# THE DESIGN PROCESS PARADOX. TRADITIONAL DESIGN PROCESSES VS. ECO-DESIGN PROCESSES

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## 1.1 Introduction

The Brundtland Report (WCED, 1987) best known for its popularisation of the concept of sustainable development, also made recommendations for a new approach to design and production, setting out terms for: *'a production system that respects... the ecological base'* and *'a technological system that searches continuously for new solutions'*.

The industrial production, consumption and waste treatment of products today causes a large amount of various environmental burdens. The development and design of new products with reduced environmental impact is one of the new challenges towards a more sustainable society and is therefore an important task in the near future.

The global environmental challenges demand radical thinking in defining the design criteria, which shall be guidelines for the development of sustainable products and services. In the product design process, the designer has a great influence by drawing solutions, which are based on the objectives and guidelines towards the direction of environmental sustainability. Research indicates that in 80-90% of products, the economic and environmental impacts are largely determined at the design stages (Design Council, 1997).

It is no longer a contentious issue that the climatic changes observed during the course of the past decades are directly linked to the decline in living conditions and the degradation of our Planet's natural resources. Realities such as the greenhouse effect, the expanding hole in the ozone layer, desertification and impoverishment of the soil are accompanied by phenomena like floods and droughts, with increasingly serious consequences. All these factors testify to the damaging action produced by mankind on their environment.

## 1.2 Definitions

Eco-design[1] is the consideration of the eco-impact of the product during the design stage. The aim of eco-design is to avoid or minimise significant environmental impacts at all stages of the life cycle of a product, from sourcing of raw materials, design and manufacture, to distribution, use and end-of-life disposal, without compromising other product requirements.

Over the years eco-design has come to mean different things to different people. Most of the time, however, eco-design means the introduction of environmental aspects in 'traditional' product design with the aim of improving the environmental performance of the product without drastically changing the product concept. In this way, eco-design is not a defined way of creating new, environmentally friendly products, but rather a way of manipulating environmental parameters together with usual design parameters in the product development process.

Eco-design is also known under a collection of other titles. For example: Green design, Eco-innovation, Eco-product Development, Design for Sustainability, Sustainable Product Design, Environmental Design, Environmentally Conscious Design, Life Cycle Design and Design for 'X' where 'X' may be the 'environment', 'remanufacture,' 'disassembly,' 'recyclability' and or a host of other eco-issues (Wong, 2000).

While the terms are often considered near synonyms, several authors delineate subtle differences in meaning.

**Green design**, for example, is limited to tackling one element of the lifecycle or environmental problem (Demi, 2002).

**Ecological design** aims to reduce the environmental impact of materials throughout its life cycle and is most commonly found in architectural studies. According to Sim Van Der Ryn and Stuart Cowan (2002) the five principles of ecological design are:

> *Solutions grow from place*: Ecological design begins with the intimate knowledge of a particular place. Therefore, it is small-scale and direct, responsive to both local conditions and local people. If we are sensitive to the nuances of place, we can inhabit without destroying.
>
> *Ecological accounting informs design*: Trace the environmental impacts of existing or proposed designs. Use this information to determine the most ecologically sound design possibility.
>
> *Design with nature*: By working with living processes, we respect the needs of all species while meeting our own. Engaging in processes that regenerate rather than deplete, we become more alive.

1 The term eco-design is commonly used in Europe, but in the United States of America this concept is often called Design for Environment (DfE).

*Everyone is a designer*: Listen to every voice in the design process. No one is participant only or designer only. Everyone is a participant designer. Honour the special knowledge that each person brings. As people work together to heal their places, they also heal themselves.

*Make nature visible*: De-natured environments ignore our need and our potential for learning. Making natural cycles and processes visible bring the designed environment back to life. Effective design helps inform us of our place within nature.

**Eco-innovation** aims to develop new products and services that are not based on redesign or incremental changes to the existing product but rather on providing the consumer with the function that they require in the most eco-efficient way. Examples of such function-oriented redesign are solutions that 'dematerialise' the product and replace it by a service. An example of such a 'product to service shift' is the network-based telephone answer service, which is replacing electronic answering machines. These telephone answer services are accessed by a standard telephone and require no other hardware in the home, thereby removing the production, materials, packaging and logistics impacts of the electronic product (Low, 2000).

**Eco-product Development** (EPD) is a broader concept than eco-design (CFSD, 2002)[2]. EPD considers the integration of environmental considerations through the product development process, in each stage of product development:

– Idea generation
– Concept development
– Evaluation
– Prototype building
– Testing
– Manufacturing
– Launch
– Product management
– 'End-of-life' management.
– Therefore, eco(re)design (existing product adaptation) and eco-innovation (new product development) are EPD strategies.

**Sustainable product design** favours the lifecycle, just as eco-design does, but places considerable emphasis on the additional inclusion of social and ethical considerations necessary to achieve sustainable development. Sustainable product design was defined as the balancing of economic, environmental, ethical and social issues in product design and development. Sustainable product design requires creativity, innovation and the participation of many different actors such as policy makers, business strategists, managers, designers, engineers, marketing managers, consumers, etc. (Jones, 2001)

A further distinction between sustainable design and the other terms is their time-scale. Sustainable design has a highly prominent long-term time component, in line with the concept of

2 CFSD – Centre for Sustainable Design, UK.

inter-generational equity inherent in sustainable development. In contrast, for example, green design and eco-design have no manifest time dimension. Sustainable design is also systems focused, where green and eco-design have a product focus.

Product-oriented environmental management systems (poems), sustainable service strategies, product stewardship, supply chain management and Integrated Product Policy (IPP) are other examples of concepts that have become popular within the business sector as well as with policymakers in the last years.

Although all the above concepts have sometimes a difference in focus, they all have the same aim: to reduce the impact of products and services on the environment. Despite the several definitions of eco-design found in literature and guidance, they commonly suggest several key concepts that are:

– To integrate environmental concerns of a product into early design process;
– To consider environmental concerns together with other product requirements such as quality, cost, safety, etc.;
– To deal with the whole impact of a product through the whole life cycle from 'cradle to grave' (material use optimisation; clean manufacturing; efficient distribution; clean use/operation and end of life optimisation);
– To start at the front end of design process.

The reason that this article uses the term 'eco-design' rather than any of the alternatives is because eco-design tends to be the most widely used in industry/academia and also the one that has more consensus. Each of the alternative terms tends to have specific connotations or refer to specialised design techniques/areas, and also because eco-design is the most generic term.

## 1.3 The Environment as a Part of Product Development

The main purpose of eco-design is to create products and services for achieving a sustainable society. These products have to contain as few resources as possible without reducing performance. In other words, without compromising other criteria such as functionality, quality, cost and appearance.

When designing products for a sustainable society, several other constraints apart from the environmental ones have to be considered, including economics, technological possibilities and limitations, and the needs and benefits of the customer (Luttropp & Lagerstedt, 1999). This means that environmental demands have to coexist with all the other requirements and constraints of a design process. In order to achieve this, environmental issues and demands must be integrated into the product development process.

To understand how this can be achieved, a basic theory of product development and design as well an environmental one is presented here.

## 1.4 Characteristics of the Design Process Model

Product development in industry today is a multi-faceted activity, often characterised by a large organisational structure, the involvement of a lot of people, and a multitude of disciplines such as design, research, marketing, production and management.

The product-development process has been described in detail by many researchers and they all describe a few main steps that must be carried out during the design process.

Although almost all models of the product-development process appear in sequential flowchart form, real–life design is executed in an iterative fashion, and the real creative mental process is still unknown.

To assist this research, a design process model is presented, which has been translated from Pahl & Beitz (1998). Because of the iterative character of a design process this model cannot be seen as strictly linear.

## 1.5 Pahl & Beitz Design Process Model

The Pahl & Beitz design process model is a method of evolution based on use-value analysis, as shown in figure 1. The overall design of the product is broken down into designs for separate functional modules. Each module can then be considered independently with the interactions between them being kept to a minimum.

The first stage – clarifying the task – involves the collection of information about the requirements to be embodied in the solution and also about the constraints. The drawing up and elaboration of a detailed specification or requirements list follow it.

The second stage – conceptual design – includes the establishment of function structures, the search for suitable solution principles and their combination into concept variants. Concept variants that do not satisfy the demands of the specification have to be eliminated and the rest must be judged by the systematic application of specific criteria based on the requirements of the specification.

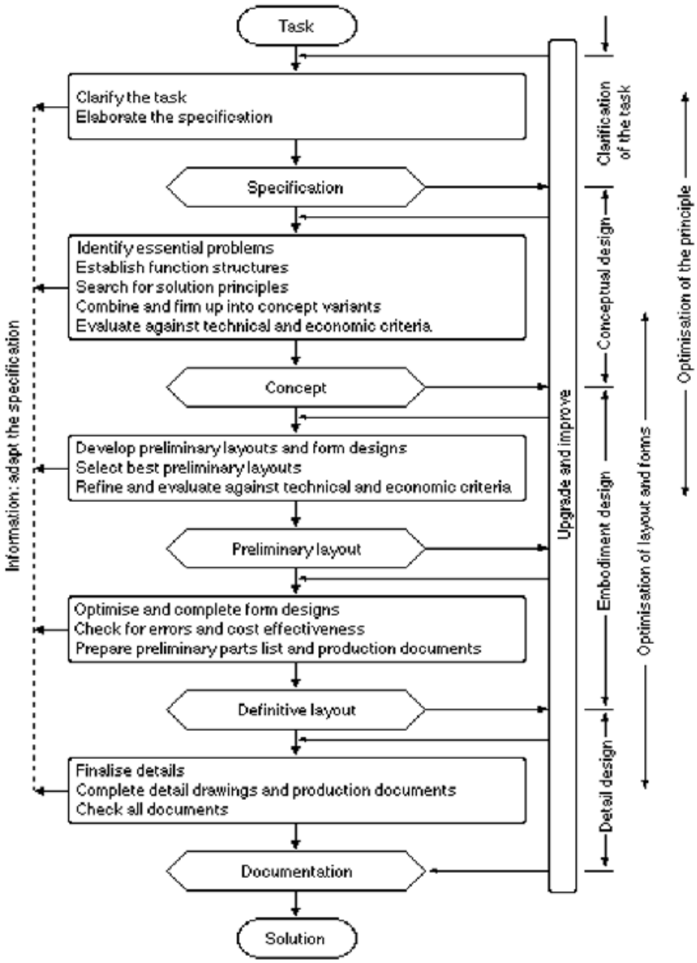
In the third stage – embodiment design – the designer, starting from the concept, determines the layout and forms, and develops a technical product or system in accordance with technical and economic considerations. The definitive layout selected in this stage provides a check of function, strength, spatial compatibility and so on.

In the fourth stage – detail design – the arrangement, form, dimensions and surface properties of all the individual parts are finally laid down, the materials are specified, the technical and economic feasibility re-checked, and all the drawings and other production documents are produced.

In general a typical product design process does not incorporate environmental assessments until late into the design process, if at all. Environmental information when introduced into the design process is done after much of the design work has already been completed. At this point, it is difficult and costly to make substantial design modifications to improve environmental performance.

*Figure 1*

**Steps of the Design Process (G. Pahl & W. Beitz, 1998)**

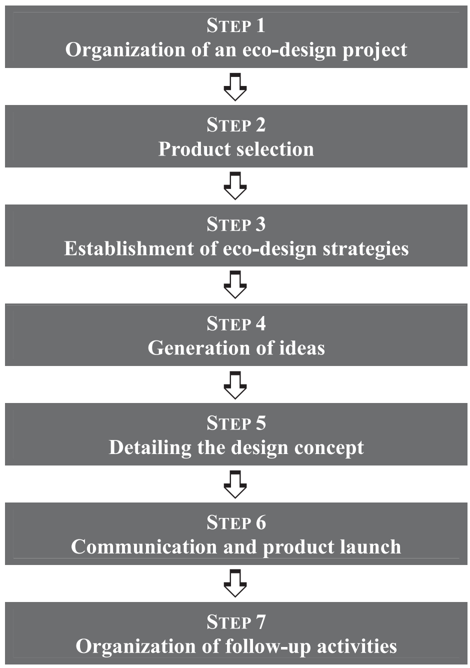



## 1.6 Eco-Design Process (Brezet et al., 1997)

The Eco-design Process from the Eco-design Manual from Brezet *et al* (1997) was chosen to compare with the traditional design model developed by Pahl & Beitz. The eco-design manual suggests 7 steps to design environmentally-friendly product as shown in figure 2. In each step attention is focused on those aspects which are specifically related to eco-design. The steps deal with the organization of an eco-design project (Step 1), product selection (Step 2), the establishment of eco-design strategies (Step 3), the generation of ideas (Step 4), detailing the design concept (Step 5), communication and product launch (Step 6) and the organization of follow-up activities (Step 7).

*Figure 2*

**The Eco-Design Process (Brezet *et al*, 1997)**




In the first step the eco-design project is initiated. An important activity in this step is getting management's commitment for the eco-design project at the highest possible level. Subsequently, the project team's composition is discussed. Experience shows that these two activities are crucial for the success of eco-design within the firm in both the short and the long term. Finally, guidelines for implementation and planning are presented, and advice is given on how to estimate a budget for the project.

Selecting a product for the project is the next step. The task involved in this step is the identification of a product, which promises high potential environmental merit and high market potential. This includes doing an estimation of its market potential, the potential environmental improvement and its technological feasibility. After this, the product is selected and a detailed design brief formulated. Only then can the project team be determined in detail since the character of the product can imply the participation of specific team members.

Step 3 focuses on establishing the most promising eco-design strategy for the project. The problem that was defined in the design brief in Step 2 is now analysed in greater detail. Based on the analysis of the environmental product profile and the company's drivers for eco-design, priorities are set concerning the most suitable eco-design strategy to follow in the project. Step 3 ends with a specification of the environmental requirements for the planned product.

In step 4, starting from the list of requirements made in the previous step, product solutions are generated. Several techniques are discussed for producing ideas for new products and product systems and for improving existing ones. Finally, this step explains how appropriate ideas can be tested against the list of requirements.

Step 5 of the eco-design process entails developing product ideas into product concepts and working out the specifications for the selected concept until it becomes a definitive design. It is at this stage that the materials, dimensions and production techniques for the new product design are actually determined. The product design, the production plan and the marketing plan are also established in detail, as they are the fundamental elements of the maintenance and repairs plan, and the end-of-life scenario. The new design can now be presented to management and to those responsible for preparing technical drawings, renderings, three-dimensional models, and a realistic and working prototype.

Step 6 describes the steps that will lead to the successful realization of the new design. These include promoting the new design internally, market research and developing a promotion plan, plus the preparatory work for production. At the end of Step 6 the product will be ready for production and for the launch of the product.

Step 7 presents ideas on evaluation and eco-design follow-up activities. Two evaluation options are explored: a product evaluation and a process-oriented project evaluation. Eco-design follow-up activities are then discussed. The in-house development of an eco-design programme is central here. Such a programme should include the production of an in-house eco-design manual, information management, agreements reached with suppliers and customers, and an in-house training programme.

## 1.7 Comparison of Brezet et al Eco-Design Process and Pahl & Beitz 'Traditional' Design Process

The table below presents a comparison of Eco-design Manual (Brezet *et al*, 1997) and Pahl & Beitz (1998) design processes. The Eco-design manual divides pre-design stage into two phases - product planning and product specification. These stages include all of the actions that should be taken before actual product design activities. It is in the product planning activity that the goal and scope of the project is defined, the objective of the product is selected and the cross-functional design team is organized. Clarification of the task of the design team is also a part of the product planning activity. Pahl & Beitz do not give much consideration to this activity while the Eco-design manual stresses the need for this activity.

For the product specification the manual deals with problem definition. Product specification activity includes environmental analysis and environmental priority setting in general. The eco-design process recommends making an environmental analysis and setting environmental priority. In this process, a designer tries to clarify and analyse the environmental problem of a reference product. For Pahl & Beitz, however, the identification of the problem belongs to the conceptual design step.

The Eco-design manual distinguishes two design stages: conceptual and detail design. However, the Pahl & Beitz model distinguished three stages: conceptual, embodiment and detail design. The choice between two or three stages seems rather arbitrary and not rigidly differentiated.

Finally, the Eco-design manual follows the product design step with other activities, such as communication and product launch and organization of follow-up activities.

| | ECO-DESIGN MANUAL | PAHL & BEITZ |
|---|---|---|
| PRODUCT PLANNING | STEP 1<br>Organization of an eco-design project | TASK |
| | ⇩ | |
| | STEP 2<br>Product selection | |
| | ⇩ | ⇩ |
| PRODUCT SPECIFICATION | STEP 3<br>Establishment of eco-design strategies | Clarify the task<br>Elaborate the specification |
| | | SPECIFICATION |
| | ⇩ | ⇩ |
| CONCEPTUAL DESIGN | STEP 4<br>Generation of ideas | Identify essential problems;<br>Establish function structures;<br>Search for solution;<br>Combine and firm up into concept variants;<br>Evaluate, etc. |
| | | CONCEPT |
| | ⇩ | ⇩ |
| DETAIL DESIGN | STEP 5<br>Detailing the design concept | Develop preliminary layouts and form designs<br>Select, Refine, Evaluate etc. |
| | | PRELIMINARY LAYOUT |
| | | Optimise and complete form designs<br>Check for errors, etc. |
| | | DEFINITIVE LAYOUT |
| | ⇩ | |
| IMPLEMENTATION | STEP 6<br>Communication and product launch | |
| | ⇩ | |
| | STEP 7<br>Organization of follow-up activities | |

Comparison of Eco-design (Brezet *et al*, 1997) and Pahl & Beitz (1998) Design Processes

## 1.8 The Link Between Eco-Design and 'Traditional' Design Processes

As demonstrated in the analysis of the table above, the basic structure of the product development process does not change when environmental requirements are integrated with it. However, the environment does add new aspects to the steps involved in product development. For instance, the environmental profile of the existing product must be specified.

Considering again Pahl & Beitz's design process, in the first step that concerns the clarification of the task, the product definition is in a crucial stage in the product development process. It is at this point that the environmental attributes of a product can be identified and built into the design. It is important to recognize that eco-design will require some portion of the designer's effort, and that, like all other aspects of design, thoughtful choices made early in the design process are by far the most cost-effective. It is in this step that usually companies decide strategic issues associated with supply chain, life cycle support and manufacturing management.

The conceptual design step is the most important phase after the product definition phase. Approximately eighty percent of a product's life cycle costs are committed through design choices, such as materials and manufacturing process selections in this phase. Tools used for environmental design in this phase must be able to deal with an unclear situation, as the design is still on a conceptual level, with properties such as final shape, component weight and materials yet to be established.

Detail design embarks on the actual physical design of the product using CAD models to determine the physical worthiness of the product. Often, design problems found later in the design process (embodiment or detailed design stages) cause costly and time-consuming redesigns of the product, extending the product's delivery or introduction to market. Eco-checklists, LCA or MIPS can be used in this phase.

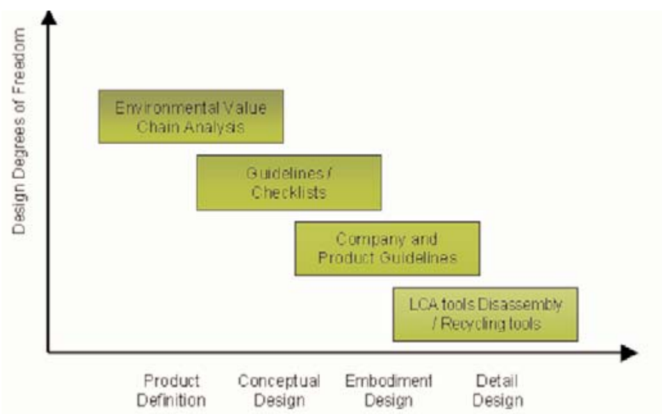
## 1.9 The Design Process Paradox

When designing a new product, at the beginning of the process, the knowledge of the new product is little but the freedom is almost total, since nothing is established. As the product develops, the information about the product increases, but this happens at the cost of design freedom. By the end of the process the knowledge of the product is greater but the possibilities for changing the design are reduced. Global design decisions are already taken and only minor changes can be made.

Figure 3 shows the different design stages and the degrees of freedom to change design. The figure presents a development of the design process paradox (Ullman, 1997) and the design process (Pahl & Beitz, 1998) including the eco-design tools and methods for each stage of the design process.

*Figure 3*

**Degrees of Freedom in Various Stages of Design**



In the first step of the design process where design freedom is greater, global design decisions concerning major principle inputs such as material selection are still issues. This means that major efforts can be directed towards designing sustainable products at this point. At the same time, there is very little firm information about the new product, which means that quantitative methods would be difficult to apply, as they are data intensive. Consequently, few environmentally oriented design methods are available.

At the same time, management has to deal with environmental issues relating to legislation, market constraints, financing and profits. As almost nothing about the product is finalised yet, the information in this first phase has to be non-quantitative, general and easy to understand.

In the second step, product design comes to a defining moment where eco-design evolves into formulating company-specific eco-guidelines, putting constraints on the new product. Main principles are firmly established, helping and guiding the designer. These environmental goals and eco-guidelines must be linked to the evolving product as closely as possible.

In the third design phase, general eco-guidelines of an advisory nature are not going to be of much help, as what can be referred to as environmental common sense is too vague and cannot be evaluated against the functional demands placed on the product. Being more effective than general guidelines, company and product specific guidelines will provide a brief compass bearing in this step (Luttropp, 2000).

The fourth phase is the refinement phase. The product can be presented here as a prototype, where detailed product or property-specific requirements and eco-checklists can be used. LCA (Life Cycle Assessment) or MIPS (Material Intensity Per Service unit) calculations requiring quantitative data can be performed, as the data necessary for these are present. Since the product materials have been finalised, only minor changes can be made like exchanging materials, which is a typical result of LCA/MIPS calculations in the fourth design phase.

The design paradox is that when a new design project begins, very little is known about the final product, especially if the product is a new one for the designers. So the freedom to design an environmental-friendly product is enormous but the tools to accomplish this task are ambiguous in the first stages. Only in the final stages of product development, where minor changes can occur, are tools able to give detailed information.

## 1.10 Final Remarks

In summary, the basic structure of the product development process does not change when environmental requirements are integrated in it. However, the environment does add new aspects to the steps involved in product development. As has been demonstrated, the integration of environmental considerations into early product development process is essential for the success of eco-design and even for product development in general. Yet the tools to evaluate the environmental impact of products in the first design stages are very uncertain, since the data available are unclear. So when designers have lots of freedom to project a product with reduced environmental impact they do not have the correct instruments. Nevertheless, there are some common aspects of the eco-design process that have to be tackled in order to make eco-design work (Eco-guide, 2002):

**– Integration of environmental issues during product development**

In product development, eco-design should be built into all the stages of the design procedures of a company. Moreover as the environmental impact is mainly defined at the design phase, eco-design has to be taken into account at each stage of the design process, from idea generation to the design detail phase. Companies normally have a distinctive and customised product development process. Therefore, it is necessary to customise the integration of the environment into the process according to the company's culture, and the characteristics of its products and processes.

**– Early intervention in Design**

It is vital to have senior management commitment and an extended design team, which considers eco-design from the very start of a project. Such an approach is extremely relevant, because in most cases more than 70% - and often as much as 90% - of the costs, as well as the environmental inputs are fixed during the research and development stage. Therefore, the earlier the complete life cycle is taken into account, the higher the potential for improvements and for cost savings.

**– Continuous Improvement**

The integration of the environmental dimension into design should be a continuous improvement process where impacts are being reduced while innovation builds upon experience. All technical or market developments should be taken into account, both upstream (e.g. the development of new materials) and downstream (e.g. the drawing up of new recovery processes) of the product's life cycle.

Ideally, the information acquired from the different experiences should be organised to constantly feed into a knowledge base so that all data required for conducting an environmental assessment or set of design rules are gathered.

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