodesign studies obtained during the systematic literature review (see section 4.2) was conducted. As a result, 40 potential qualified experts (Appendix D) that could evaluate the Ecodesign Maturity Model (EcoM2) were identified.

The selected experts were contacted by e-mail and invited to contribute in the evaluation of the Ecodesign Maturity Model (EcoM2). The e-mail sent to the experts (Appendix E) included information about the:

- Researcher´ background and the University of São Paulo;
- Researches and context of the research group;
- Motivation for the development of the Ecodesign Maturity Model;
- Purpose of the evaluation meeting.

From the initial list of 40 experts identified, 12 replied positively about the interest in participating in the Ecodesign Maturity Model (EcoM2) evaluation. In this occasion, two of them suggested to add two experts from their universities to be interviewed: Anna Hedlund-Åström from the Royal Institute of Technology (Sweden) and Alan Lelah from Grenoble University (France). In total, a set of 14 experts on ecodesign were interviewed (Table 8).

Table 8: Ecodesign experts who evaluated the Ecodesign Maturity Model

Name	University/Company
Ab Stevels	Delft Technical University/Philips (Netherlands)
Anna Hedlund-Åström	Royal Institute of Technology (Sweden)
Alan Lelah	Grenoble University (France)
Casper Boks	Norwegian University of Science & Technology (Norway)
Conrad Luttropp	Royal Institute of Technology (Sweden)
Erik Sundin	University of Linköping (Sweden)
Fabrice Mathieux	Grenoble University (France)
Han Brezet	Delft Technical University (Netherlands)
Mark Goedkoop	PRe Consultants (Netherlands)
Martin Charter	University for Creativity Arts (England)
Mattias Finkbeiner	Technical University of Berlin (Germany)
Mattias Lindahl	University of Linköping (Sweden)
Tom Swarr	Five Winds International (United States of America)
Tracy Bhamra	Loughborough University (England)

The experts represent academia knowledge (mostly European), practical experience in industrial companies (like Phillips) and consulting companies (like Pre-Consultants). Moreover, different styles of ecodesign implementation are well represented in the selected experts.

4.5.3 Execute the evaluation meetings with the experts

The meetings to evaluate the Ecodesign Maturity Model (EcoM2) occurred from May to August 2010, while the researcher was performing a doctorate sandwich at the Technical University of Berlin (TU Berlin) within the context of a cooperation program between Brazil and Germany (BRAGECRIM - Brazilian and German Collaborative Research on Manufacturing).

The methodology designed for carrying out the interviews presented in the previous section was successfully applied during the meetings, which were recorded in a way agreed by the experts and then documented.

The average time of the interviews was 150 minutes. Most of the interviews were performed face to face (13 of 14), but due to some logistical issues, one of them was performed by using an online communication tool in the internet (sound and image), without prejudice to the results of the interview. In most of the cases, the researcher went to the universities/companies in where the experts work in order to perform the evaluation meetings.

4.5.4 Consolidate the expert´s comments about the EcoM2

The feedbacks about the EcoM2 are presented by a transcription of the interviews[53]. The comments are grouped according to following the topics:

- General concept of the model (section 4.5.4.1);
- Ecodesign practices (section 4.5.4.2);
- Ecodesign maturity levels (section 4.5.4.3);
- EcoM2 application method (section 4.5.4.4); and

[53] A selection of the commentaries to be presented in the thesis was performed from the total amount of circa 35 hours of interviews. Punctual commentaries, such as those related to the classification of the ecodesign management practices in the evolution levels, were not included in the thesis, but were fully considered to perform the improvements of the EcoM2.

- Other remarks (section 4.5.4.5).

It can be observed in the transcripts the richness discussions carried out with the experts: each of them with their personal background and focus has contributed to analyze the EcoM2 on complementary point of views.

4.5.4.1 EcoM2 general concept

"*Your model seems to be very ambitious; it is complete and covers all the areas of Ecodesign*".

"Well, nice. It is interesting that it takes a management perspective, it is very important to have a better understanding. But for me it would be special interesting if you could synthesize a little bit more."

"*It seems very interesting, impressive and fantastic to have all of the techniques together in one tool*".

"*Sounds very smart and clever model that help the companies to get into it right*".

"*The model and your effort are really interesting. I think it is interesting to have these general view of considering strategies, guidelines, techniques and tools together. The idea and initiative are both very good*."

"*I feel happy and to some extent relieved that you put Ecodesign maturity in strong relationship with business process management and companies (environmental) strategy. Few ecodesign practitioners do that and the consequence is a wide array of misunderstandings, frustrations and failures and to turn to the other side, it will make your approach special and valuable*."

"*I really appreciate that you have made an overview of all these things and compared things. I think that both from an academic point of view but also in practice you have a good approach. I expect that you have problem in testing many parts of your model because companies are at low maturity levels. You* *have to adapt a lot of things very practicable and they will test you also on your contribution for the company. In that sense, before you go to companies, it would be good to have very superficial tests with ten companies also*".

"*I really like the idea and I just think that it will be challenging for you to make it feasible and work. From a theoretical point of view it fits very nicely and I like the way you have put together most the different techniques, approaches, models, tools and everything into only one thing. It is obviously a lot of work. The implementing is the hard aspect, proving that it works through the whole cycle*."

"*You got it right: ecodesign isn't just technical, it is also organizational. One of the key issues to get things adopted in the organization is to translate into the business benefits to the organization in the different functions*."

"*It [management issues] is very much a key aspect. That´s what I think we failed with Eco-it, it is integrated. It has to be a little bit more specific for a company*."

"*I think it's a really nice idea and I like the way it works and I can see that it can be good for relative large companies. I think it would be a complete another piece of work to work with small companies, you'll have to look to the differences in which they operate the management practices, but for a large organized company it would fit very well.*"

"*You have done an enormous work on collecting them [ecodesign practices]. It's really a big system you have created. It's interesting, a really amazing job. I've never seen anyone such ambitious, putting everything together. What I especially like is that you have techniques and tools related to management and operational practices*".

"*Who is the audience for your model? One of the main drivers for the managers is what the competitors are doing. That is a really important point, so if you have a key driver. Some of the companies will benchmark best practices even in other sectors."*

4.5.4.2 Ecodesign practices

"*It shows that your literature survey is very good, you could find some ecodesign techniques and tools that have just 2 or 3 papers on that*."

"*Maybe it would be interesting to classify the guidelines according to the environmental aspects and product life cycle phases*."

"*It´s impressive [ecodesign operational practices], it´s so many! The problem with that is that they are contradicting… people get completed confused by these contradictions. Especially for a type of product, it is clearer."*

"*What you find when you look at ecodesign is a lot more stuff on tools and on techniques but when you look at the reality of organizations, it is much less than that. This is one of the key issues*."

"*I've seen so many tools developed, you have a lot in your list, and very feel of them are really used. One reason is that a lot of people are developing tools without asking the potential users on what they need, what is the interface?"*

"*Do you think that ecodesign techniques and tools are necessary? If you have a strategic way, if you really want, the environment can be included in the traditional tools. If it is successfully done, they do not need these ecodesign techniques and tools.*"

"*We can find almost no correlation between universities tools and approaches and successes in the market with the exception of this benchmarking approach, companies are learning between each other, but they had already did that for years… Inside companies there's a fight between product manager and environmental manager. Maybe for companies it is better go in the simple things and forget about techniques and tools.*"

"Eco-it was never a success. Actually there is very few ecodesign tools which really works, I sometimes have made a presentation on why ecodesign tools aren´t used. And one of the big problems is that is it often addressed on the final stages of the design process, when it should be on the initial phases. Designers are too struggling to look into numbers, because they want new concepts, which is vague. Cradle to cradle is getting popular here, because they say you should not make product less bad, but you must design good. Nobody knows what it means, but everyone is happy with that. So designers aren´t really engineers who want to see numbers and calculate, so they don´t really like LCA because it limits their freedom to do whatever they like"

"*In the early phases of ecodesign in Philips, there was an obsession about doing LCAs and then what you get through to the important point is not doing LCAs because it is costly, time expending and also do not give perfect results. So then the mature organizations are developing embedding life cycle thinking, simpler tools that early in the process they can identify hot spots and then more selectively they are using LCAs on sensitive products. It's quite an interesting indicator of maturity, the type of tool and how the organizations moved to more simplified tools. Designers, generally speaking, don't want to be Eco designers. They want to and should be in a position in what it is one of the criteria that is considered, and they need to know if it is good, bad or uncertain and then they need to assess information to make better decisions. So that's often a point that is forgotten, they do a lot of pressure in designers, they do not want to be experts, etc. So, the designer has the costumer of ecodesign*."

"*There is a strong tendency in the Netherlands and Germany to focus in completely other things than what is on the list: number 1 is cradle to cradle thinking and number 2 is the inspiration by biomimicry, getting inspiration from nature. It cannot be measured by LCA, for example, you get completely other rules. It's an ongoing process of finding process and shutting at all directions*."

"*My feeling is that the reference model [for product development] is very engineering oriented, as to say. There are a lot more stress on portfolio management, market research, this kind of stuff. Many people that work with* *ecodesign are from engineering background and start with the end (recycling), etc. These people are just now starting to care about environment. If you look for sustainability is more important, what and how are just details. The most important question is WHY?*"

4.5.4.3 Ecodesign maturity levels

"*I like the basic concept of the five levels and your definition of them. I think that it is very good. It has already been made before, but I think that you have a very good way of addressing this and I think that it is very good*".

"*This [the maturity levels] makes sense to me*".

"*Why did you choose 0 to 4 and not 1 to 5 [maturity levels]? No one wants to be zero. From a promoting and pedagogic point of view, I think you should change to 1 to 5.*"

"*How to measure how the companies are performing the management practices?*"

"*I was thinking first about the levels. I agree in general with this but would be possible that a company could be in one level for knowledge and one level for innovation*".

"Basic understanding [on ecodesign maturity levels] is clear for me. I know from literature that they talk about these different innovation levels a lot. In practice, I never was in a company who said "now we make a redesign or a new concept". Just from my experience, in practice this is less relevant than in the scientific literature."

"*Knowledge level and innovation level on ecodesign are not really strict to say that… they must be independent. Maybe you should take out the innovation level; I don't think it is relevant for the levels. There can be companies with the* *integration of ecodesign into strategy and just perform incremental projects. It can also be companies that have a lower maturity level that does leap frogs*".

"*The organization can be in different levels of knowledge and innovation. The determination of the levels should be different for each dimension*."

"*Strategy must be held before technical integration, because the company needs to be compromised with that*".

"*There are two approaches [for ecodesign adoption]: it is basically top-down and bottom-up. Basically, in top-down come corporate through business units, you need much higher senior level buyer. If you got the challenge, you don't want to set up two systems, so you don't want to set up a pure ecodesign management system, it is an argument about how you transition environmental aspects to speak on product development. If you are going to do that, and that is strategically, then you have actually to do it with a lot of training. In a lot of organization, they put tools in the intranet and then don't tell anything to anybody about it and neither on how to use that. Training and communication is really important. Bottom-up is what you see more traditionally, the company starts with one product and then try to understand what it means for the organization, and so on. It all depends on what the starting point is. Philips probably started bottom-up, to prove the business benefits and get managers more interested. There might be a transition approach, if we see the drivers becoming stronger; more organizations are starting to get top-down. It is still a little bit. There's something about learning and feedback loops. The lessons from the pilot projects have been learning by everyone in the organization.*"

"*One key thing is also if you suddenly are required to do ecodesign, an issue there is how to integrate that task into the job description and how you are evaluated in a way where you are integrating ecodesign in your daily to daily work. They may know that from a higher level, but they will not do that unless they are forced to that*."

"*My point here is that awareness creation is necessary to create a basis for increasing maturity of Ecodesign (and to get acceptance anyway). This is to be done through visible, separate Eco projects where the main emphasis on the environmental issues linked to business success. This will overcome the prejudices and will open the door to successful integration in the usual procedures and processes in the business*."

"*You build the model up and then you need to do some studies to see how useful the model has been, what has been the impact. Most of companies start on zero. If it is not a real top priority, there is a whole phase of them rising awareness, understanding, etc. before they even thinking about it in terms of product development. So the time from start to actually, physically coming up with potentially ecodesign incremental product can actually be a long time. It isn't just 18 months product development project. It is internal buying, and so on, it is an action really very challenging. The time issue is a really important issue on what we can achieve on a time scale*."

"*Probably there is something between pilot products and technical integration, but I don't know what. My feeling is that actually there's another stage, which is sort of post-pilot, pre-integration. The organization makes a decision in whether they see benefits on it and if they probably got another dimension in here that is yes or not, based on the pilot projects. So, yeah, there is something else that needs to come up from that*."

"What is the best way to do a pilot project: a radical product or an incremental one?"

"*We know we can't implement that [ecodesign] from the day to the night. It needs to have a continuous monitoring of legislation, customer needs, change of drivers… Full integration is a process, but deciding to go towards that is a strategic decision, which means resources, money, etc. It is a very important decision*."

"*In my experience, the priorities are already quite advanced on an explicit level. The risk with that is that it changes very often. In an early stage, the problem is that the priorities are somehow taken from the outside, but to establish internal priorities are a very advanced practice."*

"*What I would like to stress as a driver for Ecodesign is the opportunities it gives to add value to the company's products and services. This goes far beyond just cost reduction and innovation*."

"*Legislation is often cited as a driver for Ecodesign, but it can lead you completely on the wrong track. The reason is that environmental legislation is primarily the result of politicking rather than being supported by a strong scientific basis. This is posing a lot of dilemmas for companies wanting really to do something good for the environment!*"

"*The legal part is of course always important for companies, but from my personal understating compliance to law cannot be an advanced level, because you have to. Compliance with environmental law is not an environmental issue, it is a cost issue. Once you have the law, you have to fulfill it. In my experience, sometimes laws are even in conflict with ecodesign because they stop innovation. If you have a recycling quota, they will achieve it, but no other incentive. Also in my experience, this is very often a starting point.*"

4.5.4.4 EcoM2 application method

"*Well done, it was a lot of work. I think that the key thing is testing and validating with the companies, identifying the different types of organizations in terms of B2B or B2C and their stage at the value chain because that will have influence in the model. If the goal is to people actually use it, which should be, because there are a lot of ecodesign techniques and tools that are used just for few people. It would take time to think about how you can identify some motivated companies and individuals that will go into the tool and comment about it.*"

"*The model can be an extremely helpful tool for consulting, but maybe it is too difficult for a company to apply that by themselves*".

"*How much did you talk to industrial users up to now? Do you know what their needs are?"*

"*The biggest things to company is always simplifying, and simplify… the details must be undertreated*. *You have to get that [ecodesign] embedded, so everyone new that enters just sees that as part of their work*."

"*It is important to teach companies on how to use ecodesign and Ecodesign Maturity Model.* I *wonder if companies will manage to use the method without consulting*."

"*The only issue with that is that if it still looks like a lot of cycles in order to achieve a goal, it would not be motivating for the company… You need to think on how you are going to sell that to companies, they need to see the benefits*."

"*If you try to sell that to companies, then you will have the problem on how to do it. How this should be used is something that you still need to think about. It's just based on literature review; let's see how it happens in reality. I wonder who is supposed to use this, the managers?"*

"*Another key thing is that for a lot of organizations, they want to be told there are the three tools that are recommended to you, because I don't have the time to select it. It's important to think in a mechanism to identify which tools are more useful for the company. That is actually quite important, I think. A number of large organizations have a set of senior design, which has a lot of power in the organization and if they say that it is the tool, it will be that tool that will be used. Companies want answers on what they need to do, what is the best way to go further. That is something to be thought about, because I think that it is something that is missing*".

“*Probably what you are going to find is that most of the companies are at low maturity levels. You will be shocked by the practical level of these companies. Be prepared to that*. *There are a lot of companies that do not apply ecodesign, but claims to apply. You need to take care to what people say.*”

“*My advice is to narrow down in terms of the companies that you try for the PhD. A PhD only has to show a contribution, a small step forward, and I think you are giving a quite big step forward. So in terms of the implementation phase, if you could work with certain types of companies then you can talk about how it could be applied more widely. It would be a shame if you could not get the cycle*.”

4.5.4.5 Other remarks

“*You should consider ISO 14006 standard for the management of Ecodesign (in fact it is a focused detailing connected to ISO 14001). For your case particularly clause 4 and Annex A are relevant.”*

“*Study the relation between ecodesign and ISO 14.000 standards, how they need to adapt their systems to consider ecodesign.*”

“*One of the things that you should go in here is the guidance that can be provided by standards, like ISO14.062, ISO 14.006, that can provide guidance into the integration to ISO 14.001 and ISO 9.000. In reality, the companies do not want new systems, they want to have things integrated into the systems that they already have. So you need to take care of that in your model. Particularly, when you take to a level of integration, you need to take care on how it would work with the existing systems*.”

“*You did a great effort to see all the experts in the field and hope you appreciate their diversity in characters and interests.”*

“*You have a pretty good coverage of the people working on Ecodesign*”.

"*I believe that organizational capabilities in eco are just as important as the "technical" capabilities in Ecodesign*"

"*I have some doubts… there are two different things: writing a PhD and doing something to be applied by companies. The model may be so complicated for companies… maybe is better just to select the best two or three better techniques and tools and that's all*".

"*It is important to perform the case studies in the companies to see the differences between them, in the drivers, and in the methods to be used. It would be really interesting. The case studies are very important to test and validate the model*".

4.5.5 Data analysis and improvement of the EcoM2

The suggestions for improvements made by the experts were systematized and analyzed in order to select those ones to be implemented into the EcoM2. Analysis of correlation, complementarities and divergences were performed on the suggestions for improvements among different experts. The feasibility of the incorporation of the improvements was also analyzed, in order to select those ones that would be implemented into the EcoM2.

The implemented improvements on the second version of the Ecodesign Maturity Model, classified according to the elements of the EcoM2, include:

- EcoM2 general concept
  - Initially, the EcoM2 was meant to be applied by any company, regardless the level of systematization of the product development process. During the interviews, it was detected that the EcoM2 was more suitable to be applied in companies which already presents a relatively mature[54] product development process. So, the scope of the project was narrowed down and focused on this type of company;
  - On the second version, it was clarified that the Ecodesign Maturity Model (EcoM2) should be used by managers rather than by

[54] Business are likely to have formal or informal product development processes, and the formalization of the process is likely to be a function of the size of the organization – the larger the organization the more formal the process is likely to be (CHARTER, 2001)

designers, i.e.by the people responsible for the implementation of ecodesign in the company. In the first version of the model, the user of the model had not been clearly mentioned;

  - The second version reinforced the focus of the EcoM2 on process improvement rather than on product improvement – some confusions on the experts feedbacks in this relation were identified during the interviews;
  - The EcoM2 would be as simple as possible and of easy understanding for the companies. After the interviews, the way in which the model and its elements are presented was improved, aiming for simplification;

- Ecodesign practices
  - By the analysis of the experts, some similarities among the ecodesign management practices were identified. In order to avoid redundancies, the ecodesign management practices were analyzed one by one in order to identify those ones that should be merged into only one. Additionally, there are some practices that were deleted, according to the experts' suggestions;
  - Since the ISO 14.006 had not been launched by the time of the interviews, it had not been considered in the identification of ecodesign practices to be adopted in the model. The experts recommended analyzing the ISO 14.006 at its launch and studying it in detail. Its practices and concepts were fully integrated into the second version of the Ecodesign Maturity Model (EcoM2);
  - The ecodesign management practices were rewritten in order to bring a positive perspective to companies (for example, instead of saying "minimize environmental impacts", the experts suggested to say "improve the environmental performance");
  - In the first version of EcoM2, the ecodesign operational practices were not classified according to the environmental aspects and phases of product life cycle. This classification was implemented as a suggestion of the experts, since it can lead to a fast identification of those ecodesign operational practices that are more suitable to

product design according to the most relevant environmental aspects and product life cycle phases for a given product;

    - In the first version of the model, the ecodesign techniques and tools were not classified according to the maturity levels. A classification of the techniques/tools based on the maturity level was implemented in the second version of the EcoM2, according to an expert suggestion;

- Ecodesign maturity levels
    - Initially, the ecodesign maturity levels were numbered from 0 to 4. After a suggestion of the experts, the levels was changed from 1 to 5, in order to be more didactic for companies – “no one wants to be zero”, as one of the experts stated;
    - In the first version of the EcoM2, the innovation level on ecodesign was used as an element to define the ecodesign maturity levels. It was highly criticized by the experts. The experts argued that the innovation level on ecodesign is more related to the strategic positioning of a company than to the maturity in ecodesign implementation. It does not has a directly relation with the ecodesign maturity profile of the company. A company can be relatively mature on ecodesign and just perform incremental projects. In this sense, the second version does not consider the innovation level on ecodesign anymore in the definition of the maturity levels;
    - In the second version of the EcoM2, the capability level is considered in the definition of the ecodesign maturity levels, in combination to the evolution level on ecodesign. The goal is to measure how well the ecodesign management practices are being applied by the companies during the maturity assessment;
    - Adjustments on the classification of the ecodesign management practices in the evolution levels were performed based on the experts´ suggestions and also after the redefinition of the ecodesign maturity levels.
- EcoM2 application method
    - In the first version, it was intended that the model would be used for self-assessment of companies regarding its maturity level and definition of improvement ecodesign projects, such as OPM3 (see

section 3.2.2.2). As one of the interviewee argued, it would be difficult to companies to apply the EcoM2 by themselves. So, the scope was narrowed down and the focus was on the development of an application model that would support companies when applied by a third person.

The most substantial changes derived from the experts' evaluation of the EcoM2 were performed on the ecodesign practices and on the definition of the ecodesign maturity levels, regarding the innovation level, which was excluded from the definition of maturity. Minimal changes were proposed in the application method, since it is more related to practical application than to theoretical development. It must be stated, furthermore, that the description of the application method at this moment was still vague and incomplete.

Most of the experts agreed on the importance of the Ecodesign Maturity Model (EcoM2) for academia (mainly in relation to the systematization of the ecodesign practices) and for industry (despite still having some doubts on how the model should be applied at the companies). Additionally, the adopted approach to the development of the Ecodesign Maturity Model (EcoM2) regarding its management perspective linked to the operational activities was reinforced as a positive point by the experts.

4.6 Improved version of the Ecodesign Maturity Model based on the experts evaluation (second version)

In this section, the improvements performed at the theoretical version of the Ecodesign Maturity Model (EcoM2), according to the suggestions of the experts, are presented. In order to avoid the repetition of information, just the elements that were changed are presented.

Section 4.6.1 presents the improvements of the EcoM2 general concept and is followed by the clarification of the changes in the ecodesign practices (section 4.6.2) and ecodesign maturity levels (section 4.6.3).

4.6.1 Improvements on the EcoM2 General Concept

The Ecodesign Maturity Model (EcoM2) focuses on process improvement (product development and related processes) rather than on product improvement (improved environmental performance of a product/family of products). The maturity levels are tied to the degree to which companies have institutionalized ecodesign practices internally. It is assumed that, if ecodesign practices are properly taken into consideration during the product development and related processes, the natural consequence will be products with better environmental performance[55].

Due to the strategic nature of the decisions to be undertaken, the EcoM2 should be used by managers rather than by designers, i.e. by the people who are responsible for the ecodesign implementation into the company (also known as "environmental champions"). Once defined the practices to be applied, the projects are deployed into the tactical and operational levels based on the established relationships between the ecodesign practices (see section 4.2.2.4), with the definition of the ecodesign operational practices and techniques and tools to be applied. In this sense, the EcoM2 covers strategic, tactical and operational levels related to ecodesign implementation.

4.6.2 Improvements on the ecodesign practices

After the reorganization performed due to the experts' suggestions, the Ecodesign Maturity Model (EcoM2) contains a set of 62 ecodesign management practices (Appendix A[56]). The reorganization included merging among practices, exclusion of practices and addition of new practices related to the ISO standards. Moreover, a review was performed on the classification of the ecodesign management practices into the evolution levels and on the dependences and relationships with ecodesign techniques/tools and operational practices.

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[55] In this regards, CMMI-dev affirms that "the quality of a system or product is highly influenced by the quality of the process used to develop and maintain it" (CHRISSIS et al., 2003). This assumption is also in accordance to the ISO definitions of process improvement.

[56] As previously mentioned, the Appendix A presents the final consolidated version of the ecodesign management practices.

The ecodesign operational practices were classified according to the phases of the product life cycle (pre-manufacturing, manufacturing, distribution and packaging, use and maintenance and end-of-life) and to the environmental aspects (material, energy consumption, solid waste, waste water and emissions) (adapted from DfE Matrix by Yarwood and Eagan (2003)). In order to perform this classification, each guideline was analyzed in relation to the effect of its consideration in the product life cycle phases and also to the affected environmental aspects. This classification indicates where the guideline can influence the environmental performance of a product and supports the selection of the most appropriated operational practices according to the characteristics of environmental impacts over the whole life cycle of the product under development. Additionally, the operational practices were reviewed in order to eliminate redundancies. The results are presented in the Appendix B.

A new criterion was added to classify the ecodesign techniques and tools related to the maturity level of a company for their application. More sophisticated and complex tools are more suitable for companies with higher maturity levels. On the other hand, simplified tools such as checklists and matrixes can easily be implemented by companies with lower maturity levels.

4.6.3 Improvements on the ecodesign maturity levels

The ecodesign maturity levels of the Ecodesign Maturity Model (EcoM2) were redefined by the combination of two dimensions: evolution level on ecodesign and capability level[57] of the application of the ecodesign management practices:

- Evolution level on ecodesign: describes the way in which companies evolves in the ecodesign application. It is strictly related to the evolution of the process improvement for ecodesign implementation carried out by companies (and not to the product design itself), and is directly connected to the ecodesign management practices for this reason;
- Capability level: evaluates how well the ecodesign management practice is being applied by the company;

[57] As previously mentioned, the innovation level was excluded from the definition of the maturity levels following the experts' suggestions.

The evolution and capability levels defined by the EcoM2 are detailed described in sections 4.6.3.1 and 4.6.3.2, respectively. The maturity levels definition based on the evolution and capability levels are presented in section 4.6.3.3.

4.6.3.1 Evolution level on ecodesign

The ecodesign evolution levels of the EcoM2 are described as follows:

- Evolution Level 1: Company has no experience in ecodesign and does not yet apply ecodesign practices to improve the environmental performance of products. The environmental issues of products and the benefits of adopting ecodesign are not so far exploited. At this level, the company must understand the concept of ecodesign, define its internal and external drivers for the adoption of ecodesign, carry out a benchmark study to understand what competitors are doing in this area, and make a compilation of all the legal issues and standards related to the environmental performance of its products.
- Evolution Level 2: Company has taken the first steps in the application of ecodesign and is familiar with some of its practices and potential benefits. Pilot and punctual projects are implemented focusing on the incremental improvement of the environmental performance of existing products, usually with emphasis on specific phases of the products' life cycle. The company uses punctual and non-consolidated approaches to ecodesign practices involved in product design. At this level, company endeavors to generate awareness and motivation for ecodesign and begins a formal Ecodesign Program. Simplified life cycle assessment tools to identify hot spots for improvement of the environmental performance of products are used.
- Evolution Level 3: At this level, the company recognizes the importance and benefits of ecodesign based on the results of its application in the pilot projects and in the recognition of the Ecodesign Program. The experienced obtained during the pilot projects can be systematized in order to support the improvement of the product development process itself, in a way that all of the development projects carried out by the company will considerate the environmental issues. In this level,

ecodesign is technically integrated into the product development process, and the first steps are taken to structure an environmental approach and common patterns.

- Evolution Level 4: Ecodesign practices are systematically incorporated into the product development and related processes starting from the initial phases (e.g., idea generation and portfolio management). The main difference from level 4 is the expansion on the ecodesign influence sphere, to more business and management areas, besides the technical ones. At this level, functionality analysis is applied to conduct ecodesign, which enlarges the opportunities for improvements.
- Evolution Level 5: Environmental issues are fully incorporated into companies' corporate, business and product strategies. Environmental issues are considered jointly with technical and economic issues to reinforce the decision-making process. The company aims at system innovation through the development of new products and services that require changes in its product-related infrastructure[58].

4.6.3.2 Capability level on ecodesign

The capability levels defined by the Ecodesign Maturity Model (EcoM2) are used to qualitatively measure how well an ecodesign management practice is being applied by a company. The capability levels were adapted from CMMI (CHRISSIS et al., 2003)) and can be defined as follows:

- Capability level 1 - Incomplete: the ecodesign management practice is not applied or is applied in an incomplete way by the company;
- Capability level 2 - Ad hoc: the ecodesign management practice is applied in an ad hoc way, i.e., in order to fix a problem or to accomplish a

[58]One very special remark must be made concerning the evolution level 5. By fully incorporation of environmental issues and ecodesign into the company´s corporate, business and product strategies it is meant that ecodesign effectively is part of the strategic decisions of the company and is fully incorporated in its way of thinking, doing and communicating business, i.e., it is intrinsically incorporated into the way the company creates value to its customers. The evolution level 5 is not related to the strategically driver of the company for adopting ecodesign, neither with bottom-up or top-down approaches for ecodesign incorporation. It is argued in this research that the evolution path for both approaches is similar: the company needs first to learn what is and how to do ecodesign before being able to effectively incorporate ecodesign and environment issues into its strategy and way of doing business.

specific task by some individuals of the company, but not yet in a formalized and systematized way;

- Capability level 3 - Formalized: the application of the ecodesign management practice is formalized in documented processes. The infrastructure to support the process is well-established. The process is planned and implemented in accordance with company policy. The allocation of responsibilities and resources needed to produce the desired outputs are in place;
- Capability level 4 - Controlled: the application of the ecodesign management practice is formalized and controlled, with measurement and monitoring of the performance of its application. The process is used as a reference to conduct all projects in the company;
- Capability level 5: Optimized: the performance measurement of the application of the ecodesign management practices are carried out and the information obtained are used for managing the continuous improvement of the process.

4.6.3.3 Definition of the ecodesign maturity levels

As previously mentioned, the ecodesign maturity levels in the EcoM2 are defined by a combination of the evolution and capability levels, as presented in Table **9**.

In order to be classified in the maturity level 1, the company would need to apply the ecodesign management practices of the evolution level 1 with capability 3 (in a formal way). A maturity level 2 means that the ecodesign management practices of the evolution level 2 are applied with capability 3 (in a formal way) and the ecodesign management practices of the evolution level 1 are applied in a capability 4 (in a controlled way). The progression continues over the next maturity levels until the maturity level 5, where all the ecodesign management practices (from evolution levels 1, 2, 3, 4 and 5) are applied with capability 5 (in an optimized way).

Table 9: Definition of the ecodesign maturity levels

		Maturity Level in Ecodesign				
		1	**2**	**3**	**4**	**5**
Evolution level in ecodesign	**1**	Capability 3	Capability 4	Capability 5	Capability 5	Capability 5
	2	-	Capability 3	Capability 4	Capability 5	Capability 5
	3	-	-	Capability 3	Capability 4	Capability 5
	4	-	-	-	Capability 3	Capability 5
	5	-	-	-	-	Capability 5

The ecodesign maturity levels defined by the EcoM2 can be understood as a reference to which the company will be compared to. It does not have the goal to the prescriptive, but rather to indicate the path to be followed by a company for ecodesign implementation, considering its current situation on ecodesign adoption.

This section presented the theoretical development of the Ecodesign Maturity Model (EcoM2), composed by a systematic literature review and an evaluation by experts on ecodesign, which leaded to the second version of the EcoM2. In the next section, the results of the empirical development of the EcoM2 by its application into an action research are presented.

5 Empirical development of the Ecodesign Maturity Model (EcoM2)

The theoretical version of the Ecodesign Maturity Model (EcoM2) was further improved in the third phase of the research based on its application in an action research, as described in the methodology section 2.2.3.

The EcoM2 was improved at the same time it was being applied at a company, considering the valuable inputs of a real application and the intrinsic challenges related to the action research methodology.

The main goal of the action research was to further develop the first two steps[59] of the EcoM2 application method:

(1) Diagnosis of the current maturity profile on ecodesign; and

(2) Proposition of ecodesign management practices and improvement projects.

The action research was performed into three main cycles, as represented in Figure 10: (1) diagnosis of the current situation; (2) determination of the maturity profile on ecodesign; and (3) proposition of ecodesign practices to be adopted.

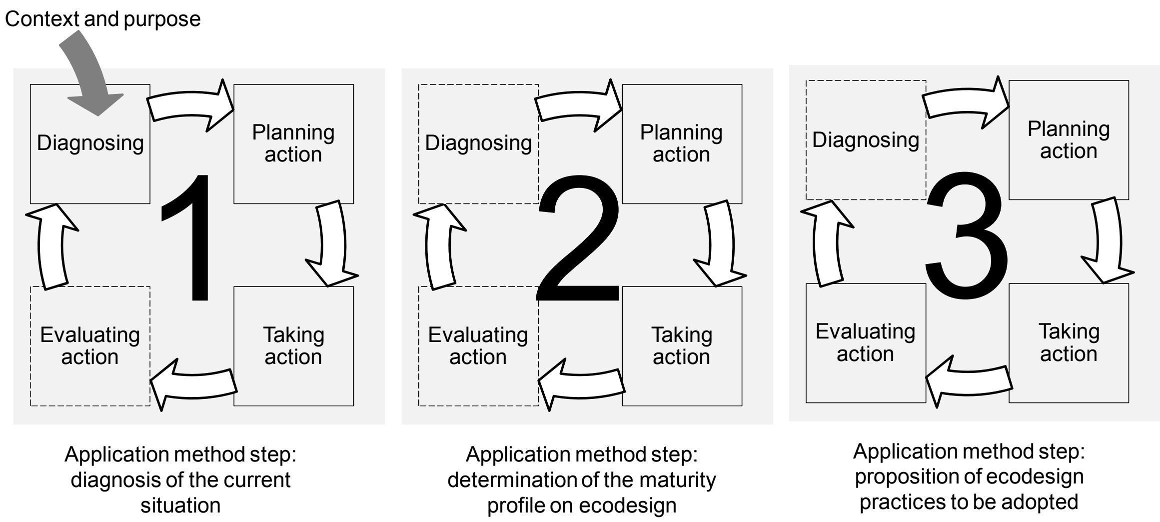

Figure 10: Cycles carried out during the action research

[59] The action research did not expect to establish and define how the other steps of the EcoM2 application method would be performed (see section 4.4). It is argued that these steps should be carried out using the best and current practices for project management and process improvement adopted by each company. In addition, their execution should be aligned with organizational structure, culture, values, etc.

Each cycle comprised four main phases: “Diagnosing”, “Planning action”, “Taking action” and “Evaluating action” proceeded by “Context and purpose definition”. Note that the “Diagnosing” phase was carried out only in the first action research cycle, while the “Evaluating action” phase was performed just in the third action research cycle (the steps that were not carried out in each action research phase are represented by dotted boxes in Figure 10).

The “Context and purpose definition” step took place at the beginning of the action research, before the first research cycle. The goal of this step was to describe the company and the context in which the research was going to be conducted. The results of “Context and purpose definition” are described in section 5.1.

The first action research cycle comprised the definition and application of the methodology to be employed in order to perform the diagnosis of the current maturity profile in ecodesign of the company. The results of the first cycle are presented in section 5.2.

In the second cycle, the data obtained in the diagnosis carried out in the first cycle were an input to the definition of the methodology to delineate the ecodesign maturity profile of the company, which was planned (planning action) and implemented (taking action). Section 5.3 presents the results of the second action research cycle.

Finally, at the third action research cycle, the way in which the ecodesign practices should be selected, based on the Ecodesign Maturity Model (EcoM2), was further studied. At the end of this cycle, the evaluation activity was performed aiming to analyze the results of the action research as a whole i.e. how satisfied the company was with the results obtained by the EcoM2 application. The results of this section are presented in section 5.4.

Finally, in section 5.5, the improvements implemented into the Ecodesign Maturity Model (EcoM2) during the action research are summarized. As a result of the action research, a third version of the EcoM2 was developed (final version – presented in section 5.6) and a first assessment of the results obtained by the application of the method was obtained, which provided the first evidences on the usability of the model.

5.1 Context and purpose

The action research was performed at Company 1[60], which can be classified under the division 30: Manufacture of other transport equipment[61] of the ISIC classification framework. Multinational with more than 40 years of experience, Company 1 is one of the biggest companies in the sector it operates, employing circa 20.000 staffs around the world.

Driven by environmental legislation, business opportunities, customer' pressures and by the advance of competitors in ecodesign, Company 1 realized the great importance of considering environmental issues in an integrated way during the product development process (PDP).

A project was set up at Company 1 in order to deal with the integration of ecodesign into the PDP and a senior manager was assigned to this task. In order to improve the knowledge and skills to carry out the project, the senior manager began to research the subject on scientific papers and to establish partnerships with universities and sectors groups. The researcher was contacted by Company 1 within this context.

The company expressed the need of getting knowledge in order to apply ecodesign and asked for support in ecodesign implementation[62]. The goals of the Ecodesign Maturity Model (EcoM2), still under development, were presented and a partnership was proposed for carrying out an action research at Company 1. As a result, the company would get guidance for ecodesign implementation and the researcher would have the opportunity to apply the model in practice aiming to its further improvement.

During the action research, the company would have access to a diagnosis of its current maturity on ecodesign, a list of the most suitable ecodesign practices to be applied and the description of the proposed ecodesign projects to be developed.

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[60] In order to select the company to participate on the action research, the domain in which the Ecodesign Maturity Model (EcoM2) is valid was considered (see section 1.2). In this sense, the company selected belongs to the section C (Manufacturing), presents a structure product development process and aims for ecodesign implementation.

[61] Due to the non-disclosure agreement signed, there is a set of information that cannot be published and was omitted from this document, including the identification of the company.

[62] This fact reinforces the need for models that guides companies in the adoption of ecodesign practices, especially for companies that are initiating in this field.

After realizing the potential benefits of the application of the EcoM2, a partnership was established for the application of the model in an action research at Company 1. The company ensured support and commitment for the application of the Ecodesign Maturity Model (EcoM2), concerned to the provision of the needed information and access to the relevant employee. The support and commitment of the company were essential for ensuring the success of the action research.

5.2 First action research cycle: perform the diagnosis of the current maturity profile

The goal of the first action research cycle was to further improve the first step of the EcoM2 application method, i.e. the diagnosis of the company's current maturity profile on ecodesign (section 4.4). The diagnosis of the current maturity profile aims to identify which ecodesign management practices are applied by the company and with which capability level. The next sections present the phases carried out in the first action research cycle: diagnosing (section 5.2.1)[63], planning action (section 5.2.2), taking action (section 5.2.3) and evaluating action (section 5.2.4).

5.2.1 Diagnosing

In the beginning of the first action research cycle, the need to first understand how the company carried out the product development process and how it was organized was observed, mainly for two reasons:

(1) Understand the process and vocabulary adopted by the company; and

(2) Identify the key people to be interviewed for maturity assessment.

In this sense, in order to understand how the product development process was organized, structured and documented at the company, a documentary analysis

[63] The difference among the diagnosis of the current ecodesign maturity profile of a company and the diagnosing step of the action research methodology must be clear to the reader. The diagnosing step of the action research aims to gather information in order to perform the activities of each action research cycle, while the diagnosis of the current maturity profile aims to identify which ecodesign management practices are applied by the company and with which capability level.

of the product development process related documents[64] was carried out. Company 1 provided the following documents in order to perform this analysis:

- Overview of the product development process;
- Scope of the product development process;
- Description of the phases, macro-processes and tools of the process;
- Roles and responsibilities in the process;
- Main requirements of the products;

During this stage, eight key employees[65] were interviewed in order to understand how the process was performed in the day-to-day business and to clarify issues which were not clear on the analyzed documents. The comments registered during these interviews were documented and expressed a strong recognition of the employees on the importance of the consideration of environmental issues during the product development process[66].

This step was important in order to verify how the documented process were actually being applied at the company, what were the perception of the employees in relation to the process and how process improvement was carried out at the company. Additionally, questions from the documents were clarified during these interviews.

5.2.2 Planning action

The goal of this step of the action research was to plan how the diagnosis of the current maturity profile in ecodesign was going to be carried out at Company 1, in the context of the EcoM2 application method.

The research method selected to perform the maturity assessment comprised face-to-face interviews with key employees that participate on the product development and related processes. Face-to-face semi-structured interviews were selected as the method for data gathering due to the richness of the information to be collected and also to the close contact with the employees it

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[64] Due to the non-disclosure agreement signed, the information contained in the analyzed documents cannot be published and was omitted from this document.

[65] Including managers, engineering supervisors, environmental managers of the plant and designers.

[66] Due to the non-disclosure agreement signed, the information obtained during the interviews cannot be published in this document.

enables, which also contributed to increase the awareness on ecodesign implementation.

In order to adapt the vocabulary of the forthcoming interviews according to the vocabulary adopted in Company 1, the standard questionnaire[67] for maturity assessment was revised and, when necessary, some terms were changed in order to ensure that the interviewee would understand the content of the questions and reply it accordingly.

The employees to be interviewed during the maturity assessment were identified jointly with the company. The need to interview people from different hierarchical levels and functional areas aroused during the selection process. It has the potential to provide a broader overview of the application of the ecodesign management practices at the company and to get the perception of different users and actors in the processes.

The company was responsible for organizing the schedule for the performance of the interviews, to contact the people to be interviewed explaining the general context of the project and to provide the resources needed to this aim.

5.2.3 Taking action

The goal of this stage was to evaluate which ecodesign management practices were applied by the company and with what capability (i.e. to perform the interviews for the diagnosis of the current ecodesign maturity profile of the company) (see section 4.6.3.3), according to the questionnaire for maturity assessment previously adapted.

A total of 19 (nineteen)[68] face-to-face semi-structured interviews for maturity assessment were performed at Company 1 with employees from different hierarchical levels (from managers to designers) and areas of the product development and related processes (such as quality, supply-chain, after-sales, engineering, etc.).

[67] The questionnaire for maturity assessment contains the ecodesign management practices in a question format. The interviewee is asked about the capability level in which a given ecodesign management practice is currently being applied in the company. After the response, a commentary that justifies the capability level assigned is required and also additional information about the application of the practice (see Appendix F).

[68] Including product and process engineers, technical leaders, managers, designers and coordinators from various areas related to the product development process.

The average duration of the interviews was 105 minutes. The interviews were recorded and the following topics were discussed:

a) Introduction to the topic: what is ecodesign, its relation to the product development process, the context of ecodesign application at Company 1 and the goal of the interview;
b) Application of the structured questionnaire adapted to the company: questions about the capability level application of each ecodesign management practice;
c) Final remarks: commentaries on new practices that were not asked during the interview and final considerations about the ecodesign implementation at the company.

During the 19 interviews, the ecodesign management practices were evaluated according to their capability level of application, in order to determine the current maturity profile of the company. The commentaries of the interviewee were registered and analyzed in order to drawn up the current maturity profile on ecodesign of the company.

5.2.4 Evaluating action

As previously mentioned, this activity was not performed in the first cycle of the action research.

5.3 Second action research cycle: define the ecodesign maturity profile

In this section, the activities performed in the second action research cycle, which aims to define the ecodesign maturity profile of a company when applying the EcoM2, are presented.

5.3.1 Diagnosing

This step was not performed in the second cycle of the action research. The information for developing the ecodesign maturity profile of the company was already gathered during the previous cycle (section 5.2).

5.3.2 Planning action

The results of the interviews performed in the previous cycle were summarized in a spreadsheet. The answers of the employees were analyzed against their own commentaries in order to guarantee coherence and consistence of the capability levels assigned for each ecodesign management practice. Whenever necessary, the capability level was changed based on the commentaries and also on the evidences of the documental analysis.

At this moment, the need to present the results of the current maturity profile in a visual and easy to understand way was realized. It would not be possible to present the results just in the spreadsheet, as stressed by the company, because the communication of the results would be very difficult and ineffective. For this reason, a graphical representation of the current maturity profile on ecodesign of the company was developed in the next step: taking action.

5.3.3 Taking the action

In order to represent the results of the current maturity profile of a company in a graphical way, the Ecodesign Maturity Radar was developed during the second cycle of the action research. The Ecodesign Maturity Radar (Figure 11) is an important tool to communicate a company's environmental performance in ecodesign, since it provides a clear and graphic representation of the current maturity profile in ecodesign, showing strengths and weaknesses and identifying gaps for improvement in ecodesign application. It also allows comparisons to be made between previous and current situations so that the improvements achieved over a certain period of time can be monitored.

In the Ecodesign Maturity Radar, the ecodesign management practices (EMPs) are represented by their codes (Table 6) and organized according to the evolution level (section 4.6.3.1) of each practice following the clockwise direction. The capability levels (1 to 5) (section 4.6.3.2) correspond to the axis of the circumference. The colored lines inside the circumference represent the standard maturity levels, as defined by EcoM2[69] (Table 9).

[69] The ecodesign maturity levels in EcoM2 are defined by a combination of the evolution and capability levels of an ecodesign management practice (Table 9). For example, to be classified as maturity level 1, the ecodesign management practices of evolution level 1 must be applied with capability level 3 (formalized).

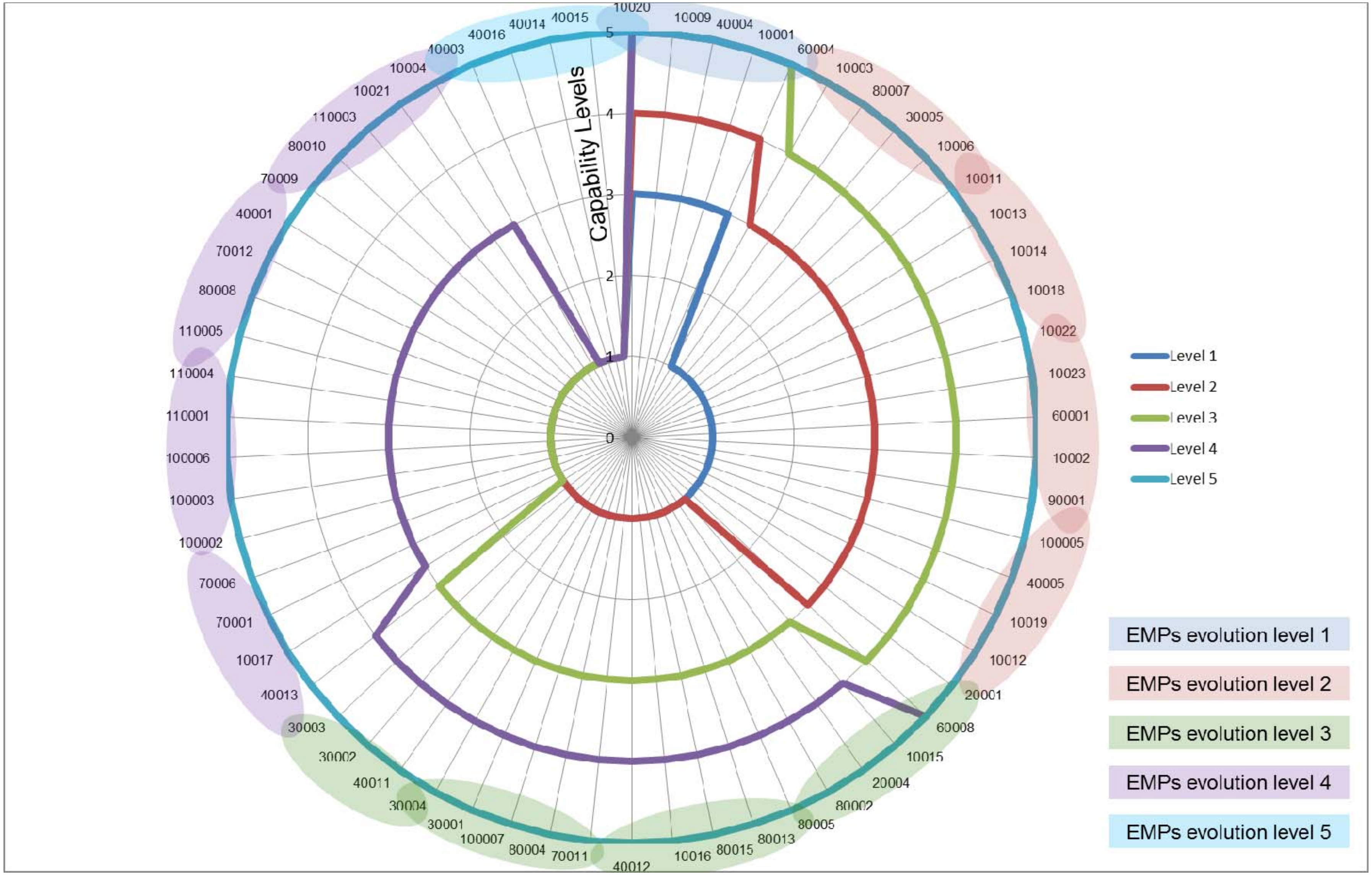

Figure 11: Ecodesign Maturity Radar: graphic representation of the ecodesign maturity profile

The reason why just the ecodesign management practices are represented in the Ecodesign Maturity Radar is that the Ecodesign Maturity Model (EcoM2) has a focus on process improvement rather than on product improvement, as previously mentioned (section 4.6.1). Nevertheless, the ecodesign management practices are linked to ecodesign operational practices and ecodesign techniques and tools that can support their application (section 4.2.2.4). Once identified which are the gaps in the application of the ecodesign management practices, the actions can be deployed into the tactical and operational levels and get into the ecodesign operational practices and ecodesign techniques and tools.

The results of the interviews for maturity assessment carried out in Company 1, which indicate the capability level of the application of the ecodesign management practices, were plotted in the Ecodesign Maturity Radar. The Ecodesign Maturity Radar of Company 1 is presented in Figure 12. The orange solid area represents the current ecodesign maturity profile of the Company 1, i.e. it indicates which ecodesign management practices are currently being applied by the Company 1 and with which capability level, according to the perception of the interviewed employees.

The maturity radar shows that Company 1 does not apply or applies in an incomplete way (capability level 1) most of the ecodesign management practices of the EcoM2 (from the lowest to the highest evolution levels). Even the ecodesign management practices of the evolution level 1 are not yet applied by the company. It means that the company has a low level of knowledge about ecodesign and does not yet understand how ecodesign could be incorporated into its product development and related processes. There are, however, some practices that are applied in an ad hoc way (capability level 2) and also two practices applied in a formal way[70] (capability level 3).

In summary, the conclusion is that the Company 1 has a low maturity level on ecodesign implementation, as represented by its current ecodesign maturity profile on ecodesign (Figure 12).

[70] The practices applied in a formalized way (capability 3) are: 10001: Formulate a company environmental policy; 10021: Integrate environmental issues into the corporate strategy.

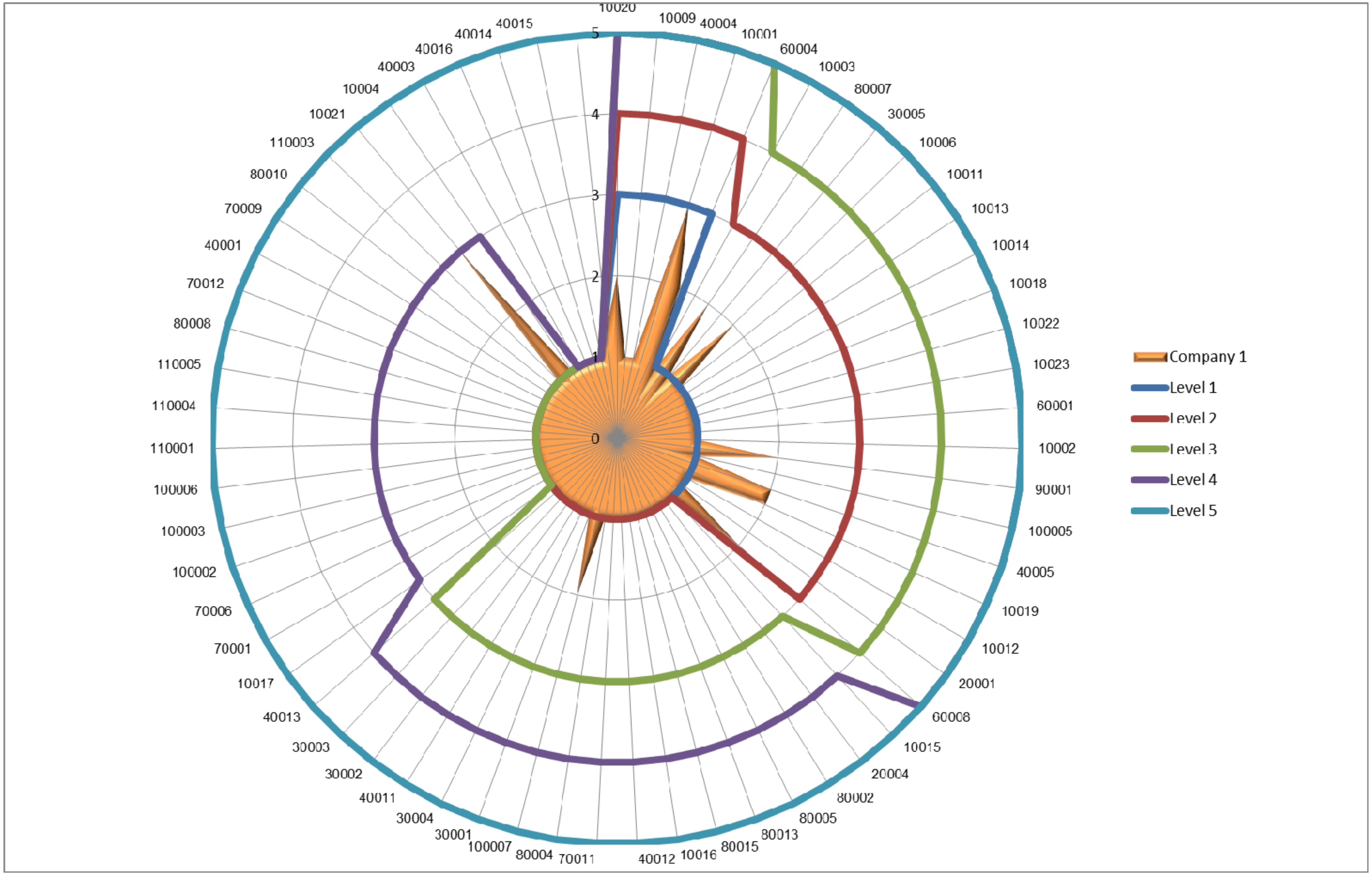

Figure 12: Ecodesign Maturity profile of Company 1

5.3.4 Evaluating action

As previously mentioned, this activity was not performed in the second cycle of the action research. It is performed in the third cycle (section 5.4.4).

5.4 Third action research cycle: proposal of the ecodesign practices to be adopted

In this section, the activities performed in the third action research cycle are presented. The third research cycle aims to propose the ecodesign practices and the improvement projects to be adopted by Company 1.

5.4.1 Diagnosing

This step of the action research cycle was not performed, since the information needed to propose the ecodesign practices to be adopted by Company 1 was already gathered during the previous cycles of the action research and represented by the Ecodesign Maturity Radar of Company 1 (Figure 12).

5.4.2 Planning action

During the action research, the researcher realized that there may be different approaches for process improvement based on the current maturity profile of a company. The same conclusion was obtained by analyzing consolidated maturity models, such as the CMMI (CHRISSIS et al., 2003).

In this sense, two approaches for ecodesign implementation were derived for the EcoM2 (adapted from Chrissis et al. (2003)).

- Staged approach for ecodesign implementation: suitable for companies that has a low maturity profile on ecodesign:
    - Provides a systematic and structured manner to process improvement based on the implementation of a stage (maturity level) at a time. Each stage indicates that the process already has the appropriate foundation and structure to the next stage.
    - The ecodesign management practices are organized by maturity levels, which prescribe the order for the implementation, providing a way for organizational improvement from an initial level to an optimum level.

    - The improvement path to be followed by the organization is characterized by the maturity levels. Each maturity level contains a set of ecodesign management practices to be applied according to a certain capability that characterize different organizational behaviors.
- Continuous approach: recommended when the company have sufficient knowledge on ecodesign implementation to select the ecodesign management practices to be implemented, based on the identification of the improvements opportunities provided by the current ecodesign maturity profile:
    - Provides maximum flexibility in the application of the Ecodesign Maturity Model (EcoM2) for process improvement;
    - The company can choose to improve the performance of specific practices related to a single evolution level, or focus on several areas that are closely aligned to business goals and strategy;
    - Allows the company to improve different ecodesign management practices at different capability levels, but the dependencies among the ecodesign practices must be considered;
    - The relative improvement of an individual ecodesign management practice is characterized by the capability levels.

5.4.3 Taking action

In cases like Company 1, where the maturity profile is characterized by low capability levels of the application of the ecodesign management practices, the staged model for process improvement is suggested, i.e. following the stages defined by the ecodesign maturity levels (see section 4.6.3.3). In this sense, Company 1 would better succeed in the application of ecodesign if it starts the application of the ecodesign management practices of the evolution 1 with capability 3 (ecodesign maturity level 1), and then proceeds to the application of the second maturity level. In this sense, the goal of the first improvement cycle for Company 1 was defined as to reach a maturity level 2 on ecodesign application. In this sense, the application of the ecodesign management practices related to maturity levels 1 and 2 (Figure 13) are proposed.

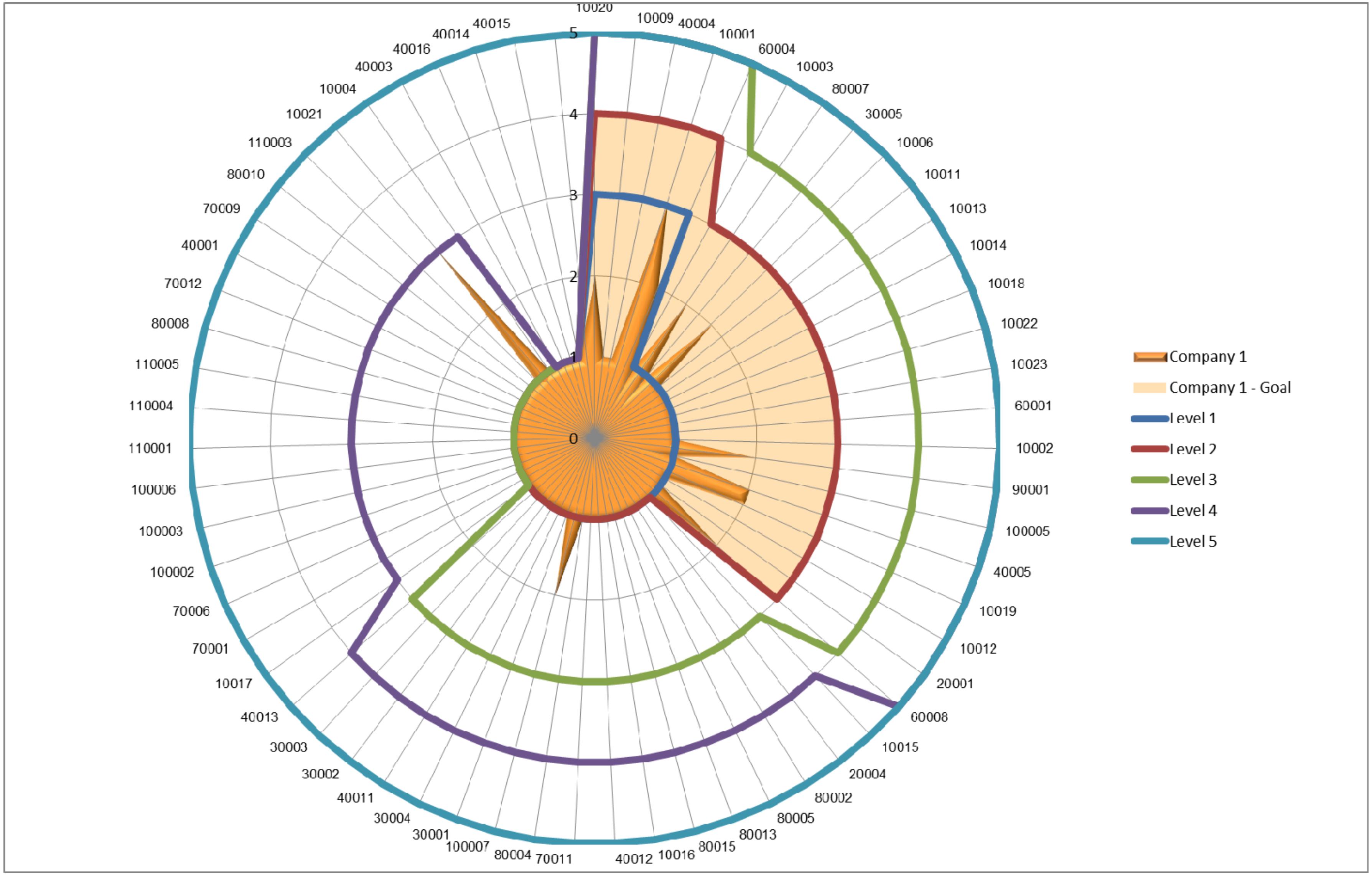

Figure 13: Goal of the Company 1 for the first improvement cycle on ecodesign implementation

In order to reach the maturity level 2 on ecodesign implementation (Figure 13), Company 1 should apply:

- the ecodesign management practices of the first evolution level with a capability 4 (in a controlled way); and
- the ecodesign management practices of the second evolution level with a capability 3 (in a formal way).

Once the ecodesign management practices to be applied were defined, the relationships and dependencies among the ecodesign management practices, the operational practices and the ecodesign techniques/tools were assessed (see section 4.2.3.4). As a result, a set of the most suitable ecodesign management practices, ecodesign operational practices and technique/tools to be applied by Company 1 was proposed.

The definition of the ecodesign projects was performed by grouping similar and convergent ecodesign practices (according to the relationships and dependences among the ecodesign practices). The practices were grouped in projects in order to support an integrated implementation by the company, considering its singular characteristics and aims. The description of each project contained the following information:

- Goals of the ecodesign project;
- Ecodesign management practices;
- Ecodesign operational practices (when applicable);
- Ecodesign techniques and tools (when applicable).

The specific technique/tool to be used by the company in order to implement the ecodesign management practices and ecodesign operational practices was not defined. However, a set of techniques/tools that could be used to support the application of the ecodesign practices was provided.

The selection of the technique/tool to be used must be performed internally by the company and can be supported by the classification criteria provided by EcoM2 (section 4.2.3.3). Subsequently, pilot applications of the selected tools must be performed. Whenever necessary, customizations and adaptations of the tool to the company reality must be implemented (see section 4.2.3.3).

In total, eight projects[71] for ecodesign implementation were proposed to be developed by Company 1:

Project 1 – Get knowledge on ecodesign and disseminate among all participants of the PDP

The goal of this project is to establish a structured process to gather knowledge on ecodesign approach, ecodesign practices and tools in order to create the basis for ecodesign application at Company 1.

Moreover, a process to provide training in ecodesign to the different functions involved in the product development and related processes must be developed, clarifying the potential benefits for the company with ecodesign adoption.

The ecodesign management practices suggested for implementation in this project are presented in Table 10, which includes also the current and the future capability levels for each ecodesign management practice.

Table 10: Ecodesign management practices - Project 1 (Company 1)

Ecodesign management practices	Capability Level	
	Current	Goal
Get and disseminate knowledge on ecodesign approaches and practices	**2**	**4**
Start the ecodesign application by increasing people consciousness about the application opportunities	**2**	**3**
Provide training in ecodesign approach and practices for employees involved in the product development and related processes	**1**	**3**

There are no ecodesign tools/techniques and operational practices that can support the implementation of these ecodesign management practices.

Project 2 – Gather information about legal issues and standards related to the environmental performance of products

The goal of the project 2 is to create a controlled process (to be performed periodically) to obtain and analyze environmental product-related legislation,

[71] Due to the non-disclosure agreement signed, the confidential information contained in ecodesign projects cannot be published and was omitted from this document.

directives and standards in the countries that Company 1 operates. Additionally, in order to ensure compliance with these laws and standards during the product development and related processes, the creation and continuously update of mandatory rules to be followed in every development project are suggested.

The ecodesign management practices suggested for implementation in this project are presented in Table 11, which presents the current and the future capability levels to be achieved in order to reach the goal settled.

Table 11: Ecodesign management practices - Project 2 (Company 1)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Collect information about environmental product-related legal issues and standards	**2**	**4**
Formulate and monitor mandatory rules concerning environmental issues for the enterprise to comply with law/regulations and internal standards/goals	**2**	**3**

In order to perform the ecodesign management practice 60004 the following ecodesign tools can be applied:

- m00038 – Eco-roadmap;
- m00040 – EEE-Pilot;
- m00041 – EIA track;

Project 3 – Perform benchmarking studies in ecodesign to understand what competitors are doing

The goal of this project is to create a controlled process (to be performed periodically) that enables the benchmarking and analysis of the competitors' practices, programs and products in relation to ecodesign, in order to drive the internal activities.

The ecodesign management practice suggested for implementation in this project is presented in Table 12, which presents also the current and the future capability levels to be achieved in order to reach the goal settled.

Table 12: Ecodesign management practices - Project 3 (Company 1)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Perform benchmarking internally (to set environmental improvement goals) and externally (to understand what competitors are doing in ecodesign)	**1**	**4**

In order to perform the ecodesign management practice 10009 the following ecodesign tools can be applied:

- m00018 – Ecobenchmarking;
- m00022 – Ecodesign Method for Electronics Products;
- m00049 - Environmental Benchmarking.

Project 4 – Analyze trends and drivers for ecodesign adoption

Project 4 aims to establish a controlled internal process (to be performed periodically) to clearly define which are the internal and external drivers for the development of products with a better environmental performance at Company 1. The drivers must be communicated to the relevant employees, so to increase awareness of ecodesign´ importance. Additionally, a process to identify customers´ and stakeholders´ requirements in relation to the environmental performance of products and to assess the technological and market trends in this regards should be established.

The ecodesign management practices suggested for implementation in this project are presented in Table 13, which also presents the current and the future capability levels to be achieved in order to reach the goal settled.

Table 13: Ecodesign management practices - Project 4 (Company 1)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Examine the relevant internal drivers (as cost reduction and improvement of company's image) and external drivers (customers requirement and legislation/regulation) for ecodesign adoption	**1**	**4**
Identify the customer and stakeholders requirements and priorities concerning the environmental issues	**1**	**3**

Assess technological and market trends (including new customer requirements) that embraces the trends of products with better environmental performance and develop a list of potential products and market strategies according to the new trends	**2**	**3**

In order to perform the ecodesign management practices 40004, the following ecodesign tools can be applied:

- m00038 – Eco-roadmap;
- m00082 - Philips STRETCH (Selection of sTRategic EnvironmenTal CHallenges);

In order to perform the ecodesign management practice 60001 the following ecodesign tools can be applied:

- m00036 – Eco-QFD (Ecological Quality Function Deployment):
- m00038 – Eco-roadmap;
- m00050 – EQFD (Environmental quality function deployment);
- m00051 - Environmental Value Chain Analysis (EVCA);
- m00083 – ECQFD (Environmentally Conscious Quality Function Deployment);
- m00086 – QFDE (Quality Functional Deployment for Environment);
- m00107 – EcoValue;

In order to perform the ecodesign management practice 40005 the following ecodesign tool can be applied:

- m00038 –Eco-roadmap;

Project 5 – Establish an Ecodesign Program at the company

The goal of this project includes the establishment of an ecodesign program at the company which will be responsible for ensuring commitment and resources for conducting the activities related to ecodesign, involving the relevant people, the deployment of responsibilities for the consideration of the environmental issues, etc.

The ecodesign management practices suggested for implementation in this project are presented in Table 14, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 14: Ecodesign management practices - Project 5 (Company 1)

Ecodesign management practices	Capability Level	
	Current	Goal
Formulate a company environmental policy/strategy	3	4
Establish a prioritized ecodesign program at the company	1	3
Define and measure performance indicators for the environmental performance of ecodesign program	1	3
Ensure commitment, support and resources to conduct the activities related to ecodesign	1	3
Ensure appropriate communication among the departments and different levels concerning product-related environmental issues	1	3
Involve the relevant functions across the company in the ecodesign activities	1	3
Deploy product-related environmental responsibilities among person of different levels of the organization	1	3

There are no ecodesign tools/techniques and operational practices that can support the implementation of these ecodesign management practices.

Project 6 – Deploy the environmental policy of the company for products

The goal of this project is to create a structured and controlled process to perform the deployment and maintenance of an environmental policy for products, based on the environmental policy/strategy of the company. Moreover, the communication of this strategy to the employees involved in the product development and related processes should be ensured.

The ecodesign management practice suggested for implementation in this project is presented in Table 15, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 15: Ecodesign management practices - Project 6 (Company 1)

Ecodesign management practices	Capability Level	
	Current	Goal
Deploy and maintain an environmental policy/strategy for products	1	3

There are no ecodesign tools/techniques and operational practices that can support the implementation of this ecodesign management practice.

Project 7: Assess the environmental impact of a reference product

The goal of this project is to evaluate the environmental impacts of a reference product in order to identify the product life cycle phases and environmental aspects with higher importance in the total environmental impact of the product. Additionally, the life cycle thinking should be implemented at the company.

The ecodesign management practices suggested for implementation in this project are presented in Table 16, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 16: Ecodesign management practices - Project 7 (Company 1)

Ecodesign management practices	Capability Level	
	Current	Goal
Select, customize and implement ecodesign techniques/tools according to the company's needs	1	3
Implement a life-cycle thinking in the company	1	3
Evaluate the environmental performance of products	1	3

In order to perform the ecodesign management practice 20001 the following ecodesign tools can be applied:

- m00002 - ABC Analysis;
- m00004 - AT&T's Green Design Tool;
- m00006 – Life Cycle Assessment (LCA);
- m00015 - DfE Matrix;
- m00019 - Eco-COMPASS (Comprehensive Product Assessment) technique;
- m00020 - ECODESIGN Checklist Method (ECM);
- m00026 - Ecodesign Web;
- m00028 - Eco-indicator 99;
- m00042 - EIME software (Environmental Information and Management Explorer);
- m00045 - Environmental Design Strategy Matrix (EDSM);
- m00047 - Environmental Effect Analysis (EEA);
- m00048 - Environmental Efficiency Potential Assessment method (E2-PA);

- m00061 - Instep-DfE;
- m00064 - Life Cycle Check (LCC);
- m00068 - LIME method;
- m00069 - MECO Matrix;
- m00070 - MET Matrix;
- m00072 - Method for Sustainable Product Development (MSPD);
- m00081 - Philips Fast Five Awareness;
- m00085 - Product Life Cycle Planning (LCP);
- m00095 - Strategy List;
- m00100 - Environmentally Responsible Product Assessment Matrix (ERPA);

Project 8: Perform pilot projects on the application of Ecodesign

The goal of this project is to perform pilot projects at the company in order to start learning in practice how ecodesign can be considered during the product development and related processes and the real benefits the company can obtain with its application. The projects can include optimizations in the production process, in packaging and distribution or the use of new technologies, for example.

The ecodesign management practices suggested for implementation in this project are presented in Table 17, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 17: Ecodesign management practices - Project 8 (Company 1)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Consider the environmental aspects in the identification/qualification of potential suppliers	**2**	**3**
Optimize the production process to improve the environmental performance of products during manufacturing	**2**	**3**
Include packaging and distribution process of the product under the ecodesign considerations (it brings quick wins and supports the creation of awareness of the ecodesign programs)	**1**	**3**
Search technologies that can contribute to improve environmental performance and achieve the goals	**2**	**3**

In order to perform the ecodesign management practice 80007 the following ecodesign tool can be applied:

- m00037 – Ecoquest;

In order to perform the ecodesign management practice 90001 the following ecodesign tool can be applied:

- m00073 - Method to Assess the Adaptability of Products (MAAP);

In order to perform the ecodesign management practice 100005 the following ecodesign operational practices can be applied[72]:

- c00003 - Minimize or avoid Packaging;
    - m00080 - Packaging Impact Quick Evaluation Tool (PIQET)[73];
- c10002 - Minimize energy consumption during transportation and storage;
- c20002 - Select Non-toxic and Harmless Energy Resources;
- c20006 - Select Renewable and Bio-compatible Materials;
- c20007 - Select Renewable and Bio-compatible Energy Resources;

After the first improvement cycle, the diagnosis of the current maturity profile on ecodesign of the Company 1 can be re-assessed and new ecodesign practices and improvement projects for ecodesign implementation can be proposed to be adopted by the company, aiming towards higher maturity levels on ecodesign implementation.

Is must be noted, however, that the proposed projects for ecodesign implementation can be arranged and reorganized according to the companies´ needs and priorities. More important than the projects themselves, it is the identification of the ecodesign practices to be applied and/or improved by the company, as a result of the ecodesign maturity profile of the company.

[72] The design options can be consulted in the Appendix C.

[73] The PIQET tool is available at http://piqet.sustainablepack.org/login.php

5.4.4 Evaluating action

The results of the EcoM2 application at Company 1 were presented in a workshop for 47 employees, ranging from directors to designers (most of the interviewees attended the presentation).

In order to increase the perception of the participants on the ecodesign implementation, transcripts of the interviews were included into the presentation, which corroborated the diagnosis of the current maturity profile of the company.

The dynamics of the diagnosis also allowed the dissemination of the ecodesign concept among a set of employees, which started to talk and think about ecodesign implementation in a more holistic way. Similarly, the internal communication of the ecodesign project of the company was improved.

In order to evaluate the EcoM2 application, a questionnaire which includes a set of criteria for model evaluation (Appendix G) was developed. The questionnaire contains questions related to utility, consistence, completeness, scope, broadness, precision, depth, simplicity, clarity, objectivity, coherence, instrumentality, forecast and measurement (adapted from Vernadat (1996)) . The following scale for assessment was adopted:

- 4 - Very satisfactory
- 3 - Satisfactory
- 2 - Needs improvement
- 1 - Unsatisfactory

The questionnaire was sent to the company after the presentation of the results of the EcoM2 application at the workshop. Additional comments of the company concerning the experience of the EcoM2 application and further suggestions for improvement were also required.

The result of the evaluation of Company 1 in the application of the EcoM2 according to the criteria previously defined is presented in Figure 14.

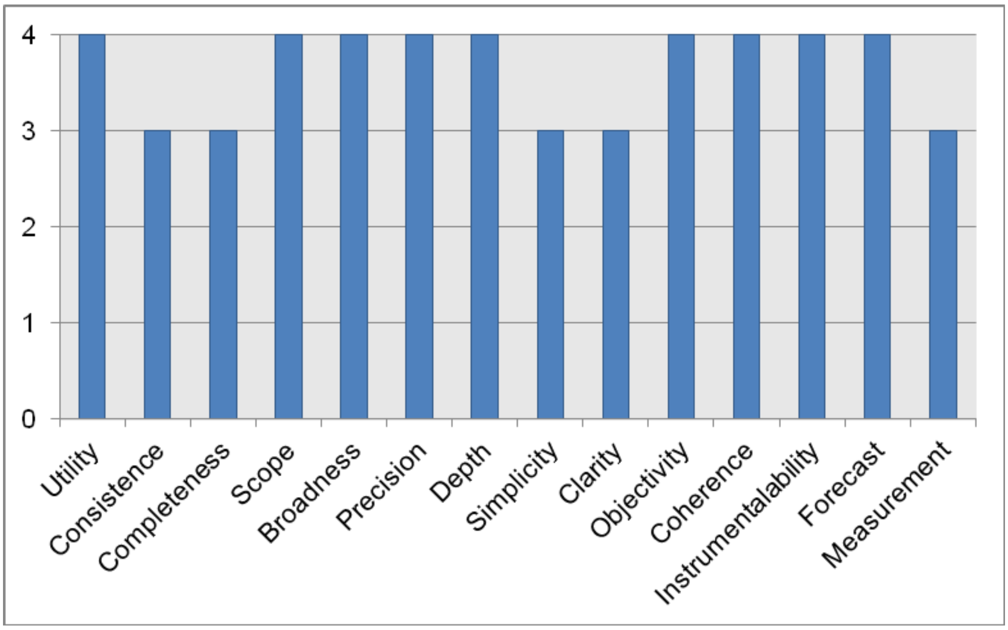

Figure 14: Evaluation of the EcoM2 application by Company 1

Company 1 evaluated as very satisfactory (4) the majority of the criteria used for the assessment of the Ecodesign Maturity Model (EcoM2) (Figure 14). This includes utility, scope, broadness, precision, depth, objectivity, coherence, instrumentability and forecast. The other criteria were evaluated as satisfactory, which also represents fulfillment of the company needs with the results obtained with the EcoM2 application.

The commentaries provided by the Company 1 reinforced the evaluation performed. The company stated, amongst other comments, that "Besides showing the maturity of the company, the presentation of the results is very illustrative, contributing to raise awareness among the managers and employees responsible for the implementation of ecodesign in the company" and "The method is very complete and shows the improvement potentials, achieving its purpose" (completeness).

In relation to the diagnosis methodology, Company 1 argues that "The interviews carried out for the development were very broad and comprehensive." However, a suggestion was provided to improve the application method: "Regarding the EcoM2 application method, it would be interesting to consider the period of time that the employee work at the company in order to select those to be interviewed (in theory, people who are working longer for the company understand better and have more knowledge about what is applied or not)".

The company also argued that “The model is easy to understand, as far as it is presented by a specialist in ecodesign” and “It would be interesting to structure a template to facilitate the selection of tools for companies that will implement the improvement projects identified by the model”. "The evaluation of the results is well documented by the radar (maturity profile). How to perform the monitoring of improvements is, however, not so clear."

In overall, the company got very satisfied with the results obtained with the EcoM2 application. The comments of the company elucidate that the EcoM2 concept and elements were well understood by the company.

The EcoM2 provided as a result for the company meaningful ecodesign projects to be developed and also an overview about the current profile on the adoption of ecodesign practices. As a consequence, a common view of the process, the current and the desired situation were established at the organization[74].

5.5 EcoM2 improvements during the action research

The Ecodesign Maturity Model (EcoM2) was improved during the action research, mainly in relation to the EcoM2 application method. The two first phases of the EcoM2 application method (diagnosis of the current maturity profile and proposition of ecodesign practices and improvement projects) were refined and detailed in order to better cope with companies´ dynamics.

The main improvements carried out during the empirical development of the EcoM2 based on the action research at Company 1 comprehend:

- Inclusion of a step to analyze the current product development process of the company in the diagnosis phase. The documental analysis aims to provide a better understanding on how the process is carried out at the company, to adapt the vocabulary of the questionnaire for maturity assessment and to define the key employees to be interviewed;
- Selection of face-to-face semi-structured interview as a technique to gather the primary data related to the application of the ecodesign

[74] After the application of the Ecodesign Maturity Model (EcoM2) at the Company 1, the portfolio management of improvement projects and the roadmap definition were performed internally at the company, as well as the project planning with the definition of responsibilities, resources, schedule, etc. The company has already implemented three of the eight projects proposed and are starting the implementation of the others.

management practices at the company (diagnosis of the current maturity profile on ecodesign implementation);

- Development of the Ecodesign Maturity Radar[75], which presents the ecodesign maturity profile of the company in a visual and easy to understand manner;
- Proposal of the continuous and staged approaches for ecodesign implementation, based on the ecodesign maturity profile of the company;
- Definition of the way in which the ecodesign management practices to be adopted should be selected and how to propose the improvement projects for ecodesign implementation;
- Inclusion of the perception of the employees in the presentation of the results in order to corroborate the ecodesign maturity profile;

The main output of the action research was the consolidated final version of the Ecodesign Maturity Model (EcoM2), presented in section 5.6.

5.6 Consolidated version of the EcoM2 application method

In this section, the consolidated version of the EcoM2 application method, after the improvements performed during the action research carried out at Company 1 (see section 5.5), is presented.

The EcoM2 application method aims to guide the application of the Ecodesign Maturity Model and establish a continuous improvement framework for the incorporation of ecodesign practices into the product development and related processes. The EcoM2 application method comprises six steps (Figure 15):

1) Diagnosis of the current maturity profile on ecodesign;
2) Proposition of ecodesign management practices and improvement projects;
3) Portfolio management of improvement projects for ecodesign implementation;
4) Planning of the improvement projects for ecodesign implementation;
5) Implementation of the improvement projects;
6) Assessment of the results.

[75] The ecodesign maturity radar (Figure 11) is an important tool to communicate the environmental performance on ecodesign of a company, since it enables a clear and graphical representation of the current maturity profile, the visualization of strengths and weaknesses and also the identification of gaps for improvement in the ecodesign application

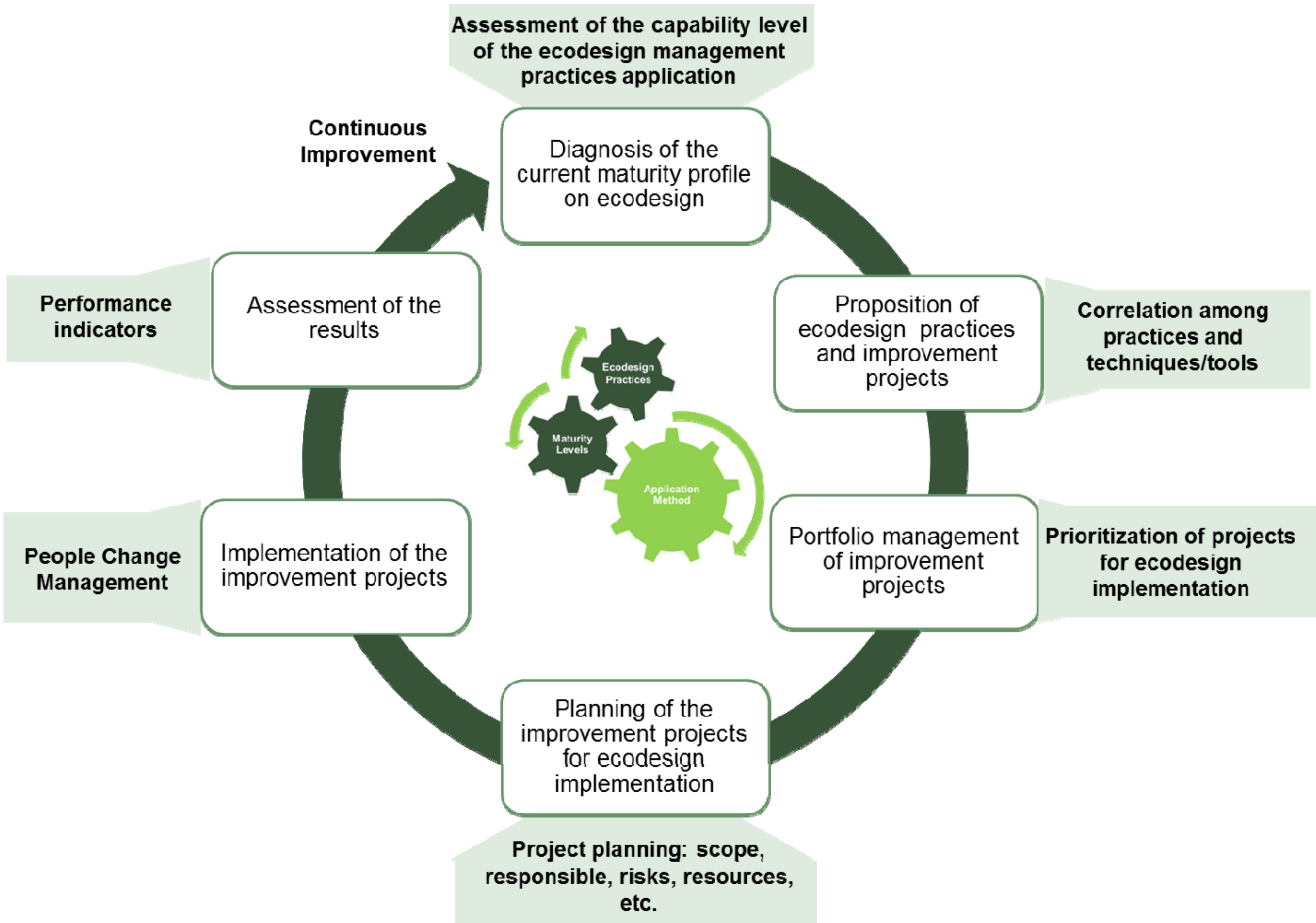

Figure 15: EcoM2 application method

A higher level of detail is provided on the description of the first two phases of the improvement cycle (diagnosis of the current maturity profile on ecodesign and proposition of ecodesign practices and improvement projects for ecodesign implementation). As previously mentioned, the EcoM2 application method does not claim to establish and define how the other activities (portfolio management of projects for ecodesign implementation, planning of the projects for ecodesign implementation, implementation of the projects for ecodesign implementation, and assessment of the results) have to be performed by the company, since each company should perform these activities using its best and current practices for process improvement and project management.

Nevertheless, the application method reinforces that these steps must be carried out during the improvement cycles towards better ecodesign maturity levels. At the end of each improvement cycle, the company can begin another improvement cycle, reassessing the current maturity profile on ecodesign, in order to define new projects to be implemented and maintain its continuous improvement towards higher maturity levels on ecodesign implementation. The steps of the EcoM2 application method are detailed in the next sections.

5.6.1 Diagnosis of the current maturity profile on ecodesign

The first step of the EcoM2 application method is the diagnosis of the company's current maturity profile on ecodesign. The diagnosis is performed in three steps: (1) product development process analysis (section 5.6.1.1); (2) interviews for maturity assessment (section 5.6.1.2); and (3) consolidation of the results (section 5.6.1.3).

5.6.1.1 Step 1: Product development process analysis

In order to understand how the product development process is organized, structured and documented at the company, a documental analysis of the product development process-related documents (such as standard reference models, organizational charts, responsibilities matrixes, environmental-related documents, etc.) is carried out in this step. Face-to-face interviews are also performed with key employees (ideally 2 – 8 people) directly involved in the product development activities, in order to gather evidence on how the process is applied in practice and what are its main deficiencies. This step is important in order to verify how the documented process are actually being applied at the company, what are the perception of the employees in relation to the process and how the process is improved internally. Additionally, questions from the documents can be clarified during these preliminary interviews.

In this step, an adaptation of the questionnaire (Appendix F) to be used in the next stage of the diagnosis for maturity assessment (see section 5.6.1.2) is also carried out, according to the company´s vocabulary. It aims to guarantee that the questions will be well understood by the interviewee and that the answers provided will be reliable.

Moreover, the key-employees (ideally 10 – 20 people) to be interviewed in the next stage of the diagnosis (interviews for maturity assessment – section 5.6.1.2) are identified jointly with the company. The selection of employees from different functions and hierarchical levels at the organization is prioritized in order to obtain a broader overview of the application of the ecodesign management practices at the company.

The company is responsible for organizing the schedule for the performance of the interviews, to contact the employees to be interviewed (explaining the general context of the project) and to provide the resources needed to this aim.

The expected duration of this step is of five days.

5.6.1.2 Step 2: Interviews for maturity assessment

The goal of this step is to evaluate which ecodesign management practices are applied by the company and with what capability, according to the perception of the key-employees selected in the previous step jointly with the company (see section 5.6.1.1).

The methodology comprises the execution of a set of face-to-face interviews using a semi-structured questionnaire adapted for the company´s vocabulary (Appendix F). The interviews are designed to take around 60 minutes and are composed by three main parts:

a) Introduction: definition of the ecodesign concept, brief explanation on the context of the application of EcoM2 at the company, clarification of the structure of the interview and discussion about the capability levels (section 4.6.3.2)[76];

b) Semi-structured interview: application of the structured questionnaire which contains questions regarding the application of the ecodesign management practices. The interviewee is asked about the capability level application of each ecodesign management practice at the company and is engaged to provide additional comments, justifying and providing evidences on the provided answer;

c) Final remarks: The interviewees are asked about additional ecodesign practices that the company applies but were not included in the questionnaire (which can be used to improve the EcoM2 itself) and to provide additional commentaries.

The expected duration of this step is of five days.

5.6.1.3 Step 3: Consolidation of the results: Ecodesign Maturity Profile

In order to consolidate the data obtained during the interviews carried out in the previous step (section 5.6.1.2), the results are summarized in a spreadsheet (Table 18).

Table 18: Example of the spreadsheet for the consolidation of the results

Ecodesign Management Practice		Capability Level
Question related to the application of the ecodesign management practice		x
Comments:		
Comments about the justification on why the company is classified in that given level and how the practice is currently being carried out at the organization		
E1	Comments of the interviewed E1	y
E2	Comments of the interviewed E2	x
E3	Comments of the interviewed E3	x
En	Comments of the interviewed En	x

[76] A description of the capability levels, which can be consulted by the respondent during the interview in case of doubt, is provided.

The spreadsheet contains the following fields: code of the ecodesign management practice, question related to the practice application, comments and capability levels assigned by each interviewee, consolidated capability level and final comments to the company regarding a justification on why the practice is classified in that given level and how it is currently being carried out at the organization, according to the perception of the interviewed employees.

The answers of the employees are analyzed against their own commentaries in order to guarantee coherence and consistence of the capability levels assigned. Whenever necessary, the capability level can be changed based on the commentaries and on the evidences of the documental analysis.

Within the results of the capability level application of each ecodesign management practice, the company current profile on ecodesign is designed, using the Ecodesign Maturity Radar (Figure 11). The expected duration of this step is of three days.

5.6.2 Proposition of ecodesign management practices and improvement projects

Once the current maturity profile of a company is determined (section 5.6.1), the most suitable ecodesign management practices to be adopted by the company must be selected based on the gap analysis and selection of process improvement approach to be adopted. Subsequently, the improvement projects for ecodesign implementation are proposed.

This is done in three steps: (1) selection of the process improvement approach to be adopted (section 5.6.2.1); (2) identification of the ecodesign practices to be implemented (section 5.6.2.2); and (3) analysis of complementarities among the ecodesign practices and proposal of improvement projects for ecodesign implementation (section 5.6.2.3).

5.6.2.1 Step 1: Selection of the process improvement approach

The first step to be carried out for the definition of the ecodesign practices to be adopted by the company is the definition of the process improvement approach to be adopted: the staged or the continuous one.

- Staged approach for ecodesign implementation

  - Provides a systematic and structured manner to process improvement based on the implementation of a stage (maturity level) at a time. Each stage indicates that the process already has the appropriate foundation and structure to the next stage;
  - The ecodesign management practices are organized by maturity levels, which prescribe the order for the implementation, providing a way for organizational improvement from an initial level to an optimum level;
  - The improvement path to be followed by the organization is characterized by the maturity levels. Each maturity level contains a set of ecodesign management practices to be applied according to a certain capability that characterize different organizational behaviors.
- Continuous approach
  - Provides maximum flexibility in the application of the Ecodesign Maturity Model (EcoM2) for process improvement;
  - The organization can choose for improving the performance of specific practices related to a single evolution level, or focus on several areas that are closely aligned to business goals and strategy;
  - Allows the company to improve different ecodesign management practices at different capability levels, but the dependencies among the ecodesign practices must be considered (section 4.2.3.4);
  - The relative improvement of an individual ecodesign management practice is characterized by the capability levels.

The selection is performed based on an analysis of the current maturity profile of the company. The staged approach for ecodesign implementation is suitable for companies who has a low maturity profile on ecodesign, i.e., to companies that presents punctual application of ecodesign management practices, but most of them still in an ad hoc way (capability 2);

The continuous approach is recommended when the company has a relatively high maturity on ecodesign, performing a significant amount of ecodesign management practices in a formalized way (capability 3) or higher, and are comfortable to select which ecodesign practices should be applied.

In this sense, the ecodesign maturity profile indicates whether it is better to adopt the continuous or staged approaches for process improvement. The expected duration of this step is of one day.

5.6.2.2 Step 2: Identification of the ecodesign management practices

In order to identify the ecodesign management practices to be implemented by the company, the goal to be reached after the first improvement cycle[77] must be defined. The goal definition is based on the selected approach for process improvement (staged or continuous) (section 5.6.2.1) and will determine the capability level to be reached for the ecodesign management practices application. For example, if the company adopts the staged approach for process improvement and establish as a goal to reach the second maturity level after the first improvement cycle, then the ecodesign management practices to be implemented are those of the first evolution level with capability 4 (in a control way) and those of the second evolution level with capability 3 (in a formal way) (Table 9).

Once the ecodesign management practices to be applied by the company are defined, an analysis is made of the correlation between the selected ecodesign management practices within the ecodesign operational practices and the ecodesign techniques/tools (see section 4.2.3.4). This is done in order to support companies in the application of the ecodesign management practices.

When an ecodesign management practice depends on others to be implemented (see section 4.2.3.4), these should be part of the first improvement projects to be implemented by the company. Operational practices and techniques/tools related to the management practices should support their application. If more than one technique/tool is associated with the same practice, the selection of the most suitable one can be performed using the classification criteria (see section 4.2.3.3), the ecodesign maturity level and the

[77] The goal definition can be defined jointly with the company or proposed by the researcher and then validated by the company.

needs and characteristics of the company. The expected duration of this step is of one day.

5.6.2.3 Step 3: Proposal of improvement projects for ecodesign implementation

The improvement projects for ecodesign implementation should be designed to incorporate the application of one or more practices in a joint and integrated manner, considering the particularities of the companies.

In this step, an analysis of complementarities and synergies among the ecodesign practices is performed based on the relationships and dependences established by the Ecodesign Maturity Model (EcoM2) (see section 4.2.3.4). It is then proposed which ones should be aggregated in the improvement projects in order to be jointly applied by the company, considering the organizational structure, drivers and culture of the company. Companies with the same maturity profile and goals for the first/next improvement cycle can have different definitions of the improvement projects to be developed (although the practices are the same) due to singular characteristics of each company.

The improvement projects to be applied by the companies in order to achieve the goal set for the first improvement cycle contain the following information:

- Goal of the project: a statement which describes the goals to be reached by the project;
- Ecodesign management practices: description of the ecodesign management practices to be implemented by the company and the capability levels to be reached;
- Ecodesign operational practices and/or ecodesign tools/techniques: description of the operational practices and/or tools/techniques that are associated to the ecodesign management practices and can support their application (when applicable).

The proposed projects for ecodesign implementation can be arranged and reorganized according to the companies´ needs and priorities. More important than the projects themselves, it is the identification of the ecodesign practices to be applied and/or improved. During the portfolio management of the projects for ecodesign implementation (see section 5.6.3), the company can decide to split some projects or mix others based on the efforts needed to implement them and on the availability of resources, on priorities for improvement, etc. The proposal of ecodesign improvement projects is not prescriptive, but rather indicative on an implementation path to be followed. The expected duration of this step is of three days.

5.6.3 Next steps for ecodesign implementation

In the sections 5.6.1 and 5.6.2, the methodology to be followed to perform the first two steps of the EcoM2 application method (Figure 15) was presented:

1) Diagnosis of the current maturity profile in ecodesign;
2) Proposition of ecodesign management practices and improvement projects;

The total duration expected for performing these first two steps is of approximately 20 working days. The main results are the current maturity profile of the company and the proposed projects for ecodesign implementation.

In order to proceed in ecodesign implementation, the following steps are proposed to be performed internally by the company (Figure 15):

3) Portfolio management of ecodesign projects: in order to define which projects are actually going to be implemented by the company, a strategic alignment by means of portfolio management needs to be performed. The strategic drivers for the adoption of ecodesign need to be assessed and counterbalanced with the proposed projects for ecodesign implementation. Whenever necessary, the projects can be restructured by the company. As a result, the company will define which projects are going to be developed and establish a roadmap (i.e., a timeline) for the implementation of the projects for ecodesign implementation;
4) Planning of the projects for ecodesign implementation: once the ecodesign projects to be implemented are defined, each project has to be planned (define schedules, responsibilities, risks, resources, etc.) according to the company´s usual project management practices;
5) Implementation of ecodesign projects: during the implementation of the ecodesign practices selected for improvement projects, special care should be taken in relation to People Change Management, since people are crucial to the success of the projects implementation;

6) Assessment of the results: in order to evaluate the results of the improvement projects for ecodesign implementation, performance indicators for the implementation of the ecodesign management practices into the product development and related processes must be determined and measured.

As previously mentioned, the EcoM2 does not intend to establish and define how a company should perform these steps, since each company should carry out these activities using its best and current practices.

The total duration of each improvement cycle will depend on a set of variables (such as resources available, resistance inside the organization, projects selected, etc.) which were out of the scope of this research.

This section presented the empirical development of the Ecodesign Maturity Model (EcoM2), by its application into an action research at a large manufacturing company (Company 1). As a result, the model was substantially improved, mainly in relation to the application method, and the final version of the EcoM2 was consolidated. The results of the test of the Ecodesign Maturity Model (EcoM2) carried out in two case studies for theory testing are presented in the next section.

6 Test of the Ecodesign Maturity Model (EcoM2)

In this section, the results of the application of the final version of the Ecodesign Maturity Model (EcoM2) in two case studies for theory-testing (phase 4 of the research – section 2.2.4) are presented.

As previously mentioned in section 1.2, the domain in which the Ecodesign Maturity Model (EcoM2) is applicable is composed by companies that present a structured product development process (PDP) and are classified in the category C-Manufacturing by ISIC (International Standard Industrial Classification of All Economic Activities) (UNITED NATIONS, 2008). Moreover, a pre-requisite for the company to be included as a case study is to aim at ecodesign implementation. In order to test the Ecodesign Maturity Model (EcoM2), two companies[78] inside this domain were selected:

- Company 2: classified under the division 20: Manufacture of chemicals and chemicals products;
- Company 3: classified under the division 28: Manufacture of machinery and equipment.

In the next sections, the results of the cases studies for theory-testing of the Ecodesign Maturity Model performed at Company 2 (section 6.1) and Company 3 (section 6.2) are presented. The case studies followed the methodology defined at the EcoM2 application method (section 5.6) to perform the diagnosis of the current maturity profile on ecodesign and propose the ecodesign practices and improvement projects for ecodesign implementation to be carried out[79]. Finally, the sections 6.1.3 and 6.2.3, present the evaluations of the EcoM2 performed by the Companies 2 and 3, respectively.

6.1 Case study for theory-testing at Company 2

Company 2 is strategically driven by sustainability issues, with high market share in the market where it operates. Multinational with more than 40 years of experience, the company is nationally recognized for the quality of the

[78] Due to the non-disclosure agreement signed, there is a set of information that cannot be published and was omitted from this document, including the identification of the company.

[79] The total duration of each case study was of approximately four weeks.

developed products. Company 2 is currently expanding its activities internationally and employs circa 5.000 people.

The company already presents a set of activities and products which incorporates sustainability issues, i.e. economic, social and environmental aspects. The marketing area explores the communication of the sustainability efforts and the results obtained. As a consequence, the company and its brands are highly recognized for their sustainable value. The motivation for the application of the EcoM2 came from the need of the company to develop/apply ecodesign tools that could support the product development process (PDP).

The results of the diagnosis of the current maturity profile on ecodesign of the Company 2 (step 1 of the application method) are presented in section 6.1.1. The section 6.1.2 presents the proposition of ecodesign practices and improvement projects for ecodesign implementation (step 2 of the application method). Finally, in section 6.1.3, the evaluation of the application of the EcoM2 by Company 2 is presented.

6.1.1 Diagnosis of the current maturity profile on ecodesign - Company 2

The first step of the EcoM2 application method is the diagnosis of the company's current maturity profile on ecodesign. In this section, the results of the three diagnosis steps: (1) product development process analysis (section 6.1.1.1); (2) interviews for maturity assessment (section 6.1.1.2); and (3) consolidation of the results (section 6.1.1.2) are presented according to the methodology presented in section 5.6.1.

6.1.1.1 Step 1: Product development process analysis

The goal of this step is to understand how the product development process is organized, structured and documented (section 5.6.1.1) at Company 2.

The following documents of Company 2 were analyzed[80]: overview of the product development process (PDP) with definition of the main phases; requirements addressed during the phase assessments (or gates) of the PDP; responsibility matrix and organizational charts related to the product development process.

[80] Due to the non-disclosure agreement signed, the information contained in the analyzed documents cannot be published and was omitted from this document.

An interview about the product development process was held with one key employee with high experience on the process. Additionally, the environmental-related activities currently performed at the company were introduced during this interview. The total duration of the interview was circa 105 minutes.

The questionnaire for maturity assessment was adapted to the vocabulary of the company and the employees to be interviewed were identified jointly with the company[81]. In total, 15 employees that are directly related to the product development process, from different areas (marketing, supply-chain, legal compliance, etc.), functions and hierarchical positions, were selected. The company was responsible for contacting these employees, for setting the meetings and for providing the infra-structure to carry the interviews out. The total duration of this step was of 5 working days.

6.1.1.2 Step 2: Interviews for maturity assessment

The goal of this step was to evaluate which ecodesign management practices are applied by the company and with what capability. In total, 15 face-to-face semi-structure interviews were carried out during 5 working days at the Company 2. The average duration of the interviews was 60 minutes and the methodology described in section 5.6.1.2 (which comprised an introduction before the questions for maturity assessment and was followed by final discussion) was employed.

In the 15 interviews performed, the ecodesign management practices were evaluated according to their capability level of application in the company, in order to determine the current maturity profile of the company. The comments and evidences provided by the interviewee were documented, in order to support further analysis and provide facts on the results obtained.

Additionally, the researcher had the opportunity to participate on some management meetings of projects under development, which improved the richness of the analysis carried out and made possible data triangulation.

[81] Due to the non-disclosure agreement signed, this information cannot be published and was omitted from this document.

6.1.1.3 Step 3: Consolidation of the results: Ecodesign Maturity Profile

The data obtained during the 15 interviews carried out in the previous stage were consolidated, according to the methodology presented in section 5.6.1.3.

The answers of the employees were analyzed against their own commentaries in order to guarantee coherence and consistence of the capability levels assigned. Whenever necessary, the capability level was changed based on the commentaries and on the evidences of the documental analysis.

Within the results of the capability level of application of each ecodesign management practice, the Ecodesign Maturity Radar of Company 2, presented in Figure 16, was developed.

The analysis of the Ecodesign Maturity Radar provides evidence on the application of several ecodesign management practices with high capability levels (15% of the practices are applied with capabilities 4 and 5), including also practices with a high level of evolution (evolutions levels 3, 4 and 5). This fact reflects the strong strategic positioning of Company 2 on environmental issues, with the establishment of clear management procedures for implementing the environmental issues, the definition of clear goals and metrics and also the deployment of responsibilities among the relevant employees.

However, some basic ecodesign management practices of lower evolution levels (such as get knowledge in ecodesign) are still applied by Company 2 with low capability levels. In this sense, the ecodesign maturity profile of the Company 2 shows that there is a lack of deployment of the strategic environmental issues into the operational activities of PDP, deficiencies in training on ecodesign concept/tools and lack of a holistic and systemic view to deal with the environmental issues in the product development and related processes.

The findings are reinforced by excerpts from the interviews[82] and reflect the perception of the interviewed employees in relation to the consideration of the environmental issues in the product development and related process of Company 2.

[82] Due to the non-disclosure agreement signed, the information obtained during the interviews cannot be published and was omitted from this document.

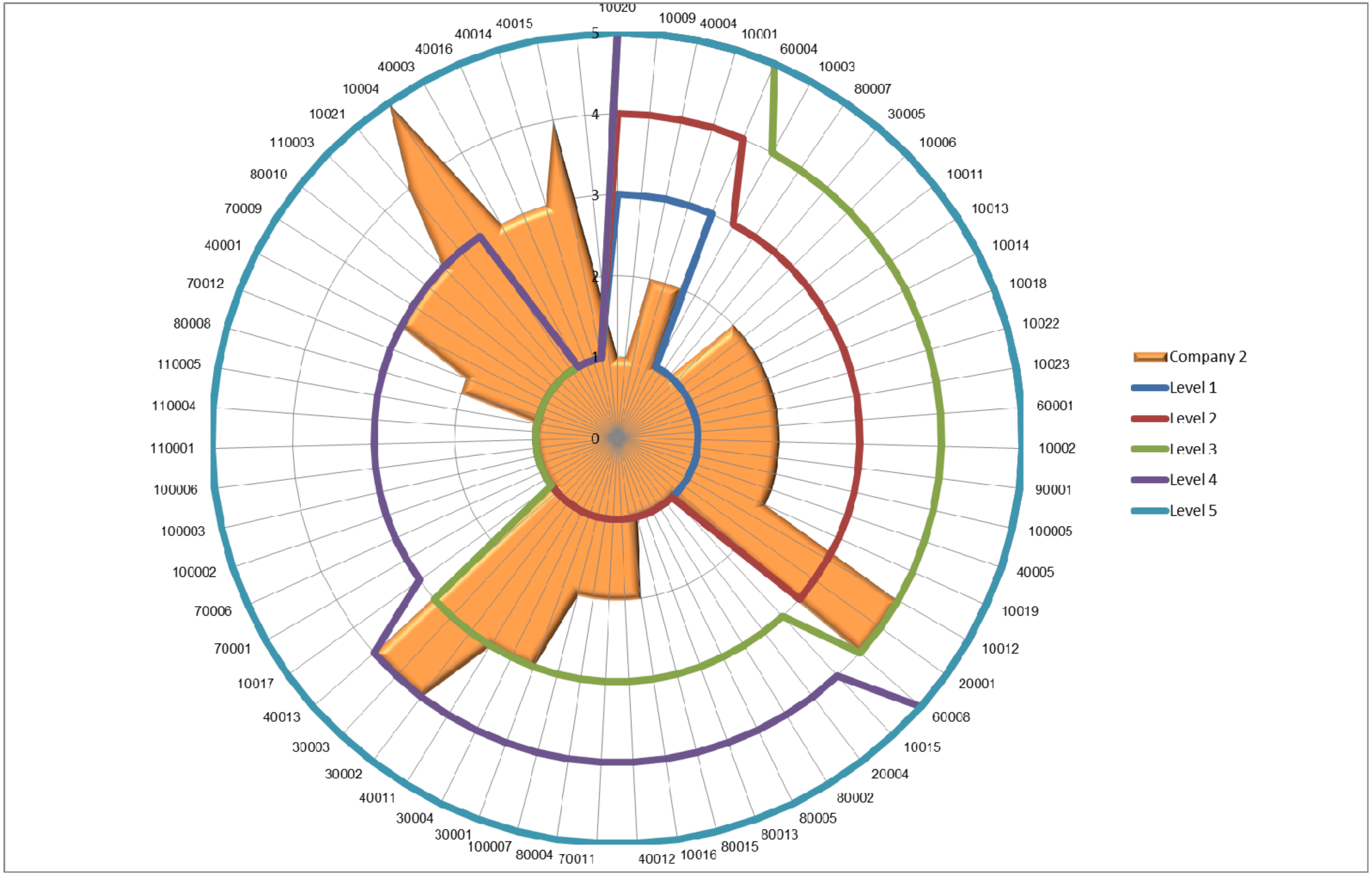

Figure 16: Ecodesign Maturity Profile of Company 2

6.1.2 Proposition of ecodesign practices and improvement projects - Company 2

In this section, the ecodesign practices and improvement projects to be applied by Company 2 are presented. The case study was set up according to the three steps defined in the application method (section 5.6.2): (1) selection of the process improvement approach to be adopted (section 6.1.2.1); (2) identification of the ecodesign practices to be implemented (section 6.1.2.2); and (3) analysis of complementarities among ecodesign practices and proposal of improvement projects for ecodesign implementation (section 6.1.2.3).

6.1.2.1 Step 1: Selection of the process improvement approach

Based on the ecodesign maturity profile of the Company 2 (Figure 16) the continuous approach for process improvement was selected. The choice is justified by the fact that the company has a relatively high maturity on ecodesign, performing a significant amount of ecodesign management practices in a formalized way (capability 3). In the continuous approach for process improvement, the evolution based on the ecodesign capability levels defined by the EcoM2 (section 5.6.2.1) is followed.

6.1.2.2 Step 2: Identification of the ecodesign management practices

The opportunities for improvements in the ecodesign application at Company 2 were identified considering the continuous approach for process improvement, through the analysis of the ecodesign management practices with low capability levels. Since there are still a considerable amount of practices with low capability levels, the focus of the first improvement cycle for ecodesign implementation at Company 2 was set to include the implementation of the ecodesign management practices with low capability levels of the evolution levels 1, 2 and 3. However, two practices from higher evolution levels was added and one practice from the evolution level 3 (capability 1) was excluded due to specific needs and prioritizations of the company for the first improvement cycle. These alterations were possible due to the selection of the continuous approach for process improvement. The goal to be reached by Company 2 after the first improvement cycle is presented in Figure 17.

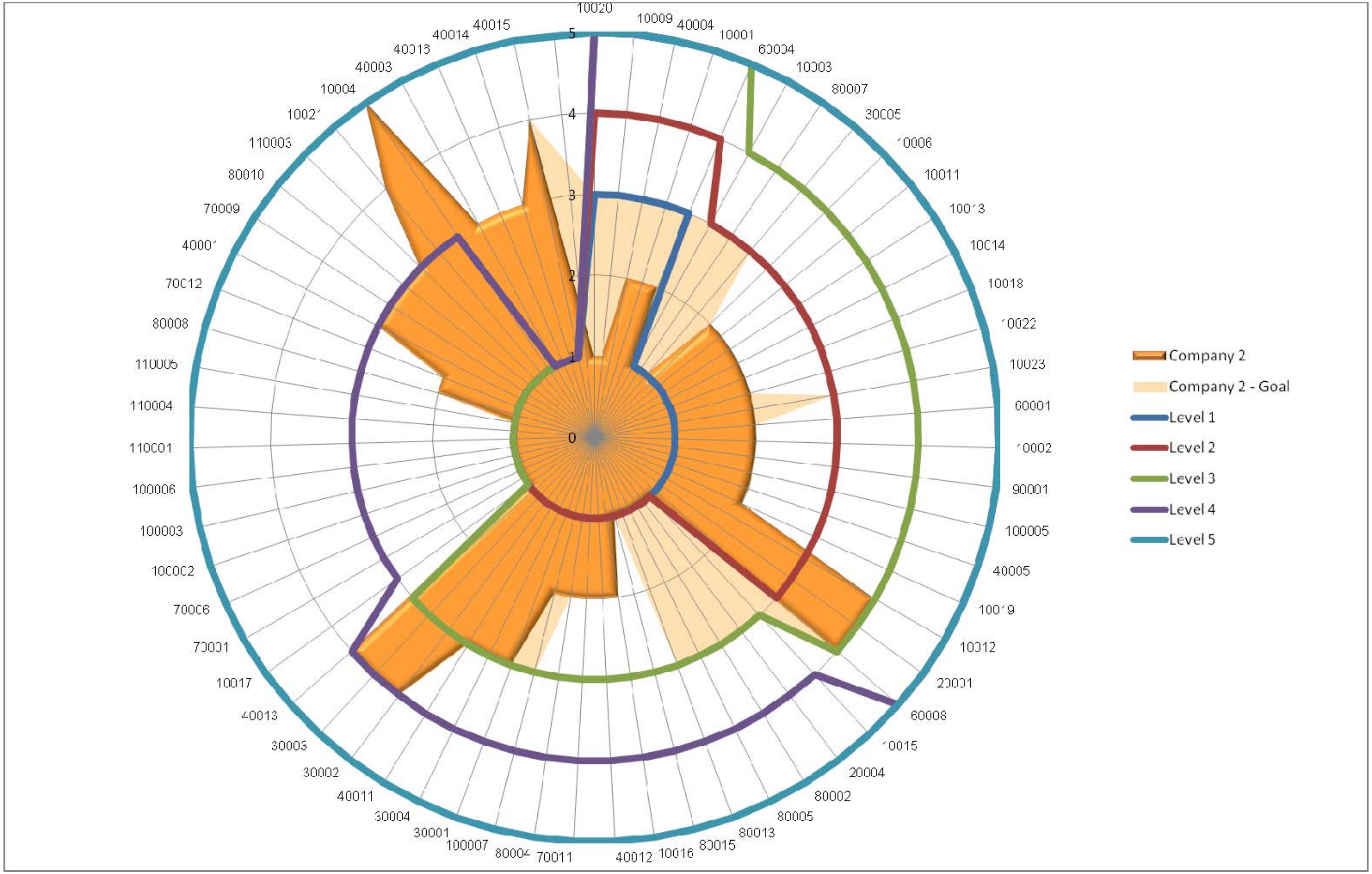

Figure 17: Goal of the Company 2 for ecodesign implementation in the first improvement cycle

Once defined the ecodesign management practices to be applied, the relationships and dependencies among the ecodesign management practices, the operational practices and the ecodesign techniques/tools were evaluated. As a result, a set of the most suitable ecodesign management practices, ecodesign operational practices and technique/tools to be applied by Company 2, according to its maturity profile on ecodesign, was obtained.

6.1.2.3 Step 3: Proposal of improvement projects – Company 2

The definition of the ecodesign projects was performed by grouping similar and convergent ecodesign practices in order to support an integrated implementation according to the methodology presented in section 5.6.2.3. In total, seven ecodesign projects[83] were proposed to be implemented by Company 2:

Project 1: Establish an ecodesign program at the company

The goal of this project for ecodesign implementation is to establish an ecodesign program at Company 2 in order to effectively deploy the environmental strategy of the company into the product development and related processes. The aim is to make ecodesign part of the daily activities of Company 2.

The ecodesign program should include the obtainment and dissemination of knowledge on ecodesign to the employees directly related to the product development and related processes and the collection of product-related environmental legislation and standards applicable to the products developed by the company. Additionally, the internal and external drivers for ecodesign implementation must be clarified for everyone at the company.

The ecodesign management practices suggested for implementation in this project are presented in Table 19, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

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[83] Due to the non-disclosure agreement signed, the information contained in ecodesign projects cannot be published and was omitted from this document.

Table 19: Ecodesign management practices - Project 1 (Company 2)

Ecodesign management practices	Capability Level	
	Current	Goal
Get and disseminate knowledge on ecodesign approaches and practices	**1**	**3**
Examine the relevant internal drivers (as cost reduction and improvement of company's image) and external drivers (customers requirement and legislation/regulation) for ecodesign adoption	**2**	**3**
Formulate a company environmental policy/strategy	**2**	**3**
Collect information about environmental product-related legal issues and standards	**2**	**3**
Establish a prioritized ecodesign program at the company	**1**	**3**
Define and measure performance indicators for the environmental performance of the ecodesign program	**1**	**3**
Make ecodesign tasks a part of the daily routine for the relevant employees	**1**	**3**

In order to perform the ecodesign management practices 40004, the following ecodesign tools can be applied:

- m00038 – Eco-roadmap;
- m00082 - Philips STRETCH (Selection of sTRategic EnvironmenTal CHallenges);

In order to perform the ecodesign management practice 60004 the following ecodesign tools can be applied[84]:

- m00038 – Eco-roadmap;
- m00041 – EIA track;

Project 2: Disseminate life cycle and systemic holistic thinking

The main focus of this project is to disseminate the life cycle thinking, i.e. the consideration of the whole life cycle phases of a product during its development – from raw material extraction to end-of-life issues. Additionally, the consideration of all environmental aspects (e.g. resources consumption,

[84] The tool m00040 – EEE-Pilot was not suggested for use because Company 2 do not develop electronics products

recyclability, etc.) pertinent to the product under development in an integrated way is expected.

The ecodesign management practice suggested for implementation in this project is presented in Table 20, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 20: Ecodesign management practices - Project 2 (Company 2)

Ecodesign management practices	**Capability Level**	
	Current	**Goal**
Implement a life-cycle thinking in the company	**2**	**3**

There are no ecodesign tools/techniques and operational practices that can support the implementation of this ecodesign management practice.

Project 3: Create a trade-off methodology for ecodesign metrics

The goal of this project is to develop a methodology that can support trade-off analyzes among the different ecodesign metrics already considered by Company 2 and the traditional requirements of a product, such as quality and cost. Additionally, the tool would need to provide prioritization among the metrics in order to support the decision making process.

The ecodesign management practices suggested for implementation in this project are presented in Table 21, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 21: Ecodesign management practices - Project 3 (Company 2)

Ecodesign management practices	**Capability Level**	
	Current	**Goal**
Establish priorities on the environmental impacts to be minimized (invest time and effort in activities with significant contribution)	**1**	**3**
Consider the trade-offs among the different ecodesign strategies, the product life cycles and the traditional requirements of a product (such as quality, cost, aesthetics, etc.)	**1**	**3**

In order to perform the ecodesign management practice 20004, the company can get inspiration from the tool:

- m00078: New DFE Targeting and Tracking System – HP;

In order to perform the ecodesign management practice 80002 the following ecodesign tools can be applied:

- m00016 - Dominance Matrix or Paired Comparison;
- m00031 - Eco-Innovative Tool;
- m00075 - Method to Support Environmentally Conscious Service Design Using Quality Function Deployment (QFD);
- m00091 - Conceptual Design Tool for Resolving Conflicts Between Product Functionality and Environmental Impact;
- m00092 - Simple Additive Weighting (SAW) Method.

Project 4: Develop a guide to support the technical consideration of ecodesign during the product development process

The goal of this project is to develop a guide which presents the guidelines for product design that can be used in order to develop products with a better environmental performance. The guidelines should provide information to support the decision making process by the product development teams.

The ecodesign management practices suggested for implementation in this project are presented in Table 22, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 22: Ecodesign management practices - Project 4 (Company 2)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Customize the strategies/guidelines/design options for product design individual changes to reach the environmental goals	**1**	**3**
Ensure coherency between the environmental goals and the product architecture (e.g. develop easy disassemble products if the goal is to improve remanufacturing)	**1**	**3**

In order to perform the ecodesign management practice 80005 the following ecodesign tools can be applied[85]:

- m00023 - Ecodesign Online:
- m00024 - EcoDesign Pilot;
- m00025 - Ecodesign strategy wheel:
- m00032 - Eco-Kit;
- m00045 - Environmental Design Strategy Matrix (EDSM):
- m00053 - EPP (Environmentally Preferred Product) Design tool:
- m00060 - Information/Inspiration web-based tool;
- m00061 - Instep-DfE:
- m00063 - LiDs Wheel:
- m00095 - Strategy List:
- m00103 – The Ten Golden Rules;
- m00104 – TRIZ and Eco-Innovation.

Additionally, the ecodesign operational practices, in their totality, can also be used to develop the guide. Nevertheless, they need to be customized to the characteristics of the products developed by Company 2.

Project 5: Develop/implement a benchmarking tool to be used during the product development process

The goal of this project is to develop and implement a benchmarking tool to be used by Company 2 during the product development process, in order to understand what are the best practices and design solutions adopted by competitors in ecodesign (the company already perform internal benchmarking using a home-made tool).

The ecodesign management practice suggested for implementation in this project is presented in Table 23, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

[85] The following tools were excluded from the list due to the sector that Company 2 operates: m00014 – Design Guidelines for Renewable Energy Powered Products; m00022 – Ecodesign Method for Electronics Products; m00040 - EEE-PILOT.

Table 23: Ecodesign management practice - Project 5 (Company 2)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Perform benchmarking internally (to set environmental improvement goals) and externally (to understand what competitors are doing in ecodesign)	**1**	**3**

In order to perform the ecodesign management practice 10009 the following ecodesign tools can be applied[86]:

- m00018 – Ecobenchmarking;
- m00049 - Environmental Benchmarking.

Project 6: Include the environmental performance of products in the supplier management

The goal of this project is to increase the consideration of the environmental performance of products during the supplier management. The ecodesign management practice suggested for implementation in this project is presented in Table 24, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 24: Ecodesign management practice - Project 6 (Company 2)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Consider the environmental aspects in the identification/qualification of potential suppliers	**1**	**3**

In order to perform the ecodesign management practice 80007 the following ecodesign tool can be applied:

- m00037 – EcoQuest;

[86] The tool m00022 – Ecodesign Method for Electronics Products was not suggested because it is aimed at electronics products.

Project 7: Develop/implement a methodology to communicate the environmental performance of products to customers

The goal of this project is to improve the current methodology used by the company to communicate the environmental performance of products to the customers. The project is relevant because the current information communicated is not completely understood by the consumers and even by the internal employees of the organization.

The ecodesign management practice suggested for implementation in this project is presented in Table 25, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 25: Ecodesign management practice - Project 7 (Company 2)

Ecodesign management practices	Capability Level	
	Current	Goal
Communicate the environmental benefits of the product as part of the total value proposition of the product	**2**	**3**

In order to perform the ecodesign management practice 100007 the following ecodesign tool can be applied:

- m00017 - Eco-communication:

The selection of the specific tools to be used in each of the proposed projects must be performed internally by the company and can be supported by the classification criteria provided by EcoM2. Additionally, the portfolio management of the improvement projects should be performed by the company, as well as the project planning with the definition of responsibilities, resources, schedule, etc. and the subsequent steps of the application method. Whenever needed, the company can rearrange the improvement projects, as far as the ecodesign management practices are applied.

6.1.3 Evaluation of EcoM2 application by the company 2

The methodology employed and the results of the EcoM2 application (Ecodesign Maturity Radar and proposed projects for ecodesign implementation) were presented at Company 2 for seven employees[87] in a meeting that lasted about 2 hours. After the presentation, a report with all the results was provided and the Company 2 was asked to answer the evaluation questionnaire (Appendix G), in order to expose their impressions about the application of the EcoM2, the results obtained and how they satisfied their needs. The results of the evaluation of Company 2 related to the application of the EcoM2 are presented Figure 18[88].

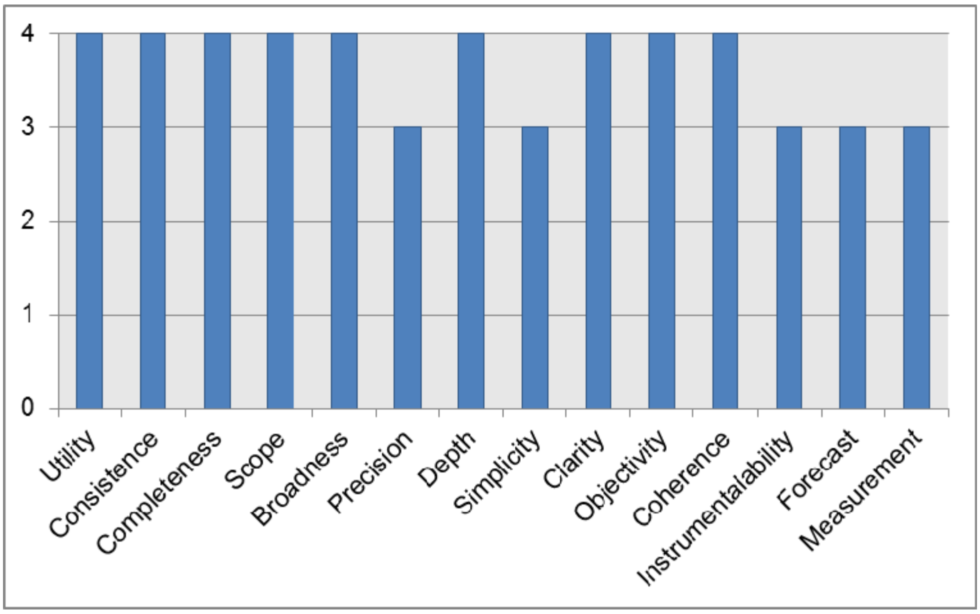

Figure 18: Evaluation of the EcoM2 by Company 2

In overall, company 2 was very satisfied with the results obtained with the EcoM2 application (9 from 14 criteria were classified as “very satisfactory”, including utility, consistence, completeness, scope, broadness, depth, clarity, objectivity and coherence) and satisfied with the other 5 criteria (precision, simplicity, instrumentability, forecast and measurement).

"Our perception is positive about the potential usefulness [of the EcoM2]. Also, we would like to address that the model is suitable for R&D and innovation management" and “I think that the model and the results are accurate. Now the challenge is a complete understanding of the issue in its complexity and further spread to the various involved audiences”.

[87] Most of the interviewees did not attend the presentation – this fact may be related to the company dynamics on time allocation.

[88] The following scale for assessment was adopted: (4) Very satisfactory; (3) Satisfactory; (2) Needs improvement; and (1) Unsatisfactory.

In regards to the completeness of the EcoM2, Company 2 states that "The perception is very positive. However, it is noteworthy that the experience is very recent, we cannot conclude on the effectiveness and completeness with confidence, considering that the evolution process is relatively slow and complex". The commentary related to the simplicity of the EcoM2 is “As mentioned, this type of model is complex by nature. But I think that the pedagogy is appropriate. One point still a little confusing/challenging is the distinction between tools and practices.”

In relation to scope and broadness, the company stated that “In our analysis still in progress, other dimensions that must be considered to guide the company in implementing the Ecodesign were identified. I understand that the focus of EcoM2 is on the innovation process, but other important points are: people and company culture, organization and context of the company, the company's own experience and tools”.

“The model is straightforward. Sometimes it is needed to analyze and discuss the evaluation further, as we did for some indicators, but I believe that it is possible to reach a consensus in the evaluation”, affirms the company. Talking about coherence, the comment of Company 2 is “The question of improvement projects is more complex, as stated before. In my view, the diagnosis is a very useful analysis and photography; however the definition of improvement projects depends on many internal issues. Further analysis need to be performed in order to define the ecodesign projects.”

The instrumentability of the EcoM2 is evaluated as: “I believe the model addresses well the use of methods and tools associated with the ecodesign practices. However, in the conclusions and suggestions for improvement, perhaps the distinction may be clearer”. Finally, in regards to measurement, the company states “I think the model is useful for this purpose, but it is quite not explicit. Also, I consider that the model provides a "snapshot" of ecodesign in the product development process as a whole, but other measures need to accompany the finest results”.

6.2 Case study for theory-testing at Company 3

Company 3 is one of the world´s leading manufacturers in the sector it operates, covering approximately 50% of the world market. It is a European multinational company with more than 60 years of experience, represented by more than 80 companies in 55 countries[89]. Company 3 employs circa 17.000 people around the world.

Sustainability is one of the values of the company. The company sustainability strategy has just been launched and is currently under a deployment process into the other business processes. The Ecodesign Maturity Model (EcoM2) was understood by Company 3 as a tool to be used to deploy the sustainability strategy into the product development process as regards to environmental considerations.

The first two steps of the EcoM2 application method were applied in the case study for theory-testing at Company 3. The results are presented in the next sections.

6.2.1 Diagnosis of the current maturity profile on ecodesign of the Company 3

In this section, the results of the three steps for performing the diagnosis of the current maturity profile on ecodesign implementation are presented: (1) product development process analysis (section 6.2.1.1); (2) interviews for maturity assessment (section 6.2.1.2); and (3) consolidation of the results (section 6.2.1.3), according to the methodology presented in section 5.6.1.

6.2.1.1 Step 1: Product development process analysis

The goal of this step is to understand how the product development process is organized, structured and documented at Company 3 (see section 5.6.1.1).

Full access was provided to the intranet portal of the Company 3, where all the processes, templates, guides and tools are available for consultation. The following documents of Company 3 were analyzed[90]: PDP-related documents

[89] The case study was carried out in the headquarters of the company in Europe.

[90] Due to the non-disclosure agreement signed, the information contained in the analyzed documents cannot be published and was omitted from this document.

(guides, templates, tools, processes, standards and criteria for gate assessments), support-processes-related documents (input and output data, responsibilities matrix, processes definition, templates, and guides), environmental-related documents (sustainability strategy, processes, tools, guides, reports, etc.) and organograms of the company.

During this step, three key-employees (two directly related to the product development process and one from the environmental department) were interviewed in order to elucidate how the process is performed in a daily basis and to clarify issues on the analyzed documents. Additionally, the environmental-related activities currently performed at the company were introduced during the interview.

The questionnaire of the second step of the diagnosis was adapted to the company vocabulary and the employees to be interviewed were identified jointly with the company[91]. All of the support processes for the product development process were analyzed and at least one employee from each support process was selected to be interviewed. A total of 22 employees from different areas (such as service development, engineering, maintenance, technology development, etc.), functions and hierarchical positions were selected.

The company organized the schedule for the performance of the interviews, contacted the people to be interviewed explaining the general context of the project and provided the resources needed to this aim.

6.2.1.2 Step 2: Interviews for maturity assessment

In total, 22 semi-structure interviews[92] were carried out in one week at the Company 3. The average duration of the interviews was 57 minutes, following the methodology described in section 5.6.1.2 (which consists of an introduction before the questions for maturity assessment and was followed by final discussion).

During the 22 interviews, the ecodesign management practices were evaluated according to their capability level of application in the company, in order to

[91] Due to the non-disclosure agreement signed, this information cannot be published and was omitted from this document.

[92] One of the interviews was carried out by phone, because the employee was ill at home at the date of the interview. This fact did not impair the results of the diagnosis.

determine the current maturity profile of the company. The comments of the interviewees were documented, in order to support further analysis and provide evidences on the results obtained.

6.2.1.3 Step 3: Consolidation of the results: Ecodesign Maturity Profile

In order to consolidate the data obtained during the interviews carried out in the previous stage, the results were summarized in a spreadsheet. The answers of the employees were analyzed against their own commentaries in order to guarantee coherence and consistence of the capability levels assigned. Whenever necessary, the capability level was changed based on the commentaries and on the evidences of the documental analysis.

Within the results, the Ecodesign Maturity Radar of Company 3 was built (Figure 19). The analysis of the Ecodesign Maturity Radar indicates that the Company 3 has low knowledge on ecodesign (consideration of the environmental issues during the product development process) and that the ecodesign approach has not been fully implemented yet.

Company 3 already applies some ecodesign practices (29%), but most of them still in an ad hoc way (capability 2). A huge amount of practices (65%) are applied in an incomplete way (capability 1). The practices applied with higher capabilities (3 – formalized (3 practices) and 4 – controlled (1 practice)) are related to the consideration of the environmental issues during the production process.

The company follows a reactive approach for ecodesign implementation, focusing mainly on legislation and cost reduction. Historically, the company focuses on one environmental aspect in a single life cycle phase, mainly due to market competitiveness and total value of ownership of the products.

Besides the increasingly incorporation of the environmental issues into the company´s strategy, the deployment to the daily activities is still incomplete. However, the employees of the company are engaged and understand the company values towards sustainability.

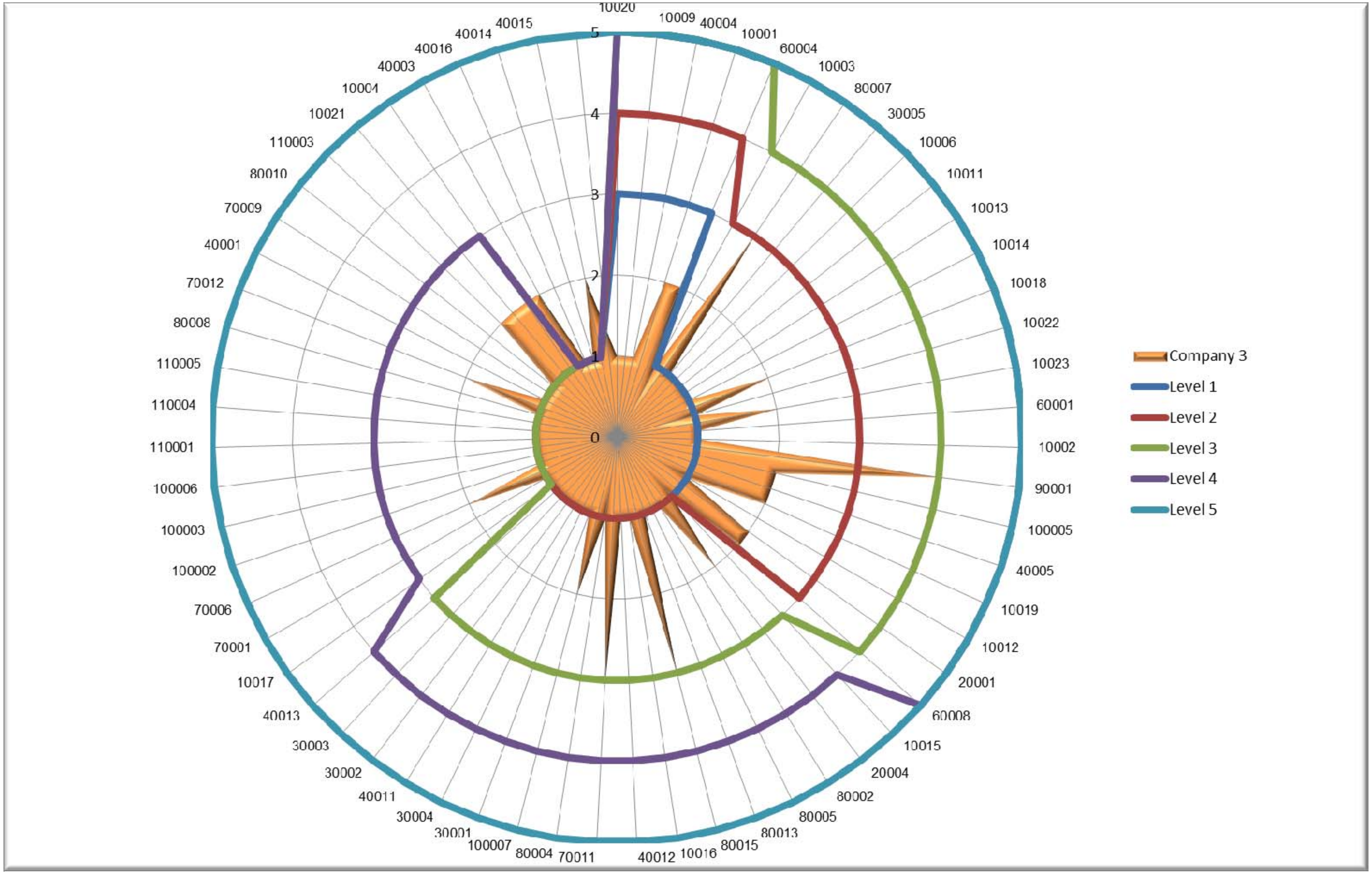

Figure 19: Ecodesign Maturity Profile of Company 3

6.2.2 Proposition of ecodesign practices and improvement projects to be applied by the Company 3

The proposition of ecodesign practices and improvement projects to be applied by Company 3 was performed in three steps: (1) selection of the process improvement approach to be adopted (section 6.2.2.1); (2) identification of the ecodesign practices to be implemented (section 6.2.2.2); and (3) analysis of complementarities among the ecodesign practices and proposal of improvement projects for ecodesign implementation (section 6.2.2.3).

6.2.2.1 Step 1: Selection of the process improvement approach

The staged approach for process improvement is the most suitable one to be implemented by Company 3, according to its current ecodesign maturity profile (Figure 19). The staged approach follows the maturity levels defined by the EcoM2 and provides a systematic and structured way for implementing process improvements based on the implementation of one stage (maturity level) at a time (section 5.6.2.2). Each stage indicates that the process already has the necessary foundation and structure that qualify it for the next stage.

6.2.2.2 Step 2: Identification of the ecodesign management practices

In accordance to the staged approach for process improvement, the implementation of the ecodesign practices must follow the maturity levels defined by the EcoM2.

A goal for the first improvement cycle to reach a maturity level 2 in ecodesign implementation (Figure 20) was established by Company 3. In order to reach the second maturity level, the ecodesign management practices to be implemented by Company 3 are those of the first and second evolution levels:

- the ecodesign management practices of evolution level 1 must be applied with capability 4 (formalized); and
- the ecodesign management practices of evolution level 2 must be applied with capability 3 (controlled).

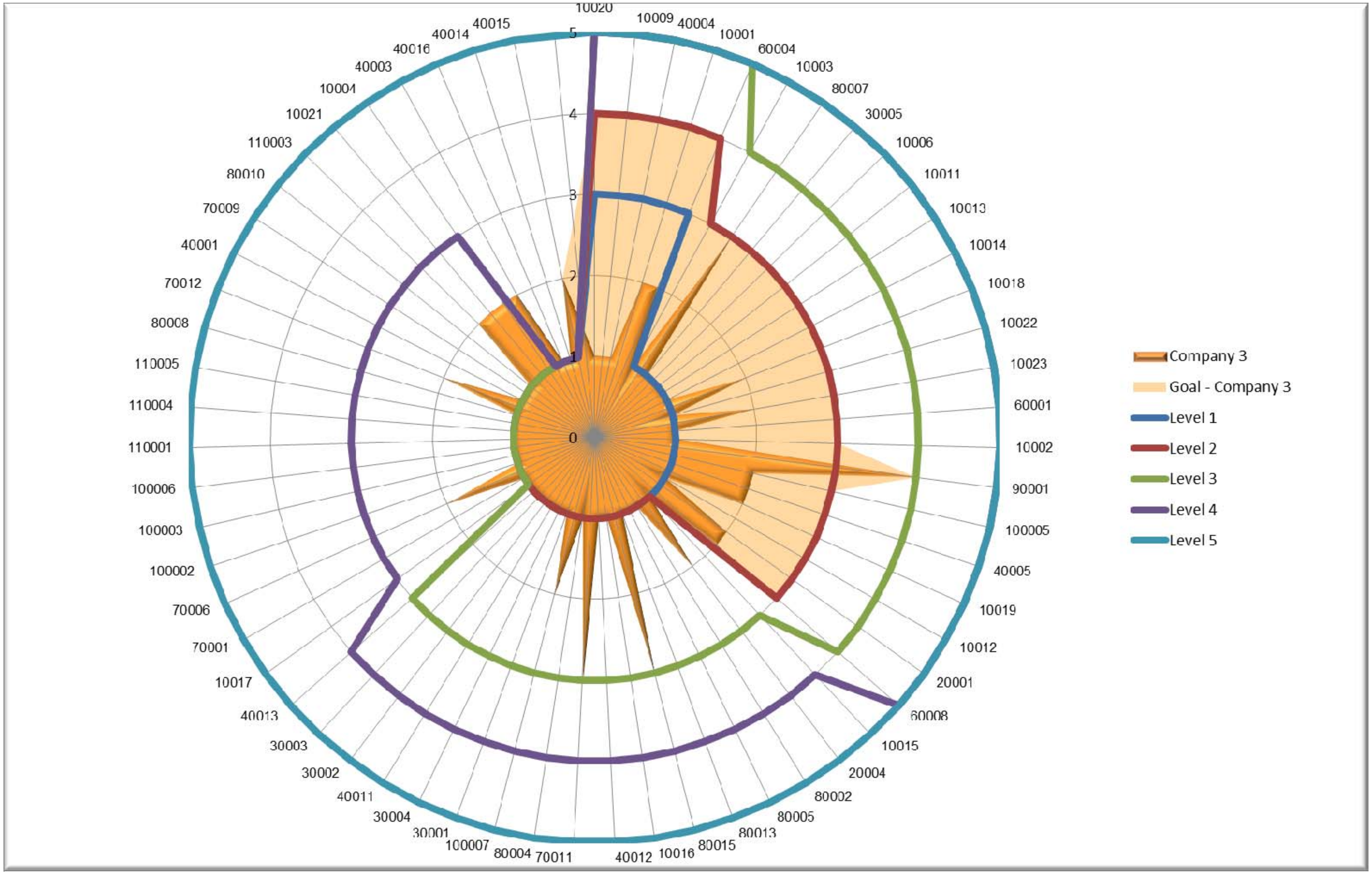

Figure 20: Goal of the Company 3 for ecodesign implementation in the first improvement cycle

At the end of the first improvement cycle, the company can begin a new improvement cycle, reassessing the current maturity profile in ecodesign, in order to define new projects to be implemented towards higher maturity levels on ecodesign implementation.
Once the ecodesign management practices to be applied were defined, the relationships and dependencies among the ecodesign management practices, the operational practices and the ecodesign techniques/tools were assessed. As a result, a set of the most suitable ecodesign management practices, ecodesign operational practices and technique/tools to be applied by Company 3 was proposed, according to its maturity profile on ecodesign. Those practices are presented in the next step (section 6.2.2.3), in the description of the improvement projects.

6.2.2.3 Step 3: Proposal of improvement projects for ecodesign implementation

A cluster analysis was performed in order to identify synergies among the ecodesign management practices and propose the improvement projects for ecodesign implementation, based on the characteristics and culture of the Company 3. The improvement projects were designed for the joint and integrated incorporation of the application of one or more practices. In total, 4 projects[93] for ecodesign implementation were proposed to Company 3:

Project 1 – Set an organizational structure for ecodesign implementation

The goal of this project is to establish the organizational structure at Company 3 that will be responsible for the integration of the environmental issues into the product development and related processes by the deployment of the sustainability strategy (i.e., for ecodesign implementation). In order to succeed in this task, the attribution of responsibilities and resources to perform these activities is of high importance.
Options for the organizational structure for ecodesign implementation includes: the environmental group, the product development department, the creation of a new group for ecodesign implementation (such as quality), etc. The decision of the best organizational structure must be performed internally by the company.

[93] Due to the non-disclosure agreement signed, the confidential information contained in ecodesign projects cannot be published and was omitted from this document.

The ecodesign management practices suggested for implementation in this project are presented in Table 26, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 26: Ecodesign management practices - Project 1 (Company 3)

Ecodesign management practices	**Capability Level**	
	Current	**Goal**
Ensure commitment, support and resources to conduct the activities related to ecodesign	**1**	**3**
Ensure appropriate communication between the departments and different levels concerning product-related environmental issues	**1**	**3**
Involve the relevant functions across the company in the ecodesign implementation	**1**	**3**
Deploy product-related environmental responsibilities among employees of different levels at the organization	**1**	**3**

There are no ecodesign tools/techniques and operational practices that can support the implementation of these ecodesign management practices.

Project 2 – Establish an ecodesign program

The goal of this project is to establish an ecodesign program at Company 3 to perform the deployment of the sustainability strategy into the product development and related processes. The ecodesign program should be implemented by the organizational structure settled in the previous project (Project 1 - Set an organizational structure for ecodesign implementation).

The ecodesign program should include the collection and dissemination of ecodesign-related knowledge, the increase of awareness and commitment of the involved people to perform the activities related to the integration of the environmental issues into the product development and related processes, and the provision of new tools that can support the development projects in the integration of the environmental dimension into the decision making processes.

In the scope of the ecodesign program, pilot projects should be carried out in order to test the tools and practices and understand how they work in practice and what the real benefits that the company can get are. The results should be used to set goals for ecodesign implementation at the company.

The ecodesign management practices suggested for implementation in this project are presented in Table 27, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 27: Ecodesign management practices - Project 2 (Company 3)

Ecodesign management practices	**Capability Level**	
	Current	**Goal**
Get and disseminate knowledge on ecodesign approaches and practices	**1**	**4**
Examine the relevant internal drivers (as cost reduction and improvement of company's image) and external drivers (customers requirement and legislation/regulation) for ecodesign adoption	**1**	**4**
Start the ecodesign application by increasing people consciousness about the application opportunities	**1**	**3**
Provide training in ecodesign approach and practices for employees involved in the product development and related processes	**1**	**3**
Select, customize and implement ecodesign techniques/tools according to the company's needs	**2**	**3**
Implement a life-cycle thinking in the company	**2**	**3**

In order to perform the ecodesign management practice 40004 the following ecodesign tools can be applied:

- m00038 – Eco-roadmap;
- m00082 - Philips STRETCH (Selection of sTRategic EnvironmenTal Challenges);

The projects 3 and 4, to be presented in the following sub-sections, must be part of the ecodesign program.

Project 3 – Clearly define the role in the support processes for ecodesign implementation

The environmental considerations must be spread across the organization. All of the support processes for the product development must be aware of what are their roles in the ecodesign implementation. The activities that must be performed to ensure that products with better environmental performance are being developed must be clarified. This project must be held in the context and supported by the ecodesign program.

The ecodesign management practices suggested for implementation in this project are presented in Table 28, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 28: Ecodesign management practices - Project 3 (Company 3)

Ecodesign management practices	**Capability Level**	
	Current	**Goal**
Perform benchmarking internally (to set environmental improvement goals) and externally (to understand what competitors are doing in ecodesign)	**1**	**4**
Collect information about environmental product-related legal issues and standards	**2**	**4**
Identify customer and stakeholders requirements and priorities concerning the environmental issues	**1**	**3**
Deploy and maintain an environmental policy/strategy for products	**1**	**3**
Include packaging and distribution process of the product under the ecodesign considerations (it brings quick wins and supports the creation of awareness of the ecodesign programs)	**2**	**3**
Assess technological and market trends (including new customer requirements) that embraces the trends of products with better environmental performance and develop a list of potential products and market strategies according to the new trends	**2**	**3**
Formulate and monitor mandatory rules concerning environmental issues for the enterprise to comply with law/regulations and internal standards/goals	**2**	**3**
Deploy product-related environmental responsibilities among employees of different levels at the organization	**1**	**3**
Search technologies that can contribute to improve environmental performance and achieve the environmental goals	**2**	**3**

In order to perform the ecodesign management practice 10009[94] the following ecodesign tools can be applied:

- m00018 – Ecobenchmarking[95];
- m00049 – Environmental Benchmarking Methodology;

[94] The method m00022 (Ecodesign Method for Electronics Products) was not included as a possible tool to be implemented by company 3 because it applies just for electronics products.

[95] It is also known as “environmental benchmarking”.

In order to perform the ecodesign management practice 60004 the following ecodesign tools can be applied:

- m00038 – Eco-roadmap: see description in practice 40004;
- m00040 – EEE-PILOT[96];
- m00041 – EIA track[97];

In order to perform the ecodesign management practice 60001 the following ecodesign tools can be applied:

- m00036 – Eco-QFD (Ecological Quality Function Deployment):
- m00038 – Eco-roadmap;
- m00050 – EQFD (Environmental quality function deployment);
- m00051 - Environmental Value Chain Analysis (EVCA);
- m00083 – ECQFD (Environmentally Conscious Quality Function Deployment);
- m00086 – QFDE (Quality Functional Deployment for Environment);
- m00107 – EcoValue;

In order to perform the ecodesign management practice 40005 the following ecodesign tool can be applied:

- m00038 –Eco-roadmap;

In order to perform the ecodesign management practice 100005 the following ecodesign operational practices can be applied[98]:

- c00003 - Minimize or avoid Packaging;
    - m00080 - Packaging Impact Quick Evaluation Tool (PIQET)[99];
- c10002 - Minimize energy consumption during transportation and storage;
- c20002 - Select Non-toxic and Harmless Energy Resources;
- c20006 - Select Renewable and Bio-compatible Materials;
- c20007 - Select Renewable and Bio-compatible Energy Resources;

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[96] The tool is now called EEG-PILOT and can be accessed in the website: http://www.ecodesign.at/pilot/eeg/ENGLISH/INDEX.HTM

[97] Check the website: http://www.eiatrack.org/

[98] The design option can be consulted in the Appendix B.

[99] The PIQET tool is available at http://piqet.sustainablepack.org/login.php

Project 4 – Evaluate the environmental impact of products during the PDP

The goal of this project is to provide tools, resources and the infrastructure to evaluate the environmental impact of the products during the product development. The evaluation should support the decision making process and the identification of opportunities for improvements in product design. The results can also be used to support the goals definition in the context of the ecodesign program.

The ecodesign management practices suggested for implementation in this project are presented in Table 29, which also includes the current and the future capability levels to be achieved in order to reach the goal settled.

Table 29: Ecodesign management practices - Project 4 (Company 3)

Ecodesign management practices	Capability Level	
	Current	**Goal**
Define and measure performance indicators for the environmental performance of ecodesign program	**1**	**3**
Evaluate the environmental performance of products	**2**	**3**

In order to perform the ecodesign management practice 20001 the following ecodesign tools and techniques can be applied:

- m00002 - ABC Analysis;
- m00004 - AT&T's Green Design Tool;
- m00006 – Life Cycle Assessment (LCA);
- m00015 - DfE Matrix;
- m00019 - Eco-COMPASS (Comprehensive Product Assessment) technique;
- m00020 - ECODESIGN Checklist Method (ECM);
- m00026 - Ecodesign Web;
- m00028 - Eco-indicator 99;
- m00042 - EIME software (Environmental Information and Management Explorer);
- m00045 - Environmental Design Strategy Matrix (EDSM);
- m00047 - Environmental Effect Analysis (EEA);
- m00048 - Environmental Efficiency Potential Assessment method (E2-PA);
- m00061 - Instep-DfE;
- m00064 - Life Cycle Check (LCC);

- m00068 - LIME method;
- m00069 - MECO Matrix;
- m00070 - MET Matrix;
- m00072 - Method for Sustainable Product Development (MSPD);
- m00081 - Philips Fast Five Awareness;
- m00085 - Product Life Cycle Planning (LCP);
- m00095 - Strategy List;
- m00100 - Environmentally Responsible Product Assessment Matrix (ERPA);

The specific tool to be used by the company was not defined; however a set of tools that could be used to support the application of the ecodesign practices was provided. As previously mentioned, the selection of the specific tool to be used must be performed internally by the company and can be supported by the classification criteria provided by EcoM2.

Whenever possible, the environmental considerations should be incorporated into the traditional methods and tools used by the company. For example, if the company already has a well-established benchmarking process, the required changes in order to include the environmental issues in the studies should be analyzed. The identification of needed improvements can be done by assessing the characteristics and type of input/output data of the ecodesign methods and tools developed for this purpose (such as the Eco-benchmarking, for the previous example).

6.2.3 Evaluation of EcoM2 application by the Company 3

The methodology employed and the results of the EcoM2 application (Ecodesign Maturity Radar and proposed ecodesign projects) were presented at the company for 35 employees (most of the interviewees attended the presentation) in a meeting that lasted circa 120 minutes and was followed by a comprehensive discussion on how the company should proceed in the implementation of the proposed projects for ecodesign implementation. The results of the evaluation of Company 3 using the evaluation questionnaire presented in Appendix G in the application of the EcoM2 are presented in Figure 21[100].

[100] It was adopted the following scale for assessment: (4) Very satisfactory; (3) Satisfactory; (2) Needs improvement; and (1) Unsatisfactory.

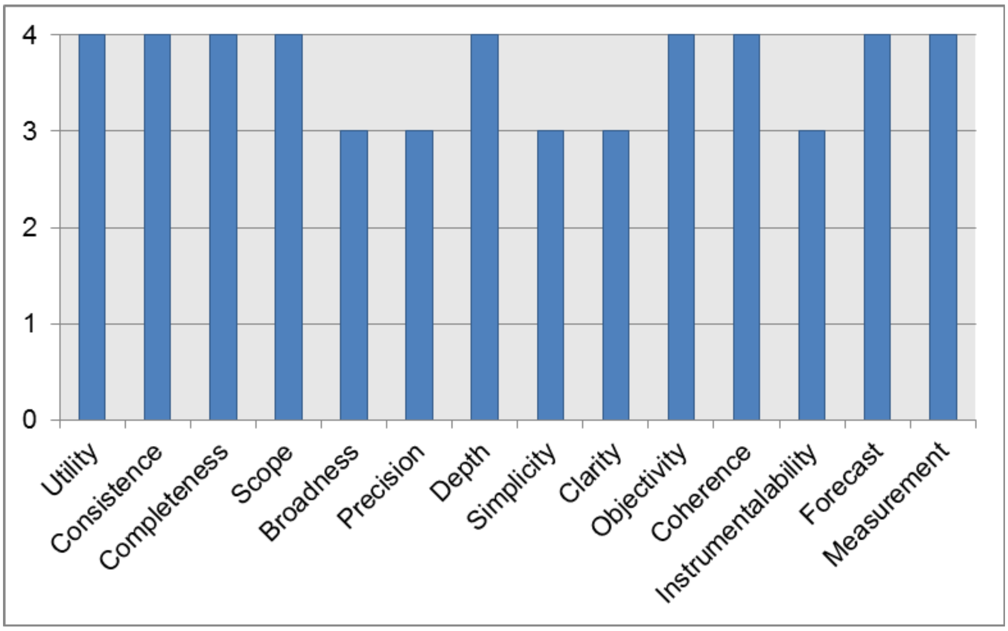

Figure 21: Evaluation of the EcoM2 by Company 3

Company 3 evaluated as very satisfactory most of the criteria used to assess the Ecodesign Maturity Model (EcoM2) (9 from 14) and as satisfactory the others (including broadness, precision, simplicity, clarity and instrumentability). None of the evaluation criteria were classified as “needs improvement” or “unsatisfactory”. It provides evidence that the Ecodesign Maturity Model (EcoM2) provided the expected results for Company 3 and can support the ecodesign implementation.

In relation to the broadness of the EcoM2, the company stated that it was expected to have being performed interviews with other employees from some other areas that were not initially defined in the step 1 for the diagnosis of the current maturity profile of the company (such as purchase). Additionally, the company affirms that “maybe a review from a communication and a layout expert could make it [the EcoM2l] even better and clearer to understand for everyone, no matter which background they have.” To conclude, Company 3 affirmed that “many participants to your presentation were very impressed [with the results]”, i.e. they agreed with the diagnosis of the current maturity profile of the company and with the ecodesign projects and improvement projects for ecodesign implementation proposed by the Ecodesign Maturity Model (EcoM2).

7 Conclusions and Final Remarks

This section presents the conclusions and final remarks of the research. It is divided into two sections related to the results and research objectives (section 7.1) and to the future researches (section 7.2).

7.1 Results and research objectives

Ecodesign has emerged as a promising approach to integrate environmental concerns into the product development and related processes in order to minimize environmental impacts throughout the product's life cycle, without compromising other essential criteria such as performance and cost. Despite the recognition of the ecodesign potential benefits, its application has not reached companies worldwide over the last years mainly due to difficulties in the management of ecodesign, which include: lack of systematization of ecodesign practices; lack of integration into the product development process, management and corporate strategy; and lack of a method to support the selection of the most suitable ecodesign practices to be applied. This fact was evidenced by the need of Companies 1, 2 and 3 for a model that could support them in ecodesign implementation and management. In order overcome these barriers, this thesis introduced the Ecodesign Maturity Model (EcoM2), a framework aimed at supporting companies in the ecodesign management based on their maturity profile and strategic objectives and drivers for ecodesign implementation.

The Ecodesign Maturity Model (EcoM2) was developed in the context of the hypothetic-deductive approach, combining the theoretical and empirical development. Initially, the theoretical version of the model was developed based on a literature review and subsequent evaluation by experts on ecodesign. The systematic literature review carried out indicated the existence of 62 ecodesign management practices, 468 ecodesign operational practices, and 107 ecodesign techniques and tools (section 4.2). These practices are presented in the literature in a fragmented and not integrated way. Additionally, there is no systematization of the ecodesign practices, indicating when and how they should be applied. This further hampers the incorporation by companies. In this research, the practices were systematized and relationships among them were established, in order to facilitate their selection and implementation (section 4.2). Moreover, the ecodesign maturity levels and the

EcoM2 application method were developed based on a literature review and integrated to the ecodesign practices, in order to build the first theoretical version of the Ecodesign Maturity Model (EcoM2).

The evaluation of the Ecodesign Maturity Model (EcoM2) by fourteen ecodesign experts (section 4.5) enhanced the relevance of the model and highlighted the strengths (such as the managerial consideration for ecodesign implementation and the comprehensive collection of existing ecodesign practices linked together for application) and the weaknesses of the approach adopted (such as the feasibility of effectively applying the model into companies). Based on the suggestions for improvements gathered from the experts' evaluations, the theoretical version of the EcoM2 was improved to the second version, with most expressively improvements related to the definition of the ecodesign practices and the ecodesign maturity levels. The innovation levels on ecodesign were excluded from the definition of the maturity levels and the capability level was incorporated as a dimension to be considered in the definition of the ecodesign maturity levels (section 4.6).

The improved theoretical version was then empirically further developed by means of an action research at a large manufacturing company (Company 1), which had a structured product development process and aimed at ecodesign implementation (section 5). The contributions from the practice gathered during the action research enabled the further improvement of the Ecodesign Maturity Model (EcoM2), especially in relation to the application method. The steps that should be performed during the diagnosis of the current maturity profile of a company (section 5.6.1) were defined, a graphical representation of the maturity profile of the companies using the Ecodesign Maturity Radar (Figure 11) was elaborated and the proposition of ecodesign practices and projects for ecodesign implementation (section 5.6.2) was detailed. Besides enabling a broad understanding of the current situation of the company on ecodesign implementation, the method employed turns in the direction of improving the awareness of the involved employees on ecodesign implementation and provides an opportunity for further reflections on the topic. Similarly, the presentation of the results in workshops and the discussion of the improvement projects together with the decision-makers at the organization is a very positive outcome of the EcoM2 application. The final version of the Ecodesign Maturity Model (EcoM2) was consolidate, as a result of the action research.

Subsequently, two case studies for theory-testing were carried out at Company 2 and Company 3, which brought richness to the understanding of how the application of the Ecodesign Maturity Model (EcoM2) is done in practice in companies and what are the results that can be expected with its application. The hypothesis advocated in this research that the Ecodesign Maturity Model can support the selection of ecodesign practices to be applied by a company was confirmed by the evaluations of the EcoM2 performed by the companies. All of the criteria defined for the EcoM2 evaluation were evaluated as very satisfactory or satisfactory by these companies (sections 6.1.3 and 6.2.3). In order to gather more evidence on the confirmation of the hypotheses and establish generalizations of the application of the EcoM2, however, replication of the case studies must be performed in future researches.

From the abovementioned, it can be concluded that the application of the Ecodesign Maturity Model (EcoM2) can successfully provide to companies:

I. Benchmarking of ecodesign practices: the EcoM2 presents a structured systematization of practices for ecodesign implementation (ecodesign management practices, ecodesign operational practices and ecodesign techniques and tools), obtained by means of a systematic literature review (section 4.2) which can be used to compare the current situation of a company with the state of the art in ecodesign implementation;

II. Assessment of weaknesses and strengths of the company concerning the ecodesign implementation: the performance of the diagnosis of the current maturity profile of a company following the methodology defined by the EcoM2 application method (section 5.6) results in the Ecodesign Maturity Radar (Figure 11) of the company, a graphical representation of which ecodesign management practices are applied by the company and with which capability, enabling the identification of strengths and areas for improvement;

III. Guide for ecodesign implementation: once the current ecodesign maturity profile of a company is defined in the diagnosis step (section 5.6.1), an evaluation of opportunities for improvements is then carried out. Afterwards, the approach for process improvement to be adopted (staged or continuous) is defined, the goal for the improvement cycle is established and the ecodesign practices to be implemented (section 5.6.2) are identified. The proposal of the ecodesign improvement projects (5.6.2.3) is performed based on the characteristics, culture, strategy and organizational structure of the company under analysis. It contains the description of the goals, ecodesign management practices and ecodesign operational practices and/or techniques and tools (when applicable). Moreover, the EcoM2 application method provides a framework for continuous improvements (section 5.6.3) and the general activities to be performed in order to implement the projects towards higher maturity levels on ecodesign implementation.

IV. Common language and a shared vision across the organization for ecodesign implementation: the graphical representation of the current ecodesign maturity profile (section 5.6.1), the definition of the goals to be achieved for ecodesign implementation after the first improvement cycle (section 5.6.2.2) and the proposal of the projects for ecodesign implementation (section 5.6.2.3) enables the understanding at the organization on the current and desired situation at the same time it shows the path to be followed by the company to achieve the goals.

The conclusion is that the EcoM2 successfully achieved the objective of the research, which were to support companies with different maturity levels and strategic drivers in the selection of the most suitable ecodesign practices to be integrated into the product development and related process.

The main limitations of the Ecodesign Maturity Model (EcoM2) are related to the implementation of the ecodesign practices and projects into companies after their proposition, i.e., on how to perform the next steps of the application method (section 5.6.3). The EcoM2 application method does not provide guidance to companies on how to perform the portfolio management (and what are the factors to be taken into account), on how to plan the improvement projects for ecodesign implementation (by defining the resources and efforts required, for example), on how to implement the projects and on how to evaluate the results. The Ecodesign Maturity Model (EcoM2) developed is unprecedented and, besides its practical application, it contributes to the systematization of knowledge in the product development and ecodesign areas, as it seeks to reconcile them by adopting a common language that can increase their application and contribute to the generation of new knowledge.

7.2 Final Remarks: future researches

As a consequence of the limitations of the Ecodesign Maturity Model (EcoM2) and the maturity of the researcher on the topic, a set of subjects expressed in questions to be developed and explored in future researches was identified:

- How to keep the Ecodesign Maturity Model (EcoM2) up to date considering the increasingly development of new ecodesign practices?
- How to ensure that a company with a high maturity level on ecodesign (related to process maturity) will develop products with higher environmental performance?
- Which are the organizational factors that influence the implementation of ecodesign in companies? How to deal with them in the Ecodesign Maturity Model (EcoM2)?
- How the Ecodesign Maturity Model (EcoM2) can be related to the Environmental Management Systems (EMS) of an organization?
- What are the relationship of the maturity level of a company in the product development process and the ecodesign maturity level? What are the influences of one in the other?
- Can the adoption of ecodesign practices interfere in the efficiency of the product development process?
- Which diagnosis tools (other than documental analysis and interviews) could be used in order to identify the current maturity level on ecodesign? Is there a more suitable tool according to the current ecodesign profile of a company?
- Is that possible to perform the diagnosis in multiple companies using surveys and tools for quick diagnosis? What adaptations would be required?
- What adjustments need to be done in the EcoM2 in order to be self-applied by companies?
- How to support companies in the implementation of the ecodesign practices and improvement projects proposed by the Ecodesign Maturity Model (EcoM2)?
- How to define, evaluate and monitor the performance of the ecodesign improvement projects? Are there environmental indicators already available? How to select them?

- What is the ecodesign role as a source of eco-innovation and sustainable value creation in companies?
- How to incorporate the social dimension of the product development process in the Ecodesign Maturity Model (EcoM2) in order to broad the scope to consider sustainability?
- What is the ecodesign maturity profile of companies around the world? Are there geographical or sector differences for ecodesign implementation?
- Which formalism is more adequate to the representation of the Ecodesign Maturity Model (EcoM2)?
- Is that possible to apply the EcoM2 in companies with a low structured product development process? What adjustments would need to be done?
- How to evaluate the complementarities and overlapping of the ecodesign techniques and tools? How to suggest an integrated approach for the use of techniques/tools with different goals?
- How to support companies in the customization and implementation of techniques and tools? What are the success factors for new tools introduction?
- How to spread the application of the EcoM2 across the whole value chain of a given product? How to deploy its application among suppliers using the EcoM2?
- How to further develop the EcoM2 in order to make it a certification tool for companies in relation to ecodesign implementation and management?
- How long does it take each improvement cycle of the Ecodesign Maturity Model (EcoM2)? What are the influent factors in the total duration?
- How to compare ecodesign maturity profile of different companies? Is there a pattern for ecodesign implementation? Is that possible to compare companies of different sectors using the EcoM2?
- How to expand the influence area of the Ecodesign Maturity Model (EcoM2) in order to fully incorporate the other dimensions of organizational change, such as culture, people, strategy, structure, etc.?

There will come a time when you believe everything is finished. That will be the beginning.

(Louis L'Amour)

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Appendix A – Ecodesign Management Practices

Appendix A presents the final version of the systematization of the ecodesign management practices.

Table 30: Ecodesign management practices: final version

Ecodesign Management Practices
Formulate a company environmental policy/strategy
Deploy and maintain an environmental policy/strategy for products
Establish a prioritized ecodesign program at the company
Clearly define the environmental goals for a company as a whole and deploy for product development
Start the ecodesign application by increasing people consciousness about the application opportunities
Perform benchmarking internally (to set environmental improvement goals) and externally (to understand what competitors are doing in ecodesign)
Ensure commitment, support and resources to conduct the activities related to ecodesign
Deploy product-related environmental responsibilities among employees of different levels at the organization
Ensure appropriate communication between the departments and different levels concerning product-related environmental issues
Provide training in ecodesign approach and practices for employees involved in the product development and related processes
Make ecodesign tasks a part of the daily routine for the relevant employees
Integrate ecodesign into the procedures of work of the product development and related processes
Conduct management reviews on the effectively of the environmental issues consideration in the product development and related processes
Select, customize and implement ecodesign techniques/tools according to the company's needs
Formulate and monitor mandatory rules concerning environmental issues for the enterprise to comply with law/regulations and internal standards/goals
Get and disseminate knowledge on ecodesign approaches and practices

Integrate environmental issues into the corporate strategy
Identify the relevant functions across the company to be involved in the ecodesign implementation
Implement a life-cycle thinking in the company
Develop a green incentive scheme for managers and employees involved in ecodesign
Evaluate the environmental performance of products
Clearly define the environmental indicators and the methodology to be used during the gates (phases assessments)
Check the environmental performance of products in the gates in a systematic manner
Define and measure performance indicators for the environmental performance of ecodesign projects and products according to the goals agreed
Define and measure performance indicators for the environmental performance of the ecodesign program
Integrate the environmental issues as an aspect to be considered during the decision making process jointly with the traditional aspects
Establish vision, strategy and environmental roadmaps in the strategic level
Examine the relevant internal drivers (as cost reduction and improvement of company's image) and external drivers (customers requirement and legislation/regulation) for ecodesign adoption
Assess technological and market trends (including new customer requirements) that embraces the trends of products with better environmental performance and develop a list of potential products and market strategies according to the new trends
Ensure alignment among strategic and operational dimensions concerning environmental issues
Include the environmental goals into the product target specifications
Clearly define goals to improve products environmental performance (according to law, benchmarking, phases/aspects with higher improvement potential, etc.)
Ensure coherency among the environmental goals of the product and business during strategic planning
Incorporate environmental considerations into the technological strategy
Consider the environmental issues in the company portfolio management
Analyze and monitor the environmental feasibility of the development projects

Identify customer and stakeholders requirements and priorities concerning the environmental issues
Collect information about environmental product-related legal issues and standards
Search technologies that can contribute to improve environmental performance and achieve the environmental goals
Perform functionality analysis and find new ways/solutions to deliver the same functions with a better environmental performance
Improve the interaction between product and service development in order to explore the potential to offer solutions with better environmental performance
Assess and mobilize the technology which allows better environmental performance
Incorporate the environmental concern in the identification of less harmful production processes during the product development process
Select the product concept with better environmental, economic and technical performance
Establish priorities on the environmental impacts to be minimized (invest time and effort in activities with significant contribution)
Consider the trade-offs among the different ecodesign strategies, the product life cycles and the traditional requirements of a product (such as quality, cost, aesthetics, etc.)
Analyze and select the suitable ecodesign strategies/guidelines/design option according to the environmental goals of the product
Customize the strategies/guidelines/design options for product design individual changes to reach the environmental goals
Consider the environmental aspects in the identification/qualification of potential suppliers
Involve the total value chain both upstream (suppliers) and downstream (after sales, service providers, recyclers) in order to improve the environmental performance of products
Establish cooperation programs and joint goals with suppliers/partners/universities aiming to improve the environmental performance of products
Ensure coherency between the environmental goals and the product architecture (e.g. develop easy disassemble products if the goal is to improve remanufacturing)
Plan the disassembly process in a way to make possible environmental improvements by enabling end-of-life strategies such as reuse, remanufacturing, recycling, etc.
Optimize the production process to improve the environmental performance of

products during manufacturing
Develop the technical support process (e.g. maintenance, change of spare parts, etc.) considering the environmental issues
Define the reverse logistics strategy to be addressed according to the end-of-life phase of the product
Include packaging and distribution process of the product under the ecodesign considerations (it brings quick wins and supports the creation of awareness of the ecodesign programs)
Supply consumers with information about the environmental performance of the product and provide recommendations for use and end-of-life phases
Communicate the environmental benefits of the product as part of the total value proposition of the product
Monitor the product environmental performance during the life cycle phases (such as use and end-of-life)
Communicate the environmental achievements of the company´s portfolio of products to customer and stakeholders (environmental reports; brochures at point of sale; messages in advertising; internet; press releases/free publicity; technical)
Supply the product development process with information from the supply chain related to the environmental performance of the product (such as materials, components, processes, etc.) and recommend changes in the product, process, packaging, end-of-life, etc. if needed

Appendix B – Ecodesign Operational Practices

The final version of the ecodesign operational practices of the EcoM2 are presented in Appendix B. The first level (**in bold**) corresponds to the ecodesign strategies, the second level (*in italic*), to the ecodesign guidelines and the third level to the design options, which are ideas of what can be done to achieve a particular guideline (section 4.2.2.2).

Table 31: Ecodesign operational practices – final version

Ecodesign Operational Practices
Minimizing Material Consumption
Minimize Material Content
Dematerialize the product or some of its components
Digitalize the product or some of its components
Miniaturize
Avoid over-sized dimensions
Reduce thickness
Apply ribbed structures to increase structural stiffness
Avoid extra components with little functionality
Minimize material content of discarded products
Investigate technological alternatives for achieving the same function of the product with less material content
Reduce the material content by integrating functions
Minimize cabling and wiring between subassemblies by appropriate product architecture
Minimize Scraps and Discards
Select processes that reduce scraps and discarded materials during production
Engage simulation systems to optimize transformation processes
Use as much recyclable material in the process as possible
Optimize the reuse of scraps and discards during manufacturing
Minimize or avoid Packaging
Avoid the use of packaging that do not have a specific function
Design the package to be part (or to become a part) of the product

Use recyclable, reusable and returnable packaging
Use refills for consumer products
Eliminate secondary and tertiary product packages whenever possible
Minimize the number of different materials that are used in manufacturing through packaging
Avoid the use of toxic materials in the product packaging
Arrange the return of packaging for reuse and recycling
Facilitate the separation of different materials of the product packaging
Assess alternatives for packaging
Print clearly the instructions for recycling the packaging itself in it
Minimize the weight and/or volume of product packaging
Integrate the development of packaging for transport to the development of product packaging
Avoid packaging procedures that consume much energy
Encourage suppliers to minimize the quantities and types of packaging of their products
Encourage suppliers to collect the packaging of their products
Minimize the intake of packaging suppliers at the company and have them use the smallest possible number of different materials
Maximize opportunities for reuse and reduce packaging waste when the components / products are transported between facilities
Explore the use of reusable packaging for distribution among the business facilities
Explore the use of reusable packaging for distribution between the company and its suppliers
In the development of packaging, prioritize the reduction of volume rather than weight reduction
Recycle excess material used for packaging instead of disposal in landfill or incinerated
Provide information to customers on the provision of packaging and products
Increasing the impact resistance of the products or reconciliation of the fragility of the product with the concept of packaging
Minimize Materials Consumption During Usage
Design for more efficient consumption of operational materials
Design for more efficient supply of raw materials
Design for more efficient use of maintenance materials
Design systems for consumption of passive materials
Facilitate the user to reduce materials consumption
Set the product’s default state at minimal materials consumption

Ensure that the controls for the resource economy are easy to use and understanding;
Using a standard mechanism for setting up more efficient use of resources;
Engage digital support systems with dynamic configuration
Design dynamic materials consumption for different operational stages
Engage sensors to adjust materials consumption according to differentiated operational stages
Reduce resource consumption in the product’s default state
Minimize the need for periodic disposal of solid waste as cartridges, containers or batteries, researching alternatives and incorporate them wherever possible
Avoid the use of toxic or undesirable in consumables, research alternatives to the use of these materials and incorporate them wherever possible
Develop processes to use the least amount of consumables
Implement procedures to recycle the largest possible fraction of consumables
Develop processes to use recycled supplies by outside vendors
Investigate alternatives to the use of consumables and incorporate them wherever possible
Avoid the use of consumables consisting of scarce materials
Develop the product for a minimum consumption of materials during use
Use consumables from renewable sources
Closing the cycle of consumables used during the product use
Using feedback mechanisms in the product to display the amount of resources being consumed
Minimize Materials Consumption During the Product Development Phase
Minimize the consumption of stationery goods and their packages
Engage digital tools in designing, modeling and prototype creation
Engage digital tools for documentation, communication and presentation
Minimizing Energy Consumption
Minimize energy consumption during pre-production and production
Select materials with low energy intensity during pre-production and production
Select processing and testing technologies with the lowest energy consumption possible
Engage efficient machinery
Use co-generation, heat exchange and other techniques to reuse emitted energy
Use computer systems to manage the energy consumption
Equip the machinery with intelligent power-off utilities
Engage pump and motor speed regulators with dynamic configuration

Optimize the overall dimensions of the engines
Facilitate engine maintenance
Define accurately the tolerance parameters
Optimize the volumes of required real estate
Optimize stocktaking systems
Optimize transportation systems and scale down the weight and dimensions of all transportable materials and semi-products
Engage efficient general heating, illumination and ventilation in buildings
Monitor the energy consumption of different production equipment
Improve the energy efficiency of buildings (heating, ventilation, cooling, lighting)
Use light bulbs with energy efficient
Install automatic control systems for lighting
Encourage the housekeeping of energy consumption
Minimize energy consumption during transportation and storage
Select means of transport with low environmental impact
Plan transportation routes to minimize exhaust emissions from vehicles
Design compact products with high storage density
Design concentrated products
Equip products with onsite assembly
Scale down the product weight
Scale down the packaging weight
Decentralize activities to reduce transportation volumes
Select local material and energy sources
Develop distribution plans to minimize energy consumption
Minimize transportation between the manufacturing and the local assembly of the product
Minimize the need for transportation of materials and components
Organize services near the site of use of products in order to reduce the environmental impact associated with transportation
Increase efficiency of distribution and logistics
Select systems with energy-efficient operation and use stage
Design attractive products for collective use
Design for energy-efficient operational stages
Design for energy-efficient maintenance
Design systems for consumption of passive energy sources
Engage highly efficient energy conversion systems

Design/engage highly efficient engines
Design/engage highly efficient power transmission
Use highly caulked materials and technical components
Design for localized energy supply
Scale down the weight of transportable goods
Design energy recovery system
Design energy-saving systems
Incorporate design features to conserve energy
Investigate alternatives to energy consumption and incorporate them wherever possible
Monitor and display the information of energy consumption during product use
Analyze the energy that contributes to the function or sub-function and energy dissipated for a given product, part or component
Introduce more power options (sleeping-mode etc.)
Incorporate connectors on-off in the product
Minimize the power consumption of portable products
Eliminate superfluous components due to design history
Minimize cabling and wiring between subassemblies by appropriate product architecture
Change to rechargeable batteries
Engage digital dynamic support systems
Design dynamic energy consumption systems for differentiated operational stages
Engage sensors to adjust consumption during differentiated operational stages
Equip machinery with intelligent power-off utilities
Program product's default state at minimal energy consumption
Provide options for adjusting power consumption based on the intensity of the activity of the product or component
Minimize the demand for energy in use phase by an appropriate choice of the principles of solution
Human powered products or application of other 'alternative' power sources.
Provide information to customers to optimize the operation from the environmental point of view
Minimize energy consumption during product development
Engage efficient workplace heating, illumination and ventilation
Engage digital tools for communicating with remote working sites
Selecting Low Impact Resources and Processes
Select Non-toxic and Harmless Materials

Avoid toxic or harmful materials for product components
Minimize the hazard of toxic and harmful materials
Eliminate or minimize the use of solvents, paints and adhesives with high rates of evaporation of volatile organic compounds
Avoid additives that emit toxic or harmful substances
Avoid the use of materials that will result in significant generation of gaseous emissions from transport
Avoid technologies that process toxic and harmful materials
Select machinery and equipment enabling the closure of the cycle of toxic substances used during the production process and waste generated
Avoid toxic or harmful surface treatments
Design products that do not consume toxic and harmful materials
Avoid materials that emit toxic or harmful substances during usage
Avoid materials that emit toxic or harmful substances during disposal
Prevent and minimize the use of substances that cause depletion of the ozone layer and / or global warming and search for replacement materials
Explore design alternatives that do not involve dissipative emissions and implement them where possible
Develop the process to use recycled materials from external suppliers
Develop processes to recycle the largest quantity of waste generated by manufacturing in the facility
Recycle the waste that cannot be recycled within the facility in other plants
Reformulate the product so that the dissipative unintentional emissions are minimized
Evaluate the use and generation of VOCs in manufacturing processes and minimize the consumption / generation
Investigate alternatives to the use of toxic or undesirable substances of the product, especially if they are needed for routine or maintenance
Minimize the environmental impact of products that are dissipated during use
Minimize the generation of gaseous emissions in manufacturing
Minimizing the generation of solid waste in manufacturing and reuse as much as possible
Making biological waste inert and non-toxic-infectious before disposal
Evaluate the use and generation of greenhouse gases in the manufacturing process
Minimize the need for replacement coolants or lubricants
Avoid the use of materials that need to be disposed of as hazardous waste
Take the maximum spill prevention and hazardous liquids during transport
Evaluate the use and generation of "odorants" in the manufacturing process

Maximize the opportunities to capture and reuse of liquid by-products generated during the manufacturing process
Minimize, assess and investigate the use of substitutes for trace metals, nutrients, organic species, acids, etc.
Minimize cleaning equipment that generate effluents or solid waste to the maximum
Investigate and incorporate alternatives to the use of liquids with high potential for impact wherever possible
Avoid the use of consumables that contain toxic substances or other undesirable material
Replace all lead by other substances
Buy lead-free components
Buy lead free solders
Choose alternative technologies to weld
Choose surfaces PCB lead-free
Inspect the welding system that exists on its suitability to produce lead-free
Adapting the system to a new profile of lead-free soldering
Redesign the modules
Replace all mercury by other substances
Replace the switches and sensors for mercury-free alternatives to mercury
Minimize the maximum content of mercury in fluorescent lamps
Identify the content of mercury in fluorescent lamps in use
Avoid the use of mercury in contacts
Replace all the cadmium by other substances
Replace plastics containing cadmium by other materials
Buy cadmium-free electronic components
Use cadmium-free contacts
Replace all the hexavalent chromium by other substances
Use components with surfaces free of hexavalent chromium
Avoid anti-corrosive
Use coatings without hexavalent chromium
Replace all polybrominated biphenyls (PBBs) and polybrominated all difenils polybrominated by other substances
Use of alternative flame retardants
Choose flame retardants with alternative modes of operation
Select Non-toxic and Harmless Energy Resources
Select energy resources with less environmental impact
Select energy resources that reduce dangerous emissions during pre-

production and production
Select energy resources that reduce dangerous emissions during distribution
Select energy resources that reduce dangerous emissions during usage
Select energy resources that reduce dangerous residues and toxic and harmful waste
Investigate the process of generating alternative energy and choose the alternative with the least environmental impact
Select Renewable and Bio-compatible Materials
Use renewable materials
Avoid exhaustive materials
Use residual materials of production processes
Use retrieved components from disposed products
Use recycled materials, alone or combined with primary materials
Use bio-degradable materials
Prevent and minimize the use of scarce materials or will become scarce during the manufacture of the product and search for replacement materials
Using recycled materials instead of virgin materials wherever possible
Investigate alternatives to the use of toxic solvents and oils
Do not use toxic substances and, when necessary, use closed cycles for toxic
Understand that natural materials are not always the best
Avoid the use of inseparable composite materials
Avoid raw material and components from problematic origins (such as wood deforestation).
Avoid the use of pigmented plastics whenever possible
Prefer the use of plastics to metals in products
Evaluate the effect of replacing a toxic substance in physical function
Evaluate the possibility of getting help supply chain to replace a toxic substance
Search current and future laws concerning the use of toxic substances
Find alternatives to the use of materials / components that contain banned substances or about to be banned
Minimize the use of materials whose extraction and processing involves the generation of large quantities of gaseous emissions
Minimize the use of materials whose extraction and processing involves the generation of large quantities of solid waste
Minimize the use of materials whose extraction and processing involves the generation of large quantities of liquid
Conduct pilot projects to evaluate alternatives to replace toxic

Select Renewable and Bio-compatible Energy Resources
Use renewable energy resources
Engage the cascade approach
Select energy resources with high second-order efficiency
Preferably use the energy resources available regionally
Make possible the use of renewable energy sources while using
Use rechargeable batteries
Develop products driven by human force or application of alternative energy sources
Product Lifetime Optimization
Design for Appropriate Lifespan
Design components with co-extensive lifespan
Design lifespan of replaceable components according to scheduled duration
Select durable materials according to the product performance and lifespan
Developing the product in a modular fashion, so that obsolescence occurs with the components and not the entire product
Avoid selecting durable materials for temporary products or components
Ensure that the product is durable enough for reuse, refurbishing and / or remanufacturing
Design for Reliability
Reduce overall number of components
Simplify products
Eliminate weak liaisons
Facilitate Upgrading and Adaptability
Enable and facilitate software upgrading
Enable and facilitate hardware upgrading
Design modular and dynamically configured products to facilitate their adaptability for changing environments
Design multifunctional and dynamically configured products to facilitate their adaptability for changing cultural and physical individual backgrounds
Design onsite upgradeable and adaptable products
Design complementary tools and documentation for product upgrading and adaptation
Facilitate Maintenance
Simplify access and disassembly to components to be maintained
Avoid narrow slits and holes to facilitate access for cleaning
Prearrange and facilitate the substitution of short-lived components

Equip the product with easily usable tools for maintenance
Equip products with diagnostic and/or auto-diagnostic systems for maintainable components
Design products for easy on-site maintenance
Design complementary maintenance tools and documentation
Design products that need less maintenance
Develop sub-components for ready maintenance rather than disposal after malfunction
Design mechanical parts individually repairable or replaceable
Design products that require minimal cleaning and maintenance as possible
Develop modules for prompt removal by the customer and encourage them to remanufacture, replace or upgrade programs for "take-back
Avoid the use of toxic or undesirable to cause adverse environmental impact during maintenance procedures
Concentrate the wear in replaceable components of the product
Flag wear for easy viewing
Indicate the service intervals required for the product;
Facilitate Repairs
Arrange and facilitate disassembly and re-attachment of easily damageable components
Design components according to standards to facilitate substitution of damaged parts
Equip products with automatic damage diagnostics system
Design products for facilitated onsite repair
Design complementary repair tools, materials and documentation
Ensure a self-explanatory structure or provide information to repair the product
Ensure easy access to components for repair or replacement
Ensure availability of spare parts
Standardize components and / or use the same structural components for different product variants
Ensure the recycling of worn components;
Use remanufactured components and spare parts
Facilitate Reuse
Increase the resistance of easily damaged and expendable components
Arrange and facilitate access and removal of retrievable components
Design modular and replaceable components
Design components according to standards to facilitate replacement
Design re-usable auxiliary parts

Design the re-filling and re-usable packaging
Design products for secondary use
Ensure simple assembly by the hierarchical structure of the product
Ensure simple assembly by reducing the parts used
Create a new collection system or use an existing for product take back
Ensure high rates of return of products at the end-of-life
Preview oversize material components in order to reuse
Label components to indicate the time remaining life
Using elements, parts and standardized components to facilitate reuse
Reuse components in other products
Reuse parts and remanufactured components;
Use identical parts for different variants of a product
Develop components / parts with high added value for reuse
Facilitate Remanufacturing
Design and facilitate removal and substitution of easily expendable components
Design structural parts that can be easily separated from external/visible ones
Provide easier access to components to be re-manufactured
Calculate accurate tolerance parameters for easily expendable connections
Design for excessive use of materials in places more subject to deterioration
Design for excessive use of material for easily deteriorating surfaces
Provide equipment for tests and measures for remanufactured components
Intensify Use
Develop User-oriented products, aiming at a high frequency of use
Developing products easy to use
Designing the human-machine interface ergonomically
Develop the product for a great adaptability to different users
Minimize the space required for storage of the product when not in use
Minimize the time required for preparation and monitoring of the product
Optimize product functionality
Ensure high reliability of the product
Ensure high quality functional (interaction between parts and components) of the product and minimize the possibility of disturbances
Develop the product to allow updates
Develop products for multifunctional uses
Develop simple operating principles

Develop the product for adjustment and adaptation in the use phase.
Consider electrical and mechanical features individually in the design
Carry a balance between the different types of features (physical, economic, intangible and emotional)
Changing paradigms to deliver the same functionality
Apply different principles of solution
Develop a modularization of the functionality
Increase the durability of the product
Develop products with timeless design
Ensure high appreciation of the product
Developing products for long lifespan
Develop resistant products
Design for emotional product attachment
Make sure the surfaces are friendly
Extending the Lifespan of Materials
Adopt the Cascade Approach
Arrange and facilitate recycling of materials in components with lower mechanical requirements
Arrange and facilitate recycling of materials in components with lower aesthetical requirements
Arrange and facilitate energy recovery from materials throughout combustion
Use recycled materials wherever possible
Develop considering the use of secondary materials after recycling
Avoid potential barriers to recycling such as use of additives, plastics, metal treatment, application of paints in plastic or use of material composition unknown
Develop products to be managed in closed loops
Select Materials with the Most Efficient Recycling Technologies
Select materials that easily recover after recycling the original performance characteristics
Avoid composite materials or, when necessary, choose easily recyclable ones
Engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers
Prefer thermoplastic polymers to thermosetting
Design considering the secondary use of the materials once recycled
Prefer heat-proof thermoplastic polymers to fireproof additives
Avoid waste of materials which consume much energy for recycling
Facilitate End-of-life Collection and Transportation

Design in compliance with product retrieval system
Minimize overall weight
Minimize cluttering and improve stock ability of discarded products
Design for the compressibility of discarded products
Provide the user with information about the disposing modalities of the product \or its parts
Sort products (household, commercial or dual)
Establish a system of collection and treatment or participate in an existing system
Disclose the type of collection and treatment system
Predicting the pre-treatment of the material collected
Get high rate of return of products.
Consider the opportunities provided for the End User and provide instructions for disposal
Provide information to users and treatment facilities
Prepare and provide information on the components / materials of the product for the plant
Prepare and deliver information to users on how to return and collect waste electrical and electronic
Identify Materials
Codify different materials to facilitate their identification
Provide additional information about the material's age, number of times recycled in the past and additives used
Indicate the existence of toxic or harmful materials
Facilitate the identification and separation of toxic materials, when used
Use standardized materials identification systems
Arrange codifications in easily visible places
Avoid codifying after component production stages
Minimize the Overall Number of Different Incompatible Materials
Integrate functions to reduce the overall number of materials and components
Monomaterial strategy: only one material per product or per sub-assembly
Use only one material, but processed in sandwich structures
Use compatible materials (that could be recycled together) within the product or sub-assembly
Avoid together different materials so that it is difficult to separate them later
For joining use the same or compatible materials as in components (to be joined)
Avoid metal inserts in plastic screw

Avoid the use of "plated metals"
Avoid painting or any tampering with the plastic components, minimize or eliminate fillers
Mount the product using elements of joint type clips or hook and loop "instead of chemical bonds or welds
Use whenever possible thermoplastic plastics instead of thermosets
Facilitate Cleaning
Avoid unnecessary coating procedures

Appendix C – Ecodesign Techniques and Tools

This appendix presents the ecodesign techniques and tools obtained by means of a systematic literature review (section 4.2.2.3). Emphasis is given to the presentation of the ecodesign techniques and tools. Additionally, the result of a joint analysis of ecodesign techniques/tools based on their classification according to the criteria described in section 4.2.2.3 is presented.

Table 32: Ecodesign techniques and tools – final version

Technique/Tool
10 Guidelines for Ecodesign
ABC Analysis
Alternative Function Fulfillment (AFF) Methodology
AT&T’s Green Design Tool
ATROiD EcoDesign Tool
Life Cycle Assessment (LCA)
Computer-Based Cooperative Technique to Consider the Entire Life Cycle
D4N
Decision Supporting Tool for Environmentally Conscious Product Design
Design Abacus
Design Environment of CRC 392
Design for Recycling Methodology
Design for upgradability involving changes of functions
Design Guidelines for Renewable Energy Powered Products
DfE Matrix
Dominance Matrix or Paired Comparison
Eco Communication Matrix
EcoBenchmarking
Eco-Compass technique
ECODESIGN Checklist Technique (ECM)
Eco-design Matrix
Ecodesign Technique for Electronics Products
Ecodesign Online
EcoDesign Pilot
Ecodesign strategy wheel
Ecodesign Web
Eco-efficiency

Eco-indicator 99
Eco-indicator tool (Eco-it)
Eco-innovative Product Design Technique
Eco-Innovative Tool
Eco-Kit
Eco-material evaluation diagram
Econcept Spiderweb
Eco-Products and Environmental Efficiency
Eco-QFD (Ecological Quality Function Deployment)
Ecoquest
Eco-roadmap
ECO-track
EEE-PILOT
EIAtrack
EIME software
End-of-Life Design Advisor (ELDA)
Environmental Design Industrial Template (EDIT)
Environmental Design Strategy Matrix (EDSM)
Environmental Design Support Tool (EDST)
Environmental Effect Analysis (EEA)
Environmental Efficiency Potential Assessment technique (E2-PA)
Environmental Information and Management Explorer (EIME)
Environmental quality function deployment (EQFD)
Environmental Value Chain Analysis (EVCA)
ENVRIZ
EPP (Environmentally Preferred Product) Design tool
euroMat
Factor X Tool 2001
Generic Environmental Benchmark Technique
grEEEn Technique
Green Design Advisor (GDA)
Hierarchy of Focusing
Information/Inspiration web-based tool
Instep-DfE
IZM-EE ToolBox
LiDs Wheel
Life Cycle Check (LCC)
LIfe Cycle COSting Tool (LICCOS)

Life Cycle Design Structure Matrix (LC-DSM)
Life Cycle Scenario Description Support Tool
LIME technique
MECO Matrix
MET Matrix
Checklist-Based Assessment Support System for Ecodesign (CHASSE)
Technique for Sustainable Product Development (MSPD)
Technique to Assess the Adaptability of Products (MAAP)
Technique to Grasp the Corporate Profit Contribution Rate of Eco-friendly Products
Technique to Support Environmentally Conscious Service Design Using QFD
Methodology based on MCDM techniques to Identifying the greatest environmental impact value
Modular Design Technique for Inverse Manufacturing
New DFE Targeting and Tracking System - HP
Novel Design Methodology for Services to Increase Value Combining Service and Product
Packaging Impact Quick Evaluation Tool (PIQET)
Philips Fast Five Awareness
Philips STRETCH (Strategic Environmental Challenge)
Environmentally Conscious QFD (ECQFD)
Product Improvement Matrix
Product Life Cycle Planning (LCP)
Quality Function Deployment for Environment (QFDE)
Quotes for environmentally Weighted RecyclabiliTY and Eco-Efficiency approach (QWERTY-EE)
Recovery Systems modeling and Indicator Calculation Leading to End-of-life-conscious Design (ReSICLED)
Recyclability evaluation technique
Remanufacturing Guideline
Conceptual Design Tool for Resolving Conflicts Between Product Functionality and Environmental Impact
Simple Additive Weighting (SAW) Technique
Multi-Attribute Decision-Making (MADM)
Simple Life Cycle Assessment Technique for Green Product Conceptual Design
Strategy List
STRETCH (Selection of Strategic Environmental Challenges)
Sustainable Product and Service Development (SPSD) technique

Ternary diagrams and emergy accounting
The Eco-Function Matrix
The Environmentally Responsible Product Assessment Matrix (ERPA)
The ideal-eco-product approach
The Morphological Box
The Ten Golden Rules
TRIZ and Eco-Innovation
Two-dimensional diagram
Volvo´s Black, Gray and White Lists
EcoValue

The main conclusions drawn from the results of the analysis of the techniques and tools records based on the criteria defined in section 4.2.2.4 are:

- Analytical techniques/tools are more frequently used than prescriptive and comparative ones;
- There is a tendency to use matrices, which are tools that contain a predefined scale for the assessment of a product's environmental performance by means of the relationship between two relevant aspects in the ecodesign techniques/tools;
- There is a balance between the input and output data required for the application of a technique/tool (qualitative vs. quantitative);
- The techniques/tools originate mainly from the area of ecodesign, or from the broader area of environmental management. Most of the techniques/tools originating from the PDP were adapted from traditional tools of the area;
- Despite the intense theoretical development and experimental validation of the techniques/tools, they are still not employed regularly by companies;
- Most of the techniques/tools are presented concisely in the studies;
- There is a clearly discernible concern about environmental aspects related to materials and energy;
- Most of the techniques/tools consider all the phases of a product's life cycle;

- 83% of the techniques/tools lack an environmental impact assessment technique;
- Most of the techniques/tools require high user specialization for their application.

Appendix D – List of experts on ecodesign

This appendix presents the ecodesign experts identified to participate on the evaluation meetings of the EcoM2. A recurrence analysis of the authors with more publications and citations in the ecodesign literature was conducted and, as a result, 40 potential experts to evaluate the Ecodesign Maturity Model (EcoM2) were identified, presented in Table 33.

Table 33: List of potential experts to evaluate the Ecodesign Maturity Model

Name	University/Company	City/Country
Ab Stevels	Delft University of Technology/Philips	Eindhoven/Holland
Arnold Tukker	TNO Built Environment and Geosciences	Delft/ Netherlands
Carlo Vezzoli	University Politecnico di Milano	Milan/Italy
Casper Boks	Norwegian University of Science & Technology	Trondheim/Norway
Conrad Luttropp	Royal Institute of Technology	Stockholm/Sweden
Dorothy Maxwell	Global View Sustainability Services Ltd	London/UK
Joust Duflou	Katholieke Universiteit Leuven	Heverlee/Belgium
Elisabeth Hochschorner	Royal Institute of Technology	Stockholm/Sweden
Erik Sundin	Linköpings universitet	Linköping/Sweden
Fabrice Mathieux	Grenoble University	Grenoble/France
Frank Boons	Erasmus Universiteit Rotterdam	Rotterdam/Netherlands
Glenn Johansson	Jönköping University	Jönköping/Sweden
Han Brezet	Delft University of Technology	Delft/Holland

Henrikke Baumann	Chalmers University of Technology	Göteborg, Sweden
J.C. Aurich	Kaiserslautern University of Technology	Kaiserslautern, Germany
Jacqueline Cramer	Government of Netherlands	Amsterdam/Holland
Jan-Gunnar Persson	Royal Institute of Technology	Stockholm/Sweden
Jessica Lagerstedt	AF Consult/Ecodesign Center	Stockholm/Sweden
Johan Tingstrom	University of Kalmar/Vexillum/Scania	Kalmar/Sweden
Joseph Sarkis	Clark University	Worcester/UK
Karsten Schischke	Fraunhofer Institute IZM	Berlin/Germany
Mark Goedkoop	PRe Consultants	Armmersfoort/Holland
Martin Charter	University for Creative Arts	Farnhan/UK
Matthew Simon	Sheffield Hallam University	Sheffield/UK
Mattias Lindahl	Linköpings universitet	Linköping/Sweden
Mattias Finkbeiner	Technische Universität Berlin	Berlin/Germany
Michael Hauschild	Technical University of Denmark	Lyngby/Denmark
Nils F. Nissen	Fraunhofer Institute IZM	Berlin/Germany
Reine Karlsson	Lund University	Lund/Sweden
Ritzén Sofia	Royal Institute of Technology	Stockholm/Sweden
Robin Roy	The Open University	London/England
Sandström Gunilla	Royal Institute of Technology	Stockholm/Sweden

Sophie Byggeth	Blekinge Institute of Technology	Göteborg/Sweden
Thomas Magnusson	Linköping University	Linköping/Sweden
Tim McAloone	Technical University of Denmark	Lyngby/Denmark
Tom Swarr	Five Winds International	Seville/Spain
Tracy Bhamra	Loughborough University	Loughborough/UK
Ursula Tischner	Econcept	Köln/Germany
Vicky Lofthouse	Loughborough University	Loughboroughh/UK
Wolfgang Wimmer	Ecodesign Company/Vienna University	Vienna/Austria

Appendix E – Invitation letter to EcoM2 evaluation by experts

This appendix present the invitation letter sent to EcoM2 experts by mail.

“Dear Expert,

Firstly, let me introduce myself. My name is Daniela Pigosso, I have got a bachelor degree in Environmental Engineering from University of São Paulo (USP), Brazil, and I am pursuing a PhD in Industrial Engineering in the area of Product Development at the same university. University of São Paulo (www.usp.br) is the largest institution dedicated to higher education and research in Brazil, and in 2009 it was classified by Webometrics as the 38th better university in the world (www.webometrics.info).

In the University of São Paulo, I take part of the research group Integrated Engineering (EI2 - www.www.numa.sc.usp.br/grupoei), coordinated by Professor Dr. Ing. Henrique Rozenfeld (full professor). In the group, over the past ten years, it has been conducted researches and projects on the field of new product development (NPD), with focus on reference models for NPD processes, strategic planning and business process management models. The subject ecodesign was introduced as a research area in our group in 2006 and since then I have been researching it in strict collaboration with others PhD researchers.

It has being carried out researches on identification and systematization of ecodesign best practices, techniques and tools, and then their integration into the product development process. During the research process, it was noticed that companies are increasingly demanding knowledge about ecodesign best practices, techniques and tools and how to incorporate them into their product development process, taking into account their strategic goals. As companies are not in the same maturity level of ecodesign application, it also must be considered.

In this context, my research aims to propose a general ecodesign maturity model combined with an application technique for business process improvement to guide companies in the effective implementation of ecodesign best practices into the product development process in accordance with their strategic objectives and drivers. The maturity model will can be used to guide product development process improvement across a project, a division, or an entire organization. Currently I am doing part of my PhD thesis at the Technical University of Berlin, and the main goal now is to validate the model with experts on ecodesign.

As you work for a long time in the field of ecodesign, it would be of an important contribution to my research and to our research group if I have the opportunity to present you the Ecodesign Maturity Model and get your impressions and *suggestions about that, so we can improve it and make it applicable for companies... So, in this sense, I would like to invite you to support the Ecodesign Maturity Model validation. It takes no longer than 3 hours and I can go to you in order to perform the validation.*

I will be pleased to provide any further information necessary. Thank you very much for your attention.

Kind Regards,

Daniela Pigosso"

Appendix F – EcoM2 questionnaire for maturity assessment

In this appendix, the standard questionnaire for maturity assessment used during the diagnosis step of the EcoM2 application method (section 5.6) is presented. The questionnaire is composed by the ecodesign management practices of the Ecodesign Maturity Model (EcoM2) in a question format. The capability level of the application of each ecodesign management practice is evaluated by each interviewee (E1, E2, (…), En). The comments justifying and providing evidence on the reason why a given practice was classified in a given capability level are also documented in Table 34.

Table 34: Example of the Standard questionnaire for maturity assessment

	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to get knowledge on ecodesign at the company? What´s your knowledge level on ecodesign?											
	Comments:											
E1												
	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to perform benchmarking on environmental issues and ecodesign practices?											
	Comments:											
E1												

	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to examine the relevant internal drivers (as cost reduction and improvement of company's image) and external (customers' requirement and legislation/regulation) for ecodesign adoption?											
	Comments:											
E1												
	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to formulate and update the company environmental policy/strategy?											
	Comments:											
E1												
	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to consider the environmental issues in the company portfolio management?											
	Comments:											
E1												
	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to ensure coherency among the environmental goals of the product and business during strategic planning?											
	Comments:											
E1												

	Ecodesign Management Practice	Capability Level										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	En
	Is there a structured process in place to incorporate environmental goals into the technological strategy?											
	Comments:											
E1												

Appendix G – Questionnaire to evaluate the EcoM2

The Appendix G presents the questionnaire developed to evaluate the Ecodesign Maturity Model (EcoM2) results according to the company perception after its application. It includes a set of criteria for model evaluation related to utility, consistence, completeness, scope, broadness, precision, depth, simplicity, clarity, objectivity, coherence, instrumentality, forecast and measurement (adapted from Vernadat (1996)).

1. *Utility*: How do you evaluate the utility of the Ecodesign Maturity Model (EcoM2) in supporting companies in the selection of the most suitable ecodesign practices to be applied?

( ) Very satisfactory
( ) Satisfactory
( ) Needs improvement
( ) Unsatisfactory

Comments, suggestions, critics:

2. *Consistence*: How do you evaluate the consistence and coherence of the ecodesign practices and improvement projects for ecodesign implementation proposed by the Ecodesign Maturity Model (EcoM2)?

( ) Very satisfactory
( ) Satisfactory
( ) Needs improvement
( ) Unsatisfactory

Comments, suggestions, critics:

3. *Completeness*: How do you evaluate the completeness of the improvement projects for ecodesign implementation proposed by the Ecodesign Maturity Model (EcoM2)?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

4. *<u>Scope</u>*: How do you evaluate the Ecodesign Maturity Model (EcoM2) in relation to the adequacy of the scope for the proposition of ecodesign practices and projects for ecodesign implementation into companies?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

5. *<u>Broadness</u>*: How do you evaluate the Ecodesign Maturity Model (EcoM2) in relation to its applicability in manufacturing companies from different sectors?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

6. *<u>Precision</u>*: How do you evaluate the EcoM2 in relation to the precision in the definition of the ecodesign maturity profile and on the proposition of ecodesign practices and improvement projects for ecodesign implementation?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

7. Depth*: How do you evaluate the Ecodesign Maturity Model (EcoM2) in relation to the depth of the diagnosis of the current maturity profile and proposition of ecodesign practices and improvement projects?*

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

8. *Simplicity*: How do you evaluate the Ecodesign Maturity Model (EcoM2) in relation to the simplicity of the results presented (for example: the ecodesign maturity radar and the improvement projects)?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

9. *Clarity*: How do you evaluate the Ecodesign Maturity Model (EcoM2) in relation of the clarity in which the results are presented, i.e., on how easy to understand they are to the stakeholders in the company?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

10. *Objectivity*: How do you evaluate the objectivity of the EcoM2 in performing the diagnosis of the current situation and proposing the ecodesign practices and improvement projects to be applied by the company?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

11. *Coherence*: How do you evaluate the coherence of the ecodesign practices and improvement projects for ecodesign implementation proposed by the Ecodesign Maturity Model (EcoM2)?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

12. *Instrumentability*: How do you evaluate the EcoM2 in relation to its instrumentability in the proposition of the ecodesign techniques and tools associated to the ecodesign practices in the improvement projects?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

13. *Forecast*: How do you evaluate the EcoM2 in relation to the definition of the next steps to be taken after the proposition of the improvement projects for ecodesign implementation?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

14. *Measurement*: How do you evaluate the EcoM2 in relation to the measurement of the current maturity profile on ecodesign during the diagnosis step?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

15. Do you have other general comments about the Ecodesign Maturity Model (EcoM2) and its application at the company?

Comments, suggestions, critics: