The Crucial Role of the Designer in EcoDesign

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Doctoral Thesis
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The Crucial Role of the Designer in EcoDesign

Doctorial thesis

This is an academic thesis, which with approval of the Department of Machine Design, Royal Institute of Technology, will be presented for public review in fulfillment of the requirements for a Doctorate of Engineering in Machine Design. This public presentation will be made at Royal Institute of Technology, Kollegisalen, Vallhallavägen 79, Stockholm, 10:00 9th September 2003.
Abstract

This goal of this thesis is to present an overview of the designer’s situation in Swedish companies in relation to environmental work in the product development process. The overall aim is to describe the designer’s situation and his/her potential to minimize the environmental impact of products.

Awareness of the environmental problems has led to a new approach to product development, and today EcoDesign is being integrated in many Swedish companies. However, if products are to be improved from an environmental aspect, it is not only necessary to integrate the issue in the product development process, but designers themselves must also be given the possibility of actually designing environmentally friendly products. This makes the designer a key actor in EcoDesign.

There are different levels of support for designers during the various stages of product development. The most common environmental work within Swedish companies is to perform Life Cycle Assessment (LCA) or to introduce an environmental management system (EMS), most commonly ISO 14000. In order to optimize a product from an environmental view, it is necessary not only to know how the product affects the environment but also how to evaluate different solutions and concepts. In order to do this, LCA can be a support but it does not lead to the finding of new solutions or concepts. There is control of the product’s content and restrictions on substances that cannot be used. The focus of the product’s environmental impact is not only in the manufacturing and use phase but also in the end-of-life phase. This focus is due to a new type of legislation, the producer responsibility law. The overall aim of this regulation is to increase reuse and recycling. To make this economically possible, the present efforts to adapt products to recycling must be vastly increased.

Finally, in order to integrate the environmental issue in the everyday work of designers it is necessary to have the following conditions:

- Environmental expertise available
- An evaluation tool in order to confirm and choose alternatives
- Education and information for designers to spread knowledge and to motivate them
- Constant stress on the importance of environmental adaptation
- Documentation routines and guidelines connected to the product development process to ensure that the issue is considered at every step

Integrating the issue in the product development process can clearly make significant environmental product improvements. For all companies, however, the overall aim is to make as much money as possible, and it is evident that any major product changes also have to lead to an increased customer benefit. If significant product changes are necessary for environmental improvements, further driving forces, such as governmental regulations, may be needed in order to develop such products.

Keywords: EcoDesign, designers, environmental product development, design for environment.
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August 2003, Stockholm
Appended papers


III. Åkermark A.-M., Tingström J., (2003), "New requirements for environmental education for designers and environmental engineers", proceedings from The International Conference on Engineering Design, ICED03, Stockholm, Sweden, August 19-21

IV. Åkermark A.-M., (2003), "Vehicle recycling from a designer perspective”, proceedings from 10th CIRP International Seminar on Life Cycle Engineering, Copenhagen, Denmark, May 21-23


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APPENDED PAPERS

PAPER I  Design for environment, the perspective of designer’s in a number of Swedish companies
PAPER II  ISO 14001 from a Designer Perspective
PAPER III  New requirements for environmental education for designers and environmental engineers
PAPER IV  Vehicle recycling from a designer perspective
PAPER V  Inclusion environmental aspects in the product developing process: existing and desired methods
1 Introduction

This chapter is an outline of the thesis, describing its background, purpose, and approach.

1.1 Background

There is no doubt that our society today faces great environmental problems. Fortunately, awareness of this has increased, and there is a realization that human activities affect the environment in a number of different ways. According to Flavin (1997), three main global environmental problems must be solved: (1) global warming, (2) decreased biological diversity, and (3) population growth in combination with an increased standard of living. The two major reasons for these problems are the lack of development in the Third World, resulting in poverty that will lead to overexploitation of resources, and the waste that is evidenced in the rich parts of the world (Göthe, 1995). Although the environmental problems are increasing, there is clearly a wish to solve them and to achieve sustainable development towards a sustainable society. Such a society has to live on its interest and not on its capital (Daly, 1992). According to the World Commission on Environment and Development (WCED) “a sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

The large numbers of products that are considered necessary for the functioning of our society give rise to a number of environmental problems. During the respective life phases of these products, the environment will be affected in different ways. Awareness of this has led to a new way of approaching the environmental issue; it is no longer just a question of cleaning up outlets and processes. In fact, many products have an environmental impact during every phase of their life cycle (raw material extraction, materials processing, production, distribution, usage, and disposal) (Wenzel, Hauschild & Alting, 1997). Within industrial companies, therefore, the attitude has changed to one where environmental work has become more product-oriented. Today, many companies not only act in accordance with legislation but also work actively with environmental issues to minimize the environmental impact of their products: “The design of eco-efficient or more sustainable processes and products has become a standard practice in many firms around the globe” (Ehrenfeld, 2001).

EcoDesign considers environmental aspects at all stages of the product development process, striving for products that make the lowest possible environmental impact throughout their life cycle (Brezet & van Hemel, 1997). Design For Environment (DFE), or EcoDesign, was launched during the early 1990s (Stevels, 2001). Today most companies have started to implement this concept throughout the entire product development process. A number of different measures are taken in order to reduce the environmental impact, for instance, Life Cycle Assessment (LCA), implementation of Environmental Management Systems (EMS), and material restrictions. An important actor in all these activities is the designer. Designers and product developers have a large impact on the ability to develop a sustainable society since product development always includes designing. This implies that designers not only have a technical responsibility but also an environmental responsibility and should be able to provide an analysis of how the environment is affected by the
products they develop (Ryding, 1995). The engineering designer is the only person who has
the ability to transform the mental image (desire) of a human being to real material
technical processes, systems, or products. Engineering designers’ activity may be guided
towards better living conditions if design research advances the practice of design (Hongo
& Amirfazli, 1995). The designer is an important participant in attempts to solve the
problems of waste and overexploitation of resources by improving future products from an
environmental perspective. By designing for more efficient material use, with less
consumption of material and energy and new technical solutions, for example, important
contributions can be made to the development of a sustainable society. In this thesis, the
focus of the research is on designers and the contexts in which they work.

1.2 Objectives and research approach

This research started with a focus on design for recycling, and on the integration of this into
the product development process. The aim was to investigate what support designers need
and to find general guidelines for design for recycling. The results of this initial research
were presented as a licentiate thesis (Åkermark, 1999a; see also Persson et al., 1995;
Åkermark, 1997; Åkermark, 1999b). It was found that in order to contribute efficiently,
designers need to have knowledge of the recycling industry and of the methods for
disassembly and separation of materials. It was also essential to consider the recycling and
reuse of materials and components in new designs. Finally, it seemed that designers need
more information on general environmental problems and the environmental impact of
different materials.

Design for recycling is part of design for environment. The overall goal is to minimize a
product’s total environmental impact, and it is clear that one environmental aspect cannot
be separated from the other. From the designer’s point of view, it is important to focus on
improving the environmental effects of the products. The focus of the current project was
therefore changed to design for environment, with the aim of gaining a better understanding
of EcoDesign from the designer’s perspective. The objective of the research described in
this thesis is thus to describe the current situation for designers with regards to
environmental issues in general, and specifically to study to what degree the environmental
issue can be integrated into the product development process.

According to Cross (1995), three forms of research in design are useful: research into
design, by various kinds of observations; research for design, to create tools, design
methods, forms of modeling; research through design, abstraction from self-observation
and other observations during designing, hypothesizing, and testing. The research approach
chosen in this thesis is best defined as research into design, and the approach is to describe
the designer’s current situation from two main aspects:

1. What environmental work is being done at the designers’ level in Swedish
companies today?
2. How do the designers work with the environmental aspect and to what extent are
they integrated into the product development process?
The selected research approach has been to conduct interviews with designers in order to collect empirical data to be analyzed in regards to five aspects:

1. The designer’s general perspective on EcoDesign: Is there environmental work in the companies at the designer’s level? How is this organized? Are there restrictions? What are the support, tools, and methods for environmental work?
2. The effect of ISO 14001: How are the designers affected by the implementation of Environmental Management Systems (EMS).
3. The education: Have designers received environmental education? What kind of environmental education do they look for?
4. The producer responsibility law: To what extent does this legislation affect the designers?
5. The use and need of methods: What kinds of methods are used by designers? Is the support sufficient? Do the designers need more methods?

The scientific foundation for this thesis has been gathered from three main areas: environment, product development, and EcoDesign, as shown in Figure 1.1. The basis for the work has been a review of the literature and a set of semi-structured interviews, the aim being to study the designer’s situation in relation to these three different areas.

Figure 1.1. Main foundation of knowledge for this research

The thesis considers environmental work within product development, in particular the designer’s or engineer’s activities and positions. There are several activities relating to environmental issues within companies, such as strategic decisions at the management level and the development of cleaner production processes. In order to improve products from an environmental point of view, the product developer must have the opportunity to carry out the intended environmental improvements. While project management sets the framework for all product development projects, the actual products have to be developed by designers. Furthermore, today there is great pressure on designers since the products have to be developed within shorter and shorter timeframes while at the same time more functions have to be integrated into the products.
1.3 Scope of the results

Figure 1.2 depicts the relationship of five papers appended to this thesis and summarized in Chapter 4. General aspects of EcoDesign are discussed in all five papers. Paper I provides an overview of environmental work in Swedish companies. Paper II describes the effect of the implementation of ISO 14001 at the designer’s level. As knowledge is necessary to be able to improve or change products, it is therefore essential for designers to receive a proper education on EcoDesign, so Paper III discusses different aspects of education for designers and engineers. Paper IV is an examination of how producer responsibility affects designers and the product development process. Finally, Paper V discusses the designers’ need, access to, and use of methods in the product development process.

Figure 1.2. The research topics in Papers I through IV

1.4 The outline

The first step in this research project was to gather general information about the state of the art of EcoDesign, in academia as well as in industrial enterprises. The second step was to study the actual process of EcoDesign, and how designers are affected by different environmental activities as well as their current situation. As a third and final step, a series of interviews were conducted with engineers working with design at Swedish companies representing different product types, both capital goods and household appliances. The results of the interviews have been analyzed with a focus on how to accomplish environmentally friendly design.

The present chapter presents the research area and the formulation of the objective. Chapter 2 presents the theoretical foundation of the research; the product development process and the design process in particular are discussed in the context of EcoDesign. Chapter 3 describes the research approach and methodology.
The five appended papers are then summarized in Chapter 4. In Chapter 5, the results are presented and discussed, and the contribution of the thesis is summarized and put into the context of related research. Chapter 6 offers conclusions and proposals for further research.

2 Research method

The aim of this work has been to describe the designer’s role in relation to EcoDesign. The methods used are literature surveys, information gathering, and semi-structured interviews. Examples of important questions are these:

- How are designers affected by legislation (producer responsibility), ISO 14000, education, and organization?
- What is being done? What could be done? Why is not more being done?

Other questions include those on how the environmental work is organized; whether there are guidelines, knowledge, and support; and what are prevailing attitudes about the environmental issue? So if you want to know how people interpret their world, why not talk to them? Qualitative research interviews thus aim at understanding the real world-view of those interviewed (Kvale, 1997).

A problem with the environmental issue is that it is hard to measure in easy terms such as cost. The problem is not only to know what to do or how to do it, but also to know whether the taken measures actually result in an environmental gain. To be able to drive and improve the environmental work within a company, the employees want to have and be given space to do so. The present research aims at describing and enlightening the designer’s opportunities and constrains when it comes to environmentally adapted product design. In order to find out how designers experience different support tools and experts, the best way is to ask the designers. The goal is not to try to change or influence the product development process but to describe, analyze, and concretize the designers’ views on the environmental work within the companies.

2.1 Why semi-structured interviews?

The purpose of the interviews in this project was to survey designers’ views and opinions, with a focus on how they experienced the environmental work within their companies. As may be seen from the various interview methods summarized in Table 2.1, the role of the interviewer depends on the chosen method. In order to make sure that the questions would cover the research area, an interview guide was used and the interview itself was recorded, transcribed, and analyzed.
Table 2.1. A range of interview models (Westlander, 2000)

<table>
<thead>
<tr>
<th>Study method</th>
<th>Role of the interviewee</th>
<th>Role of the interviewer</th>
<th>Interview aids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A: Unstructured personal interview</td>
<td>Decides what will be discussed and to what extent.</td>
<td>Wants to investigate the individual’s own view of the situation.</td>
<td>Notes taken freely during/after the interview, possibly following a predetermined frame.</td>
</tr>
<tr>
<td>Type B: Semi-structured interview</td>
<td>Has the freedom to specify what and how much will be taken up within the frame of each topic.</td>
<td>Wants to investigate the individual’s own view of the conditions within each subject area.</td>
<td>Interview guide + notes taken freely during/after the interview.</td>
</tr>
<tr>
<td>Type C: Structured interview</td>
<td>Tied to questions posed by the interviewer.</td>
<td>Wants to assess and compare responses from a number of questions.</td>
<td>Interview form.</td>
</tr>
<tr>
<td>Type D: Printed questionnaire</td>
<td>As in Type C.</td>
<td>As in Type C.</td>
<td>As in Type C.</td>
</tr>
</tbody>
</table>

From a strict natural science perspective, interviews might seem a rather suspect choice of research method. Natural science research generally requires the possibility of replicating an event, experience, or phenomenon. This requires a detailed documentation of the constraints, surroundings, methods, and equipment. It is evident that no interview could be repeated and yields exactly the same answers a second time. In this interview series, therefore, a validation of responses was made during the interviews by repeating the given answers as a question in order to verify the interpretation. The interviewees were also given the opportunity to comment on that interpretation.

To summarize, qualitative research interviews were chosen as the research approach since the aim was to:

- Describe how designers experience the environmental work within their companies;
- Strive for a balanced description of designers working situation; and
- Obtain an answer to the questions “why,” “why not,” and “in what way”—questions that require more distinctive options for the answers than would be available in a questionnaire.

2.2 Companies selected for interviews

The empirical studies were conducted at 19 small and 5 large Swedish companies. The designers interviewed were working with ordinary product development, not special Ecodesign projects.

The five large companies utilize advanced technology within their different fields of heavy vehicles, vehicles, electrical motors, busses, and household appliances. All companies have
more than 10,000 employees, have a world leading position within their fields, and have been in business for many years. These companies have somewhat different customer categories. There are, however, similarities between the products: They are all mass-produced, active products, and consist of many different components and materials. All the companies have formalized product development processes and develop and produce their own products.

Table 2.2  Distribution of interviews among the companies

<table>
<thead>
<tr>
<th>Company</th>
<th>Number of interviewees</th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8 + 4</td>
<td>Papers I, III, V</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>Papers III, V</td>
</tr>
<tr>
<td>C</td>
<td>3 + 3</td>
<td>Papers I, III, V</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>Papers I, II, III, V</td>
</tr>
<tr>
<td>E</td>
<td>6 + 5</td>
<td>Paper IV</td>
</tr>
<tr>
<td>Small companies</td>
<td>19</td>
<td>Paper I</td>
</tr>
</tbody>
</table>

The small companies have 6 to 20 employees. They are also world leaders in their fields but with a limited market since they produce specialized products for specific industries or companies. They produce 5,000 to 20,000 products a year. All companies export a large part of their products (on average, 40%). Their customers range from governments to supermarkets. In the small companies, products are developed within the companies but are actually produced by other companies.

2.3 Subjects interviewed

The choice of interview subjects is obviously important but it can be difficult. In case studies at larger companies, it can be hard to know how the subjects have been selected for interviews. Since this research was carried out not at the request of the companies but at the initiation of the researcher, it is quite clear that it is hard to evaluate how the interview subjects have been chosen. It was not possible for an “outsider” to know who were the optimal persons to interview. The contact persons at each company chose the interviewees, and all interviewees themselves agreed to be interviewed. There was no special selection method for choosing the interviewees.

All product development is a co-operation between the individuals participating in the specific product developing team. There are both formal and informal contacts between departments and team members, so the information flow varies with the group members and their mutual relationships.

There are six quality criteria for an interview according to Kvale (1997):

- The extent of spontaneous, rich, specific, and relevant answers from the interviewee.
- The shorter the interviewer’s questions and the longer the subject’s answers, the better.
• The degree to which the interviewer follows up and clarifies the meanings of relevant aspects of the answers.
• The ideal interview is to large extent interpretations of the subjects’ answers in the course of the interview.
• The interviewer attempts to verify his or her interpretations of the subject’s answers in the course of the interview.
• The interview is “self-communicating” – it is a story contained in itself that hardly requires much extra description or explanation.

It is evident that while the outcome of the interviews thus depends on both the interviewer and the interviewee and the relation between them, the quality of the interview is determined largely by the last four of Kvale’s criteria.

2.4 Interview guide

An interview guide specifies the topics that will be investigated and in what order they will be addressed. The guide could consist of just the topics or it could detail the specific questions. The interview guide used during the interviews in this study comprised semi-structured questions, all with the aim of answering a research question. For every research question there were a number of interview questions, as shown in the examples in Table 2.3.

Table 2.3. Examples of research questions and interview questions

<table>
<thead>
<tr>
<th>Research question</th>
<th>Interview questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which aids for designing for environment are available and how are they used?</td>
<td>What computer programs do you use?</td>
</tr>
<tr>
<td></td>
<td>Are there handbooks and/or guidelines?</td>
</tr>
<tr>
<td></td>
<td>How often do you use these?</td>
</tr>
<tr>
<td></td>
<td>When do you use them?</td>
</tr>
<tr>
<td>How is the environmental work organized?</td>
<td>Who are responsible for recycling?</td>
</tr>
<tr>
<td></td>
<td>Who/where do you turn to when you have a question regarding environment?</td>
</tr>
<tr>
<td></td>
<td>Which responsibilities do you have?</td>
</tr>
<tr>
<td></td>
<td>Who controls your work?</td>
</tr>
<tr>
<td>Are there any restrictions?</td>
<td>How is your work controlled?</td>
</tr>
<tr>
<td></td>
<td>Are there any guidelines regarding the environmental aspect?</td>
</tr>
<tr>
<td></td>
<td>Who makes product decisions?</td>
</tr>
<tr>
<td></td>
<td>How are product decisions made?</td>
</tr>
<tr>
<td></td>
<td>Do you have any list of forbidden materials?</td>
</tr>
</tbody>
</table>

2.5 Analysis of interviews

The interview analysis starts during the interview, where uncertainties are discussed and more questions are asked in order to follow up uncertainties and gaps. When the interviews are finished, the material can be collected and compiled for analysis. According to Kvale (1997), there are five different methods of analyzing the material:
1. **Meaning condensation** entails an abridgement of the meanings expressed by the interviewees into shorter formulations, and reduction of large interview texts into briefer, more succinct formulations.

2. **Meaning categorization** implies that the interview is coded into categories. By categorization a large text can be reduced and structured into a few tables and figures.

3. **Narrative structuring** entails the temporal and social organization of a text to bring out its meaning. It focuses on the story told during an interview and works out the structures and their plots.

4. **Meaning interpretation** goes beyond a structuring of manifest meanings of a text to deeper and more or less speculative interpretations of the text.

5. **Generating meaning through ad hoc methods** is an eclectic approach. A variety of commonsense approaches to the interview text, as well as sophisticated textual or quantitative methods, can be used to generate the meaning in words, numbers, figures and flow charts, or some combination of these media.

The interviews in this study were analyzed using meaning condensation and generating meaning through ad hoc methods. The aim was to describe the designers’ situations and their options, but not to test any given hypothesis.

### 3 Theoretical background

This chapter presents the theoretical background of the research. The starting point is defined by the environmental problems caused by human society; the goal of the work is to contribute to building a sustainable society. Following an overview of current environmental problems and a discussion of whether a sustainable society can be achieved in a reasonable time, the environmental issue is presented from a somewhat unusual perspective—that of the company and the designer. The third section of the chapter presents the concept of EcoDesign, in particular from the designer’s perspective, and the state of the art within this research area. Working with sustainability from a company perspective means minimizing the environmental burden from all company activities: “EcoDesign considers environmental aspects at all stages of the product development process, striving for products that make the lowest possible impact throughout the products life cycle” (Brezet & van Hemel, 1997). Designers form a very important group of actors in the product development process. The overall aim of product development is to produce products that meet the needs of the market. No matter which subject is in focus, the environment, cost, function, safety, assembly, and process of designing are the same. There are many different product categories, leading to different demands on the product development process. This means that a number of different factors such as project time, cost, and market demands will put restrictions on the process. This is the reality for designers in the design process, no matter what issue is to be implemented.
Figure 3.1 shows a simplified schematic view of the designer’s context within a system. Designers work within a company on product development projects. Designers work directly with suppliers, resulting in products that will ultimately affect the ecology system of our planet. Their work, including environmental considerations, will be determined by company policy and strategy, which in turn depend on the demands of owners and customers, and on governmental regulations. Depending on the product category, an environmentally adapted design will require a somewhat different strategy than design in general. To improve a product from the environmental aspect, it is necessary to understand how it affects the environment and what should be targeted to optimize it from an environmental point of view.

### 3.1 Environmental problems and sustainability

Environmental problems are closely linked to a growing population and an increased use of technology. To feed and provide for the human population, an increasing amount of raw materials, energy, and land are required, leading to a pressure on the earth’s ecological balance. This raises the question of how serious is the environmental problem. The total environmental load of human population and activities cannot exceed the earth’s carrying capacity in an ecologically enduring society. The environment’s carrying capacity is its maximum persistent support load. The human population’s carrying capacity changes over time due to a number of factors. Until now, human carrying capacity has continuously been increased by elimination of other species, by importing locally scarce resources, and by use of technology. Conventional economic planners generally reject the concept of limits when
applied to people and claim that there is no limit to the earth’s carrying capacity. At present, however, both human population and average consumption are increasing, while the total area of productive land and stocks of natural capital are fixed or in decline. Among natural and social scientists there is a growing consensus that sustainability depends on maintaining the natural capital and stopping the decline.

To achieve a sustainable society, humanity must thus live within nature’s carrying capacity. Measuring tools are essential in order to check that humanity’s demands do not exceed the interest from the globe’s natural capital stock (Wackernagel et al., 1999). Instead of asking what population a particular region can support in a sustainable way, the critical question becomes: How large an area of productive land is needed to support a defined population indefinitely? Formally defined, the ecological footprint (EF) is the total area of productive land and water required to continuously produce all the resources consumed and to assimilate all the wastes produced, by a defined population, no matter where on Earth that area is located. As noted, the ecological footprint is a land-based surrogate measure for the population’s demands on natural capital. The ecological footprint is a portrait of how things stand right now under prevailing circumstances (Rees & Wackernagel, 1996). According to estimates based on the EF-concept, the earth’s ecological capacity has in fact been exceeded ever since 1980 (Ecological footprint accounts, www.RedefiningProgress.org).

The negative environmental impact of currently increasing consumption is continually becoming more evident. Sustainable levels of material flow will not be reached until the material consumption of the OECD countries is reduced by a factor of ten (von Weizsäcker, 1997). Such a dramatic reduction of material flow implies either increasing the effectiveness of products or reducing consumption, or both. Kong et al. propose a change of current patterns at the household level, representing a significant change in lifestyle that can lead to sustainable consumption. The success of such a change depends on two factors: (1) how much consumers feel empowered to make a difference through their purchasing decisions; and (2) how the act of purchasing will affect (that is, improve) consumers’ quality of life. In order to achieve this change in consumer behavior, Kong et al. argue for a proactive partnership between business/industry and non-governmental organizations (NGOs) (Kong et al., 2002).

There is a strong belief that environmental problems are caused by technology and could therefore be solved with technology. Technology is assumed to be the solution for current environmental problems for these reasons:

1. Science can provide us with enough detailed knowledge about Nature to solve and prevent environmental problems.
2. Remediation technologies can successfully remove pollution without causing other unforeseen negative environmental impacts elsewhere.
3. It is possible to prevent pollution in the future and develop “clean” industrial processes that have no environmental impacts.

Huesemann (2001) is highly critical of these three assumptions and urges a better understanding of the limitations of technological approaches as solutions to environmental problems. In order to erase the effects of past pollution or to protect against future
environmental damage, it is necessary to understand all possible cause-and-effect relationships that might occur in nature as a result of human manipulation. Even if only one cause–and-effect relationship is overlooked during a scientific investigation, it may well prove to be an extremely critical one that could cause serious harm if ignored. Long-term protection of the environment is only possible by reducing and limiting both the size of the human population and the per-capita consumption (GDP/person). Unfortunately, the opposite has been the case: “The public is led to believe that all problems are going to be solved by science and technology and that no change in values or behavior is necessary.” Huesemann claims that solving current and future environmental problems is not primarily a technical problem but rather a social and moral problem (Huesemann, 2001).

Similarly Carvalho (2001) argues that sustainable development “is something that cannot be achieved within the current system by just a little tweaking and ‘slight greening’ of the current development model.” It requires fundamental changes—changes in economic, political, and social structure, at both the international and domestic levels, in order to avoid the growing environmental crisis facing humanity (Carvalho, 2001). Ayres claims that sustainability “implies radical change.” The present strategy of achieving growth is increasing the productivity of labor and increasing the use of material capital and energy. Ayres proposes a new strategy, radical dematerialization. This new strategy must gradually but massively substitute the use of fossil energy by human labor. The industrial world has to cut back its material consumption by a factor of ten over the next two generations. Technologically, a factor ten increase in resource productivity is certainly possible, but it cannot be achieved painlessly. It will require unprecedented collaboration between business and government. A new and more sophisticated awareness of the nature of the problems (and opportunities) is also needed (Ayres, 1996).

While Huesemann, Carvalho, and Ayres call for radical changes in order to achieve a sustainable society, Huber proposes that sustainability can be achieved with three “conventional” strategies:

1. Sufficiency with regard to population growth, as well as the level of affluence, lifestyle, and consumption patterns
2. Efficiency with regard to production processes and the use of products
3. Ecological consistency of production processes and products in order to achieve compatibility between the industrial and natural metabolism (Huber, 2000)

In order to reach a sustainable society it seems necessary that these strategies are coupled to the concepts of ecological footprint, Earth’s carrying capacity, the factor ten notion, or all three.

Around the world, a number of political activities are underway to solve environmental problems. In Sweden, to promote an ecologically sustainable society by 2020, 15 environmental quality objectives have been proposed, based on five fundamental principles: the promotion of human health, the preservation of biological diversity, the preservation of cultural and historical assets, the maintenance of long-term productive capacity of ecosystems, and the assurance of prudent management of natural resources. The 15 environmental quality objectives are: clean air, high-quality groundwater, sustainable lakes
and water courses, flourishing wetlands, a balanced marine environment, sustainable coastal areas and archipelagos, no eutrophication, natural acidification only, sustainable forests, a varied agricultural landscape, a magnificent mountain landscape, a good urban environment, a non-toxic environment, a safe radiation environment, a protective ozone layer, and limited influence on climate. (Swedish Environmental Protection Agency, http://www.naturvardsverket.se/dokument/hallbar/miljomal/brscheng.pdf)

3.2 Companies and environment / sustainability

As mentioned in Chapter 1.1, all products will affect the environment during production, usage, and disposal. From a company aspect, the environmental issue implies knowing how the environment is affected by the company's activities. For this to happen, it is necessary to improve both the work within the company, as well as its products, from an environmental aspect. It is important to distinguish between customer driven and environmentally driven product development. For example, car sharing or choosing a different transportation system could mean a greater environmental improvement than reducing the fuel consumption of the car. For product-developing companies it is the products that are in focus. This means to solve a problem with as little cost as possible.

![Figure 3.2. How the environmental focus has changed over time (modified from Brattebø, 1997)](image)

The environmental focus has changed over time (see Figure 3.2) and this change has led to new demands on companies. There are a number of different driving forces for companies when it comes to sustainability and environment. The factors that will drive environmental work can be divided into external and internal factors, as indicated in Table 3.1.

<table>
<thead>
<tr>
<th>Company-internal drivers</th>
<th>Company-external drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management commitment</td>
<td>Environmental legislation</td>
</tr>
<tr>
<td>Employee involvement</td>
<td>Market pressure</td>
</tr>
<tr>
<td>Cost awareness</td>
<td>Public pressure</td>
</tr>
<tr>
<td>Occupational health and safety programs</td>
<td>Product liability</td>
</tr>
</tbody>
</table>


The internal drivers are the most powerful in driving ongoing industrial ecology (IE) activities in the long term, while external drivers might rather promote short-term environmental improvements (van Berkel et al., 1997). Global manufacturing firms are paying more attention to their environmental performance. Handfield et al. point to a number of external driving forces that contribute to this effect:

- The claim, by proponents of environmental responsibility, that organizations can reduce their costs in the form of reduced waste management/disposal costs, reduced penalties and fines, reduced future liabilities, and lower regulatory driven costs.
- Increasing governmental regulation
- The advantage of ISO 14 000 (with emphasis on international standards for environmental compliance)
- The potential for publicity (both good and bad)
- Increasing demands from customers for goods and services produced by environmentally friendly processes and design (Handfield et al., 2001)

Ertel points out that today companies “beyond legislatorial incentive do care for environmental excellence to achieve economic and business advantages” (Ertel, 2001). Several enterprises in various geographic regions recognize that good environmental performance is an important factor for their future success and do a lot to reduce environmental impacts by treatment actions, implementation of cleaner technologies, and by product modification (Nielsen & Wenzel, 2001). Environmental design may become a significant competitive advantage, through reduction of manufacturing costs, due to satisfaction of customer demands, and easing of regulatory burdens. Consequently, firms are looking for ways to improve their environmental design capabilities. There is a growing awareness of the importance of the environmental issue in product development. Environmental design capability often derives from the integration of individual expertise already residing in the enterprises (Lenox & Ehrenfeld, 1997). There has been a shift in the nature of environmental work; earlier it was just a matter of the cost incurred in clean-up processes and products, while today it is in some sense regarded as a business opportunity.

According to Madsen and Ulhøi, regulations are the main environmental driving force in most companies, and without these the greening process is not likely to be very rapid: “In fact, it cannot be ruled out that industry in general will remain locked in a reactive attitude to environmental initiatives” (Madsen & Ulhøi, 2001). The most apparent reasons for industry not to participate in the “Ecodesign demonstration project (LIFE) – Examples of eodesign in Belgian industry” were as follows:

- Defensive attitude towards environmental issues in general
- The fact that EcoDesign was not covered by legislation
- Companies not convinced of the advantages of EcoDesign, with the impression that it was more a theoretical concept than a useful tool
- Customer requirements that outweighed all other requirements, thus also the environmental effects of a product

The clear opinion in one company was that it was difficult to consider environmental issues as just as important as other product requirements. This attitude will probably only change
if the external pressure increases (Vercalsteren & Jansen, 2001). But if a company can see business benefits deriving from a responsible environmental image, it will operate proactively. Environmentally responsible companies quantify environmental liabilities and develop plans for minimizing them and thereby move well beyond regulatory requirements (Rondinelli & Berry, 2000). Companies can use functional sales as a business strategy in order to lower the environmental impact from their products. In Öhlund licentiate thesis an empirical studies in six Swedish companies has been with the purpose to explore how the environmental issue has been taken in consideration (Öhlund, 2003).

Industrial organizations are facing a change in the required attitude to environmental aspects and impacts. Any company is part of a supply chain, communicating with its suppliers and clients, and subjected to a continuously developing legislation. The suppliers’ responsibilities to society (the client) consequently extend from a need for technical performance and reliability to care for the environment and attention to occupational health and safety. In practice, greening the business creates clear “win-win” situations with respect to material, non-material, and emotional aspects for the stakeholders (that is, the industrial company, the client/user, and society at large), as indicated and explained in Table 3.2.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Stakeholder</th>
<th>Rationale: tangible benefit description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Company</td>
<td>Cost reduction; higher margin/lower price</td>
</tr>
<tr>
<td></td>
<td>Customer</td>
<td>Lower cost of ownership</td>
</tr>
<tr>
<td></td>
<td>Society</td>
<td>Usage of less resources</td>
</tr>
<tr>
<td>Immaterial</td>
<td>Company</td>
<td>Simpler to produce, to sell</td>
</tr>
<tr>
<td></td>
<td>Customer</td>
<td>Easier and more fun; better product</td>
</tr>
<tr>
<td></td>
<td>Society</td>
<td>Better compliance to legislation and regulation</td>
</tr>
<tr>
<td>Emotional</td>
<td>Company</td>
<td>Employee motivation</td>
</tr>
<tr>
<td></td>
<td>Customer</td>
<td>Feel good with product, quality of life</td>
</tr>
<tr>
<td></td>
<td>Society</td>
<td>“We make actual progress in green” feeling</td>
</tr>
</tbody>
</table>

“Realization of big jumps in environmental gain (decrease of environmental load by factors) has much wider implications than can be addressed by just the industry or individual companies. The “stakeholder dialogue” about this issue needs to be intensified and brought to a higher level (Stevels, 1999). Although there are some contradictory views on environmental work within different companies, it is quite clear that the issue has been integrated to some extent in many companies, and there are proactive actions in order to minimize the impact from products and processes. But as Ohashi and Matsumoto point out, “Industrial enterprises are entities that offer product choices to consumers, and actually introduce products in society. As such, from an environmental perspective, industry has a tremendous responsibility. However, the ability of industry to realize the desired reforms is limited by the fact that companies must earn a profit and reward their stockholders” (Ohashi & Matsumoto, 2001).

Product-related environmental protection is a well-established goal within companies. Although much progress has been made in the last ten years, the final breakthrough towards sustainability has not been reached. Current legislation in Europe is causing intense investigations within industry with respect to take-back preparedness, the availability of
suitable methods for product rating, the marketing and product strategies. Beyond legislatorial incentive, companies do care for environmental excellence to achieve economic and business advantages (Ertel, 2001).

### 3.3 Design for Environment (DFE), EcoDesign

There are different names for the development of environmentally adapted products such as design for environment, EcoDesign, life cycle design, and industrial ecology. These concepts have no distinct definition but a number of different definitions have been suggested:

- Industrial ecology has been defined as the multidisciplinary study of industrial and economic systems and their linkages with fundamental natural systems. It is a system perspective that includes the entire scope of economic activity, including consumer and producer behavior, and consequent impacts on natural systems at all temporal and spatial scales (IEEE, 1994)
- EcoDesign is an approach to design where all the environmental impacts of a product are considered over the product's life” (Dewberry, Goggin, 1996)
- Design for Environment (EcoDesign) practices are meant to develop environmentally compatible products and processes while maintaining product, price, performance and quality standards (Graedel, Allenby, 1995)
- EcoDesign is the design of a product, service or system with the aim of minimizing the overall impact on the environment (Simon, Evans et al, 1998)
- In this thesis Brezet and van Hemel definition is used “EcoDesign considers environmental aspects at all stages of the product development process, striving for products that make the lowest possible environmental impact throughout the products life cycle” (Brezet, van Hemel, 1997)

Other definitions are presented by (Fiksel, 1993) and (Poyner & Simon, 1995).

The goal is to make environmental considerations part of every strategy, design, production, and product end-of-life activity.

The development of environmental work in industry started in the 1960s and led to the EcoDesign activities of the 1990s, the environmental improvement of the entire product life phase (see Table 3.3). The overall aim of EcoDesign is to minimize the environmental impact from products and processes by these measures:

- Minimizing energy consumption
- Minimizing use of material
- Excluding hazardous materials and substances
- Making products recyclable
Table 3.3. Characteristics of product-related and process-related environmental care (Stevels, 2001)

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Environmental process improvement</th>
<th>Cleaner production</th>
<th>Environmental product improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Since 1965</td>
<td>Since 1985</td>
<td>Since 1990</td>
</tr>
<tr>
<td>Character</td>
<td>Mostly end-of-pipe</td>
<td>Reduction of resources</td>
<td>Prevention</td>
</tr>
<tr>
<td>Professional category</td>
<td>Engineers</td>
<td>Engineers</td>
<td>Designers/developers</td>
</tr>
<tr>
<td>Location</td>
<td>Factory</td>
<td>Factory</td>
<td>Laboratory/development dept.</td>
</tr>
<tr>
<td>Geography</td>
<td>Local/national</td>
<td>National</td>
<td>International</td>
</tr>
<tr>
<td>Contribution to product quality</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Financial</td>
<td>Costs/money/Investments</td>
<td>Payback?</td>
<td>Mostly cost neutral or even bringing in money</td>
</tr>
<tr>
<td>Realization</td>
<td>Mostly enforced</td>
<td>Voluntary agreement</td>
<td>Often own initiative</td>
</tr>
</tbody>
</table>

Today EcoDesign is an accepted discipline in both industry and academia even though the focus is slightly different. Industry is more focused on the immediate problems (end-of-life, limited resources, and energy consumption). Academics, on the other hand, are more concerned with moving towards sustainability (Argument et al., 1998). There are also differences in focus, depending on the region and the driving forces in these regions. These differences are to some extent caused by different environmental impact in the society (see Table 3.4). EcoDesign is a new and strong force. As Stevels states, “Applied EcoDesign has developed strongly in the last ten years and is now solidly on the business map. It has changed from a subject with a limited scope and an inward green-looking approach to a wide field, inspiring engineering, business, consumers, and society as a whole” (Stevels, 2001).

![Environmental benefit, Sustainability index](image)

**Figure 3.3** Different environmental benefits or sustainability can be reached by certain EcoDesign approaches.
Table 3.4. Drivers for EcoDesign in three different regions (Pfahl, 2001)

<table>
<thead>
<tr>
<th>Region</th>
<th>Driver</th>
<th>Focus</th>
<th>R&amp;D</th>
<th>Key programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Regulation</td>
<td>Factory</td>
<td>Manufacturing-focused</td>
<td>CFC elimination</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VOC reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lead reduction</td>
</tr>
<tr>
<td>Europe</td>
<td>Customer &amp; Regulation</td>
<td>Product</td>
<td>Model-focused</td>
<td>Design for environment</td>
</tr>
<tr>
<td>Japan</td>
<td>Government /Industry</td>
<td>Market</td>
<td>Product-focused</td>
<td>Hybrid engines</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Halogen free plastics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lead-free products</td>
</tr>
</tbody>
</table>

Figure 3.3 illustrates the relationship between time and environmental gain at different levels of EcoDesign. The relationship suggests that higher EcoDesign level leads to a longer project development time and generates greater environmental benefits or sustainability. These levels are described in a slightly different way, depending on the approach, by Brezet (1997), Charter & Chick (1997), Stevels (1999), and Meinders & Meuffels (2001), as indicated in Tables 3.5 and 3.6.

Table 3.5. The four levels according to Charter & Chick (1997), and Brezet (1997)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Repair, with minor product changes.</td>
<td>Product improvement: minor changes of the products already on the market, which will lead to small environmental benefits and take little time.</td>
</tr>
<tr>
<td>2</td>
<td>Refine, improving current product.</td>
<td>Product redesign: components within the product are redesigned leading to a higher degree of environmental improvement; basic product concepts are still applied.</td>
</tr>
<tr>
<td>3</td>
<td>Re-Design, redesigning concepts but maintaining product functions.</td>
<td>Product innovation: a new product concept is applied, a new way of fulfilling a function.</td>
</tr>
<tr>
<td>4</td>
<td>Re-Think, designing a totally new product or product functions a new product strategy.</td>
<td>System innovation: the entire technological system is changed with new products, new infrastructure, and a completely new way of fulfilling a function.</td>
</tr>
</tbody>
</table>

Table 3.6. The three levels according to Meinders & Meuffels (2001), and Stevels (1999)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Redesign: a new product concept is developed as a logical follow-up to a predecessor, but in a more environmentally conscious way. A moderate, but important green success can be achieved in a relatively short-term period.</td>
<td>Environmental improvement of existing products.</td>
</tr>
<tr>
<td>2</td>
<td>Functional innovation: this requires a longer-term approach with a focus on the basic functional requirements of the customer. This approach may result in larger environmental advantages, but requires a longer lead-time.</td>
<td>Radical redesigns based on existing concepts.</td>
</tr>
<tr>
<td>3</td>
<td>System innovation: the most difficult innovation step; requires a total reconsideration of the product/service concept.</td>
<td>3a. Green function innovation, e.g. by applying a different physical principle.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3b. Green system innovation.</td>
</tr>
</tbody>
</table>

Ehrenfeld questions the notion of stages or steps with orderly progression from top to bottom in terms of sustainability performance and claims that this has yet to be firmly
established. He also points out that the different categories are constituted by three factors of change: the artifact, the institutional arrangement in which the artifacts are used, and the user’s practice, respectively (see Table 3.7). Institutional innovations involve, exclusively or primarily, institutional or infrastructure changes. Whether these changes lead to orderly, sustainable performance has yet to be established (Ehrenfeld, 2001). Even though redesign and functional innovations might not be enough to achieve a sustainable society, these steps are much easier and do not involve as many actors as system innovations. Brezet et al. state that, “for almost all existing products, redesigns are possible that lead to a significant de-materialization, de-carbonization and detoxification at the level of individual products” (Brezet et al., 2001).

Table 3.7 Characteristics that define innovative categories (Ehrenfeld, 2001)

<table>
<thead>
<tr>
<th>Category</th>
<th>Change in device concept</th>
<th>Change in infrastructure</th>
<th>Change in user learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process and “product” redesign</td>
<td>None to minor</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Functional innovation</td>
<td>Significant</td>
<td>None to minor</td>
<td>Minor</td>
</tr>
<tr>
<td>Institutional innovation</td>
<td>None to minor</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>System innovation</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

To use system innovations for EcoDesign projects is not a recommendable strategy for companies since it involves too many actors. Realization of large jumps in environmental gain (decrease of the environmental load by factors) has much wider implications than can be addressed by just the industry and individual companies. The “stakeholder dialogue” about this issue needs to be intensified and brought to a higher level (Stevels, 1999). As Brezet et al. put it, “If EcoDesign is to be used regularly by companies as a part of their business and product development process, it’s not only necessary to create new external values (higher profits, larger own market, etc.), but also to take into account the interests of suppliers and end-of-life actors as well as to demonstrate potential added value for the internal company stakeholders” (Brezet et al., 2001). Environmental adaptation can also be profitable, since there is a potential for cost reductions directly related to design for environment. For example, EcoDesign activities can lead to direct cost reductions by decrease of weight and volume of packaging (lower material and transport cost), use of recycled material (lower material cost), reduction of material use, electronic miniaturization (lower material and component cost), reduction of disassembly time (lower end-of-life cost, lower assembly cost) (Stevels, 1999).

The experience with EcoDesign of products at the individual level has been positive, with environmental impact reductions varying from 10% to 50% in terms of LCA-indicators when comparing the new product design with the old design (Brezet et al., 2001).

To target the EcoDesign activities for every situation is complicated. Which environmental aspects should be prioritized is strongly dependent on the functionality and the business situation. It is therefore impossible to give general rules as to how to tailor EcoDesign optimally to a specific situation. As an aid, a green product creation methodology is proposed by Stevels, as in Figure 3.4 (Stevels, 2001). The first priority in the product strategy of companies should be to improve the environmental profile of those products that have a good value/cost position on the market, but with relatively high eco-cost. For most
consumers, the first filter is the quality and the price of a product. Only after these filters have been passed, does the concern for the environmental impact play a distinctive role (Brezet et al., 2001).

![Figure 3.4 Green Product Creation (Stevels, 2001)](image)

### 3.4 Product development

Modification of existing product design, rather than creation of radically new design concepts, is the goal of a majority of design projects. These modifications seek to improve a product—to improve its performance, to reduce its weight, to lower its cost, to enhance its appearance, and so on. All such modifications can usually be classified into one of two types: they are either aimed at increasing the value of the product to the purchaser or reducing its cost to the producer (Cross, 1996).

**Table 3.8. Checklist of cost-reduction guidelines (Cross, 1996)**

<table>
<thead>
<tr>
<th>Eliminate</th>
<th>Can any function, and therefore its components, be eliminated altogether? Are any components redundant?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce</td>
<td>Can the number of components be reduced? Can several components be combined into one?</td>
</tr>
<tr>
<td>Simplify</td>
<td>Is there a simpler alternative? Is there an easier assembly sequence? Is there a simpler shape?</td>
</tr>
<tr>
<td>Modify</td>
<td>Is there satisfactory cheaper material? Can the method of manufacture be improved?</td>
</tr>
<tr>
<td>Standardize</td>
<td>Can parts be standard rather than special? Can dimensions be standardized or modularized? Can components be duplicated?</td>
</tr>
</tbody>
</table>

We use a number of different products in society today, ranging from simple products such as toothpicks to complex consumer products such as computers and cars, to huge infrastructure systems, such as those for heating and transportation. Competition is intense.
between the companies that provide the market with these products; therefore the design process has to be efficient. Today, many products have become so complex that a team of people from different fields is needed to develop an idea into hardware: “The design process, then, is the organization and management of people and the information they develop in the evolution of a product” (Ullman, 2003).

The economic success of manufacturers depends on their ability to identify the needs of customers and quickly create products that meet these needs. This is not solely a marketing problem, nor is it solely a design or manufacturing problem; it is a product development problem involving all these functions: “Product development is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product” (see Figure 3.5, Ulrich & Eppinger, 1995).

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept developing</td>
<td>System-level design</td>
<td>Detail design</td>
<td>Testing and Refinement</td>
<td>Production ramp-up</td>
</tr>
</tbody>
</table>

Figure 3.5. The product development process consists of five different phases (Ulrich, Eppinger, 1995).

Changes are required during the design process in order to find a good, feasible design solution. Early changes are easier and less expensive to handle than changes during the later phases (Ullman, 2003). To be able to compete with other enterprises that develop similar products, it is important, from both a quality and an economical perspective, to make the right decisions early in the design process. If the product is to be environmentally adapted, this issue has to be integrated in the early phases of the design process and taken into account throughout the entire process.

### 3.5 Designing

Designing is a combination of many different factors—for example, creativity, technical knowledge, mathematical knowledge, and team dynamics. According to Pahl and Beitz, (1996), there are three different elements in designing:

1. The psychological aspect: Designing is a creative activity that also calls for a sound base in mathematics, physics, chemistry, mechanics, thermodynamics, hydrodynamics, electrical engineering, production engineering, materials technology and design theory, together with practical knowledge and experience in specialist fields.
2. The systematic aspect: Optimization of given objectives within constraints is required. Because both objectives and constrains will change with time, the result of the optimization will also change with time.
3. The organizational aspect: A close collaboration between specialists from many different fields is required. Information from purchasers, production, manufacturing, and customers must be coordinated.
In a similar formulation Hubka and Eder (1985) state: “The goal of designing must always and only be to achieve an optimal solution in the given conditions. Again we emphasize that invention should not be a primary objective for designers. Higher on the scale of striving should be the combination of an optimal solution and invention.” An optimal solution within given conditions means that depending on how one rates different aspects such as economy, environment, function, ease of assembly, ease of recycling etc., the solutions will differ. These different aspects are often set by company policy and market demands. This means that if the environmental issue is regarded as important, it will automatically be included in the process.

![Design process diagram](image)

**Figure 3.6.** The many results of the design process (Ullman, 2003)

Nonetheless, the goal in design is to find a good solution with a minimum of time and expenditure of other resources, yet still produce a quality product. It is important to remember that, “most design problems have a multitude of satisfactory solutions and no clear best solution” (Ullman, 2003). This means that the designer has an opportunity to change both concepts and less important issues throughout the entire product development (see Figure 3.6).

![Design process block diagram](image)

**Figure 3.7.** “Black box” block diagram of the design process (Hubka & Eder, 1995)

The engineer plays an important role in designing products, where the main task is to apply his/her scientific knowledge to the solution of technical problems and then to optimize that solution within the given material, technological, and economic constraints. The designer’s
ideas, knowledge and abilities have a fundamental effect on the nature of manufactured products, their customer appeal, and their overall profitability (Pahl & Beitz, 1996).

The task of designing consists of thinking ahead and describing a structure, which appears as the (potential) carrier of the desired characteristics (properties, particularly functions). One can express this statement also in process terms; designing is defined as the transformation of information of needs, demands, requirements and constraints (including the demanded functions) into the description of a structure, which is capable of fulfilling these demands (see Figure 3.7, Hubka & Eder, 1995). The demands include not only the wishes of the customers, but also all stages and requirements of the life cycle and all intermediate states that the product must pass through.

There is a design process paradox: In the beginning of the design process, there is very little knowledge about the design solutions and therefore large freedom in design. Designing thus means to start with little information and then continuously build up knowledge and generate data for the specific product during the entire design process.

To be successful in designing, the engineer has to “learn as much about the evolving product as early as possible in the design process because during the early phases changes are the least expensive” (Ullman, 2003).

Designing could be described as a four-stage model with an iterative feedback loop from the evaluation stage to the generation stage (see Figure 3.8). The main objective is to reduce the cost of the product development. The guidelines proposed by Cross (as in Table 3.8) can also be used for EcoDesign.

In summary, the environmental issue should be integrated from the very beginning. There is no one true solution but a multitude of different solutions to every design task, and designers have to consider the environmental as well as the other issues throughout the entire process in order to make environmentally sound products.
3.5.1 Integration of EcoDesign into Product Development

The development of new products is closely connected to both sustainable development and the standard of living. The product developer is an important participant in solving the problems with waste and over-exploitation of resources, by improving future products from an environmental perspective. By designing for more efficient material use, with less consumption of material and energy and new technical solutions, etc., important contributions can be made to the development of a sustainable society. Some of the most important decisions with respect to environmental properties of a new product are taken during product development.

Ries et al. found in a survey of a group of 20 environmental managers that barriers to integrating the environmental issue were of three different categories:

1. Low external incentive for environmentally sound products; low or no environmental concern in a given industry sector; environmental issues have no strategic relevance; and legislation guides goal settings.
2. Barriers to product-oriented environmental management systems (EMS); narrow perception of significant environmental aspects, the need to justify invested time and money for environmental programs and evolutionary aspects of EMS.
3. Barriers to environmentally oriented product development; low knowledge of the environmental impacts of specific products; cross-functional characteristic of both design and environmental issues; cost-oriented instead of strategic orientation, and lack of methods for early planning stages.

A cross-functional integration has been stressed as being an important issue for successful integration. It calls for a stepwise integration (evolutionary approach) (Ries et al., 1999).

In order to integrate environmental issues in product development, Life Cycle Assessment (LCA) can be a useful tool. Thurston et al. point out that the most pressing design need is a methodology that fully integrates life cycle analysis in computer aids for product and manufacturing process design. Specifically, the needs are (1) fundamental data and (2) analytic modeling of technical, economic, and environmental impacts of design decisions (Thurston et al., 2001). Significant environmental improvement can often be achieved by integrating environmental properties as an optimization parameter in product development, together with more traditional values such as production costs, functionality, and aesthetics. Nielsen and Wenzel suggest that these improvements can be achieved by an integration of Life Cycle Assessment (LCA) into product development. The main benefits of this approach are the following:

1. Future modifications of the studied products can be tested quite easily from an environmental point of view before implementation.
2. Conclusions with respect to processes and materials can to a large extent be transferred from the studied product to other products in the same family.
3. New LCA models of other products in the same family can be based on the existing model and the existing database (Nielsen & Wenzel, 2002).
Simon et al. argue that successful EcoDesign requires activity at two levels: strategic, to set the issue within the whole organization, and operational, to put the good intentions into practice in product development. This view applies particularly to large corporations with an international network of operating companies. Simon et al. suggest a four-stage framework that applies to both levels and provides a good framework for organizational planning of EcoDesign. This means to “Analyze, Report, Prioritize, and Improve”—or the ARPI system (see Table 3.9).

Table 3.9. A four-stage framework for organizational planning of EcoDesign (Simon et al., 2000)

<table>
<thead>
<tr>
<th>Step</th>
<th>Strategic level</th>
<th>Operational level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyze</td>
<td>Assess the external and internal drivers for EcoDesign and benchmark the organization.</td>
<td>Assess the product in light of specific drivers (e.g. legislation), using LCA or similar tools.</td>
</tr>
<tr>
<td>Report</td>
<td>Communicate the corporate environmental status and policy to improve environmental culture.</td>
<td>Communicate the results to the design team and obtain feedback.</td>
</tr>
<tr>
<td>Prioritize</td>
<td>Develop an EcoDesign strategy (within corporate product development strategy) and set overall EcoDesign objectives.</td>
<td>Set targets for the product for inclusion in the specification; targets may be chosen levels for company metrics.</td>
</tr>
<tr>
<td>Improve</td>
<td>Plan action such as pilot projects and training; develop or customize metrics, tools, and methods.</td>
<td>Carry out normal product design incorporating appropriate tools used by trained and aware designers.</td>
</tr>
</tbody>
</table>

Designers clearly need information sources to generate new EcoDesign concepts and ideas, rather than using already existing conventional product designs. The results of projects described by Sherwin and Bhamra suggest that one should not start with existing products, as is the case with LCA, as this is immediately limiting. It is therefore a need to be proactive and move beyond product specific, life cycle thinking. They also suggest that EcoDesign and environmental issues should be used for product innovation rather than “corrective” activities. EcoDesign and environmental issues will need to be considered at a more strategic level within the design process (Sherwin, Bhamra, 1999).

McAloone and Evans (1999) decomposed the act of EcoDesign into three factors:

1. Timing the scheduling of EcoDesign decisions and actions
2. Projecting the desired environmental features of the product
3. Using the tools and techniques available to achieve the features

They found that the companies in their study tackled the design process in their own way, combining tools, targets, teaming, decision timing, etc. uniquely. However, a common
pattern for the implementation of EcoDesign was observed. This was developed into a model that describes the prime components as three stages of maturity and how these changed the use of tools, the features that were targeted, and what phase of design should be used to achieve the target. McAloone and Evans proposed this model as an EcoDesign advisory tool, which could be used by companies to map their own implementation (McAloone & Evans, 1999). In a similar approach, van Berkel et al. (1997) suggest the need for four functional tools:

1. Inventory tools: to enable identification, quantification and allocation of environmental interventions to (parts of) production processes, products or life cycles
2. Improvements tools
3. Prioritization tools
4. Management tools

For the integration of Design For Environment (DFE) into product development there is a need for a variety of tools and efforts from top management to every employee in the company.

3.6 Product types

In recent years, the environmental focus has shifted from clean production to the nature of the products themselves. The reason is that it is the products that cause the major environmental impact during their life cycle—raw material extraction, material processing, production, distribution, usage, and disposal (Wenzel, Hauschild, & Alting, 1997). The aim of product development is the product: “A product is something sold by an enterprise to its customer” (Ulrich & Eppinger, 1995). There are a variety of products of different complexity, size, materials, lifetime, and function to fulfill the demands of the market. These products could be classified in many ways such as these:

- **Consumer products** are frequently consumable items and materials such as packaged butter, motor oil, purified water, and newspapers.
- **Consumer durables** last longer and must have appropriate appearance and usability. These products must also perform useful tasks, such as functioning with suitable performance parameters, and being made available at a suitable cost. Examples of such products are domestic appliances, cars, and computers.
- **Bulk or continuous engineering products** are general raw materials for other types of manufacture, e.g. lubricating oils, fuels, plastic granulates, metal rolled sections or rod and bar stock, etc.
- **Industry products** are generally items or assemblies that are purchased by a manufacturing company for assembling into their own products. Some examples of such products are ball and roller bearings, circuit boards, electrical controllers, and jet engines.
- **Industrial equipment products** are self-contained devices (e.g. machines) which can perform a complex function and which are intended for use within industry.
- **Special-purpose equipment** including jigs, tooling, fixtures, and specialized manufacturing and assembly machinery, as well as ocean-going ships.
• *Industrial plants* usually consist of collections of industrial equipment and devices to provide control and/or connections among them (Hubka & Eder, 1995).

The products could also be classified as groups with similar demands on the product development process:

- *Generic market pull*: a market opportunity appears and an appropriate technical solution is to be found to meet the customers’ needs.
- *Technology-push products*: new technology is developed, and market applications for this technology will be sought.
- *Platform products*: the products are built around a pre-existing technological subsystem.
- *Process-intensive products*: the production process places strict constraints on the properties of the product, and product design cannot be separated from the entire production process design.
- *Customized products*: these are slight variations of standard configurations e.g. motors, batteries, and switches (Ulrich & Eppinger, 1995).

The optimal product is hard to describe, but there are certain criteria that can generally describe a good product. Three main requirements can be distinguished: function, economical production, and aesthetic appearance. A product should be designed to last as long as the expected lifetime, as to choose a higher quality of assemblies will only increase the production cost. The main functions of the product have to be examined to make sure that the customer demands on the product will be met. The aesthetics for some products are as important as their technical function; for instance, with regard to cars, the customers are not only interested in their technical characteristics but also in their styling. Another example is the demand that consumers place on refrigerators (Giertz & Andersson, 1984).

There are many different product categories and therefore different demands on the product design. The product development process has to be adapted to each product category. A product could be classified as active or passive, depending on how the product behaves during the use phase. Active products use significant amounts of energy and/or ancillary materials during the use phase, while passive products do not.

Generally, users have an influence on the energy consumption and the ancillary materials needed by an active product, such as a car, a power drill, or a tumbler, but there are exceptions where the user has no influence, as for example, a monitoring camera (Dannhem et al., 1998). To predict the environmental impact during the use phase of a product is hard, since users often can have an influence on this. When using a washing machine, you can choose washing detergent, washing temperature, and to what extent the machine is full when washing. A product could be classified as active, but many parts of the product could be passive. However, even these can affect the environmental burden of the product. A car consists of many different parts, and its total weight correlates to the amount of fuel needed for transportation. Therefore, a passive part, such as a door, has an effect on the active product, the car, and an overall goal in the design of all parts of the car should be to minimize the weight. The product user phases can be modeled, based on statistics from representative users, for example, the determination of standard driving cycles for cars.
When it comes to manufacture, service and disassembly, the product structure is of great importance. The product structure is an arrangement of components, and each component requires form and dimensions, tolerance, material, surface quality, and a manufacturing method (Hubka & Eder, 1988). Product structure is sometimes referred to as product architecture, which is the arrangement of functional elements of a product into physical blocks. The physical elements of a product are parts, components, and subassemblies, which ultimately implement the product’s functions (Ullrich & Eppinger, 1995).

The product structure could also be considered as a disassembly tree, where each part/component is connected to the others by a specific bond. Each bond could then be described as a potential disassembly event. In this tree, it is possible to see which bonds have to be disconnected in order to disassemble each component. The different subassemblies and components could then be graded according to ease of disassembly.

3.7 Summary

Much has been written about specific EcoDesign projects and EcoDesign from the strategic point of view. The focus in this thesis is on designers since they are the ones who have to realize all product ideas, and very few of them are specialized on the environment.

It is quite evident that we do face serious environmental problems today with the greenhouse effect, ozone depletion, decreased ecological diversity and the like. To solve these problems a number of different actions will have to be taken. In the long term, it is probable that western life style may have to change because of the need to decrease the current use of resources. Various groups will have roles to play in building a sustainable society. Up to now, governments have mainly passed environmental laws banning hazardous substances or restricting the release of different substances, but lately more progressive laws have been passed in a number of countries. One example is the “producer responsibility” law, holding companies generally responsible for their products. It is clearly important that these laws are international, for otherwise the companies cannot compete on equal terms. Governments can also use taxes such as energy taxes as a driving force.

The goal for companies should be to make products as environmentally sound as possible, but it is individual citizens who are responsible for making sound choices when buying and using products. If you are a maker of heavy vehicles, for instance, this means minimizing the environmental impact of ton/km, rather than making customers chose a more environmental friendly transportation system. The choice of buying one product and not another is up to the customer, whereas companies try to sell as many products as possible. What companies can do, however, is to minimize the environmental burden of their specific products. All products have to be designed, whether they are environmentally sound or not. Customer demands have to be met, which means that the designers have to fulfill the product specification. But how to do this is up to the designers and leaves room for a number of different options. It is desirable now, as it certainly will be in the future, to minimize the environmental burden of the products. The designer therefore has to keep this issue in mind throughout the whole product development process.
4 Summary of appended papers

The appended papers that form the major part of this thesis consist of 5 papers. Papers I and II consist of a general discussion of design for environment from a designer’s perspective. Paper II deals with how designers are affected by the implementation of ISO 14001, and Paper III deals with how designers could profit from environmental education. Paper IV discusses the producer responsibility regulations, and Paper V analyzes the use and need of design methods.

4.1 Paper I - Design for Environment, the perspective of designers in a number of Swedish companies

(By Anne-Marie Åkermark. Presented at the 7th CIRP International Seminar on Life Cycle Engineering, Tokyo, Japan, November 27-29, 2000)

4.1.1 Purpose

The research presented in this paper aims at a better understanding of design for environment from the designer’s perspective and illuminates the designer’s situation regarding his/her potential to improve the product from an environmental point of view.

4.1.2 Research approach

A series of interview were conducted with a total of 17 designers in two large and seven small Swedish companies. All companies in this study have product development projects that advance from idea to product. Employees at the companies were interviewed according to a predetermined interview guide. This guide was slightly different for the large and the small companies.

4.1.3 Results

In the large companies, there are environmental departments with the overall environmental responsibility. In these departments, the environmental policy is stated and issues regarding the environment are coordinated. The environmental management system, ISO 14000, is implemented within the companies. There are also special research departments where different environmental aspects are handled, such as materials, new systems, and alternative energy sources. In these departments, the next generation of new products is developed. The development of products is made in a group with close contacts between production, design and purchase. The designers work within this group and therefore have access to all this expertise, and all design decisions are made by mutual agreement. A new design could be made to suit certain production methods as well as market demands.

In the smaller companies there were no environmental experts or departments to support the designers. These companies did not have an environmental policy, nor even an environmental policy to show customers if they requested one. There was no environmental
information or education within the companies. Since the companies were small, most projects involved only one designer who had external contact with the manufacturing industry and material suppliers. In this contact only functional and economical issues were discussed. The implementation of environmental management systems was to some extent discussed in all companies, but the initial cost was considered too high. However, in one case the implementation started in 2000. The driving force for this was the request or demand from the customers. There was no demand from management in the small companies for integrating the environmental issue.

In the two large companies the only method used for achieving environmentally benign design was Life Cycle Assessment (LCA). The designers did not use the LCA method themselves, but the results of the method were used to improve the products and to evaluate major design changes. LCA was considered a useful tool to get an overall insight in the environmental demands of the products, and this was useful for the designers. According to the designers in the large companies, the environmental issue was regarded as important by the management. Nevertheless, to fulfill the market demands, economy and function were generally given higher priority.

4.1.4 Conclusions

The study showed that there were major differences between large and small companies regarding implementation of the environmental issue. The designers do play an important role in developing environmentally friendly products. In the large companies, they make small decisions themselves and many decisions at product developing meetings. In the small companies, they often make the decisions by themselves in close cooperation with the customers and thereby have an even more important role.

4.2 Paper II - ISO 14001 from a Designer Perspective


4.2.1 Purpose

Today, the total environmental impact of the developed products is considered from a “cradle to grave” perspective. To meet this situation, support tools and systems are necessary. The most common support methods are Life Cycle Assessment (LCA) and Environmental Management Systems (EMS). In this study an attempt is made to evaluate how this new situation affects the designers.

4.2.2 Research approach

In order to see to what extent ISO 14001 supports the designers when implementing the environmental issue in the product development process, a series of interviews with
designers in large companies was conducted. This interview series shed light on the designers’ situation and their attitudes regarding their ability to design for environment.

4.2.3 Results

There were environmental goals within the companies that had not been quantified, such as reduction of energy consumption, amount of materials used, and design for ease of separation. An example of a specific environmental goal that directly affected the designer is the phasing out of certain materials.

All projects in the companies were carried out in integrated product development teams. This cooperation between different departments was not considered problematic but rather regarded as a support, since it was not possible to be an expert in all fields. In all companies there was a close collaboration between production engineers and designers. During product development, an efficient cooperation between production, market, and design was established, and the new products were developed with all these functions integrated.

In one of the departments in a company, the person responsible for the environmental issues had a close contact with the designers. He was located in the same building, and information from the environmental work was reported to the designers regularly. Information regarding environmental issues was also communicated through bulletins and on boards. Generally, the designers experienced a great support from this way of organizing the environmental work within the company. This organization made it possible for the designers to frequently use the knowledge and the support of the environmental expert in their work.

It is much more complicated to establish rules for designing than to “produce” documentation for the procedures of production. There are no demands on documenting how the product is developed, but there is documentation of the product as such, for instance by specification, and documentation from design meetings. This might be a bit more time consuming than previous documentation but ensures that the knowledge is preserved for the total material content and structural design of the product is preserved.

4.2.4 Conclusions

Certification according to ISO14001 requires that specific environmental goals are set. There are no product-specific goals but certain materials are not to be used. To change these materials without affecting the quality of the product is a great challenge. This is especially true for an old product where all solutions have been verified, tested, optimized, and continuously improved over many years from quality, function, and production aspects.

Today’s complex products are built up from many different parts, which are often developed by sub-suppliers. It is therefore, essential that also the suppliers develop and optimize their products from an environmental point of view.
4.3 Paper III - New requirements for environmental education for designers and environmental engineers.

(By Anne-Marie Åkermark and Johan Tingström. Presented at the International Conference on Engineering Design, ICED03, Stockholm, August 19-21, 2003). The paper was written by Åkermark and Tingström; case study (1) was conducted by Tingström and case study (2) by Åkermark.

4.3.1 Purpose

In this paper, education for designers is discussed from two different aspects, each based on a case study:

1. A survey of former students from the environmental engineering program at the University of Kalmar was carried out to obtain their view of their education. An attempt was also made to evaluate the usefulness to engineers of advanced environmental education, as for instance provided by the University of Kalmar.
2. Interviews were held with designers/mechanical engineers working in Swedish companies regarding their environmental education. The aim of the study was to see what kind of environmental education companies provide for their employees and to what extent former students of environmental engineering have use for their education.

4.3.2 Research approach

Two surveys were conducted. One consisted of a questionnaire that was sent to former students of the environmental engineering education program, at the University of Kalmar. The other was an interview study with designers working in five large Swedish companies.

4.3.3 Results

The former students from Kalmar judged that their education was sufficient for their working positions except for education regarding quality management systems.

The industrial interviewees had received environmental education within their companies consisting of an overview of the ecological restraints, life cycle perspectives, guidelines, and EcoDesign. This education had often been given when ISO 14001 was implemented and would be provided over for one or two days. According to the interviewees, the education did not provide direct support for product development (PD), but it highlighted the environmental issues.
The time pressure during PD is great. This means that very little time can be spent on education and since the environment is not a main issue for designers, they will not by themselves choose to participate in such education. The main problem for the interviewees was to find time to participate in the courses they wanted. Due to this time pressure, no education should last more than one or two days at a time.

In the organization of design, with collaboration from many different fields, all aspects should be considered and a best solution has to be found. Depending on which issues are in focus, different solutions will be found. From this perspective, all designers do need an environmental education. It is also important for designers to be familiar with environmental vocabulary in order to be able to communicate with environmental specialists. EcoDesign means optimizing according to environmental aspects, not only to fulfill the requirements in the product specification. Many different solutions exist to every design problem. Whether a solution will be environmentally sound depends largely on the degree of priority given to the issue.

4.3.4 Conclusions

There is a need for different levels of environmental education: a more general education for all engineers, and a deeper education for environmental engineering experts.

In the Swedish industries that were investigated, the designers were given environmental education. The designers pointed out the advantages of education and also of access to environmental resource persons (environmental experts).

The former students from University of Kalmar were satisfied with their education and work with contemporary environmental issues in industry. The environmental engineering education provided the expertise that had been requested by the designers.

The added value of continuing environmental education should not be underestimated. The two main advantages are that the issue is put in focus and that it is considered important at the management level.

4.4 Paper IV - Vehicle recycling from a designer perspective

(By Anne-Marie Åkermark. Presented at CIRP seminar on life cycle engineering, Copenhagen, Denmark, May, 2003)

4.4.1 Purpose

In Sweden, the producer responsibility law regarding vehicles states that at least 85% of the total weight of vehicles has to be recycled from the year 2002, and 95% from the year 2015. In order to achieve this and increase the recycling rates, both recycling systems and product design have to be modified. In a longer perspective, it can be anticipated that the producer responsibility legislation will lead to a product design that is more adapted to environmental requirements.
This paper sheds light on the designers’ situation, and presents their views on their own ability to design for the recycling of vehicles. To make this type of design possible, it will be necessary to improve both the design from a recycling perspective and the recycling systems. Specifically, the manufacture of products that are more energy efficient, are easy to recycle, and do not contain hazardous substances, must be encouraged.

4.4.2 Research

Today there is no market for recycled plastics from vehicles. The original material has a higher quality, and even if there is no demand on quality or appearance, the recycled material is still relatively expensive compared to original material. It is hard to find even 50 kg of plastics from a 1000 kg vehicle that is suitable for the recycling that is necessary for achieving 95% efficiency.

Recycling aspects have to be considered in the choice of materials by designers, and the material content has to be known. At the company used for interviews in this study, most product changes are made by modifying the existing design, and the new components are often similar to earlier ones. Usually designers work with optimization of existing products and not with entirely new concepts. They try to optimize the design for production and to make it easier for suppliers, in this way keeping the cost down. No specific environmental methods were used in the product development process, but general directions were included in the plan.

According to the company designers, sub-suppliers seldom addressed environmental information unless it was required by legislation. All interviewees had extensive contact with sub-suppliers. The suppliers had to guarantee the content of their components and declare all chemicals, materials, and packaging. The environmental demands were tough but reachable. There was a compromise between the different subsystems in order to fulfill the environmental (and other) requirements.

4.4.4 Conclusions

Few plastic parts are suitable for recycling since most of them have a number of different functions such as appearance, structure, and to hold the integrated components.

Today there is no incentive to use recycled plastics in vehicles because the original plastic materials are less expensive and of higher quality. One plastic part suitable for recycling is the vehicle bumper. However, major design changes would be necessary for most plastic parts in vehicles to be recycled at a reasonable cost.

4.5 Paper V – Inclusion environmental aspects in the product developing process: existing and desired methods.

(By Anne-Marie Åkermark, Mattias Lindahl, manuscript). The paper was written by Åkermark, the survey was made by Åkermark and Lindahl).
4.5.1 Purpose

The overall aim with this study is to investigate how the actual users of the methods experience these and what requirements they have on a method. The focus is on the method that are used and on requirements and needs for environmental methods in order to support the designer in the product development process.

4.5.2 Research approach

This survey was made at a large Swedish company and the empirical data was collected with qualitative research interviews have been used. Eleven designers working with product development were interviewed regarding their experience of methods.

4.5.3 Results

The interviewed designers used few methods. However, the method Failure Mode Effect Analysis (FMEA) was used by all of them. This method was used strictly because it was required in the product developing process in certain stages.

Within the company a product development process (PDP) has been developed and everyone worked according to this. It can be described as a large checklist where what you have to do in the different PD phases is specified.

The company that participated in the survey, similarly to many other companies, has a materials standard “black and gray” list with banned and restricted substances. There were no specific environmental goals in the projects. According to the designers, they work with weight reduction, not from an environmental aspect but rather because the customers require it.

4.5.4 Conclusions

There are a number of advantages with using a method according to the designers:

- Provides a structure way, you know what to do.
- When you use a method you have to do it.
- There is always a risk that an issue will be forgotten and this is to some extent eliminated by the use of a method.
- Using a method means that every one speaks the same language.
5 Results and discussion

The main goal for companies is to produce products that are required by their customers. These products are used in society and through their usage affect the ecological system. It requires resources not only to produce and use the products, but also, when they reach end-of-life, to “return” them to the ecological system. This exploitation of the ecological system has led to a number of different environmental problems. Today the problems are recognized, and there is a desire to solve them and to achieve a sustainable society. In order to achieve solutions, it will be necessary to reduce the use of resources and/or the number of products used. The main goal of EcoDesign is to produce products that are improved from an environmental aspect, and there is a proposal that this goal could be attained by environmental innovations.

Designers comprise one group of actors in EcoDesign but their main task is to design and improve products. If products are to be improved from an environmental aspect, it is necessary to give designers the opportunity to do so.

ISO 14001 is considered to be an important driver towards a sustainable society and has been chosen as one of the sustainable development indicators in Sweden, in terms of the number of ISO 14001 certificates and Eco Management and Audit Scheme (EMAS) registrations issued (Statistics Sweden, 2001). One of the targeted research areas, therefore, is how designers and the product development process actually are affected by the environmental management system.

In order to develop our society into a sustainable society, all interested parties have to unite and work together politicians, NGOs, consumers, and industry. As a first step, it is important to make all the fairly easy product improvements; from an environmental aspect...
perspective, there are a number of successful examples. Then it is up to designers and product developers to go further, and when new and creative solutions are required, it will be up to engineers to invent them.

5.1 The product: the result of the product development process

The main task of designers is to develop new products and to improve old products. All these improvements have to start with the customer’s demands on the product, which differ widely depending on the type of product. For a mass-produced product, the overall aim is to decrease the production cost since the development cost is almost negligible. Most products today are improvements of an old and similar product. Products can be classified according to use (Hubka & Eder, 1995). This will lead to different demands depending on the product category, such as consumer durables where there are demands on appearance, and industrial equipment where functionality is the prime concern. The product can also be classified according to the demands of the product development process (Ulrich & Eppinger, 1995). To improve a product from environmental (or any other) aspects (or any other aspect), the strategy has to be in line with the product classification. Giertz and Andersson describe three main product requirements: function, economical production, and aesthetic appearance (Giertz & Andersson, 1984). These are of top priority for designers. If the products do not have the requested functionality and the right price, no one will buy them. Companies have to develop products that are in demand from customers, with an overall aim to sell as much as possible. There is a constant stream of new products reaching the market, and there seems to be a never-ending market demand for newer, faster, better, and more modern products, from companies quite willing to meet these demands. If we want to reduce the number of products and materials, it is necessary to change customer demand and require companies to develop other types of products. However, as long as there is a demand, companies will meet it and drive it further. Designers can environmentally adapt the products, for instance, by reducing energy consumption, by choosing components with low energy requirements, by avoiding certain materials, or by designing for recycling. However, in order to reach a sustainable society and sustainable material flows in (for example) the OECD countries, material consumption has to be reduced by a factor of ten (von Weizsäcker et al., 1997). In order to reach this goal, it is not enough just to improve the products from an environmental perspective, but to bring about major changes in design and customer behavior.

In order to optimize a product design from an environmental point of view, it is necessary to know how the product effects the environment. The product can then be optimized for environmentally improved production, use, and disposal. The actual strategy chosen will depend on whether the product is “active” or “passive.” An active product has the greatest impact on the environment during use. The best way to improve an active product is therefore to increase its energy efficiency.

The designers we interviewed in the large companies were aware of how their products affected the environment in different ways, according to whether the products were active or passive. In contrast, designers in the small companies had generally not considered the environmental issue from a product perspective, and there was little awareness of the impact of the products in their different life phases. Environmental design generally implied
avoiding hazardous substances rather than minimizing the environmental impact of the product (Paper I).

How the product will be used has a great influence on the environmental impact of the product. It is also essential to inform users of how the product should be used to minimize the environmental impact. This information is necessary in order to minimize the products’ environmental impact during the use phase (Paper I).

The material content of the products has to be known in order to make sure that no unsuitable materials are spread to nature. Today most (known) hazardous materials in the products have been replaced with other materials (Papers I, II, IV, V). The products are accurately documented, and the content is known and can be used for environmental evaluation and control of product content.

The final product design depends on all design decisions made by the product developing team. The designers do have the opportunity to influence these decisions and thereby influence the product from an environmental point of view. In small companies the designers make the product design decisions themselves, while in large companies the main decisions are usually made by the development team. Designers do have a great influence on all product decisions especially in the small companies (Paper I).

5.2 Product innovations: a solution to a sustainable society?

According to Cooper (2000), there are two fundamental ways to make a product innovation. The first is doing projects right; the second is doing the right projects. In order to solve the environmental problems caused by industry, it has been claimed that the way to reduce the environmental impact by orders of magnitude is innovation (Charter & Chick, 1997; Brezet, 1997; Meinders and Mueffels, 2001; Stevels, 1999). Sherwin and Bhamra suggest that EcoDesign and environmental issues should be used for product innovation rather than the “corrective” activity it is predominantly used for. Ecodesign and environmental issues will need to be considered at a more strategic level within the design process (Sherwin & Bhamra, 1999). This approach will most probably lead to many radically improved products and is therefore a sound EcoDesign strategy. However, most product development projects do not involve real innovation.

New products can be divided into four categories:

1. Basic innovations, fundamentally new products with unknown design solutions
2. New design, products with new or other design solutions
3. Adapted design, products with a slight change of previous solutions
4. Variation design, products with the same solution but in a new way

For newly developed products, 20% are from category 2, about 50% from category 3, and about 30% from category 4. Products of category 1 are very rare, simply because innovations are hard to achieve (DIN 34). If you make an innovation, the potential for improvement is radically higher than for the other product categories. As a striking example, consider the goal of replacing fossil fuel by solar energy or nuclear fusion as our
main energy source. Such innovations are long-term goals, which would require enormous investments and research efforts. Even medium-term goals, such as the use of fuel cells or batteries that can be charged by solar energy require efforts far beyond the capacity of single companies or designers. Now and then, of course, designers do make new innovations and then the company must be prepared.

Stevens and Burley show that of the product ideas, 90% never go further than to the creator’s drawing board. The remaining 10% advance to the small project stage and 3% will become real projects. Fewer than 2% become major development efforts, under 1% are launched commercially, and only 0.3% achieve commercial success. Thus, from 3,000 innovation ideas only one commercially successful new product is developed (Stevens & Burley, 1997). This means that if the solution of environmental problems and the goal of reaching a sustainable society are to be achieved by innovations, one can estimate that for every successful, environmentally adapted product, 3,000 new projects have to be initiated.

To expect companies to pay for this scale of development is unrealistic, so the main task for companies, especially at the designer’s level, must be to optimize the products from an environmental aspect and scan the surroundings for more environmentally adapted materials, energy forms, and production processes. It is to be hoped that companies will let their research and development departments work actively with the environmental issue and not only with other product improvements. However, to solve environmental problems by innovations is a very optimistic proposal. It implies that companies should concentrate on developing their existing products, which could also lead to new inventions. McDermott and O’Connor found that in the creation of radically new products, companies consistently built on existing internal knowledge of markets and technologies. Building on internal competence, together with the creation of alliances, are methods companies use to reduce the overall risk associated with engaging in radical innovation (McDermott & O’Connor, 2002).

In summary, product innovation could be used as a strategy to develop environmentally friendly products, but the outcome of such a strategy is very uncertain and, as discussed here, very few innovations actually lead to commercial products. Therefore the main effort should be directed to “ordinary” product development projects and attempts to optimize these projects according to environmental demands. Designers do get new product ideas and it is important to make sure that these ideas are capitalized.

5.3 The designer and company responsibility

A number of different driving forces for EcoDesign in companies have been described by van Berkel et al., (1997) and Handfield et al., (2001). It is obviously favorable for companies to comply with current legislation, and there are different control functions within the companies to make sure that this is done. Personal commitment is not very often mentioned as a driving force, but in the case studies this was regarded as very important as an internal driving force.
A main issue for all product developers is to lower cost. There is a constant awareness of the price of every detail of the product. Since competition between companies today is intense, the environmentally improved product must be no more expensive to develop and produce. In every decision, consideration of the environmental issue must also take into account functionality and overall cost (Papers I, II). Until green products are demanded by customers, it is necessary for designers to give priority to cost reduction over environmental improvement. Today, customers do not require environmentally adapted products. The way to increase market share is to lower the price rather than to improve the environmental performance of the products. This means that there is little room for an improved environmental design unless other benefits can be gained. However, in many cases an environmental advantage can in fact be linked to economic benefits, such as lower energy consumption and material savings during production (Paper II).

Designers are a key factor when it comes to EcoDesign since all new products and product ideas usually have to be realized by the designer. To improve human lifestyle and not drain the resources of the environment, it is necessary to come up with new technical innovations. According to von Weizsäcker et al. (1997), material use has to be reduced by a factor of ten to achieve a sustainable society. This strategy would require the marketing of totally new product categories. The goal of reduction by a factor of ten could in principle also be reached by a change in consumer behavior. In such a case the consumer push would force companies to produce more environmentally friendly products or use the product in a more environmentally benign way. Consumers today state that they want more environmentally friendly products but when it comes to consuming they are less insistent. For example, when it comes to buying vehicles, the ones consumers buy are definitely not the most environmentally friendly products that are sold in Sweden today. The vehicles in demand are becoming heavier and heavier, which certainly is not good for the environment. For home appliances, the environmentally friendly alternatives are usually a bit more expensive, and consumers tend to choose the less expensive alternatives. There are clearly two actors in the market for environmentally friendly products—consumers and producers. Producers will produce what consumers require. Still, producers have a responsibility since the consumers can in fact only choose among products that are actually produced. It is therefore important that the environmental issue is considered at the design phase: “The amount of waste generated is a direct consequence of decisions made by designers” (Handfield et al., 2001).

5.4 The designer and EcoDesign

Initially, when implementing environmental measures, great improvements can be made quite easily. Eventually it becomes harder and harder to make significant improvements since it is a question of optimization (Paper II). There are many examples of environmental product improvements, for example, the Motorola mobile phone (Pfhal, 2001) and the Siemens Deka VII fuel injector (Ertel, 2001). Brezet et al. state that, “for almost all existing products, redesign is possible, that leads to significant de-materialization, de-carbonization and detoxification on the level of individual products” (Brezet, Diehl, & Silvester, 2001). When the environmental aspects are not considered earlier in the product development process, it is quite easy initially to make environmental improvements of products. However, it is much more complicated to make continuous improvements.
In order to design for environment, it is necessary to be aware of the products’ impact in all life phases (raw material, manufacturing, use, and disposal). There are many different product categories and each category requires a different approach in order to minimize the total environmental impact. To be able to give priority to environmentally sound materials, parts, components, and subassemblies, designers need information on the environmental impact. In large companies, this expert knowledge can be provided internally, but in small companies external sources have to be used (Paper I).

From the designer’s point of view, it is important to know how the product will affect the environment and what could be done to improve it. In the two large companies the designers had considered these questions during the design phase and were aware of the environmental impact of the products. When designing, many different aspects have to be regarded: function, economy, production, safety, and so on. When the environmental issue is integrated, product development becomes even more complex. According to Johansson (1999), integration of the environmental issue leads to an increased number of design options and an increased uncertainty regarding the optimal design decisions (Paper I).

As Pahl and Beitz point out (1996), designing consists of three different elements, the psychological, the systematic, and the organizational aspects. From the psychological point of view, designers need basic knowledge in many different areas. One such area is the environmental issue. Such environmental knowledge includes general natural science such as cause-effect chains, environmental problems, information regarding Eco-design, and guidelines. This general knowledge will not solve design problems, nor will it support the product development process. However, this knowledge will be a sound base and help in finding an environmentally acceptable solution in the processes (Paper III). The systematic aspect optimizes the given objectives within constrains from an environmental aspect. The demands and constraints change over time, as will the need for education to be able to deal with these changes (Paper III).

From the organizational aspect, with collaboration from many different fields, all aspects have to be considered and a best solution has to be found. Depending on which issues are in focus, different solutions will be found. From this perspective all designers need an environmental education. To communicate with environmental specialists it is also important for designers to be familiar with environmental vocabulary. EcoDesign means optimizing according to environmental aspects, not only fulfilling the requirements in the product specification. Many different solutions exist to every design problem (Ullman 2003). Whether any solution will be environmentally sound will depend on the degree of priority given to all the issues (Paper III).

In summary, if a company is to be able to compete, its product development process has to be optimized with regards to cost. In many cases an environmental advantage is linked to economical benefits, such as less energy consumption and material savings during production (Paper II). There is a constant awareness of the price of every detail of the product. According to designers, customers are not willing to pay extra for the environmentally adapted products. Until green products are demanded by customers, it is
necessary for designers to give priority to cost reduction over environmental improvement (Paper II).

5.5 Early stages of product design

To be successful in designing, the engineer has to “learn as much about the evolving product as early as possible in the design process because during the early phases changes are the least expensive” (Ullman, 2003). It is thus important to include environmental aspects early in the product development process, though in reality many parameters are already set even in the early phases of product development. The goal with most projects is not to satisfy a customer desire for a certain product, but rather to improve an existing product. The designers described in Papers I, II, IV, and V did work in the earlier phases of their projects, and it was clear that the earlier in the project, the fewer decisions had been made. However, it was not a “blank” start in the projects, rather an improved product specification in order to increase market share. This situation leaves little room for major environmental improvements of the products. Depending on the whether the product could be classified as: (1) basic innovation, (2) new design, (3) adapted design, and (4) variation design the importance of integrating EcoDesign early in the process differs. If the projects deals with radical product redesign EcoDesign should be integrated at the early design stages according to Sherwin and Evans (2000). However, if the products are classified in categories (3) or (4) it is best to integrate EcoDesign at the late stages.

According to Bhamra et al., there is an understanding among a number of companies of the importance of considering environmental aspects as early as possible in the design process. There is a realization that, beyond a certain point in the design process, it is extremely difficult to alter some product features that may be crucial to environmental performance. Unfortunately, the earlier stages of design suffer from lack of tools and methods for efficient environmental design. It has been recognized by some companies that EcoDesign makes good business sense and that by considering it early in the design process you can prevent costly problems arising later (Bhamra et al., 1999). Ries et al. also point out the lack of environmentally oriented methods for the earlier phases. Therefore, methods are required that aid in the definition of environmental design strategies and the setting of environmental goals at an early stage (Ries, Winkler & Züst, 1999).

5.6 Material selection

Material selection is an important step in product development. To find the best material for a required function could be rather time-consuming. It is not possible for designers to be up-to-date on all different materials, so they have to rely on suppliers and purchasing departments. Since there is a demand for timesaving in product development, companies usually have an internal materials list. Designers select materials from these lists, which are more or less updated but not complete. As a result mainly of lack of information, the optimal material is often not selected (Wansel et al., 1998).

The designers interviewed in this study used material lists, or support from material experts within the companies or their suppliers. In some cases, a material specification was transferred to the material supplier who was expected to recommend the material (Paper I).
One problem for designers was to select environmentally friendly materials. This was difficult due to lack of knowledge and information regarding the environmental impact of different materials. More environmental information was desired in order to choose among different materials (Paper I). The selection of material might be governed by the introduction of a new production method. In such cases, the material was already specified, and the designers had to fulfill the product specification (Papers I, II). In the small companies, designers had to rely on knowledge about material selection from their supplier companies since there were no experts within the companies. It could sometimes be difficult for the designers to get enough information on the different materials (Paper I).

In all the large companies that participated in the interviews, a standard of materials with “black and gray” indices was used. “Black substances” were hazardous and could not be used, while “gray substances” should be avoided. This meant phasing out a number of hazardous and potentially hazardous materials (Papers I, II, III, IV). In order to replace these (unwanted) materials, it was often necessary to choose a material of lower quality. The consequences of replacing some materials were often entirely new concepts and new production methods. To change the materials without affecting the quality of the product was a great challenge. This was especially true for an old product where all solutions had been verified, tested, optimized, and continuously improved over many years from quality, function, and production aspects (Paper I, II).

Examples of specific environmental goals that directly affect the designer are making environmental product declarations, phasing-out of certain materials, and new connecting methods to avoid hazardous substances. All these environmental goals have led to product changes. An example is the replacement of lead in a counterweight by a material with lower density in an industrial robot (Paper II). A lower density of the counter weight leads to either an increase of the lever or an increase of the volume of the counter weight. Because of the necessary compactness of the robots, this problem turned out to be quite difficult but could be solved by changed design.

5.7 Design for Recycling

There is a constant need for materials in modern society. To meet this need the materials have to be produced and they are currently obtained from three different sources:

1. Non-renewable raw materials (e.g. iron ore, oil)
2. Renewable raw materials (e.g. wood)
3. Recycled materials

In order to achieve a sustainable society, the use of materials from category (1) should be avoided and the use of materials from category (2) should not exceed what can be produced in a sustainable way. If recycled materials are to be used, there have to be systems for their collection and processes for transforming them into new raw materials of acceptable quality. Recovery or reuse of products is not very common today, and very few companies have this as a business strategy. There are some examples of products that can be reused, such as Xerox machines and “instant cameras” If products or components are to be reused,
they have to be collected, disassembled, reprocessed, and tested before it is possible to reuse them in new products or as new products. Other problems are logistical in nature. It is not possible to predict exactly when the products will reach their end-of-life, and consequently it is not possible to make sure that you have a sufficient number of components to be used in the new product line: “Many different aspects will influence the recovery aspects, such as supply, demand, environment, legislation, logistics, quality/reliability, technology, design, information, organization, economics” (de Ron & Melissen, 1999). Schwarz and Steininger (1997) suggest inter-company industrial recycling networks in order to make it possible to use a large part of the waste from one process as input in another. For participating companies this will lead to a reduction in waste disposal, raw material costs, and disposal risks.

All products will eventually come to the end-of-life and be either recycled or deposited. The last owner has different options when scrapping the product, depending on the size and product category. Take-back systems for the different product categories have to be developed and financed. For some product categories, there are already organized recycling systems since there is a value in the end-of-life of the product. For example, most used busses from the Swedish market are sold to other countries (Habashian & Åkermark, 2001).

There are three different options for material recovery from end-of-life products: disassembly, shredding, or smelting. Environmental advantages and disadvantages with these technologies are described by Furuhjelm (2000), as shown in Table 5.1. Books et al. argue that even though disassembly is the best alternative since environmentally relevant fractions can be isolated and appropriately treated, it is too costly at present and no new cost effective disassembly processes can be expected in the near future. They also showed that shredding was the most cost effective process for all brown goods (Books et al., 1999).

Table 5.1. Environmental advantages and disadvantages achieved by end-of-life treatment with different technologies (Furuhjelm, 2000)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Environmental advantage</th>
<th>Environmental disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disassembly</td>
<td>Allows reuse of parts.</td>
<td>Possible problems with occupational health.</td>
</tr>
<tr>
<td></td>
<td>Enables plastics recycling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Limited emissions from the process.</td>
<td></td>
</tr>
<tr>
<td>Shredding</td>
<td>Almost all metals can be recovered.</td>
<td>Nothing but metals is recycled in car shredders.</td>
</tr>
<tr>
<td>Smelting</td>
<td>Fewer occupational health problems occur.</td>
<td>Only copper, gold, silver, platinum, and palladium are recovered.</td>
</tr>
</tbody>
</table>

For valuable products or products containing fairly clean fractions of materials, there is economy in the recycling process. The alternative for most small products is bulk recycling, which involves the following sequence: disassembly, size reduction, ferrous metal separation, fines and air classification, non-ferrous metal separation, plastic separation, and cleaning. This is the usual flow of processes, but the sequence should not be regarded as fixed, since it depends on which material mix is being processed. If the mix contains only
small amounts of ferrous material, it would be more economic to do magnetic separation later in the sequence, if at all (Lauder et al., 1999).

Åkermark provided an overview of the state of the art in recycling, and an attempt was made to develop a method, which could be used as a general tool for analyzing existing products from the perspective of disassembly. This tool (method) was also intended to teach about disassembly and to give an understanding of the process. The primary aim was thus not to redesign any specific products and improve them from a recycling aspect, but to give the designers an analytic tool. The method described was fairly general and could be applied to a wide range of mechanical and electromechanical products. According to this methodology, the disassembly should start with a quick overview of the product structure in order to analyze the problem in such a way that new perspectives might be illuminated. The parameters used in this method all referred to time or value (Åkermark, 1999).

For companies, the main reason to take an interest in recovery and reuse is economic profit, not the potentially positive impact on the environment. However, some suppliers of components do not deliver the components needed for service any more, even though the company is still obliged to deliver service for their products. One possibility for solving this problem is reusing the components of the products in the field. De Ron and Melissen started a pilot project to investigate the possibility of recovery and reuse of components. The result of this project showed that service problems could be solved by recovering and reusing components from end-of-life products and that this business is a potential lucrative business (de Ron & Melissen, 1999).

In Sweden, the recycling of cars has worked like this for a long time: the dismantlers disassemble and sell spare parts from the scrapped vehicles. This has actually been the main income for vehicle dismantlers as up to 20% weight of the vehicle can be recycled as spare parts (Förslag till producentansvar för uttjänta bilar i Sverige, 1995). The recycling of vehicles in Sweden has been effective; prior to the producer responsibility law, most metals and many spare parts were recycled, but the plastic fraction was not, and so the aim of this legislation was to increase the amount recycled material. There are effective recycling systems available today for recovering the metal content of vehicles; the problem is how to recycle more plastic. In order to recycle more plastic, either a more effective system for plastic separation has to be found or further disassembly of vehicles must occur before shredding. To design for recycling is rather complex since it is hard to find suitable plastic parts for recycling due to the fact that most large plastic parts have a number of different demands on design such as appearance, integration of other parts or sub-assemblies, and form (Paper IV).

5.8 Sub-suppliers

Most products today are quite complex and consist of many different parts, components, and sub-assemblies. The companies’ sub-suppliers develop many of these; it is therefore essential that the suppliers also develop and optimize their products from an environmental point of view (Papers I, II). It is not possible for a company to develop and produce every part of their products. For instance, there are only a small number of producers of ball
bearings, and the optimization of such products has to be achieved by the suppliers (Paper II).

All interviewed designers had extensive cooperation with sub-suppliers (Papers I, II, IV, and V). To obtain information from their sub-suppliers regarding production methods, materials properties, component data, etc., was a bit more complicated than to receive product-specific information within the company. To receive this information was sometimes a rather slow process, especially if the sub-suppliers had to contact their suppliers. However, according to these designers, there were no problems in obtaining the required information (Paper II).

In all companies with a “black and gray list,” all sub-suppliers had to guarantee that their products did not contain any of these substances (Papers I, II, IV, and V).

5.9 Education

It is necessary to have knowledge and competence in order to be able to drive any issue and these resources could be acquired either by experience or by education. Usually the best way is a combination of both. In addition to the practice of design, designers need domain knowledge such as mathematics, material science, thermodynamics, and mechanical systems. You have to be educated in many different theoretical subjects before you can work as a designer. But design education programs last only a limited time and will always have to exclude some topics. It is important, therefore, that environmental issues are included in engineering education. Yet the top priority for engineering students’ is to learn engineering. The aim with environmental education for the future engineers should be to inform and inspire them to design more environmentally adapted products. Seliger et al. point out that there might be an area of conflict between ecological concerns and economic market demands and they state the importance of environmental engineering education bringing this understanding to engineering students (Seliger et al., 2001).

It can be concluded that there is an opportunity to more closely relate the analysis and synthesis parts of EcoDesign, and that there are relatively simple methods that can assist in this relation, giving fruitful results in projects (McAlonee, 2001).

The interviewed designers had received environmental education within their companies consisting of an overview of the ecological restraints, life cycle perspectives, guidelines, and Eco-design. This education was often given when ISO 14001 was implemented. According to the interviewees, the education did not provide direct support for EcoDesign, but it highlighted the importance of environmentally adapted products (Paper III). Complex products are divided into sub-systems in which designers work. Therefore they need not only environmental education adapted to their projects, but also information regarding environmental work within similar projects. Table 5.2 describes more specific education in the different product developing phases (Paper III).
Table 5.2 Different PDP steps and related education requirements in product development (Ullman, 2003 and Paper III)

<table>
<thead>
<tr>
<th>PDP step (Ullman, 2003)</th>
<th>Education (requested by the interviewees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning phase</td>
<td>In the planning phase, the expected product is studied to investigate the effect on the environment and to find out where the largest impact is and try to avoid or minimize it. In this phase, knowledge of ecology is needed. The outline of the new product will be made here. In this phase, education regarding new technologies (more environmentally friendly) is needed, such as alternative energy sources, new materials, and new production methods. A sound base of domain knowledge is required in order to find a more environmentally adapted design path.</td>
</tr>
<tr>
<td>Concept development</td>
<td>Education regarding different evaluation methods and possibilities. How to evaluate and grade concepts from an environmental aspect.</td>
</tr>
<tr>
<td>System-level design</td>
<td>How to take the environmental issue in account when generating a product architecture. Important to learn how to communicate an environmental message at the personal level.</td>
</tr>
<tr>
<td>Detail design</td>
<td>More information/education regarding material choices, structural optimization to minimize the environmental impact and recycling</td>
</tr>
<tr>
<td>Testing and refinement</td>
<td>No specific education requested</td>
</tr>
</tbody>
</table>

The time pressure during product development is quite great. This means that very little time can be spent on education and since the environment is not a main issue for designers, they would not by themselves choose to participate in such education. The main problem for the interviewees was to find time to participate in the courses they wanted. When people become interested in an issue it will influence them to learn more about it by themselves. Running some sort of environmental education every year will remind, inform, and highlight the issue for designers. The side effects of continuing environmental education should not be underestimated. The two main advantages are that the issue is put in focus and that it is considered as an important issue at the management level (Paper III).

In conclusion, designers develop all types of products, and they are consulted in all decisions within product development. Major decisions are made at design meetings whereas the designers themselves make minor decisions (Paper III). Designers in Swedish industry have been given environmental education by their companies. The designers pointed out the advantages not only of education but also of environmental resource persons or environmental experts (Paper III).

5.10 Methods

The only support method used frequently by designers was Failure Mode and Effect Analysis (FMEA) (paper V). As pointed out, the results from LCA are often used by designers. Designers considered themselves as experts on their products and the information from handbooks and guidelines was considered too general. However, these methods were supportive in the integration of the environmental aspect.
Environmental Effect Analysis (EEA) has to some extent been used by Swedish companies and the method and results of the methods is described by Tingström (2003) and Lindahl (2000).

Designers mainly work with modifications of existing components; any great changes would mean having to start the design process all over again. An evaluation method that includes environmental aspects would be useful. It would be a support to avoiding the primary focus on the cost of tools and equipment, to the neglect of attention to future costs of elements such as recycling (Paper III).

5.11 Life Cycle Assessment (LCA)

The most common evaluation method for environmental aspects is Life Cycle Assessment (LCA) and is used frequently in companies. To determine the total environmental impact by an LCA, extensive data are needed on both product contents and production methods. LCA is suitable for comparing different solutions or evaluating concepts or products. Bhamra et al. point out that LCA is often used at the later stages to assess a product’s environmental performance in relation to previous generations of the products or to competitors’ products. The main reason for this is the fact that LCA requires a large amount of data and is therefore hard to use in the earlier stages (Bhamra et al., 1999). However, there is also a need to confirm that the implemented changes really do mean an improvement from an environmental view. Stevels states that LCA was promoted as the driver and validation instrument for EcoDesign activities (Stevels, 2001). Today the most common environmental method in Sweden is LCA; with the development of the method and the higher data accuracy from improved software, the method is relatively easy to use.

The designers interviewed in Paper I did not use the LCA method themselves but considered it a useful tool for gaining an overall environmental understanding of the products (Paper I). Similarly, the designers interviewed in Paper II did not use LCA themselves, but used the result as a general outline to improve the product design from an environmental aspect. LCA is used as a complementary tool that points out the environmental effect, for example, of different concepts and materials. Usually, the previous product generation was still used as a reference. From these studies, the environmental impact of the products could be understood. The results were used to determine which improvements should be in focus (Paper II). Evans, Bhamra, and McAloone have obtained similar results. In the companies they studied, LCA had moved away from design and designers and become an issue for the central environmental departments (Evans, Bhamra, & McAloone, 1999).

There were major differences between large and small companies regarding implementation of the environmental considerations. In the large companies, LCA and an environmental management system were used, but in the small companies there was as yet no organized environmental work (Paper I).
5.12 Environmental management systems (EMS)

Large multinational companies, especially in the chemical, electronics, and automobile industries, also seem to be motivated by the desire to extend environmental management standards to their suppliers. ISO 14001 or EMAS certification is an indicator of environmental responsibility and is often seen as a way of developing a competitive advantage. According to Morrow and Rondinelli, the reason for implementing EMS was to improve environmental performance, make better use of energy sources, motivate employees, improve company image, increase legal certainty, and upgrade environmental documentation. Most of these case studies show that it is difficult to attribute environmental improvements directly to adoption and certification of EMS. Perhaps because EMS certification requires strong employee participation and environmental training programs, many companies report increased employee awareness of the environmental aspects of their jobs and of their responsibilities for reducing negative impacts. The positive effects of implementing an EMS tend to focus on management improvements, employee awareness, systematic and integrated documentation and procedures, and selected environmental performance improvements (Morrow & Rondinelli, 2002). According to the interviewees, they had received environmental education when ISO 14001 was implemented as a direct result of the implementation (Paper II).

![Diagram of ISO 14000 structural elements]

**Figure 5.2.** ISO 14000 consists of five main structural elements.

There are five main structural elements in ISO 14000 (see Figure 5.2). Continuous improvement means that the environmental management system is dynamic. It is a never-ending circle of planning, executing, controlling, and correcting. Planning includes forming an environmental policy, investigating which environmental aspects will be affected by the companies’ activities, and studying the link between the companies’ business activities and laws and regulations.

The environmental policy is set by the management and should be the base for the environmental work within the company. For all employees, the environmental policy should be understood, accepted, and applied. The overall goal for environmental policy is to
permeate the entire work within the company. From the interviews, it was quite clear that
the designers were aware of the environmental policy even if they could not quote it. The
environmental issue was considered important by management. However, the policy was far
too general to contain any specific information that could be used directly by designers. The
environmental policy stated that this was an important issue, but the designers’ focus was
on the products that were being developed (Paper II).

Environmental goals are set in line with the environmental policy and after making an
environmental investigation. Some environmental goals will affect the designer directly,
such as new materials required for a new production method and phasing-out of various
hazardous materials. There are also environmental goals that have not been quantified such
as to reduce the energy consumption, reduce the amount of materials used, and design for
ease of separation. Designers do not set the environmental goals but depending on the goals,
they will be more or less affected (Paper II).

Documentation according to ISO 14000 affects designers quite differently from the way it
affects production. It is much more complicated to establish rules for designing than for
documenting production procedures. There are no demands on documenting how the
product is developed but there is documentation of the product such as product
specification and documentation from design meetings (Paper II). In one department, every
part of the product was documented: the material, the weight, and connection methods. This
information could then easily be used for LCA. With such a specific and detailed
documentation, a lot of time-consuming work for the LCA will be eliminated. This
documentation might be a bit more time consuming but ensures the knowledge of the total
material content and structural design of the product (Paper II).

One way to solve a problem and get new ideas is to use old documentation (Pahl & Beitz,
1996). There are other benefits, not only environmental, of a correct and detailed
documentation of a product. According to the designers, this old documentation could be
used for finding ideas and solution to a variety of problems. A very common procedure
when starting a new product development project is to investigate old designs and similar
concepts. The knowledge build-up by other product development projects could then be
carried over to the new project (Paper II).

In Paper II, interviews were conducted at seven small companies were made; additionally,
twelve more interviews were carried out. No environmental work was performed within
these companies, mainly because their customers did not request it. Van Hemel and Cramer
(2002) showed that customer demands are in practice an even more influential stimulus
than governmental regulation. The most influential internal stimuli found were
“innovational opportunities,” “increase of product quality,” and “new market
opportunities.” Eleven different barriers for small and medium-sized enterprises (SMEs) to
implement EcoDesign were identified. Three of these should be characterized as no-go
barriers:

- Not perceived as responsibility
- No clear environmental benefit
- No alternative solution available
Increasing the use of EcoDesign in SMEs depends not only on finding alternative solutions for technical problems. Even more important are economic and social factors like the acceptance of environmentally improved products in the market and the way which the SMEs studied perceive the market perspectives of these products (van Hemel & Cramer, 2002). However, there are SMEs that do consider the environmental issue, for example, by implementation of ISO 14000. There is no doubt that EMS used correctly might lead to significant environmental improvements. Nevertheless, it is worrying that a certificate in fact does not distinguish between a company that has improved one ratio and a company that has integrated environmental issues into core business strategies and has thereby been able to reduce its overall environmental impact. An EMS is a tool that very well might lead to reduce environmental impact. However, it is crucial to focus on environmental impact rather than focus on implementing a certain tool (Ammenberg & Hjelm, 2002).

An administrative EMS should not only be considered as a technically rational management tool for analytic action that helps to plan, systemize and evaluate the environmental management tasks in an organization. An EMS should also be seen as a tool for communicative action and organizational learning. It should also be stressed that even if an EMS were to facilitate co-operation, communication, and learning in an organization, it would not necessarily lead to successful environmental management nor to sustainable development (von Malmborg, 2002). The current approach to an EMS through standards such as ISO 14000 is more practical for organizations familiar with ISO 9000, organizations where some forms of environmental management are already practiced and organizations where a commitment to introduce an EMS has already been made. Where these conditions do not apply, current EMS theory is inadequate (Kirkland and Thompson, 1999).

Vickers points out the conflict and uncertain nature of the change process, where environmental issues and key individuals wishing to influence the organization to behave in a socially responsible manner are constantly under threat by the more pressing concerns of business survival and profitability in the short term (Vickers, 2000).

ISO 14000 is a support tool for a proactive approach regarding the environmental issue. The environmental work within the company can lead to a number of different business benefits such as: reducing energy and material consumption, gaining market share or goodwill, saving transportation costs, and reducing the cost of waste. However, the effect on the product development process is limited, and the environmental improvements of the products are not directly connected to the ISO 14000 implementation. Similarly Grüner et al. found in their study of 34 German companies that “there is no or just a very weak link between the EMS system and product development” (Grüner et al., 1999).

6 Conclusions and future research

The designers’ situations are very different depending on whether they work in a large or small company. In the large companies, environmental experts are available in many different environmental areas such as LCA, recycling, and materials; also, the environmental issue has been integrated in the product development process and is considered to some extent in every product decision. In contrast, in the small companies in
the interview sample, no environmental experts were available and no proactive environmental product development was made. In the small companies, the designers were even more dependent on the sub-suppliers.

To implement EcoDesign does not mean changing the product development process. The issue can be implemented throughout the entire process without any major changes in the designers working situation.

Designers need the following:

1. Understanding of the environmental problems, since this will motivate them to work with the issue
2. Understanding of how their products affect the environment and how to improve the products
3. Environmental goals for all projects, in order to understand what should be prioritized
4. Evaluation methods to be able to choose between the different alternatives
5. Environmental experts to turn to and discuss issues with
6. Checklists and documentation routines in order to make sure that the environmental issue is considered throughout the entire process

All the large companies participating in the interview studies had “black” and “gray” materials lists consisting of materials that should not be used and materials that should be avoided. Most of the black-listed materials are substances that are constrained by regulations. The companies’ sub-suppliers have to guarantee that none of their products contains forbidden materials and declare or gray-listed materials. In several cases there are companies who use the same suppliers, and then these suppliers will try to make other companies change their “black” and “gray” lists since they want to have similar or the same products in as large series as possible. This leads to demands from the companies on the suppliers but also of demands from the suppliers on the companies.

Material selection is made with co-operation with suppliers and material departments; the usual process is that designers have a specification and this has to be fulfilled by the chosen materials. Materials are then chosen according to the internal material list, which is a standardized list according to the company standard. From an environmental view it is quite easy to eliminate certain materials and substances by controlling the product’s content, but it is much harder to evaluate the consequences of choosing different materials from an environmental view. The most important item from environmental aspect is to make sure that the material content is well known and documented to ensure that the entire material content is controlled and known.

The environmental management system ISO 14000 does not directly effect the designer or the product development process. However, it seems that the implementation the management system leads to attentions of the environmental issue and thereby environmental improvements of the product.
If in the future we are to achieve a sustainable society, it is necessary to improve all products radically from an environmental point of view. This makes the designer an important actor in the drive towards a sustainable society. One must conclude that designers do have a key position when it comes to the environmentally adapted product design, especially in the small and medium-sized enterprises.

6.1 Future research

This thesis describes the designer’s role in relation to EcoDesign.

- More detailed analysis of the designer’s opportunities and constrains when it comes to environmentally adapted product design should be made. A deeper understanding on the differences in working in a large or small company and especially how to improve environmental work within small and medium sized companies.

- There seems to be a need for further environmental education for designers this issue could be further investigated. There are quite clear that depending on your position the requirements on the education is quite different.

- The need of different support tools or methods could be further explored. It is evident that designers do work under time pressure and will therefore concentrate on the most essential issues such as cost and function. The goal with such methods would be to integrate the environmental issue in the product development process.

Research in how to further integrate the environmental issue in the product development process could be made by more empirical data from interviews, case studies, and action research. There are many different factors that effect the integration of the environmental issue and further research will be necessary.

7 References


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