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INTEGRATING REAL LIFE CUSTOMER NEEDS INTO THE ECO-DESIGN PROCESS AND GENERATING IMPROVEMENT POTENTIAL

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ABSTRACT

Many companies have identified the substantial economization potential, as well as the high innovation potential which applied eco-design can generate. Most research in the field of eco-design has been focused on various design methodologies. In practice, these methods neglect to consider the consumer. This situation can not only lead to products failing in the marketplace, but it can also hinder the eco-friendliness of such products. Thus, this piece of research is about eco-design focused on considering the level of consumers' awareness of environmental aspects of products, and their needs and behaviour, but also the perception and acceptance of environmental products. For this focus some research questions have been raised: what is an effective realization of a systematic and methodical eco-design process and how can it contribute to a successful outcome considering real consumer requirements? In-depth answers to these questions are provided in the form of a real-life product project, the "eco-designed PC mouse." The findings of a consumer survey are applied to the eco-design of a computer mouse using the Eco-Quality Function Deployment method. Furthermore, an implementation concept to combine the environmental attributes with the consumer benefits was developed (using Eco-Means-End-Chain).

As a result the eco mouse prototype has an innovative power management system. The housing material is based on natural materials with a consistency similar to that of wood, however the process attributes are comparable to plastics. Components are soldered lead-free, hazardous materials are mostly avoided (in compliance with the RoHS-Directive). It is impossible to develop a product with absolutely no negative environmental impact. Nevertheless the next generation of a product should lessen the environmental impact of its predecessor. With the eco mouse user tests, new customer requirements are identified. In the first step of the proposed eco-design process, the results of the initial survey and those of the new survey were compared to identify the requirements for further development. Based on these requirements, new strategies were generated.

Keywords: Eco-Design, consumer-requirements and consumer-behaviour

1 INTRODUCTION

Eco-design was introduced in the early 1990s and has developed steadily [1]. Some proactive industries producing technical products have applied it to their product design processes (for an example see, [16]). However, the result has been that many of the products have not sold well and consequently failed in the market [3]. Hence, most of these products never came into use and had to be directly disposed of, thus creating environmental burdens without having been of any use - exactly contrary to the initial intentions of these proactive producers. The reasons for these failures have been identified as the development of products that do not satisfy consumer needs or even ignore them [2] [3].

The process of weighing up environmental aspects against other important factors has proved to be one of the most challenging tasks in eco-design. The core problem here is the conflict between environmental aspects and other aspects, which manifests itself in almost every eco-design process. Even the most significant eco-design literature fails to deal with these difficulties (See *Table 1*).

Table 1: Dealing with consumer needs in eco-design documents

Features Documents	Importance of integrating consumer needs into eco-design	Guides for integrating consumer needs into eco-design process
CEN Guide 4 [4]	Yes	No
IEC Guide 109 [5]	No	No
ECMA 341 [19]	No	No
ISO TR 14062 [6]	Yes	No
IEC Guide 114 [7]	Yes, but only environment-related consumer needs	No

There is much literature on eco-design methods, processes and activities, yet the trade-off problems of the environmental aspects with other requirements, especially consumer requirements, have been virtually overlooked.
The goal of this project was therefore, to develop an eco-design method, which integrated consumer needs and harmonized the environmental aspects with them, and then applied this to the applied product development. An appropriate basic tool selected for the eco-design method, due to its strength in systematically integrating certain requirements with certain processes, was Quality Function Deployment (QFD) [8]. There were, in fact, already some examples of the application of QFD to the eco-design process [9] [10] [11][12], however in these QFD applications, the environmental aspects were ultimately treated as pure consumer needs in the application process. This was improved in this piece of research by introducing a 'Consumer-Eco matrix'.
Furthermore, marketers are well aware that consumers often think about products and brands in terms of their benefits rather than their features [13]. I.e., for consumers the benefits (including phycological benefits such as the feeling of "being green") are more important than the environmentally friendly features themselves. With this in mind, the 'Eco-Means End Chain' was developed, which enables the generation of consumer benefits from the environmental attributes (features) of a product. These two methods are applied to and tested as part of the development of a computer mouse.

2 ECO-DESIGN WITH THE EXAMPLE ECO-MOUSE

The goal of this project was to demonstrate eco-design potential by developing a real product. A PC mouse is a widely available and well known product. Its structure and assembly are relatively simple and at the same time its functional parts constitute a good representation of electronic consumer goods. Therefore the PC mouse is a well suited demonstrational object.

The development process (summarised in Figure 1) started with a product idea: the ecologically optimised computer mouse. In the product concept phase the initial concept was established (with the definition of product features and technologies where possible). This delivered a basis for the initial product eco assessment (simplified Life Cycle Assessment - LCA). This allows the identification of the first eco shortcomings of the design concept, which in turn allows the definition of eco criteria. To combine the technical product idea and the eco assessment with the requirements of the future consumers a market survey was carried out (see chapter 2.1). The results of the survey were used for an Eco-QFD, which translates the consumer product criteria into technical and environmental design characteristics (see chapter 2.2). Additionally an Eco-MEC was carried out (see chapter 2.3). Now we could specify the prototype attributes (after dealing with criteria conflicts) and construct the first prototype of the eco-mouse. To identify the prototype shortcomings and to establish the improvement strategies a series of functionality tests were conducted (by potential costumes in real office environments).
The "product concept" stage will not be described in more detail because it is not of key importance to this paper. A description of the subsequent consumer and test-user specific stages are presented in the chapters below.

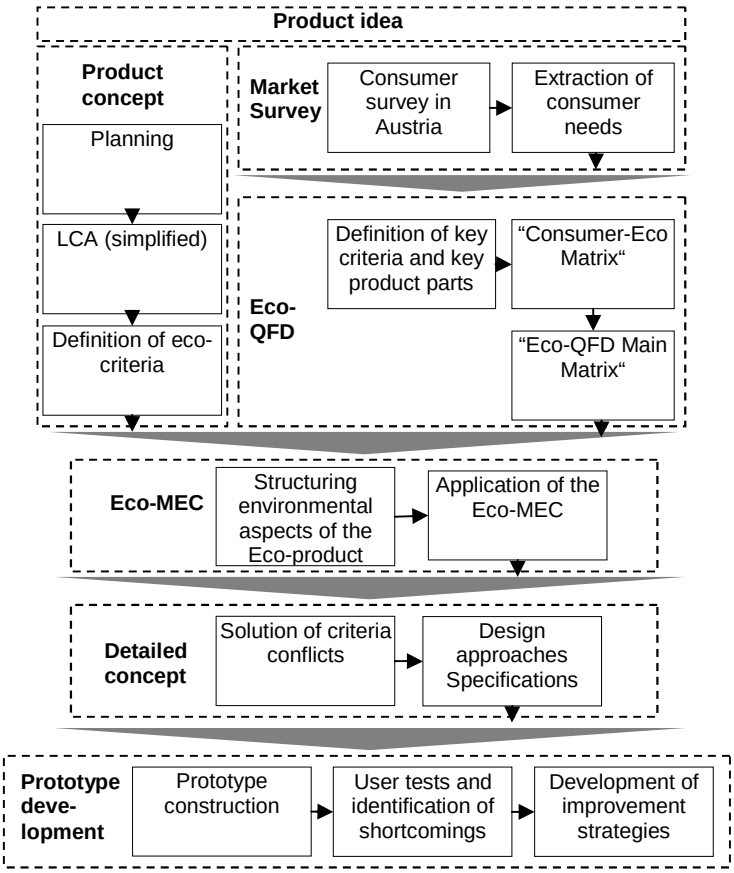

Figure 1: Design and decision process flow

2.1 Extended Survey of the Austrian Market

To investigate the consumer awareness and acceptance of environmentally friendlier electronic product ranges (especially in relation to our eco-mouse concept), a consumer survey had been undertaken in Austria in 2005. The number of respondents was 501, with age ranging from 14-59 years old, and taking into account a variety of jobs and educational levels. The survey was performed online. The selected examples of results are presented below.

Criteria for Purchasing Decision Making

Austrian consumers were asked to answer what the decisive criteria in their decision making process when purchasing electronic and electric product purchase were. The most important one was brand, with 34.5%, then came recommendation (from relatives, friends or mentors) and after that design. The environmental aspects of a product were not considered very relevant when making purchase decisions compared with other criteria, with only 12.6% (as shown in Figure 2):

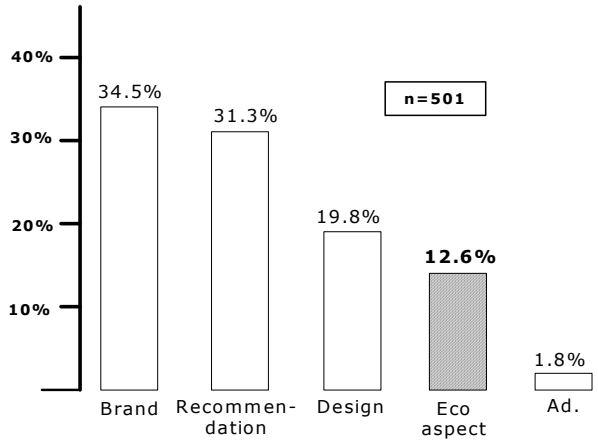

Figure 2: Decisive criteria for purchasing electric and electronic products

The survey shows that the environmental friendliness of a product is not a priority for consumers. Few consumers think it to be important. A more interesting feature is that these criteria are prioritized differently by gender. Male consumers lay stress on brand, while female consumers consider design and environmental aspects to be more important. As was also shown by Stevel's survey, it is a proven fact that female consumers are more aware of environmental aspects of products [14].

Technology, Current and Future Trend

To identify the technological trend for Austrian consumers, the survey asked about technologies present in the market. Over 40% of consumers currently have an optical computer mouse with cable, and over 20% possess an optical mouse without cable. For the next purchase, the majority of consumers (82.6 %) reported they would choose optical technology, and 56% would also opt for a wireless solution. Hence, wireless and optical sensor technology should be technical requirements for the development of a new computer mouse.

Consumers' Conventional Needs for a Computer Mouse

In this market survey, consumer needs regarding the function of a computer mouse were also investigated. According to the Austrian respondents, 'easy to grip', 'easy operation', 'less resistance to the contact area', 'easy to clean' were, respectively, the most important consumer needs as shown in Table 2.

Table 2: Consumer needs on a computer mouse

Consumer Needs	Percentage
Easy to grip	20.17%
Easy operation	17.34%
Less resistance to the contact area	15.35%
Easy to clean	14.92%
Large movement range	10.33%
Low weight	7.36%
Comfortable size	5.94%
Accessories (like color change of housing)	2.71%

2.2 Eco-QFD Application for Eco-Computer Mouse Development

To integrate environmental aspects into the product design process, the harmonization of environmental aspects with consumer needs is crucial. This aspect is key to the proposed concept of a new application of QFD; Eco-QFD. The Simplified Eco-QFD consists of two Matrices: the 'Consumer-Eco Matrix' and the 'Eco-QFD Main Matrix'. The main task of the 'Consumer-Eco Matrix' is to prioritize the environmental aspects of product with regard to the consumer needs, whereas it is the main task of the 'Eco-QFD Main Matrix' to prioritize the product parts based on the consumer needs and the prioritized environmental aspects from the 'Consumer-Eco Matrix'. The structure of the Simplified Eco-QFD is illustrated in the following illustration Figure 3.

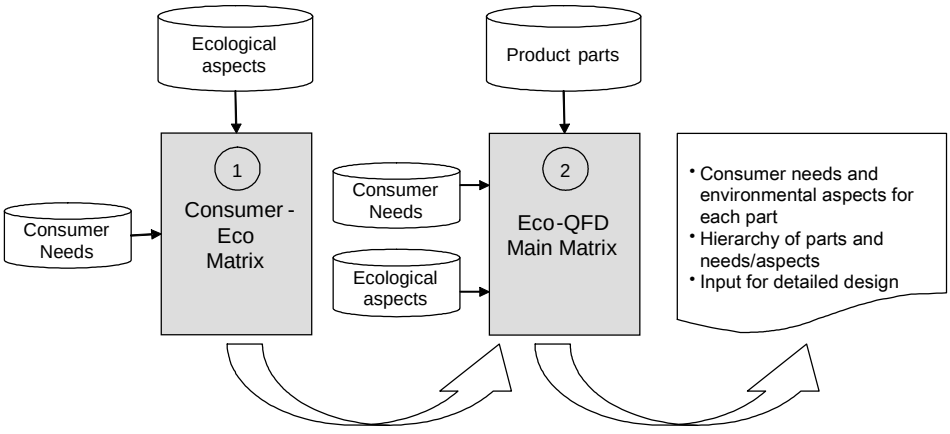

Figure 3: Structure of the Simplified Eco-QFD

2.2.1 The Consumer-Eco Matrix

The consumer needs from the survey and the environmental aspects above are the inputs to the Consumer-Eco matrix. The consumer needs taken from the survey (Table 2) are put into the upper row of the consumer-eco matrix. This consumer-eco matrix is to represent the relationship of the consumer needs of product with the possible environmental aspects of them (Figure 4). Thus, the environmental aspects of a computer mouse should be identified. The environmental aspects have bean identified during initial eco assessment of the product concept (simplified LCA). Further important aspects can be found from eco-design guidelines or from relevant legal regulations. In this case study, the further environmental aspect are extracted from ISO 14062 [6], the EUP directive (Annex 1) [15], and the eco-design guide including case studies of the European electrical and electronics industry from Ecolife [16]. The identified possible environmental aspects for an electronic product are shown in Figure 4. The level of environmental impact is expressed in a 0, 3, 6, 9 scale (values of which were categorized on the basis of the simplified LCA and decided at a workshop) and filled in for each consumer need and weighted accordingly.

	Consumer-Eco Matrix	Conventional consumer Needs on a computer mouse									Total	Pro-portion
		Easy to Grip	Easy Operation	Easy to Clean	Less resistance to the contact area	Big action range	Less weight	Confortable size	Easy and various accesibilities	Accesories (housing color change)		
	Weighting	0,2	0,172	0,148	0,153	0,109	0,07	0,05	0,05	0,02		
Environmental Aspects	Consume less material	9	3	6	6	0	9	9	3	9	5,53	0,17
	Easy to disassemble and part sorting	6	3	3	0	0	0	9	6	9	3,09	0,09
	Use renewable materials	3	0	6	6	0	9	3	0	6	3,31	0,10
	Easy to transport and storage	0	0	0	0	0	9	9	0	6	1,20	0,04
	Use materials causing low environmental impact	6	0	6	6	0	3	0	0	6	3,34	0,10
	Use recyclable materials	3	0	6	6	0	9	3	0	6	3,31	0,10
	High durability	6	0	3	6	0	6	3	0	6	3,25	0,10
	Reduce energy consumption	0	6	0	9	9	6	3	0	0	3,96	0,12
	Easy to maintain and repair	0	0	9	0	0	0	3	3	6	1,75	0,05
	Easy to reuse	0	0	0	3	0	0	0	9	9	1,09	0,03
	Low environmental risk during use	9	0	3	0	0	0	0	0	0	2,24	0,07
	Reduce packaging	0	0	0	0	0	9	9	3	9	1,41	0,04

Figure 4: The Consumer-Eco matrix for development of an eco-mouse

The results of the table are the prioritization of the environmental aspects. The importance values of both the environmental aspects and consumer needs can be illustrated in one graph, since they have the same unit (percentage). Figure 5 shows the results.

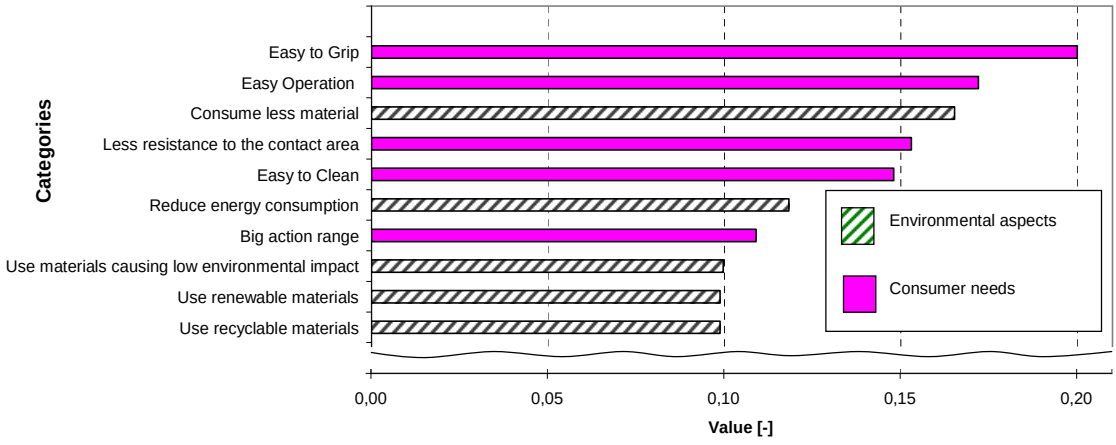

Figure 5: The importance of categories concerning a computer mouse

The six most important criteria for developing an eco-mouse are: ‘easy to grip’, ‘easy operation’, ‘consume less material’, ‘less resistance to the contact area’, ‘easy to clean’, and ‘reduce energy consumption’, respectively. In order to realize the identified important requirements in the product design, one can link them systematically to the product parts. This step is executed in the Eco-QFD Main Matrix described in the following section.

2.2.2 The Eco-QFD Main Matrix

The important criteria identified above relate differently to each product part. These ‘relationships’ for the computer mouse parts are evaluated in the Eco-QFD Main matrix (Figure 6).

There are few parts in a computer mouse: ‘housing-upper side’, ‘housing-bottom side’, ‘scrolling wheel’, ‘Printed Circuit Board (PCB)’, ‘button elements’, ‘transmission technology part’, and ‘sensor technology part’. These parts are listed in the upper row in the matrix. The middle cells express the importance of the relationships of each part to each criterion.

Eco-QFD Main Matrix			**Product Components**						
	Consumer Needs	Weighting	Housing-upper side	Housing-bottom side	Scrolling wheel	PCB	Button elements	Transmission technology	Sensor technology part
Conventional Consumer Needs	Easy to Grip	0,20	9	0	0	0	6	0	0
	Easy Operation	0,17	9	9	9	3	9	6	6
	Easy to Clean	0,15	9	9	3	0	3	0	0
	Less resistance to the contact area	0,15	0	9	0	0	0	0	3
	Big action range	0,11	0	0	0	0	0	9	0
	Less weight	0,07	9	9	3	6	3	6	6
	Comfortable size	0,05	9	9	6	0	6	0	0
	Easy and various accesibilities	0,05	0	0	3	9	0	9	9
	Accesories (housing color change)	0,02	9	0	0	0	9	0	0
	Consumer needs : Total		5,94	5,34	2,65	1,39	3,88	2,88	2,36
	Proportion (relative importance)		0,24	0,22	0,11	0,06	0,16	0,12	0,10
Environmental Aspects	Consume less material	0,17	9	9	3	3	3	0	0
	Easy to disassemble and part sorting	0,09	9	9	6	9	6	3	3
	Use renewable materials	0,10	9	9	0	0	9	0	0
	Easy to transport and storage	0,04	9	9	0	3	0	0	0
	Use materials causing low environmental impact	0,10	9	9	0	9	9	0	0
	Use recyclable materials	0,10	9	9	3	3	3	0	0
	High durability	0,10	9	9	0	6	9	0	0
	Reduce energy consumption	0,12	0	0	0	9	0	9	6
	Easy to maintain and repair	0,05	9	9	0	3	6	0	0
	Easy to reuse	0,03	9	0	0	9	0	6	0
	Low environmental risk during use	0,07	3	3	0	0	0	9	0
	Reduce packaging	0,04	9	9	0	9	0	0	0
	Environmental Aspects : Total		7,53	7,24	1,35	5,10	4,32	2,14	0,99
	Proportion (relative importance)		0,26	0,25	0,05	0,18	0,15	0,07	0,03
	SUM - Total		13,47	12,58	4,00	6,49	8,20	5,02	3,35
	SUM - Proportion (relative importance)		0,51	0,47	0,16	0,23	0,31	0,19	0,13

Figure 6: The Eco-QFD Main Matrix for a computer mouse

The table shows that the ‘housing-upper side’, ‘housing-bottom side’, ‘button elements’, and ‘PCB’ are the four most important parts, respectively (Figure 7). These parts have a greater importance than all the rest of the components. Product designers should concentrate on these parts for the best results As one can see from the result, housing and PCB of a computer mouse have the highest importance. PCB causes more environmental impact compared to housing, however it is not the most important part because housing has a greater relative importance to consumer needs which are more important decision making criteria for purchasing than environmental aspects.

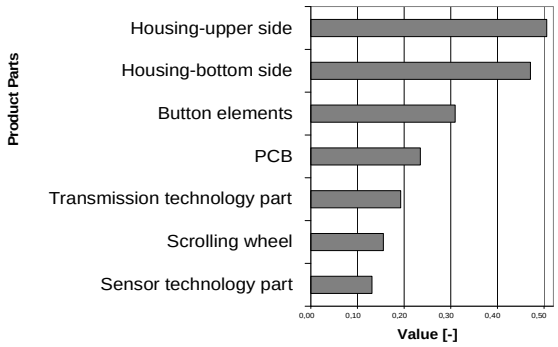

Figure 7: Component priorities for an eco-mouse

One other important merit of the Eco-QFD main matrix is the provision of an overview of the criteria per part in order to improve the part. To use 'housing-upper side'as an example, one can distinguish the importance of the criteria relevant to this part (Figure 8). They are 'easy to grip', 'easy operation', 'consume less material', 'easy to clean', and so on, respectively. Among them, three criteria are consumer needs. This means, 'housing-upper side' has strong 'relationship' with consumer needs on a computer mouse.

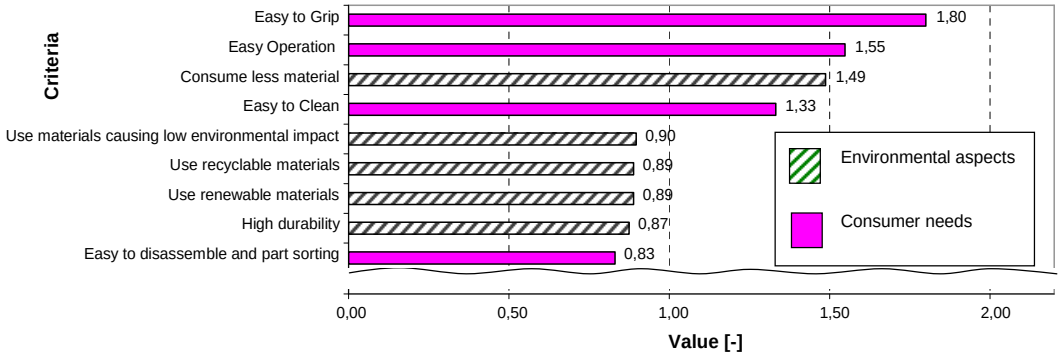

Figure 8: Criteria priority for 'housing-upper side' of computer mouse

On the other hand, the chart in Figure 9 shows the criteria for the PCB. The four most important criteria are 'reduce energy consumption', 'use material causing less environmental impact', 'easy to disassemble and part sorting', and 'high durability'. All these four criteria are environmental aspects. Therefore, the designer could conclude that focusing on the PCB would deal with significant environmental impact. However, as shown in Figure 7 housing is prioritized before to PCB when considering consumer needs and environmental aspects together. Unlike in the case of a computer mouse, in cases where products have numerous product parts, the designers can choose the most important parts based on this analysis, in order to achieve high efficiency. These selected product parts go, consequently, to the next step: product specification process.

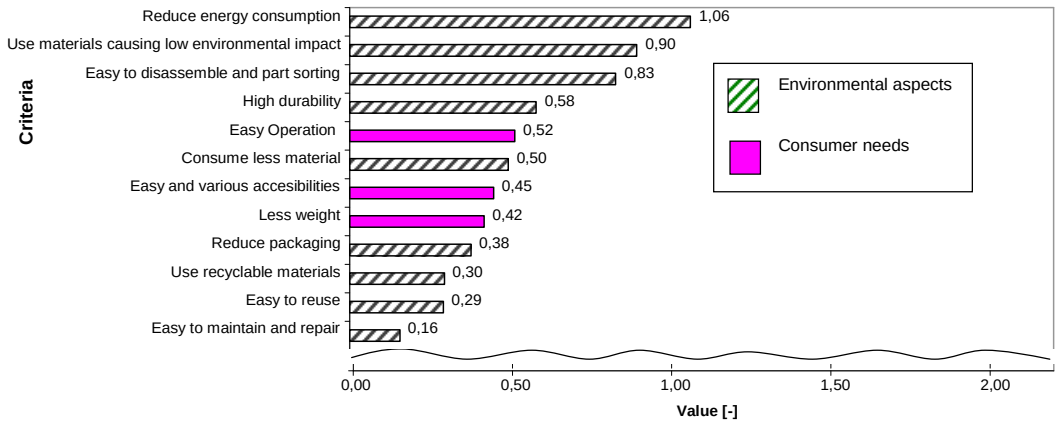

Figure 9: Criteria priority for 'PCB' of computer mouse

2.3 Eco-MEC Application for the Eco-mouse

Marketers are well aware that consumers often think about products and brands in terms of their benefits rather than thier features [13]. This means environmental aspects (features) of a product are not so important to consumers unless they recognize and understand the benefits to them. Therefore, Eco-Means End Chain (Eco-MEC) has been developed in order to establish a connection between environmental features with consumer benefits as shown in Figure 10 [17] [18]. Environmentally friendly features produce less of an environmental burden. However, the environmental feature affects its 'functionality' as well. Hence, environmental features of a product have both functional and environmental consequences. Therefore, the Eco-MEC Model has two chains, the function chain, and the environment chain (Figure 10).

Environmental features can be strategically divided into two attribute groups; main environmental attributes and sub environmental attributes. The classification of main and sub environmental attributes is related to product functions. There are main attributes, e.g. the scent of a perfume, which consumers consider to be very important, since it is related to the main function of the product. On the other hand, there are sub attributes, which are not as important as the main attributes but can be a deciding factor to the consumer's purchase (e.g. the design of the perfume's spray nozzle). The main environmental attributes and sub environmental attributes for the developed eco-mouse are shown in Figure 10.

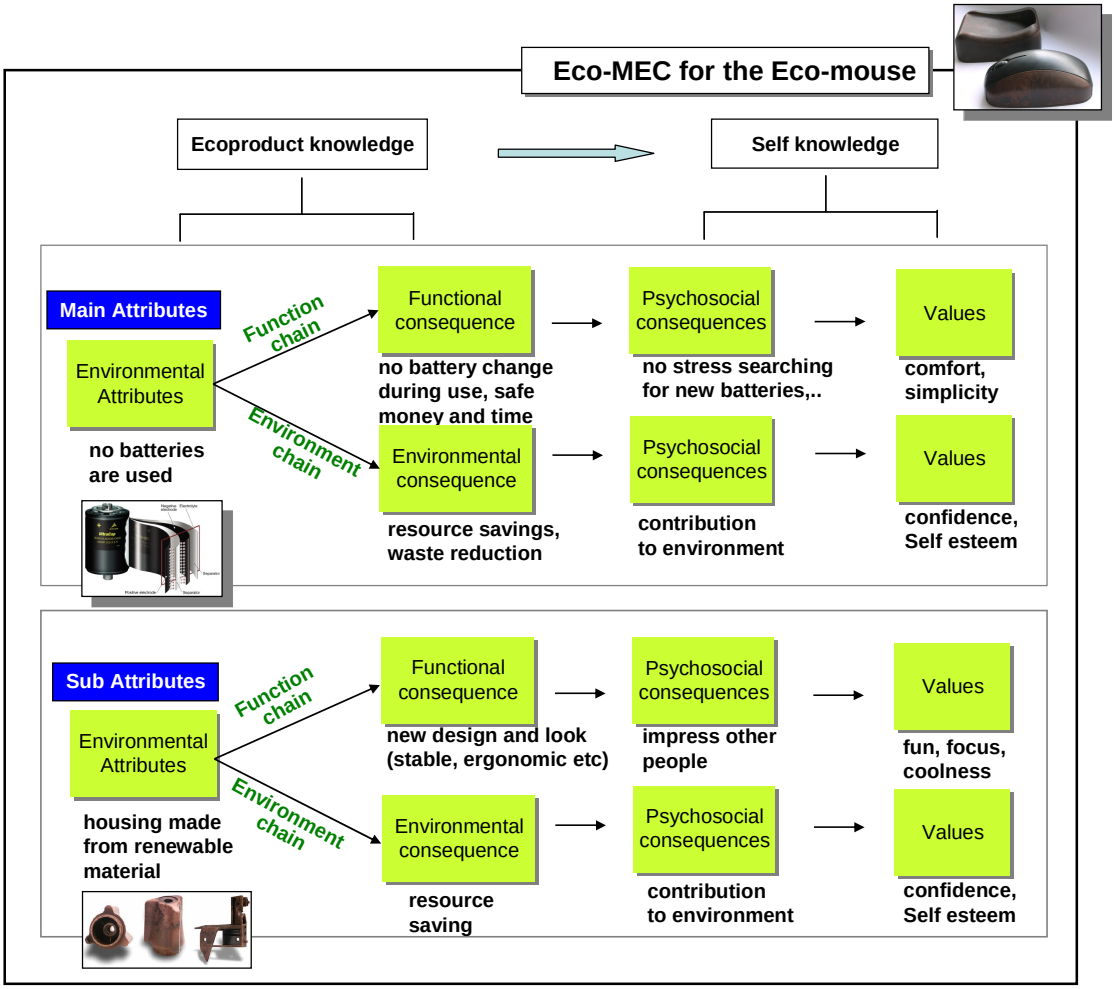

Figure 10: Eco-MEC for the eco-mouse (ref. the Eco-MEC Model [18])

One of the main environmental features is, for example, 'no batteries are used', which has a relationship with the functional use of a computer mouse (use consumes energy). The functional consequences of this attribute are as follows: one does not have to change batteries any more (but the wireless functionality is given), and it saves money and time to buy new batteries. The psychosocial

consequences are ‘no stress searching for new batteries’ and saving the maintenance costs. The environmental consequences of this aspect are resource saving and waste reduction. Both these consequences can give the consumer a feeling that he/she contributes to environmental conservation. Both upper and lower chains give the consumer finally the benefit of ‘self-esteem’.

2.4 Prototype development

Based on the user survey, the Eco-QFD and Eco-MEC analysis the relevant strategies to design a consumer-oriented mouse were established. The user survey showed that the consumer had a clear idea of the technology that should be used. So a wireless optical mouse was the basis of further developments.

Moreover, the Eco-QFD indicated that two main parts were relevant for development work:

Housing including the buttons

PCB

To meet the customer needs as well as ecological improvement options different features were implemented in the Eco mouse.

To satisfy the requirements for the PCB like “Reduce Energy consumption”, “use material causing low environmental impact” and “high durability” an energy accumulating system by means of double layer capacitors was developed. This solution of energy accumulating has a long lifetime, because the capacitors used have no memory effect and so there is no deterioration in performance. This means that the capacitors don’t have to be replaced for the complete lifetime of a computer mouse. Furthermore, a circuit to switch off the mouse when it is charging and an energy management system was implemented to reduce the energy consumption. Charging is also possible using the USB-port. So it is not necessary to use the external power supply and the no load losses can be saved. Figure 11 shows the charging time and the use time for the use of the external power supply and the USB Port (achieved results of the first prototype).

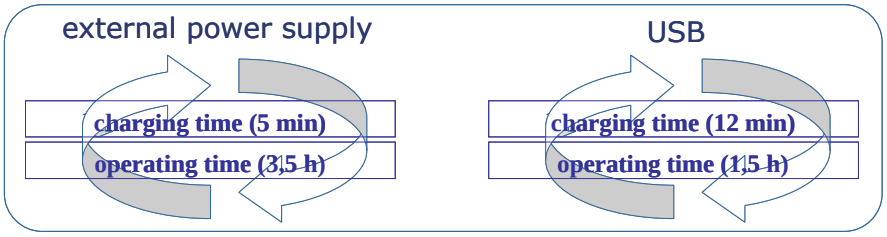

Figure 11.Use and charging times of the eco mouse

Another feature of the eco mouse is housing made of Aboform. Arboform is a renewable material based on lignin and natural fibers, it has a consistency similar to wood, and its process ability is comparable to plastics. The material allows for economical and efficient processes – less waste plus unproblematic processing, when compared to wood – while being similar in appearance. So criteria like “consume less material” and “use renewable material” can be met. To allow easy operation and easy disassembly the mouse as well as the charging station is joined by only one screw and the buttons are made of a single part.

2.4.1 User tests and identification of shortcomings

The build prototype was tested in a real office environment. For this goal 80 pieces of “eco-mouse” prototypes were manufactured by the Centre of Excellence KERP and sent to the test persons. For the collection of test results an online questionnaire was prepared. Finally 68 test reports were delivered from the test users. The results are summarised below.

Regarding the housing parameters, testers were questioned about material quality, material smell and the physical housing design. For more than 50% of users the material quality (surface feel) and the smell was assessed negatively or as needing improvement. For almost 60% of users the physical design was too large and the weight was too heavy. Regarding the physical design for more than 35% of users reported operation hand fatigue (mainly because of the ergonomics).

A very important test aspect was to evaluate the power system. An indicator for that was the charge- and discharge-times. Almost 60% users could work with the mouse between 2 and 3 hours by

charging with the power supply and about 55% could work between 1 and 2 hours by USB-charging. The results are shown in Figure 12.

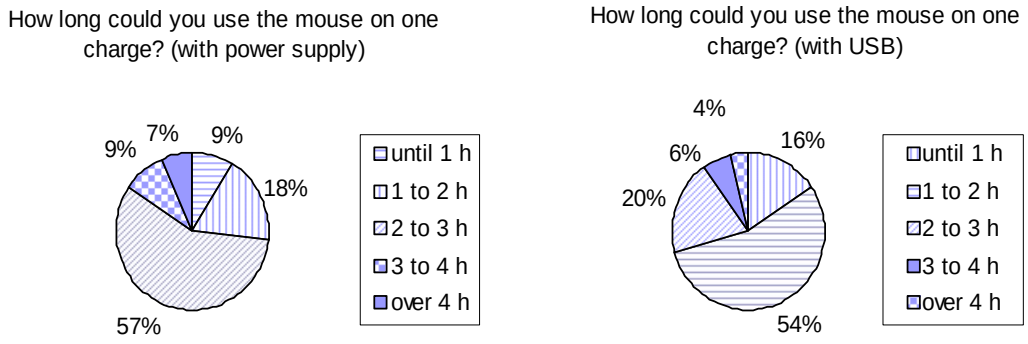

Figure 12.Test results: use and charging times of the eco mouse

For more than 55% users the usage time by USB-charging was not long enough (causing forced work breaks). By power supply charging the number decreased to 38% of users.
We also asked for redesign improvement suggestions for the eco-mouse. Some results are shown in Figure 13 (left are the most important aspects and right the less important).

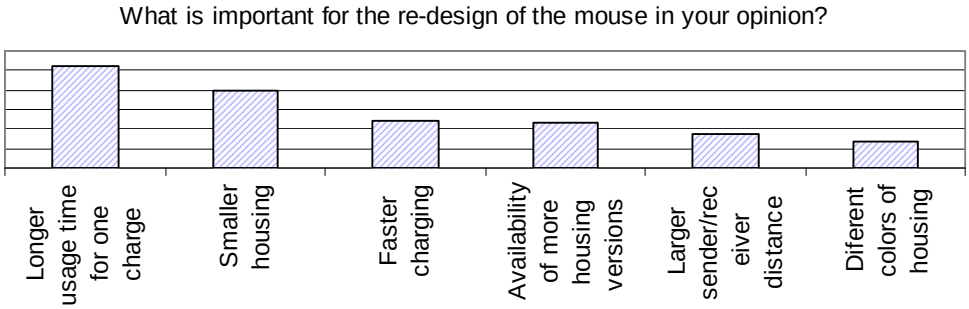

Figure 13.Test results: redesign suggestions – test user view

An interesting finding of the questionnaire was gained from the answers to the questions: “Is the idea of an ecologically friendly mouse in your opinion interesting?” and the question: “Would you buy the eco-mouse?”. For 98% people the eco-mouse is a good idea, but only 45% would buy it.
As important the results of Eco-QFD and Eco-MEC are, this project shows that not all customer needs can be considered using the product concept alone. During the test phase with a real product (prototype) the user identifies issues which can be essential but not considered before the test. So the Eco-mouse test phase identified significant new design requirements which were not considered before and could have created problems with the consumer acceptance and finally with the market success.

2.4.2 Development of improvement strategies

After the prototype test phase a number of product-redesign improvement strategies and measures could be developed. The most important strategies are summarised below (ordered by relevance):

- Extension of usage time with one charging
- Ergonomic and smaller mouse housing
- Smaller receiver housing / revision of the function principle
- Reduction of charging time
- Reduction of housing material smell / research into material alternatives
- Extension of sender/receiver distance
- Easier operation of the charging process

3. CONCLUSION

Integrating consumer needs into the eco-design process is a key success factor of eco-products on the market. For this aspect this paper introduced two development methods: the 'Simplified Eco-QFD' and the 'Eco-MEC'. The 'Simplified Eco-QFD' was developed to harmonize the environmental aspects with consumer needs, which conventional Quality Function Deployment cannot achieve. In addition, the 'Eco-MEC' enables the combination of environmental aspects of a product with consumers' benefits. These methods were verified by a real product development project: the 'Eco-mouse' project.

Both methods (eco-QFD and eco-MEC) submit a systematic approach for a comprehensive design of ecologically sound products and initiate a consumer oriented product improvement process. In turn the eco-attributes (and benefits) of a product will be better understood, accepted and finally appreciated by the consumer.

Accurate identification of real consumer needs and expected benefits not only allows for better market opportunity but also generates a specific identification of concrete improvement measures and ideas of product in the eco-design process. In result we can achieve precise designed ecologically sound products which will be treasured by consumers and ensure effective reduction of the environmental impacts.

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