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PARAMETRIC ECODESIGN – AN INTEGRATIVE APPROACH FOR IMPLEMENTING ECODESIGN INTO DECISIVE EARLY DESIGN STAGES

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1. Introduction

Experience from industry projects shows that accompanying companies during their product development process can effectively lead to the establishment of Life Cycle Thinking, green product concepts and environmentally sound products [Pamminger, Huber, Wimmer 2007]. Various tools, approaches and methods are already available which can assist product development engineers in tracking the environmental contribution of their products throughout their life cycle [Ostad-Ahmad-Ghorabi, Wimmer 2005, Lofthouse 2006]. Based on the evaluation of existing products which are already available on the market, these tools help to improve the product in further designs.

However, integrative approaches for implementing Ecodesign into the early decisive design stages usually confront designers and engineers in product development with a huge amount of data, numbers and facts. To be able to visualize life cycle assessment data and to ease their use in the early design stages, the Ecodesign Decision Boxes (EDB) were developed [Ostad-Ahmad-Ghorabi, Wimmer, Bey 2006]. This paper describes the further development of the methodological approach of the EDB which aims at gaining parametric reference models for environmental evaluation and for an effective implementation of Ecodesign into design stages, respectively.

2. Objective

The methodology of parametric Ecodesign incorporates proposing reference products systematically and will help using life cycle assessment data to optimize product designs and to implement Ecodesign strategies already in the early stages of product development. The parametric description of the reference product correlates technical and environmental data. This is done to track and influence the environmental contribution of each extracted parameter (e.g. type and amount of materials used, process technologies, surface treatment, etc…). At the same time a comparison of the resulting environmental impacts of a certain design with an appropriate reference of this product is facilitated. Just as with traditional product life cycle models, the parametric model allows tracking and comparing environmental impacts for the whole assembled product as well as for its sub-assemblies, components and parts.

Furthermore, due to the lower degree of detail regarding data (e.g. no specific materials but general material classes) the parametric model supports the designer in keeping an overview over all product life cycle stages and thus supports avoiding sub-optimisations in the form of environmental gains in one life stage potentially being overcompensated by environmental losses in another stage.

Parametric Ecodesign relates closely to the simplification concepts of aggregating "product families" and "data classes":

- A "product family" is defined as a group of products which have common characteristics, either from a functional or from a technological point of view [Lenau et al. 2002]. Within a product family, knowledge gained from detailed environmental analyses on one member of the family – the reference product – can be extrapolated and used to a certain extent for other members of the family. Thus, a lot environmental knowledge will already exist when developing new products within the same family.
  Functional familiarity applies to products which can be used to deliver the same functionality or service, e.g. "mobile telecommunication". Technological familiarity applies to products which use the same technology to deliver the functionality or service. Such technological familiarity applies to e.g. products with electric motors – their technology delivers "controlled, rotational movement of parts" in a great variety of products and applications. In a larger Danish project on environmental improvements based on product families [Lenau et. al. 2000] all five product families were based on technological familiarity.
- The concept of environmental "data classes" builds on the idea that materials as well as life cycle processes (e.g. manufacturing processes, distribution processes, etc…) can be clustered into classes according to their characteristics regarding selected environmental parameters, e.g. CO_2-equivalents per kilogram of a material. Under the precondition that technically required material-process-relations are payed attention to, environmental data classes can simplify the generation of environmental profiles for product concepts and thus support decision-making in ecodesign work.

A challenge in both concepts is to define the scope of a product family or environmental data class appropriately. The bigger the family or class is chosen, the less well-fitting the environmental results get, and the narrower the family or class is chosen, the more time-consuming data collection and life cycle modelling work will be necessary.

3. Method

Gaining an adequate reference model is a sub-step in establishing an integrative implementation of Ecodesign in product design. For the development of first approaches for extracting a reference product, product data from a multinational company producing office chairs were taken into account. Herefore, different office chairs with different designs were considered.

In order to model the first life cycle stage, all materials used in the considered office chairs were tracked and evaluated. These materials can all be classified into seven classes. Using CO_2–equivalents emmissions as a parameter for environmental impact, the materials used in the office chairs can be classified as shown in Table 1.

The size of the class (C_S) results from:

$$C_S = Max/Min \qquad (1)$$

C_S allows appropriate resolution of data; a small C_S must be chosen where more detailed and precise data is needed, and bigger where not. As with product families, choosing the appropriate scope for C_S determines the amount of data to be handled and the time needed for environmental evaluation.

The average value for the class C_A is calculated by:

$$C_A = \sqrt{(Min \cdot Max)} \qquad (2)$$

The averaged value for class M_I is defined to be 700 g CO_2-eq/kg, the one for class M_{VII} is defined to be 20.000 g CO_2-eq/kg. C_A is used as a representative value for the class; all defined parameters (e.g. materials, processes, etc…) in a certain class are expressed by C_A for environmental evaluation.

A typical office chair design consists of the following subassemblies :

1. Base
2. Mechanism
3. Seat

4. Back

and often but not necessarily

5. Arm rests

Table 1. Material classes

Material class	Range [g CO_2-eq/kg]		Size of class C_s	Average C_A [g CO_2-eq/kg]	Example
	Min	Max			
M_I	0	1000		700	Unalloyed steel,
M_{II}	1000	1500	1,5	1225	Low alloyed steel
M_{III}	1500	2500	1,7	1936	ABS with 30% glass fibre
M_{IV}	2500	5000	2,0	3536	PUR, PS, LDPE
M_V	5000	10000	2,0	7071	PC, PA, Nylon
M_{VI}	10000	15000	1,5	12247	Aluminium 15% recycled
M_{VII}	15000	max		20000	Polyester

The idea now is to provide an easy to apply systematic approach to generate reference products for the considered parts and components to the product developer. This generated reference product represents the current environmental profile of the product. The first life cycle stage of a newly designed product can be improved by aiming at using materials of lower material classes. Comparison of the impacts of the reference product and of the new product concept helps to track potential changes of the environmental profile related to the decisions made during design.

The same approach as for the materials in the first life cycle stage of the product can be used for each of the other life cycle stages of the product, i.e. manufacture, distribution, use and end of life – of course bearing in mind technologically realistic combinations of materials, manufacturing processes and end-of-life processes. This approach leads to data classes for the entire life cycle. Table 2 shows data for manufacturing processes classes.

Table 2. Manufacturing process classes

Class	Range [g CO2-eq/unit]		Average C_A [g CO2-eq/unit]	Example
	Min	Max		
P_I	0	100	70	Welding per m
P_{II}	100	500	224	Wire drawing kg, , polishing per kg
P_{III}	500	1000	707	Injection moulding per kg, painting per m^2,
P_{IV}	1000	2000	1414	Coating glass per m^2, Anodising per m^2
P_V	2000	4000	2828	Powder coating Aluminium per m^2
P_{VI}	4000	8000	5657	Pressure die casting per kg
P_{VII}	8000	Max	8500	Enamelling per m^2

In early design stages of products, e.g. of the office chair, the following parameters are defined, changed and optimized continuously amongst others:

6. Material selection and correlated to that

- manufacturing processes and surface treatment

Different materials may require different manufacturing processes and also different surface treatment. In the following, the example for the design and variation of the components "Base" and "Back" of the office chair and the change of environmental impact is demonstrated by generating an adequate reference product.

4. Application

First application of data classes show that the deviation of using classes instead of detailed LCA analysis is within acceptable scopes. Figure 1 shows the comparison of the environmental evaluation of the components "Base" and "Back" of a office chair. The results include the environmental impact of the used materials, of the manufacturing processes and the surface treatment.

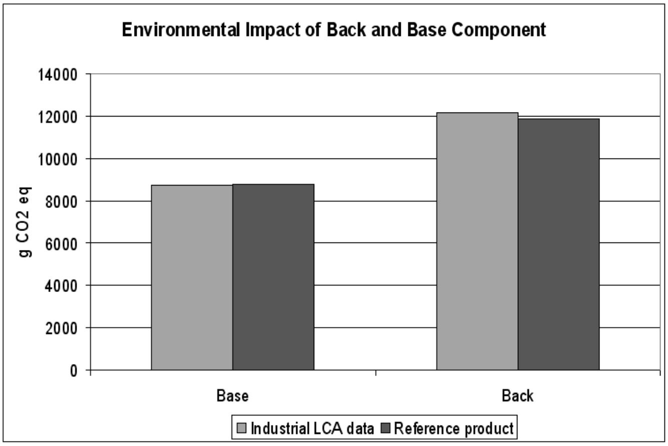


Figure 1. Comparison of detailed LCA data and using data classes

In case of material choice, the deviation of the environmental impact of the "Base" component is 0.5% when using material classes instead of detailed LCA data. The deviation of the Back component is 2.5%. Further calculations show that the total environmental impact deviation of the different office chairs through their whole life cycle remain under 10% when using data classes. Since environmental data classes ease the establishment of a reference product and may reduce the amount of different quantified data needed, this approach is a useful one to be implemented in early design stages by engineers.

By aiming at a new design for a component, e.g. for the Base component of the office chair, the results from Figure 1 can be taken to generate a reference product. Table 3 sums up the data used to generate a first reference product by using data from Table 1 and Table 2.

Table 3. Environmental impact of the reference Base component using data classes

Reference Base					Total [kg]	Total $g\text{-}CO_2$ –eq	$g\text{-}CO_2$-eq/kg Base
Materials	3.804 kg (ASt35)	0.044 kg (ABS)	0.16 kg (PA6GF30)	0.563 kg (PP)	4.57		
Class	M_{II}	M_{IV}	M_V	M_{II}		6637	1452
Manufacturing	Welding & cold transforming	Injection moulding	Injection moulding	Injection moulding			
Class	P_I	P_{III}	P_{III}	P_{III}		1075	
Surface	Polishing						
Class	P_{II}					590	
					Total	8302	1817

The question to be answered now is how a variation in design will affect the occurring environmental impacts. It is important to develop a sense whether the impacts are high or low. The current modeled

Base in Table 2 gives an adequate reference. Another task to be fulfilled is that the evaluation of the environmental performance and environmental impact respectively should be as easy as possible by using as less as possible different quantitative data. The defined material classes guarantee the latter point.
Table 4 and Table 5 show different design realizations of the Base component. To achieve a different design, different materials with different amounts are used. This change requires a change in the manufacturing processes as well as in the surface treatment.

Table 4. Environmental impact of Base 2 using data classes

Base variant 2				Total [kg]	Total g-CO_2 –eq	g-CO_2-eq/kg Base
Materials	3.38 kg (ASt35)	0.03 kg (PP)	0.674 kg (PA66)	4.08		2190
Class	M_{II}	M_{II}	M_V		8942	
Manufacturing	Welding & cold transforming	Injection moulding	Injection moulding			
Class	P_I	P_{III}	P_{III}		971	
Surface	Painted					
Class	P_{III}				952	
				Total	10865	2663

Data for the Base variant 2 in Table 4 show that by combining different materials a reduction of the weight of the Base component was achieved. Although the weight reduction is up to 11% compared to the reference Base in Table 3, the environmental impact is increased significantely by 47% due to the increase of the use of materials of class M_V and due to the different surface treatment needed (class P_{III} surface treatment instead of P_{II})
The numbers in Table 5 point out the differences to the reference Base even clearer. Base 3 was designed aiming at an advanced lightweight design and a significant optical difference to the reference Base and Base 2. Therefore, aluminium was used to design and produce Base 3. The main manufacturing process for this Base is pressure die casting. Anodising was the main process to create a bright surface of the Base.
The weight of Base 3 is 40% lighter than the reference Base but at the same time shows an increase in the occurring environmental impact up to 870% .

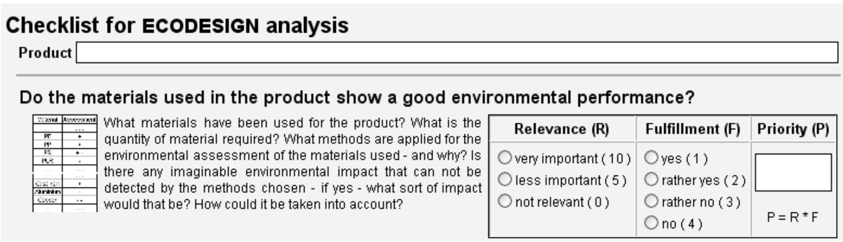
Table 5. Environmental impact of Base 3 using data classes

Base 3			Total [kg]	Total g-CO_2 –eq	g-CO_2-eq/kg Base
Materials	2.05 kg (Aluminium 15% recycled)	0.675 kg (PA66)	2.725		
Class	M_{VI}	M_V		29879	10965
Manufacturing	Pressure die casting	Injection moulding			
Class	P_{VI}	P_{III}		12074	
Surface	Anodised				
Class	P_{IV}			1272	
			Total	43225	15862

The introduced approach allows further variations and changes in design with parallel tracking of the occurring environmental impacts.

5. Results

Applying the introduced approach helps to track the influences of the decisions made during design on selected, related environmental impact in early design stages. By knowing the potential environmental impacts and by being aware whether selected impacts, e.g. g-CO_2-eq, become higher or lower due to design changes, an optimization of design and environmental performance can be achieved in those stages of product development where minimum effort is needed and maximum benefit can be achieved. Also, appropriate strategies for the optimization and improvement of the design can be extracted. For the example of the Base component one useful strategy is to reduce the amount of used materials of upper classes. To improve the Base component environmentally, lower material and process classes should be selected during product development – while still keeping in mind technologically possible or necessary combinations of materials and processes. This strategy can be followed through the entire life cycle of the chair; using parameters and data from lower classes through the life cyle will reduce the selected environmental life cycle impacts. The holistic life cycle view will avoid that environmental impacts are shifted from one life cycle to another life cycle.
The Ecodesign PILOT [Wimmer, Züst, Lee 2003] with its checklists help to find appropriate improvement strategies for all of the life cycle stages of a product. Figure 2 shows an adequate checklist selected for the considered Base component.


Checklist for ECODESIGN analysis

Product

Do the materials used in the product show a good environmental performance?

What materials have been used for the product? What is the quantity of material required? What methods are applied for the environmental assessment of the materials used - and why? Is there any imaginable environmental impact that can not be detected by the methods chosen - if yes - what sort of impact would that be? How could it be taken into account?

Relevance (R)	Fulfillment (F)	Priority (P)
very important (10)	yes (1)	
less important (5)	rather yes (2)	
not relevant (0)	rather no (3)	
	no (4)	P = R * F

Figure 2. Ecodesign Checklist suitable for the development of different office chair components

6. Outlook

A current project of the Vienna University of Technology (VUT) with an international crane producer shows that engineers in design are not willing to handle too much additional data and parameters for the environmental evaluation of products. Introducing effective but too complex methodologies will lead to a decline of these methodologies and endager the implementation of environmental issues in early design stages. Therefore an approach with manageable amount of data is needed.
The introduced approach reduces the amount of data by classifiying them. Environmental data classes are based on LCA data. The construction of a reference product allows a comparison of the design under development with designs already realized. Using parametric life cycle models and environmental data classes, e.g of materials and manufacturing processes – both incorporating a lower amount of specific environmental data – the designer's attention can more easily stay on the whole product life cycle and thus reduce sub-optimizations and overcompensations in a life cycle perspective. While working with environmental data classes within one life cycle stage shows practicable implementation without major implications, the finding of technologically feasible realistic combinations of e.g. materials and manufacturing processes as well as end of life processes and related consequences is today highly based on the product developers experience. Support of designer in this life cycle stage-crossing issue of combinations of different processes is part of further research.
Currently the VUT is working on the implementation of the introduced approach into PLM and CAD software to be able to visualize the quantified environmental data classes and thus environmental impacts of parts, components and products in these softwares. The visualized environmental performance of the design will lead to an integrative implementation of LCA and Ecodesign into design stages.

Furthermore, the current project of the VUT aims at implementing economical aspects into the product evaluation process as well. The optimal design can be found where economical benefit and the occurring environmental impacts are optimized for a product.

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