INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

USING ECODESIGN GUIDELINES FOR CONCEPT EVALUATION: FINDINGS FROM AN EXPERIMENT

I. Midžić, M. Štorga and D. Marjanović

Keywords: ecodesign guidelines, ecodesign methods, concept evaluation, environmental value, eco-value

1. Introduction

One of the most critical decision points in product development process is selecting the concept to be further developed in the design process. Concept selection is preceded by concept evaluation and usually more than one design concept is considered. The results of evaluation of design alternatives strongly influence the outcome of design process, thus selection of the optimal concept for further product development. Evaluation of design alternatives is performed with respect to one or more criteria that represent requirements, constraints and specifications, and enables designers to come up with a set of decisions for selecting the most suitable concept [Zapaniotis and Dentsoras 2011].

Most factors concerning environment and cost are determined in the conceptual design stage [Charter and Tischner 2001]. The realization that environmental friendliness need to be taken into account in the evaluation of concept feasibility together with the other traditional design criteria, has leaded to many methods and tools developed specifically for considering environmental aspects of products in decisive early design stages. However, very few models, methods and tools developed are suitable for evaluating product's concepts from environmental influence viewpoint. Concepts are often imprecise, lacking in detailing, and various aspects concerning the concept of a product are often not defined or are defined at different abstract levels. In conceptual design stage, there is still lack of knowledge about the product that is been developed and product's concepts are developed on a high abstract level.

In early design stages, many aspects relevant to product definition such as product's life cycle are unknown or vague. Mostly, because there is lack of data for life cycle impacts analysis, environmental impact assessment tools are not considered to be suitable for use in conceptual design stage or for concept evaluation purposes. For calculating environmental impacts of the product (and analysis of product's life cycle), it is necessary that it is performed the earliest when product's components are defined, so conclusions regarding product's environmental impacts can be made based upon quantitative data regarding materials, production processes and end-of-life solutions defined and decided upon. Ecodesign methods and tools for analysis of product's life cycle and assessment of its environmental impact comprise majority of ecodesign methods and tools.

Second dominant category of ecodesign methods and tools are design improvement methods and tools [Le Pochat et al. 2007]. There are considerably less ecodesign methods and tools purposed for supporting conceptual design stage of product development. Presented work's objective is to find out if ecodesign improvement methods and tools can accommodate the evaluation of product's concepts, thus can ecodesign guidelines be used for estimating environmental or eco-value of product's concept variants. In the experiment performed, novice designers were given a task to rank product's concept variants according to their environmental friendliness by using Eco-Design Value guidelines developed by Koh et al. [2007]. The method is preferably to be used for managing ecodesign objectives in product development process and consists of a list of predefined and categorized statements about the product's concept in consideration.

2. Motivation

Early design stages are widely believed to have the most influence in defining environmental aspects of products, as well as cost. Studies shows that these development stages influence over 80% of environmental impacts caused by the product [Charter and Tischner 2001]. Decisions taken in early design stages have a higher effect on the final outcome compared to decisions at the end of the design process [Derelöv 2004]. There is less knowledge about the product in early design stages, but still decisions taken have more impact or effect to final product, its features, structure and form. Efforts toward considering environmental aspects during early stages of product design are essential for the burden imposed to the environment along product's life cycle.

2.1 Elaboration of problem to be solved

One of the most crucial decisions in product development is to determine which product concept to develop, since this decision influences the direction of the remaining design activities, as well as quality of the final product [Ullman 1992]. Selecting a poor design concept can rarely be compensated at the later design stages. Changes in later design stages acquire additional costs to development process. Thus, environmental friendliness of product's concepts should be taken into account in the evaluation of concept feasibility together with the other traditional design criteria [Sousa and Wallace 2006].

The majority of methods and techniques for concept evaluation use one or more attributes (characteristics) of product concept variants and examine them with respect to design specifications. As explained by Zapaniotis and Dentsoras, these specifications and targets may come from customer requirements, design constraints or from new decisions made as design evolves [Zapaniotis and Dentsoras 2011]. Each concept's attribute is a reference entity in the evaluation process. Zapaniotis and Dentsoras conclude that relations between attributes (characteristics) of the concept and the 'internal' data about the concept (inherent in the concept description) are not straightforward and obvious, so cannot be systematically referenced. They further conclude that the reasoning process regarding assigning attribute values is thus more or less superficial and relies mostly on subjective, thus empirical estimations. Bearing this in mind, and the lack of knowledge about the future environmental impacts of the product at this product development stage, evaluating product's concepts according to its perceived environmental or eco-value is especially challenging for designers.

2.2 Environmental evaluation of product's concepts and eco-innovation

Recent trends and increase in interest in eco-innovation often emphasized by product developers, companies and customers alike, point out that developing environmentally friendly products and solutions is becoming a major driver for innovation and product development in general. This is particularly the case when developing new and sustainable alternatives to replace well-established environmentally costly products and solutions. In the focus of research presented is enabling evaluation of product's concepts that significantly deviate from its formal archetype (functional innovation). Concepts to be considered are capable of performing the same overall function, while they differ in structure, form, working principles and principle solutions used for implementing the functions and the flows of energy, material and information.

Akermark [2005] categorises new products into four categories, ranging from basic innovations (fundamentally new products with unknown design solutions), new design (products with new or other design solutions), adapted design (products with a slight change of previous solutions), and variation design (products with the same solution, but in a new way). Thus, based upon the innovativeness of the concepts, product's concepts to be considered for evaluation and selection can differ in description, detailing and level of abstraction, which makes it difficult for designers to evaluate their feasibility and environmental value objectively and with high reliability.

3. Background

Most impact on definition and structure of the product developed takes place previous to embodiment and detailing design stages [Lindeman and Lorenz 2008]. However, there is lack of methods and tools specialized for environmental impact, environmental value or environmental friendliness estimation for conceptual design stage. Main reasons for this are: 1) lack of knowledge about the product at this product development stage [Dewulf et al. 2005], [Lindahl 2006], and 2) information and data regarding product's life cycle is incomplete, vague or unknown at this early design stage. Information and data regarding product's life cycle often include information about environmental impacts in each product's life cycle stage, manufacturing processes, raw materials, outputs as emissions and waste, etc.

3.1 Ecodesign methods and tools

More product development processes are directed toward more sustainable product design with respect to the priorities of design sustainability, ecodesign and Design for environment. Sustainable product design is considered to be improvement of products to new products launched where environmental impacts are reduced [Yan et al. 2009].

The greatest number of ecodesign methods and tools exist in the two categories of assessment and improvement methods and tools [Le Pochat et al. 2007], but there are also tools for communication of ideas, tools for helping in decision-making, methods and tools for assisting creativity as stated by Fargnoli and Petruci [2004] and conventional design tools which have been modified to include the environmental aspects such as Quality Function Deployment and FMEA. Knight and Jenkins [2009] identified three large groups of methods and tools: guidelines, checklists and analytical tools. Guidelines such as Design for X tools (Design for recycling, Design for disassembly, etc.) support ecodesign process with little detail, but are applicable to entire product development process and most life cycle aspects. Checklists provide in-depth, but narrow support and are applicable at selected stages of the product development process or life cycle. Checklists allow for analysis of the product to functional characteristics, so are often used when re-designing products [Le Pochat et al. 2007]. Analytical tools provide detailed and usually systematic analysis at specific stages of product development process or its life cycle. There is a wide variety of analytic environmental methods and tools, but they are not ideally fitted for early conceptual design in an integrated modelling context [Sousa and Wallace 2006]. Most dominant methods and tools in this category are: Life cycle assessment, Environmental impact assessment, eco-indicators, Environmental effect analysis, Material, energy and toxicity (MET) matrix, Life cycle cost analysis and so on.

In relation to their purpose, analytic and assessment methods and tools are also used for verifying the improvement of environmentally conscious design, for example improvement of eco-efficiency, product's life cycle performance improvement and degree of reduction of environmental impact. Majority of methods and tools that are quantitative assessment methods and tools are considered to be beneficial for use at later design stages when information and data for calculating product's environmental impact is sufficient. Most assessment and analysis methods and tools can only be applied at later stages of the design process, when at least a material inventory of the product is available [Dewulf 2003].

3.2 Ecodesign guidelines

Due to lack of ecodesign methods and tools specialized for conceptual design development stage, Dewulf proposes to rework generic ecodesign guidelines and ecodesign experience noted in ecodesign manuscripts in order to make them sensitive to the problem situation [Dewulf 2003]. Design guidelines are a collection of general ('universal') rules for ecodesign. Guidelines are simple to use and they are more appropriate to be used by less experienced designers, and supported by additional aids for choosing solutions such as material's databases and checklists in which a designer marks whether each guideline is considered [Le Pochat et al. 2007]. ECODESIGN PILOT [Wimmer et al. 2002] and Ten Golden Rules [Luttropp and Lagerstedt 2006] are probably among the two most well known ecodesign checklist and guideline based tools. Initialy, developing ECODESIGN PILOT as described by Wimmer et al. was aimed specially at providing clear advice on how to implement ecodesign in specific products. Ten Golden Rules are composed from guidelines from different company guidelines and handbooks and other existing ecodesign guidelines. Since guidelines used by companies are company and product specific, authors made Ten Golden Rules more general, so providing a conceptual framework for designer to ask general questions and seek answers in regard to some particular product design challenge. This problematik is elaborated in detail in more recent work by Rossi et al. [2013] in which they argument how general indications (provided by the guidelines) do not represent a concrete support for the designers in the case when general guidelines are consulted for making decisions regarding specific and particular products.

Recently, guidelines for developing environmentally conscious products are developed, for example a conceptual design guide by Lloveras [2013]. Lloveras proposes a guide for analysis of the consumption of energy and water in the conceptual design stage of a product for the purpose of optimization of consumption. The guide is an example of how environmental criteria can be utilized to improve a design solution in conceptual design stage. More developments in the area of ecodesign methods and tools for conceptual stage are oriented towards integrating specific environmental criteria for evaluating design alternatives such as recyclability [Tonnelier et al. 2005] and energy efficiency [Götze et al. 2011].

4. Methodology, research approach and elaboration of the experiment

4.1 Methodology and research approach

As already mentioned, majority of ecodesign methods and tools are life cycle analysis and assessment methods and tools. They are suitable for product's environmental performance analysis throughout its life cycle or environmental impact, sustainability or eco-efficiency assessment. Common feature of mentioned ecodesign methods and tools is determined by the fact that they are developed to be used in later stages of product development, when there is sufficient information regarding the product for conducting assessments and analysis of product's life cycle. Due to relatively smaller number of ecodesign methods and tools that are applicable for conceptual design development stage than for later design stages, Dewulf [2003] proposed that some of ecodesign methods and tools, conventionally purposed for improvement of product design should be customized or slightly modified to make them applicable to a certain conceptual design related problem and situation. Objective of the presented work is to use ecodesign guidelines as eco-value criteria for product's concept evaluation purposes.

Ecodesign guidelines are among the most basic tools in design for environmental improvement of products. They are used for prioritisation of ecodesign objectives by providing a set of general rules to support designers in the process of developing environmentally friendly design. Most guidelines are general, some of them vague or ambiguous, so a question arrises weather designers can judge a certain concept using a general guideline criteria with sufficient certainty. An experiment performed by novice designers is carried out to explore the influence of introducing ecodesign guidelines as criteria of environmental friendliness and eco-value of product's concepts.

Ecodesign guidelines to be used as eco-evaluation criteria for evaluating product's concept variants are found in the work of Koh et al. on analysing ecodesign value system [Koh et al. 2007]. Ten Golden Rules guidelines were also considered, but there is only 10 guidelines and not as detailed as guidelines in Eco-Design Value Matrix [Koh et al. 2007]. Eco-Design Value guidelines is preferably used for managing ecodesign objectives and in an on-going product development process to help designers achieve a more environmentally friendly design. Guidelines are basically a list of predefined statements about the product's concept (or alternative) in consideration, so each statement is eco-value criterion for evaluation. Eco-Design Value Matrix consists of 50 design principles that are potentially guides for designers for establishing design strategies and plans consistently from ecological point of view and also for design development and evaluation purposes.

4.2 Elaboration of experiment and framework for eco-evaluation of product's concept variants

The task for 11 participants was to rank five product concept variants according to their environmental friendliness (or eco-value as perceived by the participants). In the first part of the experiment, participants were instructed to rank the concepts based upon their subjective judgement and opinion about the most environmentally preferred and environmentally undesired concept variants.

After completing that task, participants were asked to perform the ranking of concept variants for the second time, but this time, using ecodesign guidelines from Eco-Design Value Matrix [Koh et al. 2007] as eco-evaluation criteria. Participants have not used Eco-Design Value guidelines before, and were instructed to rank product's concept variants and the scoring system proposed. When scores for the concepts are assigned, the best concept alternative is identified according to the highest score obtained, and on the other hand, the worst concept alternative is to be evident from the lowest score obtained.
Product's concept variants chosen to undergo the evaluation are divergent in terms of their commercial and technical feasibility, and innovativeness in respect to their formal product concept archetype [Midžić and Marjanović 2013]. In this work, chosen formal product concept archetype is conventional laundry washing concept implemented in most washing machines on the market and in households, thus commercially available and technically feasible solution. Other four product concept variants are either commercially viable products on the market (concept variants no. 2 and 5), technically feasible, but still commercially unavailable products and solutions (concept variant no. 3) and concept variant that is yet technically not a feasible solution, but has been a part of design competition of design concepts Electrolux Design Lab (concept variant no. 4). Each concept was presented via concept and working principle descriptions, drawings and figures illustrating working principles and principle solutions, and information about estimated performance of the machines (regarding energy, water and detergent consumption if available) was supplied to each participant of the experiment (Figure 5 a).

4.2.1 Concept no. 1

Conventional washing machines use hot water, detergent and electrical energy to acquire centrifugal force for washing, cleaning and agitating laundry fibres [Germani et al. 2007]. Overview of features of a typical automatic washing machine is further to be found in the work of Webb [2000, p. 176].

4.2.2 Concept no. 2

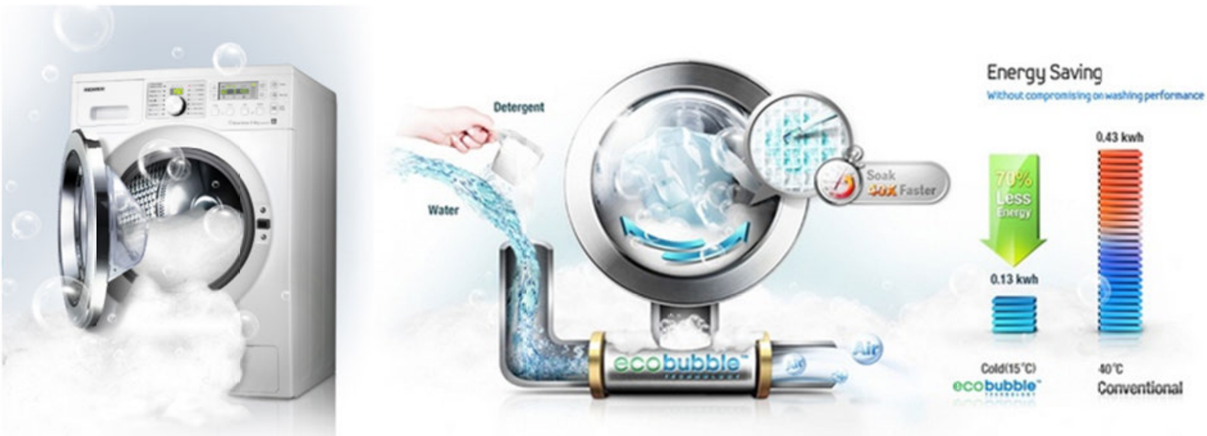
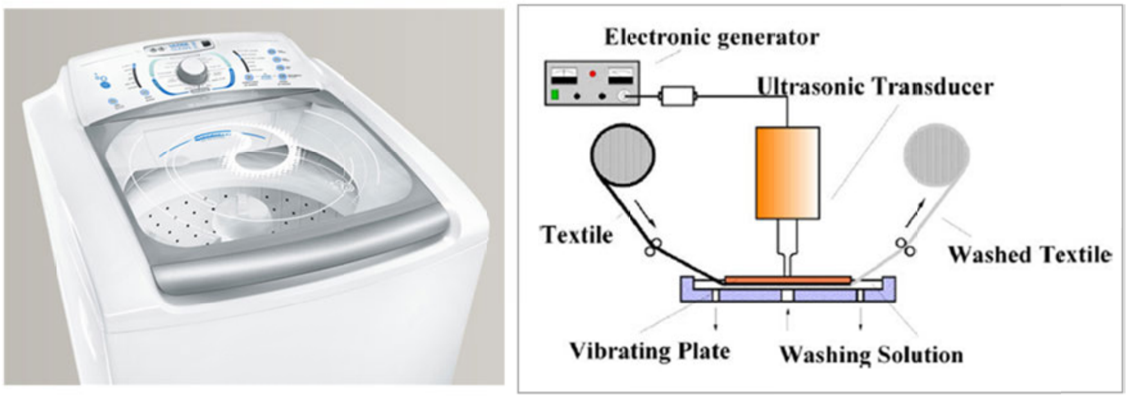


Figure 1. Samsung's EcoBubble™ washing machine ['Samsung' 2013]

EcoBubble™ ['Samsung' 2013] washing machine uses air and water to dissolve detergent and create cleansing foam. The foam penetrates and absorbs evenly into laundry up to 40 times faster than in traditional laundry washing process. EcoBubble™ is commercially available on the market, and in the United States is known as PowerFoam™. The manufacturer (Samsung) claims that laundry washing is performed with less mechanical action, is gentle towards fabrics, maintains efficacy of laundry washing even without the need for hot water and with for energy savings of up to 55 %.

4.2.3 Concept no. 3

Third concept variant is ultrasonic washing machine concept. The difference from its formal product archetype is that laundry agitation is performed by ultrasonic cleaning, e.g. cavitation effect is used to remove the dirt from the fibres and without damaging the fibres. The concept's technical feasibility is demonstrated in the work of Sethi [2012], while its commercial feasibility still remains to be proven on the market. Ultrasonic washing system is patented by Gallergo-Juarez et al. [2010]. The trend of introducing ultrasound cleaning technology for the purpose of cleaning laundry is in increase. As an example, designers at Electrolux developed a washing machine with a pen attached. The pen is designed for removing stains from the clothes and by using water and ultrasound.



a) b)

Figure 2. a) Electrolux Ultra Clean washing machine [‘Electrolux annual report 2011’ 2013], b) Scheme of the ultrasonic system for textile washing [Gallergo-Juarez et al. 2010]

4.2.4 Concept no. 4

Figure 3. ‘Orbit’ washing machine concept [‘Wired’ magazine 2013]; more figures available at [‘Apartment Therapy’ 2013]

‘Orbit’ is a concept washing machine that uses no water and cleans clothes with dry ice. The designer of ‘Orbit’ washing machine Elie Ahovi Electrolux Design Lab competition, an annually competition organized by Electrolux company where innovative product concepts can be presented to eventually one day can be turned into commercial and technical feasible products. Orbit concept is not technically feasible, since large amount of energy is required to power such a machine [‘Wired’ magazine 2013].

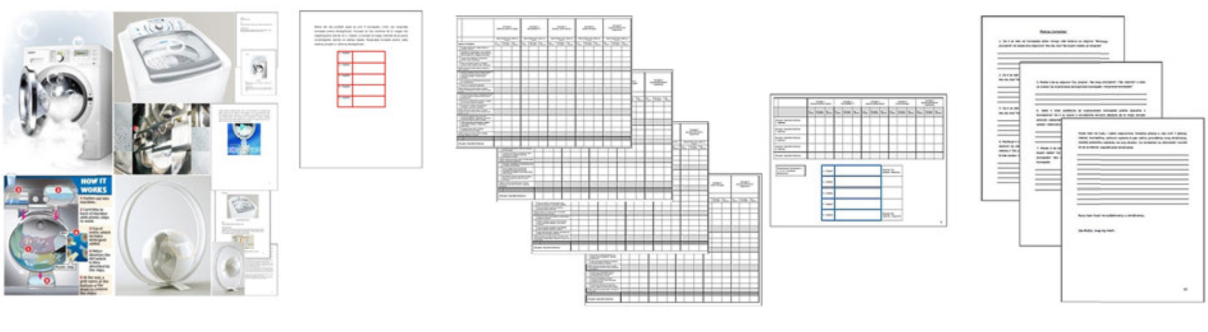
4.2.5 Concept no. 5

Researchers at Leeds University designed the machine, which is marketed by a spin-off company called Xeros Ltd. The washing machine developed uses polymer beads instead of water to clean laundry, so laundry cleaning can be achieved at lower temperatures, and with less detergent than required for traditional laundry washing process [‘Xeros Ltd’ 2013]. Water acts as a lubricant in the Xeros laundry washing process rather than as the main wash medium, so much less water is required for laundry washing. The amount of rinse water is also reduced, due to less detergent to be rinsed away. With the help of centrifugal forces, polymer beads mechanically remove soil and dirty from the laundry. For effective cleaning, around 20 kg of polymer beads is required and one cup of water. 20 kg of bead is sufficient for around 100 cleaning cycles.

The experiment of ranking of concept variants performed by novice designers was organized in two parts. At the beginning, participants were supplied with descriptions of each concept variant, figures to illustrate the solutions and description of working principles of each concept variant (Figure 1 a). Based upon their understanding about concept variants, their functions and working principles, participants were asked in the first step to rank those five concepts according to environmental friendliness of the concepts and based upon their subjective judgement. This rank was noted (Figure 5 b), and in the second part of the experiment, participants were asked to do the same, but this time they were asked to perform the ranking using Eco-Design Value guidelines [Koh et al. 2007].

Figure 4. 'Polymer Beads Cleaning' concept ['Xeros Ltd' 2013]

In second part of the experiment (Figure 5 c), novice designers were tasked to estimate if each of the 50 design principles (check points) are realized by each of the five product concept variants. There were three available answers: *'Yes'* (meaning that the principle or sub-value is inherent to the product concept variant), *'No'* (if on the contrary the principle or sub-value is not inherent to the product concept variant) and *'Estimation cannot be made'* (if the designers could not make a sound evaluation about the principle or sub-value, and due to insufficient information about the concept variant, attributes, characteristics or properties). Scores were then assigned for to the answers: 1 for *'Yes'*, -1 for *'No'* and 0 for *'Estimation cannot be made'*. Experiment ended with a questionnaire to the participants (Figure 5 d) regarding their experience as novice designers with ecodesign and concept evaluation and to allow them to report back additional comments regarding concepts, ecodesign guidelines and experiment in general.



a) b) c) d)

Figure 5. Prepared samples for conducting the experiment (procedural steps of the framework for eco-evaluation of product's concept variants)

5. Results

Results from individual participants' rankings of product concept variants indicate that majority of the participants ranked ultrasonic washing machine concept and EcoBubble™ concept as environmentally most preferable concepts. Also, according to their subjective preference, 'Orbit' concept and 'Polymer Beads Cleaning' concept were ranked at the bottom of the scale, so least environmentally favourable concepts.

Table 1. Comparison of results of ranking of concept variants (average)

Ranking level no. (1.-5.)	Results from first ranking of concept variants					Results from ranking of concept variants when using Eco-Design Value guidelines and scoring procedure				
(best concept) 1.	Concept no. 3 (64%)	Concept no. 2 (36%)				Concept no. 3 (55%)	Concept no. 2 (36%)	Concept no. 1 (9%)		
2.	C.n. 4 (46%)	C.n. 3 (27%)	C.n. 5 (9%)	C.n. 2 (9%)	C.n. 1 (9%)	C.n. 2 (46%)	C.n. 3 (18%)	C.n. 1 (18%)	C.n. 5 (9%)	C.n. 4 (9%)
3.	C.n. 5 (37%)	C.n. 2 (27%)	C.n. 4 (18%)	C.n. 3 (9%)	C.n. 1 (9%)	C.n. 5 (27,5 %)	C.n. 1 (27,5 %)	C.n. 2 (18%)	C.n. 3 (18%)	C.n. 4 (1%)
4.	Concept no. 1 (55%)	Concept no. 2 (27%)				C.n. 5 (36,5%)	C.n. 4 (36,5%)	C.n. 1 (18%)	C.n. 3 (9%)	
5. (worst concept)	Concept no. 4 (36%)	Concept no. 5 (36%)	Concept no. 1 (28%)			Concept no. 4 (46%)	Concept no. 5 (27%)	Concept no. 1 (27%)		

However, the distribution of average scores for the second and third ranking levels indicate that 'Orbit' and 'Polymer Beads Cleaning' concepts equally pretend to be ranked as second best environmentally friendly concepts as for the last ranking level (the least environmentally friendly concept). Results of average scores for product concept variants when a systematic ecodesign evaluation method is used indicate that in average group results, ranking of concept variants can be obtained without conflicts as described. The results of ranking in the second round when Eco-Design Value guidelines are used (thus guidelines as reference attribute description) indicate that a unified ranking of concept variants can be concluded upon.

Table 2. Ranking of product concept variants compiled from results of participants' group rankings by using Eco-Design Value guidelines

Ranking level no. (1.-5.)	Product concept variant
1.	Ultrasonic washing machine concept
2.	EcoBubble™ concept
3.	Conventional washing machine concept
4.	'Polymer Beads Cleaning' concept
5.	'Orbit' concept

Due to great number of ecodesign guidelines that participants were unable to relate to concept variants (or the other way around), it is questionable if this was so because certain ecodesign guidelines are too general or simply because certain information regarding concept variant is missing.

Table 3. Overview of zero scores per concept (realization of ecodesign principle or sub-value of concept variant was scored '0' as alternative answer to estimations)

Product concept variant	Range of zero scores per concept	Average of zero scores per concept

Conventional washing machine concept	2 ÷ 28	12,45
EcoBubble™ concept	5 ÷ 23	14,09
Ultrasonic washing machine concept	10 ÷ 23	22,36
‘Orbit’ concept	13 ÷ 28	23,27
‘Polymer Beads Cleaning’ concept	7 ÷ 40	26

6. Conclusion

Problems concerning eco-evaluation of product concept variants are addressed in this work. It is established that majority of existing ecodesign methods and tools are not supporting estimation of environmental or eco-value of product’s concepts at the stage when details about the future product and its life cycle is unknown or vague. Inspired by suggestion made by Dewulf [2003] to use ecodesign guidelines and principles in a way to point out to environmentally conscious product designs and solutions, Eco-Design Value guidelines developed by Koh et al. [2007] are used as criteria of environmental friendliness of product’s concept variants. An experiment was conducted by a small group of novice mechanical engineers and their task was first to rank concept variants according to environmental friendliness without using any additional methods, and then by using Eco-Design Value guidelines. Results point out that when participants were not provided with Eco-Design Value guidelines, their estimations of less environmentally friendly concept variants were very different from participant to participant. On the other hand, results were coherent when participants were choosing the most environmentally favourable concept variants. Conclusion can be made that when using ecodesign guidelines for eco-evaluation of product’s concepts, the results were less dependent on personal preferences of the novice designer performing the evaluation, so that using guidelines was a better alternative that not using any method or tool at all. That way, designers are able to evaluate product’s concepts without being puzzled with multiple and criteria prioritisation when considering environmental friendliness and eco-value of product’s concepts.

Acknowledgement

This research is part of funded project “Models and methods of knowledge management in product development” supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

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Ida Midžić, mag.ing.mech., Junior research assistant/PhD student
Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Chair of Design and Product Development
Ivana Lučića 5, Zagreb, Croatia
Telephone: +385 1 6168 117
Telefax: +385 1 6168 284
Email: ida.midzic@fsb.hr