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EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development

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Abstract

The most important moment in product development is when demands and specifications are decided for the product that is being planned. The specification defines the goal for the product development process. It is a very important steering opportunity for the continuing work and for environmentally driven demands that are to be addressed in the product development phase. The designers are said to have the key to sustainable product development through EcoDesign. Many tools have been developed in order to help them to achieve this objective. However, most tools are seldom used primarily because of a lack of sustainability oriented requirements in specifications for products. If there is no demand for improved environmental performance, then there is no need for EcoDesign tools. The lack of market demand for environmentally improved products is therefore, a crucial factor. In other words: It makes no sense to grab a screwdriver from your toolbox if you have a nail in your hand. On the other hand if you have a hammer in your hand you tend to see everything as nails! The hypothesis of this paper is that there is a strong need for a tool to facilitate the integration of reasonable environmental demands into the product development process. The presented tool, ''The Ten Golden Rules,'' can be helpful in this effort. A helpful tool must be well adapted to the task and therefore it is important that the individual product developer/designer can develop personal versions from the generic guidelines. The Ten Golden Rules provide such a possibility. They provide a common foundation, for all in the team, which can be used as a base and guidelines for development of situation specific product-design challenges.

Keywords: Ecodesign; Design for the environment; Product development; Design

1. Introduction

Increasing welfare and ambitions for growth have changed the scope of product design. One can say, ''The role of the designer has changed from meeting needs to stimulating desires'', [1]. The goal of the companies producing and selling products is not just to fulfill functional needs but also, and more importantly, to build image and desire. In a long-term business perspective the creation of market demands is more profound than the design and production of the product. This fact makes it complex to develop sustainable products. Everyone wants products to be sustainable but very few are prepared to pay for products with an outspoken environmental profile. A clear view of sustainability and environment can even be negative even if the price is the same. Lifestyle elements are the dominant elements. One can observe young urban citizens making their life a personal design project with products, education and travel, etc., as elements.

In contrast, in less developed parts of the world, prosperity is very much linked to enhanced functionality of transport, sufficient food and clean water. Both these views must be considered in the creation of sustainable products. In both types of situations, sustainable performance of products is crucial.

There is a lot of interest in sustainable product development, and many tools and guidelines have been suggested. It is unclear

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if those tools are being used and if they have any real effect on product system developments. This paper aims to make a readily understandable synthesis of the existing knowledge. The following sections describe the main parts of the input that have been used. This paper then continues by describing how the various earlier versions of ''The Ten Golden Rules,'' have been tested and refined in various educational activities.

2. Product development and the environment

The challenge for eco-product developers is to fulfill a need or to provide a benefit to the customer/user at the lowest environmental/economic ''cost''. Environmental knowledge must be implemented into basic product development otherwise environmental demands will not be properly addressed [2]. Fig. 1 illustrates this situation. One can presume that we are all aware of the relevant economic value of most of the functions surrounding us but we are usually totally unaware of the corresponding environmental costs/impacts/values.

The balance between environmental ''cost'' and functional ''income'' is essential for sustainable development as is illustrated in Fig. 1. The basic issue is how to maximize/optimize functionality and other benefits with available resources.

In short, on an abstract level, product design activities always begin with an analytical phase where the diverse parameters of the problem are studied along with the anticipated market demands. Next, resources are allocated, design records are established and concepts are generated. After that, evaluations are conducted and decisions are made on design matters, such as further analyses, new concepts, production methods, marketing considerations, etc. In order to shorten the product-development time, experts from different fields often work together, to combine their competences in product development teams. One of the most common ways of describing a design process is to see it as a chain of tasks that must be carried out when a new product is developed, tested, refined and marketed, e.g. Pahl and Beitz [3], Hubka and Eder [4] or by Roozenburg and Eekels [5]. Some models also contain a continuous evaluation and improvement procedure in a circular and iterative fashion.

On a more concrete and practical level, in most companies, product development is performed in projects with actors with diverse functions such as marketing, design, production and purchasing (these actors are referred to here as the product developers). Multifunctional teams are formed to fulfill the functional demands at certain costs within defined time limits, on a commission given by the company.

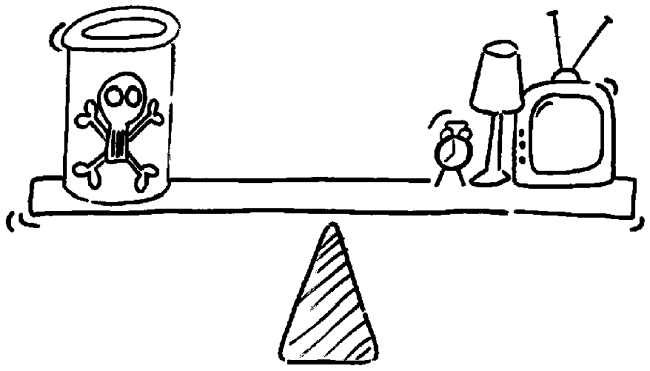

Fig. 1. The diagram is an illustration of the very important balance between benefit to the customer and the corresponding environmental impact. Most product users have an unclear view of this correlation.

The multifaceted demands mean that the product developers have to consider a large number of factors that must be balanced against cost and time. Many products are comprised of many different materials and parts. Product development therefore, is a highly complex process pertaining to product and organization. Product developers are frequently confronted with demands for improving efficiency that requires that they increase quality and reduce costs and lead-time, at the same time, in various proportions. They must ensure high precision in fulfilling the goals of the company's product development requirements.

There must always be a balanced response to all of the demands on the forthcoming product. All these demands, the ''Design Core'', as they are termed by Pugh [6], exist together, many of them at the same time. The circle diagram in Fig. 2 illustrates the amount of interconnected demands, tasks and issues that have to be considered in product development. The pieces are equally large in the figure, for pedagogical reasons, but the relative priorities vary between products and over time.

This means that environmental matters must be balanced against all other requirements for the product. Recycling and other environmentally imposed actions have to be related to all the elements in the design core without allowing them to dominate, since environmental demands can never be the only priority. Functionality and economy normally have the highest business priority. Without customers prepared to pay for the function and if companies cannot make a profit, there will be no market; no matter how well the environmental issues have been addressed [8].

These facts underscore the reality that environmental design research and product design methods will not gain acceptance from the product development teams unless the methods promote integration of the environmental priorities with all other elements in the design core; thereby, making it possible to integrate environmental demands in harmony with the other elements.

In the early phases of the design of a new product, the knowledge of the product is small, but the designer's freedom is large since nothing is settled yet. In the latter part of the process the knowledge of the product is large but the possibilities to change the design according to this knowledge are few since major decisions have been taken and only minor changes can be made (see Fig. 3). A basic dilemma is that effectual environmental solutions as well as cost allocations are primarily dependent upon decisions made in the early part of the design process.

3. How designers work

Before we discuss product designer support tools, we describe the way designers work and through this obtain a view of the types of tools that are useful.

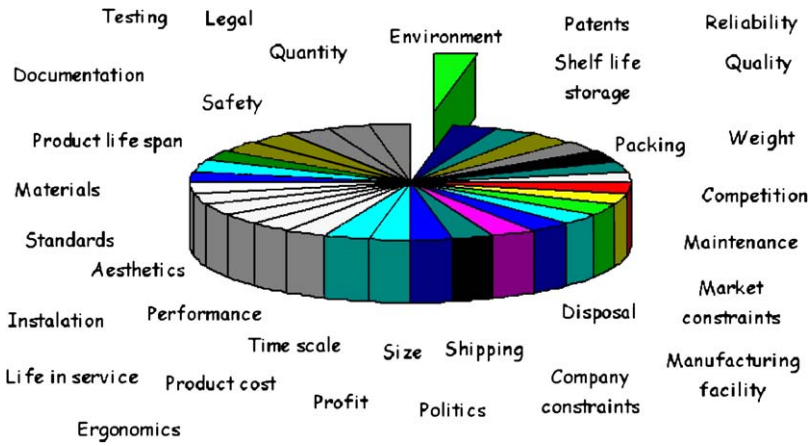

Fig. 2. This is a graphic illustration of the situation in product development. Environment is a new factor that must now be merged into "classical" product development processes. Many demands must be addressed and it is important to understand that environmental demands are one "piece of the cake". If one or more of the elements in this picture is lacking there might not be a product in the end. On the other hand, if one piece is taking over it can jeopardize the necessary "demand-compromise" that is essential for every product [7].

Design is creative and creativeness is about knowledge, fantasy and imagination. During this type of work the left half of our brain is used as some kind of personal knowledge base and the right half of the brain functions as an information processor. Professional designers have a more emotional eye-based way of thinking and acting [9]. Eugene Fergusson also states that all techniques have "non-scientific" and "non-literary" elements. Many properties and qualities in products and processes cannot be reduced to consistent verbal descriptions. Engineers therefore, develop a "tacit knowledge" that can only be communicated visually, e.g. in drawings and sketches [9].

Designers think more laterally than vertically, using de Bono's terminology, and the design tactics look very different from the strictly scientific method. Lawson [10] has described the design process from the viewpoint of the designer and he states: "… Designers must appreciate the nature of both art and science and it involves a sophisticated mental process capable of manipulating many kinds of information, blending them into a set of coherent set of ideas and, finally, generating some realisation of those ideas."

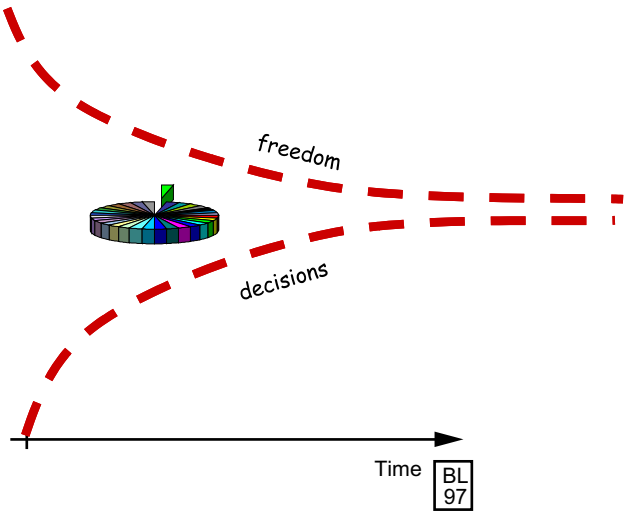

Fig. 3. If EcoDesign features shall have a chance to enter the specification compromise as described in Section 2 these demands must enter in the early phases of design. This is a point in the product development process where it is possible for environmentally driven demands to be included in the specifications.

Additionally, Dominick et al. [11] described the engineering design process as a combination of strict organization and free space for the designers.

Creativity catalyzing tools such as brainstorming, lateral thinking, Delphi and Nominal Group Techniques combined with the Theory of Inventive Problem Solving (TRIZ) can help the product designers to be more open to envisioning possibilities for the new products they are developing [11]. The core of TRIZ is to pose a contradiction and from that point to provoke inventions [12]. TRIZ is a promising tool since many designers see a contradiction between EcoDesign and economic growth.

Bragd followed the design of the XC90 the SUV from Volvo Car Corporation for two years and she uses the word "tinkering" to describe the way the designers worked. Direct decisions were very rare. It was more about feeling, intuition and rhythm [13]. During the 1970s at Flygt Pumps in Stockholm (now part of ITT) every designer had his/her own workbench in the prototype shop with his/her own tools. A multi-skilled craftsman was heading the shop. It was believed that the designers had to use all possible senses to do a good job.

4. EcoDesign tools

Guidelines, checklists and other tools have been used in product design for a long time, for many purposes other than EcoDesign. These tools differ in complexity and structure. They can be very simple such as a few rules of thumb or they can be a complete system on the web, on a CD or in a thick book.

Engineers and designers have also made their own checklists and tools to document experiences and to facilitate cooperation in product development teams.

A common starter for companies implementing EcoDesign is to develop white, gray and black checklists for materials used in company products. Typically, white lists contain materials that should be used. Gray lists contain materials that might be used if there is a good reason and black lists contain materials that are forbidden. Typical representatives of this type of tool are the white, gray and black lists of Volvo [14]. Many Swedish companies use such lists as a basis for their product development processes.

A special tool is the Ecodesign Navigator. The ''Navigator'' maps most of the relevant tools available for EcoDesign and provides a ''Road Map'' for most EcoDesign purposes; it can be regarded as the ''Yellow Pages'' of EcoDesign [15].

Some tools are simple and easy to use, concentrating on a few rules or recommendations. This family of tools can be referred to as the ''Swiss army knife'' of design for the environment (DFE); simple and handy with a multipurpose approach.

In the following section, a selected reading list is presented on tools and references relevant in EcoDesign. The list is a ''selected best reading list'' of literature that has helped in developing The Ten Golden Rules. There is no grading of these works. With reference to Section 3, one cannot say that some information is irrelevant. We do not know that in advance. In design work, one can pick up fragments of information that may seem worthless until an idea emerges in one's mind.

Tools that focus upon a special kind of product:

- Philips eco-design manual focuses on electric and electronic products [16,17]. Cramer [16] and Stevels [17] describe how Philips Sound & Vision/Business Electronics have developed and implemented EcoDesign in the company. The first reference is a ''Swiss army knife'' type summary of six guidelines and the second is a presentation of a business strategy for promoting EcoDesign in companies.
- Volvo environmental guidance for designers with a focus on cars. This is an early, small handbook on EcoDesign of cars. In Sweden it was the front-runner in EcoDesign [18].
- Electrical and electronic-practical ecodesign guide with focus on electric and electronic products by Rodrigo and Castells [19].
- The environmental code of practice, British Marine Industries Federation, with a special focus on boats [20].
- Handbok i miljöanpassad konstruktion av elektronikprodukter, a generic Swedish guidebook on EcoDesign with a focus on electronic products [21].
- konstruera för livet – en miljöhandledning för konstruktörer made by Autoliv AB Sverige (based on the Volvo handbook [18]) [22].
- http://www.ecodesignguide.dk, a web-based tool concentrating on electrical and electronic equipment [23].
- A common, often used method in design is quality function deployment (QFD). It is used mostly to explore what the customer preferences are. Masui et al. have written a paper on how to use QFD for EcoDesign [24].

The following tools incorporate a lifecycle orientation. Disassembly and recycling are core issues in EcoDesign that focus on one phase of the life cycle. Others, such as life cycle assessment (LCA) address the whole life cycle as illustrated by the following:

- Nordic guidelines on life-cycle assessment with generic focus on the whole life cycle of a product [25]. LCA is the ''classical'' analysis tool but there are no recommendations of what to do as a result of the findings, which makes it less useful for real design work.
- Miljöanpassad Produktutveckling(in Swedish) is a handbook with an LCA approach on EcoDesign with a special focus on the Swedish LCA tool, ''Environmental Priority System'' (EPS) [26].
- Automotive interiors: design for recyclability, an SAE paper on recycling of cars [27].
- Designing business machines for disassembly and recycling [28].
- Product chain management to facilitate design for recycling of post consumer plastics with focus on recycling of plastics [29].
- Recyclinggerecht konstruiren mit Kunstoffen (in German) with focus on recycling of plastics [30].
- Konstruieren recyclinggerechter technischer produkte VDI with a special focus on recycling of technical products [31].
- Ecodesign with focus on product structures. A tool for evaluation and specification of disassembly actions [32].

Some publications concentrate on resources or dematerialization, which is a core issue in EcoDesign:

- Resource flows: the material basis of industrial economies with focus on material flow and implications for economy; also with figures on material requirements for some countries [33].
- Product design to reduce restricted substances with special focus on flame retardants in vehicle design produced in cooperation with Volvo [34].
- Is energy efficiency environmentally friendly? [35].
- Negawatts – twelve transitions, eight improvements and one distraction [36].
- The sustainable information society – vision and risks with the IT society [37].
- Dematerialization as a concept to reduce and improve the use of materials. The concept is presented as MIPS by Schmith-Bleek in [38] and in a short version by Tichener in [39].
- A handbook in environmentally adapted choice of materials having all kinds of materials as the red thread; a good source for scenarios in LCA, by Dahlström [40].
- http://www.smile-europe.org/index.html, a web-based home page concentrating on mobility [41].

Some tools have been designed with high ambitions to cover the whole process of design. The dilemma is that it is

almost impossible to cover all possible situations in product development. The amount of information has a tendency to grow to a level where it is difficult to handle. Web-based techniques have made it easier to handle large quantities of information but still this kind of material has a tendency to answer direct and quantified questions formulated in a typical natural science manner while design is much more intuitive and sensitive (cf. Section 3).

Perhaps, we can clarify this with a story. Suppose you have caught a fish and are preparing the sauce for a meal with some friends. You add salt and pepper intuitively then you taste and add more if necessary, perhaps add some herbs as well.

The core questions in design work are difficult to explain in words and numbers. Typically: What if we tilt this part a little bit …. In web based tools you need numbers like, e.g. 22 degrees. What if we add some material here …. In web based tools you need numbers like, e.g. 1.2 kg. What if we change to some plastic …. In web-based tools you need numbers like, e.g. change from steel 1311-00 to PA6 (polyamid).

The following EcoDesign tools can play an important role as an inspiration for ''designing green''.

Representatives for the ''Encyclopaedia of EcoDesign'' approach are:

- ECODESIGN: a promising approach to sustainable production and consumption. A real standard in this sector. Few tools have been spread as much as this one. A revised version will soon be published [42].
- ECODESIGN Pilot: a tool with the objective to cover all EcoDesign aspects. It is available as a book and as an interactive CD [43].
- http://www.pre.nl/ecodesign/ecodesign.htm a web-based tool for every possible need in EcoDesign and related issues. Ten Golden Guidelines (not to be confused with the Ten Golden Rules but the basic concept is similar) are the core of their EcoDesign approach [44]. The tool is more thematic than life cycle oriented.
- http://www.informationinspiration.org.uk: a web-based tool especially for industrial design purposes [45].
- Ecodesign-praktisk vägledning: a book providing a large set of tools and checklists for different product design purposes (in Swedish) [46].
- http://www.econcept.org/cms: a web-based portal where one can find much EcoDesign material [47].

Good examples are very important for inspiration and motivation. Representatives of this ''department store'' of green product design tools are:

- The eco-design handbook, by Fluad-Luke, is a short presentation of many products, primarily consumer products [48].
- Green design; this book presents good examples on green design in various industrial branches [49].

All these tools and texts on EcoDesign have many facets in common. Whether the tool is product based, focuses on a special product life phase or only addresses the management of a resource, the same core elements occur. For example hazardous substances are an issue in most tools as well as product durability or power consumption during the production and user phases of the product's life cycle.

The Ten Golden Rules, described in the next section, were developed by Luttropp as the ''lowest common denominator'' of ten of the most common issues that must be addressed in EcoDesign.

Most of the previously described tools are quite specific; consequently, they are never exactly right for the new product situation that a developer may be facing. The basic idea with The Ten Golden Rules is that they are useful to guide the developer to ask the right, general questions and to challenge them to seek answers to them by applying them with ''specifications'' to their particular product design challenges.

The development of a more generic and more easily understandable synthesis of the above kinds of advice for design has to consider that there are large variations in the designer's situations. Such synthesis is difficult to structure and prove in a traditional positivistic or natural scientific sense. It is rather a pedagogically oriented free experimentation with various kinds of formulations. The above describes some of the input to those ''experiments'' and the following describes how some of the ''experiments'' were made.

5. The Ten Golden Rules: "Swiss army knife" approach

Since the goal/specification phase is the most crucial as far as product performance and properties are concerned, this is where the ''green issues'' must enter. Consequently, a tool for development of the specifications might be appropriate. This paper presents a tool for this phase. Later on, during more concrete design, each designer is supposed to develop the rules according to his/her needs. Examples on customized rules are presented in Sections 7 and 8.

The crucial point is to merge strategy and tools in order to establish goals, for the product development (PD) process, where sustainability is a substantial part. It is important to understand that there is a need for a simple tool. With reference to Fig. 2, tools addressing any of the pieces of the diagram must be simple. Imagine all aspects of the forthcoming design and a complicated tool for each of the pieces. That would be too complex for most product developers.

Design knowledge and skills are very intuitive and there is no place in product development for large books covering just one of the relevant aspects. If deeper knowledge is required, this must be taken care of through contact with specialists.

5.1. Introduction

First, it must be stated that the authors did not invent The Ten Golden Rules; they are a pedagogic summary of many of the guidelines that can be found in company guidelines and handbooks referred to in the preceding literature list. The Ten Golden Rules, as presented in this section, are generic and must be customized to be directly useful in product

development. Guidelines in a company must be company and product specific and must be implemented by the product developers. The Ten Golden Rules are not listed in a priority order but are organized according to the product life cycle (see Fig. 4). Luttropp first presented a predecessor of The Ten Golden Rules as a 12-rule version [50]. It is clear to the authors that The Ten Golden Rules have contradictory elements. In product development processes, it is hardly ever possible to maximize every rule/statement without interfering with fulfillment of the objectives of some other rule. From this point of view the rules should be a conceptual framework for the compromises that are necessary in product development.

Apart from a comprehensive literature study on EcoDesign guidelines this tool is derived from insights gained from Luttropp's design experiences during 27 years in the design and teaching areas and especially EcoDesign experience during the last 12 years.

5.2. Background

The authors developed The Ten Golden Rules in order to fulfill the need for a simple tool in EcoDesign education. At the Royal Institute of Technology (KTH) a course was founded 1996 in EcoDesign. The course has been given annually since 1996 at KTH and five times at the Université de Technologie de Belfort-Montbéliard (UTBM) in France. Approximately 400 students have taken the course to date (2005).

A major element in this course is a student project in which 2–4 students form a group with a consumer product as the study object. First, the product is examined functionally. Second, a representative product is disassembled and evaluated from an environmental point of view. Third, a redesign of the actual product is conducted. In a class with 30 students approximately 12 groups are formed and typical study objects can be: hair dryer, cell phone, timer, toy-mixer for children, computer mouse, bedside radio, classical telephone, coffee maker, iron, etc.

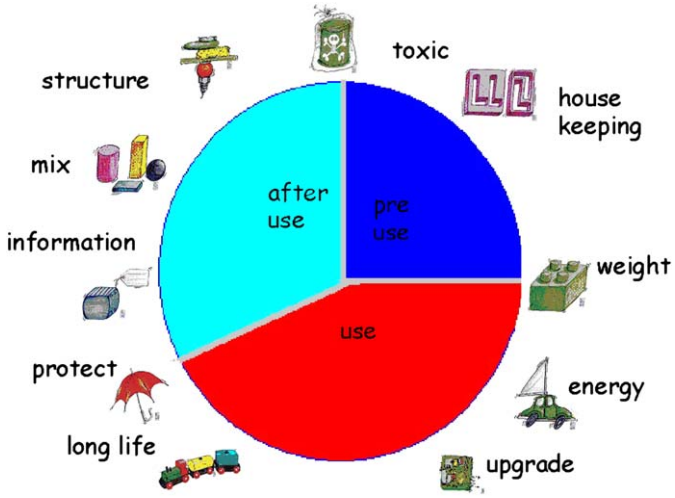

Fig. 4. The Ten Golden Rules are organized according to the life cycle of a product. Each rule is attached to a picture associated with the essence of the respective rules.

The problem then occurs: How to lecture in a class with 30 students having 10–12 different study objects?

The solution was to aggregate a library of tools, as presented in Section 3, into an approach that will work for every group. As a result, The Ten Golden Rules were developed.

The Ten Golden Rules evolved over time and students often develop "customized versions" as they apply them to their product. Three examples are presented in Section 7.

In parallel, versions of this course concept were launched in different companies (Ericsson, ABB, Öhlins, Mercatus, and Bombardier) and a similar problem occurs. The product developers/designers have different tasks in the overall creation of a new product and in order to facilitate collaboration, The Ten Golden Rules have been proved to be useful.

5.3. The tool: The Ten Golden Rules

An overview of The Ten Golden Rules is presented in Fig. 4.

This generic version of The Ten Golden Rules is stated and briefly described in the following section:

ONE Do not use toxic substances and utilize closed loops for necessary but toxic ones.
TWO Minimize energy and resource consumption in the production phase and transport through improved housekeeping.
THREE Use structural features and high quality materials to minimize weight … in products … if such choices do not interfere with necessary flexibility, impact strength or other functional priorities.
FOUR Minimize energy and resource consumption in the usage phase, especially for products with the most significant aspects in the usage phase.
FIVE Promote repair and upgrading, especially for system-dependent products. (e.g. cell phones, computers and CD players).
SIX Promote long life, especially for products with significant environmental aspects outside of the usage phase.
SEVEN Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear, thereby ensuring reduced maintenance and longer product life.
EIGHT Prearrange upgrading, repair and recycling through access ability, labelling, modules, breaking points and manuals.
NINE Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys.
TEN Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking, etc. according to the life cycle scenario.

6. Customizing The Ten Golden Rules

As stated The Ten Golden Rules are generic and are not intended for direct use in design work. For example, for the first

rule ‘‘Do not use toxic …’’ a more specific, customized set of rules can be:

- Identify which toxic substances are currently used in the product with which you are working;
- Try to find a non-toxic substitute that fulfills functional and economic requirements of the product;
- Ascertain if closed loops are already established or can be developed and utilized for recycling the materials including the toxic substances.

A similar specification for rule number eight could be:

- Label materials and try to design products that are easy to service.

A site specific formulation of rules nine and ten for recovery of the toxic substances might lead to a more detailed formulation in order to achieve the desired product safety objectives:

- Provide instructions for the removal and recycling of the toxic and scarce substances present in the product.

This customization of the rules can be made together with environmental experts as well as with managers and people with a customer perspective, i.e. product usage expertise.

A parallel to these rules is found in the rules present in many cultures and religions, e.g. ‘‘Thou shall not steal’’.

This is easy to say but not very useful as guidance to someone who is a thief. For a kleptomaniac who would like to stop this habit, you have to give him customized rules like:

- Sew your pockets together!
- Carry transparent bags!
- Leave your overcoat at the shop entrance!
- Ask someone from the shop to accompany you during your stay in the shop!

Certain advice in The Ten Golden Rules is contradictory. In most cases one cannot assign a unanimous winner. There is a need to provide guidance for making compromises and to explicate the resulting view, e.g. in dialogue between environmental experts, product developers, sales organizations and customers.

Some examples of contradictions are:

- Precious materials like gold-plated connectors can be energy savers. This may cause conflicts in seeking to implement golden rules 2, 3, 7 and 9.
- Metal in moulds in plastic parts can keep the weight down but at the same time by using metals, the product structure becomes more complex, creating a conflict between golden rules 2, 6 and 9.
- New, low weight cars can be developed to achieve reduced fuel consumption, but at the same time the resulting cars may become less safe. Products which have their most significant environmental aspect before or after the usage phase, products such as chairs, tables, stairs, and bridges, can benefit from more weight in order to lengthen the product’s life and reduce the risk for damage and human injuries. This causes a conflict between fulfillment of golden rules 3 and 4.

7. Examples of customization in student projects

As described earlier, this set of rules has a pedagogic background (cf. Section 5.2). ‘‘How can one lecture on EcoDesign guidelines to help students who have a wide variety of products as their redesign task?’’

The instruction to the students was to analyze the product and then to formulate a specification for an environmentally better product of the same kind. Next customize The Ten Golden Rules with a focus on your specific product. At the end of the course the students presented their newly ecodesigned products.

The same kind of procedure has been conducted:

- several times each year at KTH since 1996;
- five times in Belfort, France;
- three times at the AGS summer school in Zurich Switzerland;
- regularly since 1996 in recurrent courses for professional designers at Ericsson, ABB and at other companies.

The general response is always ‘‘eye opening’’ and participants emphasize that they will look upon their design with new perspectives in the future due to their experiences on the course.

This is the very essence of The Ten Golden Rules. Make use of them. Transform them according to your present task. Use them as a checklist in contact with other designers or functions in the company; such as market, acquisition, etc.

Sections 7.1–7.3 presents three sets of customized rules where the basic formulations were transformed into customized forms relevant for each student’s specific product design challenges.

7.1. Student project: squeezer

In one of the courses mentioned in Section 4.2 at Université de Technologie de Belfort-Montbéliard (UTBM) in France a customization of the Ten Golden Rules for a squeezer gave the following results [51] (directly quoted from the student report):

Rule 1: Reduce or eliminate the use of toxic substances in the products:
- Oil for preservation of transmission;
- Varnish on motor’s screws as counter movement;

Rule 2: Minimize consumption through improved housekeeping:
- The organic waste of citrus fruit cannot be reduced.

Rule 3: Minimize energy consumption:
- We can substitute the engine by a manual winding mechanism.

Rule 4: Promote repair and upgrading for system dependent products:
- We do not see any means for improving capacities.

Rule 5: Promote long-life:
- Plastic is the best material found because of the low stress usage phase. We need to improve the transmission durability by changing the material. A fuse could be needed in case of bad usage (too strong pressing that may block the engine).

Rule 6: Minimize weight:
- We can reduce the thickness of the upper squeezer's dome without reducing stiffness. Some screws might be substituted by clips or geometric lockers.

Rule 7: Protect from aggression:
- Each sensitive part is protected by the plastic structure which determines aesthetics. We could find cheaper recycling material than ABS.

Rule 8: Prearrange upgrading, repair and recycling:
- There is no information in the user's manual about how to disassemble the squeezer. Access to the screws is protected by rubber skates and these screws have special heads. So accessibility to the engine is difficult. There is no labelling except on the plastic bag. We must think about the possibility of changing parts (by the after sales service) or to repair the motor. In fact, the warranty period is one year but the price is low. That is why after this period there is no sense in repairing the product (it is more expensive than a new one).

Rule 9: Promote upgrading using simple materials:
- A lot of parts are stuck; that is why it is difficult to disassemble for recycling or repair. The upper bowl does not seem to have any functional effect. Some electric parts can be reused in other devices. Different plastic materials could be replaced by only one plastic and in only one color limiting different colored products.

Rule 10: Use few joining elements:
- Screws could be replaced by clips.
- Most of chopper parts are unique. Moulded-plastic-parts have been done alone, so we do not think this point is a way of progress.

No. 3: Minimize energy
- This kind of system does not consume much energy in the usage phase.

No. 4: Upgrading
- All components can be easily changed but this product is not very expensive (30 euros) and there is no electronic element. Therefore upgrading is not really interesting except for the engine. The whole product will be changed in case of problems.

No. 5: Life time
- This product has a short lifetime firstly because it quickly becomes dirty even if it is well cleaned. Moreover, the lifetime is about of 5–7 years because of fashion.

No. 6: Weight
- The system is well optimized for stress but we could probably minimize weight by reducing the material involved in the *start up system*.

No. 7: Protection
- The *stainless steel (chopper)* is a protection against corrosion.
- The *motor driver sub-assembly* is protected against external elements except liquids. If it would have been protected, the cover-reduction should not have been necessary.

No. 8: Prearrange upgrading
- The system is easily dismountable but some plastic parts are not labelled.

No. 9: Simplicity
- Most of parts are easily recyclable (single parts) and the *electric-engine* can be upgraded. But the chopping blade and the bowl are blended-material components (steel and plastic). The recycling of these two components is going to be harder and too expensive.

No. 10: Joining element
There is only one screw to assemble/dismount the system; most elements are fixed with snap fittings.

7.2. Student project: mini-chopper

In one of the courses mentioned in Section 4.2 at Université de Technologie de Belfort-Montbéliard (UTBM) in France a customization of the Ten Golden Rules for a mini-chopper gave the following results [51] (directly quoted from the student report):

No.1: Toxic
- *The grease* on the *cover-reduction system* is not protected whereas it is perhaps toxic (we do not know exactly its composition).

No. 2: Housekeeping
- The *packaging* is not really optimized (a lot of waste during the production).

7.3. Student project: clipper

In one of the courses mentioned in Section 4.2 at Université de Technologie de Belfort-Montbéliard (UTBM) in France a customization of The Ten Golden Rules for a clipper gave the following results [51] (directly quoted from the student report):

Rule no. 1: No toxic substances have been found in our product.

Rule no. 2: The inside shape of the case is complex. By simplifying this shape, we could reduce the quantity of raw material. Also, the packaging shape is disturbing during transport. It would have been better to make it cubic or rectangular and without parts sticking out to occupy

less volume and so economize transportation and increase the stocks in the supermarkets.
Rule no. 3: We notice that our product does not have any impact of its environment during the usage phase. Meanwhile, compared to the competition this product is heavier. If the mechanism was lighter it would probably consume less energy.
Rule no. 4: On the one hand, there is a 1 year guarantee and its price is quite affordable, so we say that they promote the repurchase rather than repairing. On the other hand, they support people to send the product for repair by their own company by providing free transportation.
Rule no. 5: The product has been designed with heavy and robust components. That makes us believe that the product's lifetime is good.
Rule no. 6: As we said in rule no. 5, our product is composed of heavy parts. Nevertheless the high weight of some parts is not justified. It could be reduced, by using other raw material or by reducing their size. This would reduce the raw material costs and also the robustness and energy efficiency in construction and usage. Designers should find the ideal raw material and its quantity to obtain a good compromise between lightness and robustness of the part.
Rule no. 7: The only components to be in direct contact with the environment are the case and the teeth. The first one has to protect the rest from humidity, heat, dirt. The raw material used for this component is a thermoplastic (probably PP), which fulfils all of these constraints. The second seems to be a stainless steel, which resists corrosion.
Rule no. 8: The designers have closed the case of the product with special screws, so that the owner can not open it himself. Only the teeth are easy to disconnect so that the owner can clean it. We can also say that, this product does not have any labelling which identifies the different kinds of materials.
Rule no. 9: The product has a mechanism which could be easier to upgrade. It contains a number of different kinds of plastics and metals. Some of those are magnetic and surface treated.
Rule no. 10: There is only one joining element. It is the part, which supports the spring. If we could find another way to support the spring, we could skip part.

We can see that the student groups, after just a few days of education, have got it right to quite some extent. We must bear in mind that they do not have the same inside information on the products as a practicing designer has. They have been provided with their product in the package just as we all meet products that we buy. The basic idea is that the tool should mirror the level of the tool-user and in that way is comfortable and useful. If we provide students with a professional version for, e.g. clipper design, the students would probably not understand it. The formulation of the rules must be adapted to the specific tool-user and his/her competence and the developing phase. The Ten Golden Rules are supposed to be a living document.

8. The process of customizing the Ten Golden Rules in DFE rules for Bombardier

In May 2003, the Bombardier Center of Competence for Design for Environment (CoC DFE) started a project to update the existing DFE guidelines. At the same time, the second author introduced The Ten Golden Rules to the group. It was decided that a new set of DFE guidelines should be developed. The project followed an iterative process, which continued until May 2004, when the Design for Environment guidelines leaflet was issued to the whole company [52].

The basic idea of this work was to establish DFE guidelines that the designers can use in their daily work at Bombardier, and thereby give the designers some general design advice to use when performing DFE. Together with earlier versions of Bombardier DFE guidelines, The Ten Golden Rules established the platform for developing a new set and layout of the DFE guidelines, i.e. a customization of The Ten Golden Rules.

At first, CoC DFE performed a brainstorming session to elaborate on some basic questions like: who are the potential users of this information, what is their background, understanding and pre-knowledge in the DFE area, what should the guidelines be used for, what type of information is needed for efficient communication, layout, languages, how do we present it and how and when should we distribute the guidelines?

Major conclusions from the brainstorming were:

- How instead of why: Main focus should stay on how to achieve environmental improvements of Bombardier's products, rather than spending time and space on motivating why to perform DFE.
- Time and space: Information should be quick and easy to understand. Because designers do not have much time to spend on DFE, the information should not exceed four pages (A4).
- Language: The idea is that the guidelines should be used by all engineers at all levels, on a day-to-day basis; however some countries and engineering departments are not comfortable with English. To avoid the risk that the DFE guidelines are not used, due to poor English understanding, it was decided to make the information available in German and French as well, since these two languages are next to English of great importance for the company.
- Wording: Some of the phrases in The Ten Golden Rules should be changed to better fit the processes and words used at Bombardier, e.g. toxic has been changed to hazardous.
- Approach: Designers are experts in their own area, but normally lack environmental knowledge. Even if designers at Bombardier work on the same or similar products, they have different areas of responsibility, e.g. bogie, interior, car body, etc. Consequently, it would make no sense to formulate exactly the same specific DFE guidelines for everyone, as they would not be valid in all situations. For example a designer of the interior would need specific DFE guidelines on fabrics, while a designer of the bogies

would need specific DFE guidelines on metals and corrosion preventing agents. Therefore, we chose a situation-specific approach.

- Remembrance: The guidelines should be easy to remember and come back to. The pictures should help people remember the leaflet. Another idea was to establish a version that could be kept as a poster on the wall, rather than keeping an electronic version, which may be lost amongst other information.

Other important information to be included in the leaflet was: details of contact persons, CoC DFE and Bombardier Engineering Book of Knowledge on the intranet (EBOK) for easy accessibility to information as needed, lists of prohibited and restricted substances, a relation to product function should be included.

The DFE guidelines should be product-oriented with generic guidelines with space for the individual company's guidelines. The DFE guidelines are now based on three levels (see Fig. 5). The first level is basically based on The Ten Golden Rules and the second level is a customization of The Ten Golden Rules to fit Bombardier and is fairly rail vehicle related. This level is merged with earlier DFE guidelines used at Bombardier. At the third level, the designers are required to write their own guidelines or action plans of what to do. Furthermore, it is important to stress that the engineers are instructed to focus on the guidelines that are suitable for their work.

8.1. The first version: first aid in design for environment

The first version, which was named "First aid in design for environment, Ten Golden DFE Rules", was tested at a DFE training session in Derby, UK. Feedback showed that the majority thought that the DFE guidelines were good or very good, informative; they stimulate ideas and are helpful. Furthermore, the DFE guidelines were considered as a good tool for daily work, but some designers expressed the point that they had problems in writing their own guidelines. The discussions in the training session were helpful.

8.2. The second version

The second version of The Golden DFE Rules (The Bombardier version of the original Ten Golden Rules) was presented to the DFE Group Team. At this stage, it was found that some words caused confusion, e.g. rule, which is used in the army and therefore understood as a must, and gold, which is related to the rare metal. To cause as little confusion as possible in introducing new names, it was decided that we should stay with the old name, "Design for Environment Guidelines".

After several revisions with the DFE Group Team on layout, wordings, and with the printing/design agency concerning layout, the leaflet was finalized in six months. The leaflet was translated into German and French.

Design for Environment Guidelines		My own action plan
Hazardous  Don't use hazardous substances and arrange closed loops for necessary ones	☐ Don't use materials on BT's lists of Prohibited and Restricted substances ☐ Try to find solutions involving non hazardous substances, which does not jeopardise the functionality and cost limitations of the product ☐ If a hazardous substance cannot be substituted consider if closed loops can be arranged i.e. recycled and taken care of at end-of-life	. . . . .
House-keeping  Minimise energy and resource consumption in production phase and transport through housekeeping	☐ Reuse parts and components if they can still guarantee the same quality ☐ Optimise and plan procurement and logistics e.g. no half empty trucks, choose less energy consuming distribution, optimise packaging ☐ Reduce use of consumables e.g. spill of oils ☐ Sort waste in recycling bins	. . . . .

Fig. 5. Snapshot of the Design for Environment Guidelines at three levels; general, Bombardier specific and the designer's own action plan.

8.3. Distribution

Finally, the DFE guidelines leaflet was launched in March 2004 via Bombardier non-stop online, which is an email addressed to the whole company, and stored on Bombardier's intranet. Bombardier DFE guidelines are found in English, German and French. The leaflets are distributed at internal DFE training courses, but also by the DFE group team.

Moreover, a clickable version was established on the EBOK (Bombardier Engineering Book of Knowledge on the intranet), where it is possible to click on each icon in the picture to get more detailed information about that specific DFE guideline (Fig. 6).

There is more information and advice behind function and design, as well as a whole set of DFE guidelines for selecting materials. Most guidelines are also accompanied by practical DFE examples. To inspire designers and to help them develop their own DFE guidelines, a gallery of examples is kept together with the guidelines in the EBOK. Printable versions of the leaflet, in all three languages, are also included.

9. How are the DFE guidelines used today at Bombardier?

The basic message in the Bombardier DFE leaflet is:

- Consider how the product interacts with the environment throughout its lifecycle.
- Identify activities in your daily work related to the DFE guidelines.
- Select the guidelines that are relevant and customize them to match your work. You are the expert in your own situation.
- Adapt the DFE guidelines to suit your needs.
- Put your own DFE guidelines on the wall as a reminder.

To avoid sub-optimization, one should try to obtain as comprehensive a design view of the problem as possible. Moreover, resource saving must not jeopardize the function of the product. For example low weight cars can be motivated by decrease in fuel consumption, but low weight should not compromise vehicle safety. The designers are therefore recommended to discuss compromises with their division contacts and groups involved in the problem and should communicate the resulting view.

With today's gigantic flow of information, it is difficult to make a lasting impression; a footprint. However, the comic images used in the DFE guidelines, each representing a specific guideline, are easy to remember. Many people within Bombardier still, 6 months after the release of the document, comment that they have seen the leaflet and remember it, and that they also like what they saw.

The EBOK consists of 26 sections and the DFE section is one. The DFE section has a lot of information on organization of environmental management. It has a list of prohibited substances and much more. The Ten Golden Rules part in the DFE section is the most visited part. This reaction from Vienna is typical feedback: "The Ten Golden DFE Rules are a very good tool for the daily work of our lead engineers and our design engineers."

Unfortunately the EBOK is only available on the intranet inside the company.

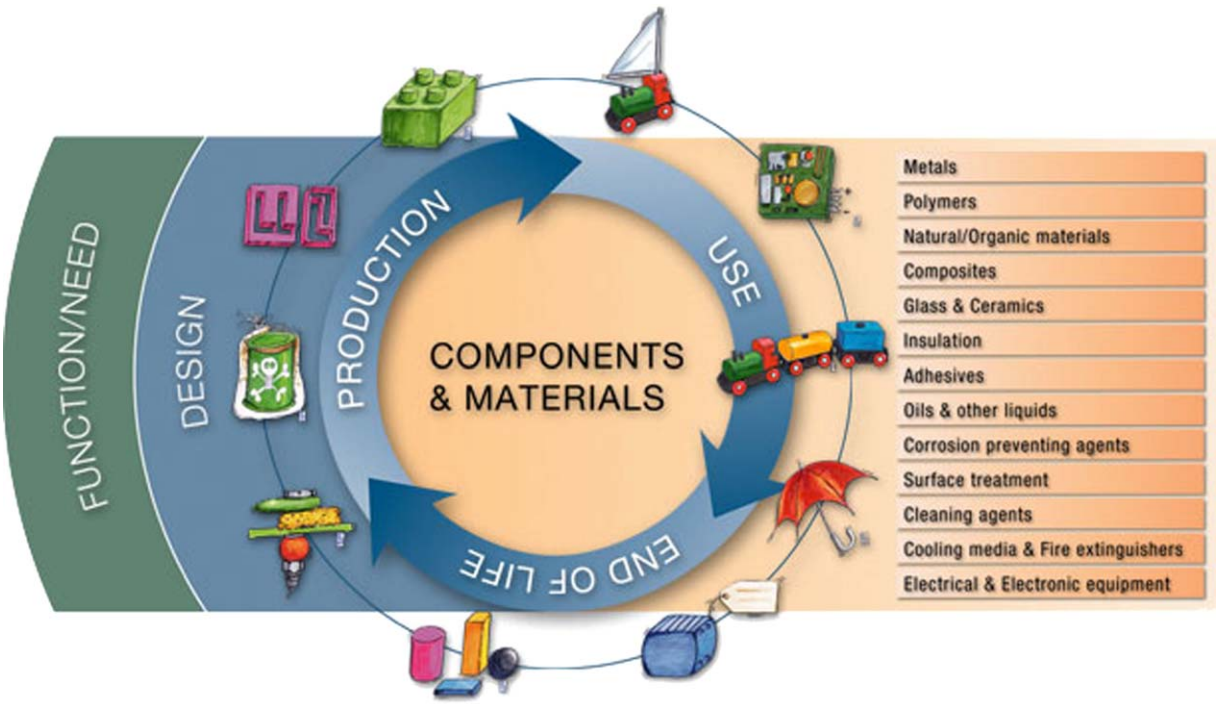

Fig. 6. A snapshot from the clickable version of the DFE guidelines on the Bombardier intranet, Engineering Book of Knowledge [52].

10. Conclusions

The Ten Golden Rules are a generalized set of guidelines that have been developed as a synthesis of a number of environmental design guidelines that are used in companies and academia. The foundation and motivation for their development was to fulfill the pedagogic need in EcoDesign courses at KTH in Stockholm, Sweden.

The rules have been found to be useful in enabling explicit EcoDesign teaching for many, small and large groups of university students. They are also being used within companies.

It is important to emphasize in the use of the rules in EcoDesign, that there is a need for background knowledge to be able to make sound use of them The user must have a basic design education. In the author's teaching, the presentation of them is always combined with a presentation of background literature, for further individual studies.

Designers always salute the possibility to get a compass course with many possibilities to maneuver/customize on their own. In that context, The Ten Golden Rules are:

- A quick and easy introduction to EcoDesign;
- Most useful when they are introduced in a DFE training session, with explicit examples of the DFE principles and training in translation to their own situation;
- Very useful as a reminder and checklist as the design work progresses.

Appendix 1. Four links to the Ten Golden Rules from other design assistance tools

A.1. The Volvo handbook

Chapter 3: choice of material … states: ''Choose materials so that the design does not contain substances which are harmful for nature and human health.'' This is similar to GR 1 and GR 3 pertaining to low weight, and with regard to ease of recycling, it is similar to GRs 8, 9 and 10. Avoid surface treatment (GRs 1, 7) and avoid additives (GR 1). Avoid adhesives (GR 9, 10).

Chapter 4: improve use of resources (GR 2) and minimize the amount of materials used.

Chapter 5: design for fuel economy (GR 4). Many specified instructions with focus on automotives.

Chapter 7: design for recycling (GRs 8, 9, 10).

A.2. Promise manual

Module A, the LiDS-wheel:

1. Selection of low-impact materials (GRs 1, 8)
2. Reduction of materials usage (GRs 2, 3)
3. Optimization of production techniques (GR 2)
4. Optimization of distribution system (GR 2)
5. Reducing impact during use (GRs 1, 4)
6. Optimization of initial lifetime (GRs 6, 7)
7. Optimization of end-of-life system (GRs 8, 9, 10) as well as Module B.

A.3. Recycling gerechtes konstruiren

Chapter 2.3.1 Materials (GR 9 as well as GRs 1, 3, 8).
Chapter 2.3.2 Design (GRs 2, 8, 9, 10).
Chapter 2.3.3 Manufacturing (GRs 2, 3).
Chapter 2.3.4 Usage phase (GRs 1, 7).
Chapter 2.3.5 Disassembly (GRs 7, 8, 9, 10).

A.4. Produktentvicklung

Chapter 1.6 Die 7 goldenen Regeln fur Produkte von Morgen

1. From cradle to grave (GRs 1–10).
2. Improve processes (GRs 2, 5, 6, 7).
3. Material intensity and factor ten (GRs 2, 3, 8, 9, 10).
4. Energy intensity and factor ten (GRs 2, 4).

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