SUSTAINABLE, USER BEHAVIOUR CENTERED DESIGN
APPLYING LINKED-BENEFIT STRATEGIES
The Logi Desk Lamp

Johannes Schmalz\textsuperscript{1,2}, Casper Boks\textsuperscript{2}

\textsuperscript{1} Institute for Engineering Design and Industrial Design (IKTD), University of Stuttgart, Pfaffenwaldring 9, D-70569 Stuttgart, Germany
Email: Johannes.Schmalz@yahoo.de
\textsuperscript{2} Department of Product Design, Norwegian University of Science and Technology, Kolbjørn Hejes vei 2b, NO-7491 Trondheim, Norway, Phone: +47 735 90102
Email: casper.boks@ntnu.no

Abstract
Design for sustainable behaviour implies applying design strategies that have been proposed to realize sustainable products that take into account human behavior, thereby minimizing user-related environmental losses. In addition, the application of linked-benefit strategies has been suggested to ensure the design of commercially interesting products, linking sustainability benefits to financial, functionality, aesthetical or convenience benefits. However, very few, if any, case studies have been reported on that aim to use both design strategies in one particular product design. Since a methodology for doing so is lacking, this paper, based on the development of a desk lamp, suggests, discusses, and evaluates possible directions for a hands-on approach. The resulting prototype is discussed, and a model is suggested for further testing.

Keywords
linked-benefit strategies, design for sustainable behavior, user centered eco design, use-related environmental losses

1. Introduction
Research on sustainable design still concentrates primarily on the environmental impact of the product itself. But as the material and energy-based environmental improvement of products is to some extent self propelling given legislative and technical progress, the
influence of the user-related losses is gaining more and more academic interest and importance in finding ways to minimize avoidable environmental impacts. There are assumptions that around 30 percent of the energy consumption of a product is due to user-related losses (Wood and Newborough, 2003).

Also, academic interest in the potential role of design as a discipline in transitions towards more sustainable use practices has grown. Several opportunities and strategies have been identified by a number of authors that have resulted in the informal establishment of a “design for sustainable behavior” research community. Here, research addresses the potential for design interventions around existing behaviours, the use of feedback, persuasion or de-familiarisation to motivate, facilitate awareness-raising and attitudinal change, interventions that steer or constrain use, that engage users in adapting their own practices, or make them keep products longer (Jelsma, 1999, Fogg, 2004, Lockton et al., 2008, Wever et al, 2008, Mazé and Redström, 2008, Lilley, 2009, Scott et al., 2009). Initial efforts have largely focused on mapping designers’ solution space (Lockton et al., 2008 Lilley, 2009), identifying suitable techniques, processes and user involvement levels (Scott et al., 2009, Jelsma, 2006, Pettersen and Boks, 2008) and assessing strategies’ effectiveness (McCalley and Midden, 2002). Commercially, a number of products exhibiting principles of design for sustainable behavior can be identified. These include for example dual-mode flushing buttons, energy meters, and television sets with automatic brightness settings. A range of products also exists that remain within the gadget domain, focusing on one particular design for sustainable behavior aspect, such as awareness raising or blocking behavior.

This paper is founded in the authors’ belief that in order to make sustainable design strategies work, including design for sustainable behavior strategies, so-called ‘linked benefits’ have to be designed into products for them to become commercially successful as a commodity product, beyond the gadget level (Stevels, 2000). This implies searching for design solutions than benefit users and producers in more than just in terms of sustainability, but offer economical, convenience and emotional (for users) and strategic (for producers) benefits as well.

2 Goal of the paper
In spite of growing interest in this research fields, academic studies exploring design for sustainable behavior methodology in practical design projects are still very few, if any. This paper aims to discuss a project in which the above challenges were tackled in a real design
project, and to explore elements that could support a design methodology in this direction. In a practical project it was tried to focus on the user and his influence on the impact of the product as well as the technical possibilities to guide the user to a more sustainable behavior. It was also tried to explicitly pay attention to potential linked benefits of various types, including economical, safety, convenience and environmental benefits, both for the user and for the producer. This means that "environment" is added as a criterion of product development alongside other classical criteria of functionality, profitability, safety, reliability, ergonomics, technical feasibility, and last but not least aesthetics.

Considerations for applying linked benefits and their influence on each other are discussed in order to understand which features are most important to make this product and its use attractive to mainstream audiences. The approach builds on a practical project focusing on the user and his influence on the impact of the product, as well as mechanisms for guiding the user towards a more sustainable behavior. The paper concludes with proposals that could be considered when designing a product with focus on the above-mentioned criteria.

3 Approach
Beforehand, an important requirement for this project to become successful was considered to be the choice of the study object. Several functions in a household were therefore analysed concerning their environmental impacts and the user-influence on these impacts, including direct and indirect consequences, and behaviours influencing consequences.

- Direct consequences are all consequences occurring directly in connection with the action itself. This is mainly electricity/energy consumption as well as the use of materials or natural products like for example water. These consequences normally increase proportionally with the number of actions.
- Indirect consequences are all consequences, which are not directly linked with the action itself. They occur as a subsequent incident; they can but do not necessarily increase due to the degeneration of an action. An example could be the packaging of a detergent.
- Behaviors influencing the consequences are all the factors, where an (bad) impact on the environment occurs due to user action. Examples are if people leave the door of the fridge open for a longer period of time or the use of too much shower gel.
Furthermore, a range of possible study objects was evaluated against a set of criteria that were selected keeping in mind that the conclusions of the project would be meaningful as basis for further research. The study object should therefore be:

- **Simple**: to be able to concentrate on the process and not too much on the technical realization is it preferable to have a rather simple product.
- **Consuming significant amount of energy**: This would increase the possibility for achieving a significant improvement potential. A household appliance was considered as a good option given the high energy consumption to size ratio.
- **A commodity product**: An important factor for the success of (sustainable designed) products is the price. Good prices will only be realized when the product is produced in mass production. A product that is standard in every household is therefore more likely to be successful from this point of view, and would be a more interesting study object.
- **Strongly user-behavior influenced in terms of energy consumption**: As the main focus of the project is on the user, behaviour leading to wasting energy is of main interest. Most of the research in the last years has been done on the intrinsic losses, meaning that improvements related to user-related losses may have considerable potential.
- **Easy to prototype**: To make the project as realistic as possible is one purpose the building up of a working prototype, allowing multiple requirements to be considered and tested in real. Furthermore it gives the possibility to evaluate the success or the improvement opportunities of the project together with users. Therefore the product should be easy to test with users as well.

To connect all these criteria with each other and rate them to make a final decision on a study object, a benefit analysis was set up.

Many activities had been considered beforehand, such as lighting, washing, shaving, tooth brushing, showering, hair drying, etc. Most of these were abandoned on basis of both the easy-to-prototype and the energy consumption criteria. As lighting scored particularly well on the commodity product and easy-to-prototype criteria, and offered challenges on the both the behavior and the energy consumption criteria, this area was chosen for further analysis.
Lighting

The design and application of lighting solutions is an area in development, stimulated by new technology development as well as by increasing environmental awareness. Even though on an individual product level, products may not be that energy consuming, in a broader context lighting is a huge factor in most of the world’s countries energy surveys; according to the EU Commission Regulation (2009) the energy consumption of non-directional household lamps in the EU in 2007 was 127TWh. It is predicted that this amount will rise to 135TWh in 2020.

From a technological advancement perspective, the maturing Light Emitting Diode (LED) technology plays an important role in stimulating the development of new lighting solutions. This technology, with excellent ecological and energy saving properties, slowly replaces more traditional ones and creates new design opportunities. A preliminary survey on domestic desk lighting revealed that even in this particular field of lighting, a wide range of design solutions can be found, resulting in a wide range of purchase prices. However, no evidence was found of any desk lamps featuring multiple design solutions to influence the user towards a more sustainable way of use.

4 Explorative development of a design approach

Once lighting, and more specifically, domestic desk lighting was chosen as a highly relevant subject for a practical study combining design for sustainable behavior and linked benefit strategies, the challenge was to develop a design approach suitable for this goal. One of the considerations beforehand was whether this project could be treated as a normal design project, or whether its specific focus would require a customized approach.

As the main goal was not to design a product itself, but to gain experience with this type of design exercise, it was decided to take an explorative approach building on existing insights. Particular attention was given to the user-benefits and the way they may be correlated, as well as mechanisms to influence the user towards more sustainable ways of using a product.

In the following subsections this approach will be discussed by addressing each step as follows: first, the rationale for including the step and the considerations on how to perform the step are discussed (subparagraphs 4.x.1), and secondly, it is explained how this worked out in the context of the desk lamp design project. This approach allows further discussion and reflection on the design result (chapter 5) and the methodology itself (chapter 6).
4.1 User definition and screening

4.1.1. Discussing the approach

Given the focus of the product, it was decided that it would make sense to first determine the intended audience for the lamp, as the prospective user group would determine both the behavioral patterns to be analysed as well as the functionality and benefits users would experience from using the lamp. An additional consideration was that attention should be paid to the fact that the person buying a product may not be the (sole) person using or interacting with it.

User interviews were chosen as the most appropriate method to gather more insights in what different user groups expect of a product in terms of functionality and benefits. A semi-structured approach was taken, in order to scan the main issues, opportunities and challenges that would need to be dealt with. It was considered that answers from prospective users may not accurately reflect their actions, behavior or even preferences in daily life. In the context of the project, it was considered that people may often have a false estimation about the environmental impact of their actions (Mansouri-Azar et al., 1996). Also, it was considered that it may be challenging to make people talk about what could be regarded as ‘bad’ or undesirable behavior in the given (sustainability) context. To tackle such challenges, some special techniques of interviewing exist, such as first asking people about bad behaviors in general using fictive scenario/personas (Blythe and Dearden 2008).

4.1.2. User screening in the context of the project

To specify the benefits people expect from a lamp a user study was done with 25 subjects in the age between 20 and 65. Issues addressed in this survey were awareness of environmental issues caused by lamps, benefits that people expect from a lamp, alternative ways to realize these benefits, anticipated behavior in operating lamps, as well as purchase decision factors. The main findings are summarized below:

- **Price:** The price seems to be one of the most important factors when people consider buying a lamp or not. The subjects mentioned clashes between price and for example top-class materials. This means, that people are aware that “quality has its price”, what therefore means that people are willing to pay more if offering them a product with additional benefits, which can e.g. be found in the other three focal points.
- **Safety:** Not only does light make people feeling safer, some people mentioned also the safety of the lamp itself as a concern.
• **Customization/product-user interaction:** There seems to be the trend that people want to adapt the kind of light to the actual mood they are in, as light can be an important factor in steering atmosphere of an environment. A parallel can be found in listening to music; people vary in their music preferences when dancing or relaxing. Also people want the lamp to fit to their personal needs and environments. Hence the more possibilities the lamp has to adapt to those needs the more customers it will target.

• **Sustainability:** The subjects were generally aware of the environmental impacts of lighting solutions, though no single subject appeared to have a complete overview. This indicated that even a rather simple product like a lamp reflects a complex issue for most users. Everybody has kind of his own perspective on what is important to ensure sustainability. As most of the people wanted a very sustainable lamp it seems preferable to relieve people from some of the problems by designing a lamp that is made in a way being sustainable no matter what the user does.

4.2 Defining the target audience

4.2.1. Discussing the approach

It was assumed that a clear definition of the target market segment would be essential for a successful design, and increase the likelihood that design features would be used as intended. After a choice of market segment would be made, this would imply mapping and analyzing different potential benefits and their correlations.

Defining the target audience then would lead to an essential step in (sustainable) design processes: the defining the design brief. In the current context, in order to allow for a correct comparison of environmental consequences between design alternatives, it was decided to include an explicit definition of a functional unit in addition to the more conventional list of requirements, which is common in industrial product design processes. Key aspects of the functional unit to be addressed would be *the functionality of the product as expected by the user; a description of the average user and his or her context; the location where the product will be used; and an assumed user scenario describing amongst others the intensity of use of the product by the user* (Boks and Diehl, 2005):

Another important consideration was to design a lamp that would target an audience as broad as possible. The motivation for this was mainly twofold: a large audience resulting in large sales number would result in a meaningful contribution to environmental impact reduction, even though the impact of a single lamp is negligible in a societal context.
Secondly, a large audience would enable mass production, and reduce production costs (and environmental impacts) per product, and therefore product price.

4.2.2. Defining the target audience in the context of the project
The consideration from the previous subparagraph resulted in the following definition of the target audience for the desk lamp:

- Young family (parents are in the beginning of the 1930s) with a baby and a small child
- Both parents are professionals, working also from at home
- Living in a middle-European country where (lowering) energy consumption is discussed a lot in media
- Interested in design and aesthetics
- Open minded with respect to untraditional design solutions

This translates to the following requirements, which will be discussed in paragraph 4.4

- The lamp is a desk lamp in the price range of 50 Euro. (IKEA 2010 oriented)
- It is used for decorative, leisure as well as professional activities at home (meaning that the lamp can be found on any table or furniture of a household)
- The lamp will be in use daily, mainly in the evening
- The lamp might be used by children

A more detailed description of functional requirements is given in paragraph 4.4.

4.3. Benefit - behaviour matching
4.3.1. Discussing the approach
The central and most challenging (and probably most innovative) step of the process would be linking the linked-benefits perspective with the insights gained from design for sustainable behavior research, since literature does not report on any such case study explicitly. The goal was to arrive at a design brief and a list of requirements that could be direct input to the development of an actual product prototype.

Beforehand, it was assumed useful to structure the different types of behavior into four ways of influencing the user as this would provide already some hints concerning possible solutions. This assumption was based on recent literature on design for sustainable behavior strategies, where different possibilities of categorization of user influencing have been proposed. Wever et al. (2008) subdivide for example in the following categories:

- **Functionality matching** aims at adapting the function of a product in a way that the existing (bad) behavior of the user is absorbed.
• **Eco-feedback** aims at just informing the user about the impacts of his action, leaving the decision to act upon this to the user

• **Scripting** aims at realizing that sustainable use of a product ‘coincidentally’ is the most simple and comfortable way of using the product for the user, allowing intuitive sustainable use

• **Forced functionality** aims at either making sure that the product is intelligent and adapts to changing environmental conditions, or at designing the product in a way that non-sustainable use is made impossible.

Several other divisions of dividing the freedom of control over behavior between the product and the user have been proposed discussed in recent literature as well (Lilley et al., 2005, Lockton et al., 2010, Elias et al., 2007, Jelsma, 2006, Pettersen and Boks, 2008) but as a starting point for demonstrating the principle, it was considered sufficient to cover all these divisions with these four umbrella terms. Extending the analysis with more or more detailed strategies, or with a selection of strategies appropriate to the problem at hand, could be subject of study, but would not principally alter the approach discussed here.

Once a number of potential benefits of a product would have been derived, these could be linked to the mentioned design strategy categories. An important input for this process would be to investigate to what extent the potential benefits would be correlated. To this end, it was suggested to develop a matrix correlating potential benefits. Benefits not excluding each other could then be allocated to different types of behaviour to get a feeling about their influence on the user and his environment and to provide input for deriving design solutions.

After these steps, the designer should have a good overview about the possibilities, challenges and interactions within the studied system, leading to an investigation which kind of user influence would be preferable. As there has not been done much research in this field, it would require a keen sense of understanding the system from the designer.

**4.3.2. Benefit - behaviour matching in the context of the project**

Based on literature and feedback obtain from the user interviews, Table 1 gives an overview of a number of possible design solutions for each type of design for sustainable behavior strategy that could be part of the final conceptual design.

<p>| Table 1: Possible design solutions sorted after design for sustainable behavior strategy |</p>
<table>
<thead>
<tr>
<th>Main strategy</th>
<th>Possible design solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality matching</td>
<td>• Lamp gives only the amount of light that is needed</td>
</tr>
<tr>
<td></td>
<td>• Lamp is able to adapt to user’s needs</td>
</tr>
<tr>
<td>Eco feedback</td>
<td>• Lamp shows user actual impact caused by using the lamp (energy, CO2, etc.)</td>
</tr>
<tr>
<td></td>
<td>• User is shown how the durability of the lamp is changing due to his use</td>
</tr>
<tr>
<td></td>
<td>• Show user how much energy was needed to produce the lamp</td>
</tr>
<tr>
<td>Scripting and/or Steering</td>
<td>• Design the lamp in a way, that using it eco friendly is fun/easy, most convenient</td>
</tr>
<tr>
<td></td>
<td>• Design the lamp that user can show of with the functionalities of the lamp</td>
</tr>
<tr>
<td>Forced functionality</td>
<td>• The lamp burns only when user is around</td>
</tr>
<tr>
<td></td>
<td>• The lamp adapts to the light around</td>
</tr>
<tr>
<td></td>
<td>• The lamp gains energy from surrounding without influence of the user</td>
</tr>
</tbody>
</table>

Those solutions were then used to determine what kind of benefits could be expected from the solutions. For example could an adaption to the light in the surrounding be seen as the benefit of being able to dim the lamp (as the adaption to the light could be combined with a dimmer).

With the above considerations in mind, a benefit correlation matrix was derived in the context of the lamp project, including the benefits as identified from the user interviews (Table 2). In this matrix, minus (-) means that the two compared benefits correlate negatively. For example: Directional light (light emitted in a controlled way) may result in a social benefit in the case a couple where one person wants to use light for reading and the other may want to sleep undisturbed by light. However, directional light will somehow make an addition of materials or technology necessary hence the costs (the price) for the lamp will under normal conditions be higher than for a lamp without this benefit. Plus (+) means that the two compared benefits correlate positively. For example: the price (or at least the costs) for a lamp with standardized socket may be cheaper as they are produced in mass production.
Table 2: Benefit correlation matrix

<table>
<thead>
<tr>
<th></th>
<th>Dimming</th>
<th>Price</th>
<th>Timeless aesthetic</th>
<th>Sustainable materials</th>
<th>Directional light</th>
<th>Standardized socket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimming</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Price</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Timeless aesthetic</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sustainable materials</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Directional light</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Standardized socket</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

A negative correlation between two benefits however may not exclude that benefit from including that benefit in the final design. For example, directional light correlates negatively with price, but may at the same time provide other benefits. A next step was included to check the benefits on their interaction with the user or the kind of benefit the user could expect. This proved to be helpful in balancing the evaluation of including different design features in the final concept.

Table 3: Benefit-interaction matrix

<table>
<thead>
<tr>
<th></th>
<th>economical</th>
<th>ecological</th>
<th>functional/technical</th>
<th>emotional</th>
<th>social</th>
<th>physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimming</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Price</td>
<td>X</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Timeless aesthetic</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sustainable materials</td>
<td>X</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Directional light</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Standardized socket</td>
<td>X</td>
<td>X</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
The results from these two matrices, of which only parts are shown in Table 2 and 3, do not directly lead to design solutions, but provided insights about which dilemmas and challenges should be addressed towards conceptualization, and as such guided the exploration of the system boundaries. They became input for determining the list of requirements (paragraph 4.4) and finally the conceptualization step (paragraph 5).

4.4. Setting up requirements

4.4.1. Discussing the approach

During the project it was discussed to what extent a conventional “list of demands and wishes” would be appropriate. It was expected that within the context of this particular design project, fulfilling demands and trying to “design in” as many wishes as possible might be an insufficient approach for reaching an optimal result. It was expected that, towards a first conceptual design, the balancing act of including as many benefits as possible for as many people as possible, and taking into account aspects as well, would be less straightforward.

From the designer it would ask for a keen sense in balancing the different benefits, as it is, as shown before, quite difficult to cover all the interactions between the benefits. This part of the process was regarded as the “marriage” between the theoretical steps done before, their concretion and the technical implementation. One of the challenges is the uncertainty whether technical implementation will be possible due to interactions of the different technical and economical requirements.

4.4.2. Setting up requirements in the context of the project

For the desk lamp design project, based on the previous analyses, the following functionalities were selected into the list of requirements for the lamp (see Table 4) – although some of them were included as wishes rather than requirements. These mostly reflect benefits that would not necessarily be negatively correlated with each other using the benefit-behaviour matching process described above.

Table 4: List of requirements

| • Dimming possible          | • The lamp should hinder incorrect and excessive use |
| • Adaption to light in surrounding | • Lamp should be easy to control |
| • Avoid to attract flies and mosquitoes | • Handling the lamp should be fun |
| • The lamp should not get hot | • The lamp should be safe for children to operate |
| • Bulb should have a long durability | • Opening only possible with tools |
| • Materials should be recyclable | • User should be able to adapt the light to his mood |
| • Directing lighting should be possible | • The illumination level should be >500Lx |
| • The lamp should switch off when not in use | • The Unified Glare Rating (UGR) should be < 22 |
| • The lamp should not fall down if someone is stumbling over the cable | • Function of the lamp shown by the design/aesthetics |
| • It should not be possible to modify the lamp | • Design/aesthetics should attract broad audiences |
| | • Make the lamp change its color |
Additional economic and safety requirements were amongst others formulated as follows:

- Maximally three different materials should be used for the body of the lamp
- Usage of standard or existing parts
- The lamp should be realized in 12V to guarantee the safety of the prototype

5. Conceptualization and technical realization of the lamp

In this section it was tried to realise all the functions listed in the list of requirements, the challenge being in the shift from the functional description to a technical implementation that fits with all the factors listed in the list of requirements. The probably most difficult part of the process is the breaking down of all the factors listed before into a physical product. Again it seemed to be preferable to do first some “technical” brainstorming (with the factors as system boundaries) and afterwards indexing these ideas. Indexing is a good tool in this case as it does not only give the process a traceable structure but also the possibility to combine completely different approaches to a completely new, innovative approach. One method used for this was the morphological box, allowing the combination of several possible solutions to quickly combine while rating them with the list of requirements.

Table 5 shows how some possible design solutions were taken into consideration by using the morphological box approach:

<table>
<thead>
<tr>
<th>Morphological Box Approach</th>
<th>read</th>
<th>work</th>
<th>bed</th>
<th>computer work</th>
<th>allround</th>
<th>relax</th>
<th>safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation mode:</td>
<td>wake-up/</td>
<td>asleep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special functions</td>
<td>wake-up/</td>
<td>asleep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction interface</td>
<td>all</td>
<td>keyless go</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>bulb</td>
<td>LED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy source</td>
<td>table (horizontal base)</td>
<td>wall (topside fixed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>fuzzy</td>
<td>photocell</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety feature</td>
<td>unburnable materials</td>
<td>standard socket</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Morphological box

Each possible solution was now rechecked with the list of requirements, which led to the solutions marked in bold and italics. Especially the economical requirements drew the range of possible solutions pretty narrow.

The most important features realized in the final prototype are the following:

- Dimmable LED light
- Safety release cable
- Directional light
- Motion detector with several sub features like timer etc.
- Light detector
- Due to safety reasons is whole system realized in 12V
- Less flies and mosquitoes being attracted
- 90-98% less energy consumption than equivalent lamp

5.1 Description of the prototype
The system itself can be seen from a functional side of view divided into five subparts: all the sensors, the electronics to dim the LED, the LED itself, the safety release cable, and the part to allow directional light. Each of these subparts are only briefly discussed below as the main focus of the project was on discussing the methodology.

Sensor system:
Translating the list of requirements, the following functions were wanted from the sensor system:
- Measure light intensity
- Check if human in surrounding
- Possibility to adapt to different environments
- Timer

The only one system found fitting with the requirements is the “PIR Motion Alarm-Module with Fresnell-Lense” from the German company Hygrosens. An interesting fact is the possibility of adapting the module to different environments as well as the customization of the whole responding behaviors (in a defined range).

Electronics:
A challenge is the fact that it is not possible to dim a LED with a normal dimmer used in lamps with bulbs. The reason is in the physical properties of the LED. (Dyble et al 2005) It is therefore necessary to use other electronic circuits to dim LED lights. One possibility is the use of the so-called “pulse width modulation”. (Wallentowitz et al 2006) This device basically modulates the current that it is changing between to values what allows to steer the output signal. This is what is installed in the prototype.

The LED:
There has been quite some progress in the LED industry in the last years. From glaring, white light that was not comparable to normal bulbs to all kinds of illuminants with the same
lighting properties as normal bulbs. Most of these new illuminants are made for standard bulb sockets and 220V. As it was decided that, due to safety research, the design should be realized in 12V, finding such a solution was quite time consuming. Closely linked to the LED is the socket. In this case a small standard socket was chosen to ensure maximum design freedom with all the benefits of a standard socket. The chosen LED provides the light comparable to a 40W bulb (what is used in most desk lamps on the market).

The safety release cable:
The idea of the safety release cable (a cable that releases when being pulled, instead of making the whole lamp falling) may sound obvious, but nevertheless it was not possible to find a cable for the needed configuration in neither Germany nor Norway. Several connectors with a defined pull-off strength were considered, but according to different manufacturers these are not advisable for the lamp.

Figure 1. Safety release cable

In the USA this kind of cable is used for different household appliances like deep fryers or raclette ovens. Therefore, one of those deep fryers was bought in the US and the main part of the safety release cable was sent to Norway. As the whole deep fryer costs about $25, the cable by itself cannot be very expensive.

Directional light:
The origin of this idea originates from the ability to have directional light as well as non-directional light coming from one single lamp. This was realized with a removable piece of
metal in tree shape which avoids the light from going into one direction while the illumination on the other side of the lamp is being increased due to the reflections coming from the tree.

5.2 Aesthetics and realization:
In a strict form-follows-function approach it was now thought about how to embed the functions into the aesthetics. Therefore several different cardboard mock-ups were built to investigate different possibilities of realizing the functions in an aesthetically pleasing system. In the lamp project there were several factors that are more important than the aesthetics of the lamp. At the same time it relates to several other factors like attractiveness, lifetime, quality properties, the usability etc. As there are some parameters determined due to the bought-in parts there is not as much freedom as designing a completely self produced product.

Figure 2: LOGI prototype (Foto by Kurisaki-Sagberg)

The mock-ups were then tested on their characteristics, especially the functional and ergonomical ones. This was especially important to ensure sufficient illumination. After an iterative process of eliminating different problems one conceptual model was chosen.

The fact that the CAD model was done after the mock up model shows the strict functional approach. As the basic appearance was set with the cardboard models, the CAD model was only used to quickly test different ratios and sizes of the parts. As a stylistic device the golden ratio (1:1,618) was used for the ratio between height and width of the lamp. Figure 2 depicts the final prototype of the lamp, which was called LOGI, after the god of fire in Norwegian mythology.
6. Evaluation of the lamp

6.1 Linked-benefits:

It can be concluded that there are at least the following linked-benefits:

- The electronics (motion detector as well as the timer) saves the installation of a switch. This saves costs as well as unnecessary use of electronic materials. (Besides the fact that the lamp is switched off when not needed). The user is in the comfortable situation not to have to switch the lamp on or off, as the lamp offers this “service”. However, the switching of the lamp is possible via the dimmer.

- Sustainable design should always aim at the highest possible life expectancy of a product. This was done in this case with a timeless aesthetic as well as the safety release cable. The cable does not only ensure a higher extent of safety for the user, but also prevents the lamp from being destroyed by falling down (what probably would end the life or lower the life expectancy of the lamp).

- The adjustable light reduces the energy-consumption on one hand; on the other hand, it increases the benefit of the user as he might adjust the light to the purpose it is actually needed.

- Light propagation might be seen as a negative environmental impact. The possibility of giving the light a direction lowers this impact. Simultaneously, the tree element leads the light to the point the user needs it and may produce aesthetically pleasing shadows on the wall.

- If the light detector was configured in the right way, it could assure that the user always has the right amount of light that is ergonomically needed. This could, especially in professional environments, make sure that there is a perfect balance between energy efficiency and the avoidance of tiredness or even damage to the eye of the user due to insufficient light.

- LED light does not only significantly reduce the energy consumption, but seems also to not attract flies and mosquitoes in a way normal lamps do. This offers completely new user-behaviours concerning the use of artificial light during summer time. Another benefit of the LED is the long life expectancy when compared to a normal bulb, which means that the user does not have to change the LED for a long time. The reduced heat-development of the LED increases the safety of the whole system. Furthermore this affects the final design, for there is less space between LED and surrounding materials needed.
6.2 User-related losses:
The lamp is an intelligent product able to reduce user-related losses to a minimum. The problem of rebound effects is rather low, for there are not only few (if any) possibilities to bypass the mechanism of the electronics, but there are also no incentives for users to want to do this. This might be the most important and most interesting fact of the whole process and the product. As such, the prototype would be a highly sustainable product, delivering exceptional service, without being invasive, and for a reasonable price.

6.3 Sustainability:
The lamp is considered to use 92.5-95.75% less energy than a comparable lamp. Most of the savings are realized by the use of the LED:

- Using a LED light (3W), which is equivalent to a 40W regular bulb, contributes to 92.5% savings.

- If this is now taken into consideration, the percentages stated by Palmborg (1986) or Gram-Hansen (2003) considering user-related losses suggest that there might be an additional 3.25% savings possible.

7. Evaluation of the process
As described above, the project can be seen as successful in terms of exploring how to combine design for sustainable behavior and linked benefit strategies considerations into developing a prototype. Within the project, this was done on an explorative basis. After evaluating the process, the approach was nevertheless considered to be in need of more structuring, especially when it would need to be applied for more complicated projects. In hindsight, a new approach was considered that could address these concerns. Linking the two perspectives could be done with a matrix based on cross comparisons not unsimilar to what is known from Quality Function Deployment (QFD) method. To this end, a matrix is proposed (Table 6) that arranges the benefits (abstracted wishes voiced by the customer) on the top side, and different types of behavior influencing (represented by design solutions concerning the specific mode of influence) on the left side of the matrix. The proposed matrix then links the solutions for each design strategy with identified benefits from the user screening. The grading of the correlation between the two factors is reflected by the figures: 9 (strong positive correlation), -9 (strong negative correlation), 6 (medium positive correlation), -6 (medium negative correlation), 3 (low positive correlation), -3 (low positive correlation) or 0 (for no correlation). Positive correlation means that the solution is expected to influence the benefit in a positive way, negative the other way round. The figures of every
solution are then summed up, one time without considering the weight of the different benefits and one time with. This allows setting up a ranking of aspiring solutions.

An extra source of information mainly for the next steps is the comparison of the benefits and the solutions, which happens in the “roof-like” parts of the matrix. This allows being aware of possible clashes right from the outset and can help when considering which functions to realize or not. It is also suggested to explore the use of TRIZ-like methods to find ways of avoiding possible clashes.

Table 6: Behaviour-benefit matrix

In the process of developing the lamp some aspects were discovered quite late in the process, some even after finishing the prototype. For example, the use of the directional light tree to gain nice shadows on the wall. The aim has to be to pull those aspects to the earlier parts of the development process. One could say that control over the benefits from the beginning allows the control over the product and the process from the beginning on. This also allows new benefit combinations to be embedded early on in the design process.
8. Conclusions
This article has described a design project with the aim of developing a lighting solution that addresses both design for sustainable behavior and linked-benefit considerations as a starting point. As no explicit method to do so yet exists, the considerations for the approach have been shared with the reader, as were the actual steps taken. The design project has resulted in a prototype that exhibits a unique set of features for a desk lamp, such as very low energy consumption and very limited electronics, combined with dimming, safety features, directional light, less attracting flies and mosquitoes, and comparably low costs. An evaluation of the approach taken has resulted in a proposal for a QFD-type matrix allowing for a more systematical simultaneous consideration of incorporating linked benefit and design for sustainable behavior strategies.

References
Blythe, M. and Dearden, A., 2008, Representing older people: Towards meaningful images of the user in design scenarios, Universal Access in the Information Society, Volume 8, number 1, pp. 21-32


Jelsma, J., 1999, “Philosophy Meets Design, or how the masses are missed (and revealed again) in environmental policy and ecodesign”, Consumption, Everyday Life and Sustainability, Centre for the Study of Environmental Change, Lancaster University


Scott, K., J. Quist, and C. Bakker, 2009, “Co-design, social practices and sustainable innovation: involving users in a living lab exploratory study on bathing”, Joint Actions on Climate Change, Aalborg, Denmark, 8-10 June 2009.


Wood, G., Newborough, 2003, Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, Scotland, UK