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NATURALLY EMERGING DECISION CRITERIA IN PRODUCT CONCEPT EVALUATION

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ABSTRACT

Successful concept selection is of paramount importance in the early phases of new product development. Concept decisions define the success of both the project and the product to a great extent. Previous research has shown that structured methods are often not used properly or at all in design practice. To shed light on the dynamics of concept selection in real life, we studied decision strategies and the use of decision criteria in concept selection. The experiment involved sixteen professional designers and utilized mixed methods, including verbal protocol analysis. The participants used a great variety of evaluation styles and criteria, sometimes changing them in midst of evaluation. Furthermore, some internal conflicts appeared between different concept evaluation tasks. These findings put designers' ability to make rational and good concept decisions under some doubt. Further research on human behavior in concept selection is deemed necessary and some prospective research questions are introduced.

Keywords: decision making, early design phases, human behaviour in design, concept evaluation

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1 INTRODUCTION

Design decisions made in the early phases of new product development (NPD), namely in the concept development phase (e.g. Ulrich and Eppinger, 2003), are critical for the success of both the product being developed as well as the development process itself. The concept development phase of the NPD process is typically considered as a divergent-convergent activity (cf. Pugh, 1991; Design Council, 2006). In this approach, a wide set of alternative product ideas or concepts are at first generated (divergence), and then evaluated and eliminated in order to select the best concept or concepts for further development (convergence). This process is often iterative in nature with several different stages of generation, selection, elimination, and combination of concepts. As an activity, concept selection has a significant impact on design success (Mattson & Messac, 2005; Stenović, Marjanović and Štorga, 2012), and failed selection may lead to disastrous results (Pahl et al., 2007). The decisions made in the concept development phase largely determine the quality, cost, and desirability of the end product (Asiedu and Gu, 1998) and failed concept selection decisions can often be compensated only with high redesign costs and increased development time during the later phases of the NPD process (Pahl et al. 2007).

The concept selection decisions are highly complex in nature and require consideration for multiple issues, such as materials, production methods, functional requirements, user needs, and market requirements. Furthermore, the requirements set by these issues are often contradictory, leading to a highly challenging, but a critical task of having to make difficult decisions on tradeoffs between the conflicting design objectives (Mattson, Muller and Messac, 2009). Reflecting this complexity, the problems designers deal with are commonly described as ill-defined or ‘wicked’ (Rittel and Webber, 1984). This implies, that problems typically have no definitely correct solutions and the quality of the solutions can often be assessed only in retrospect. The wickedness also derives from unavailability of detailed and precise information on user needs, feasibility of technical solutions, and market and financial factors. The available information typically includes a great deal of speculation (Koen et al. 2002) and decisions rely to a great extent on qualitative information and subjective judgments (Rosenman, 1993).

To address this issue, several systematic and analytic methods for concept selection have been proposed based on both academic research and practical experience. These methods range from rather straightforward scoring methods (cf. Ulrich and Eppinger, 2003) to complex mathematical, and multi-criteria decision making and optimization methods (e.g. Akay, Kulak and Henson, 2011; Matsson, Mueller and Messac, 2009). However, the use of structured methods has been reported to be somewhat limited in practice (Lopéz-Mesa and Bylund, 2011), especially when dealing with products of relatively low complexity (cf. Laakso and Liikkanen, 2012). Additionally, Kihlander (2011) even suggests that the concept selection methods proposed by literature might be of little or no use in design practice. Furthermore, the influence of systematic methods is further challenged by the high degree of decisions made by individual designers and design teams *prior* to formal concept selection and decision making (Kihlander, 2011). Moreover, many of these decisions have their justification in the previous work experience and inherent values of designers (Holm, 2006). Evidently, the personal aspects of decisions made in concept selection present an important focal point for inquiry. Understanding the strategies and naturally emerging decision criteria of designers’ decision making in concept selection is essential for improving the related practices of NPD.

Kihlander (2011) studied decision making in the early phases of product development. Her findings imply that the rational theories of decision making do not apply well to design. Moreover, concept decisions emerge dynamically during the design process, instead of formal meetings as proposed by the typical process depictions found in literature (Ulrich and Eppinger, 2003; Pahl et al., 2007). Furthermore, according to Kihlander, designers are subject to a multitude of psychological pitfalls (namely anchoring, framing and confirmation bias) as discussed by Hammond, Keeney, and Raiffa (1998). Further summarizing the research in the field, Cross (2001) proposed that designers become attached to their principal ideas, and they try to keep to them as long as possible, no matter the cost The limited use of systematic methods and the difficult nature of the task can be assumed to make the conception selection process highly susceptible to personal biases and other subjective influences.

1.1 Present study

In this study, we are looking at the strategies and naturally emerging decision criteria in concept selection with individual designers. We used a custom divergent-convergent design task of first producing a design for a bicycle rack, and then conducting evaluation and selection on multiple rack designs. The task was presented to seasoned designers,generating a concept selection situation, which was then observed and recorded using verbal protocol analysis. More precisely, we wanted to discover which criteria are used and how they are applied by the designers *in situ*, and if there any evident discrepancies between concept evaluation and decision making tasks

2 EXPERIMENTAL METHOD

A two-part experiment involving 16 participants was organized. Both parts involved the use of a think-aloud method (Ericsson & Simon, 1984) and lasted for a maximum half an hour each. In the first part, the subjects created a solution to a given design problem. In the second part, they evaluated a set of solutions candidates to the same problem with their own solution either included (redrawn to resemble the presentation style of other concepts in the set) in or excluded from the set.

2.1 Sample

The participants consisted of sixteen professional designers from nine Finnish design consultancies. The participants were selected from different companies to remove possible effects and influence of any single organizational culture. Their mean age was 38.1 years (SD = 6.9 years), and they had in average 12 years (SD = 7 years) of design work experience. All but one participant were male, but the participants will be referred to as “her” and “she” regardless of their sex.

2.2 The stimuli

We generated six concepts to be used as baseline controls in the second part of the experiment (see Figure 1 for an example of the stimuli). The pre-generated solution candidates were aimed to be as heterogeneous as possible. The concepts were sketchy, including only minimum information about the to-be designed product and the provided information was presented in an objective manner describing functionality rather than directly indicating “non-factual” issues such as benefits for the user.
After creating the concepts, we asked two outside experts to evaluate the concepts and confirm that the objective quality of our concepts differed enough. The experts, who were experienced in concept selection both in theory and in practice, evaluated the concepts based on the dimensions (usability, looks, feasibility, creativity, novelty, subjective liking) derived from the consensual technique for creativity assessment (CAT), developed by Amabile (1996). After the experiments, the same experts were asked to evaluate the validity of the concepts generated by participants.

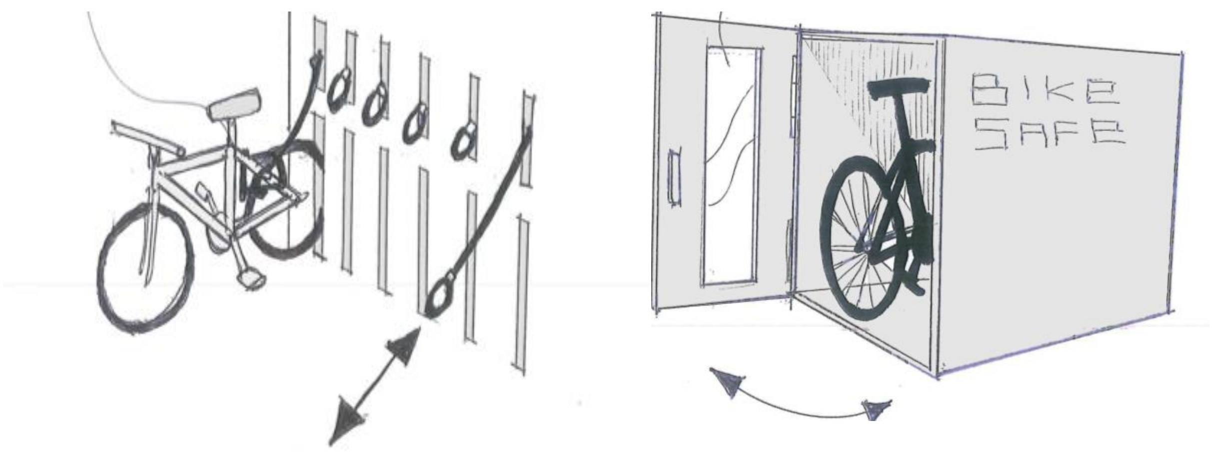

Figure 1. Two baseline concepts created by the researchers.

2.3 Procedure

The sixteen participants were organized into eight pairs. Each pair had one member belonging to *the experimental group* and another participant belonging to *control group*. The division to these two groups was conducted due to a research question not reported here and bears no direct relevance to the findings discussed in this paper. The first part of the experiment was similar to both groups (generating a concept). In the second part, the participants of the experimental group members evaluated a set consisting of the six baseline concepts and their own idea, while the control group members assessed the baseline ideas and the idea of their pair in the experimental group. That is, the concept set evaluated by the control group members did not include the concept they had generated themselves. The pairs were created so that the participants from different companies were assigned to the two groups on the basis of work experience and age, with an attempt to match these attributes. Table 1 further illustrates the participants' position in the design.

Table 1. Participants in the experimental design. Each pair is split up into an experimental group and a control group member.

Pair #	Subject #	Company	Age (yrs.)	Work experience (yrs.)	Group Experimental	Control
1	2	A	46	17.5	x	
1	1	B	35	10		x
2	4	C	49	24	x	
2	5	A	44	15		x
3	3	A	30	2	x	
3	10	D	30	2		x
4	7	E	38	12	x	
4	9	F	34	8.5		x
5	8	E	38	9	x	
5	6	E	33	6.5		x
6	12	E	44	20	x	
6	11	E	52	25.5		x
7	13	G	32	9	x	
7	14	E	36	10		x
8	15	H	32	6	x	
8	16	I	36	15		x

The two parts of the study were designated as the concept design part and the concept evaluation part. The parts were organized approximately seven days apart (M = 7.06 days, SD = 0.929, range = 3). Each participant completed the tasks individually without any information provided on the other participants.

The concept evaluation part consisted of three distinct tasks (described in detail in section 2.3.2): concept ranking task (RT), concept scoring task (ST), and concept selection task (CS). The concepts were first ranked in a joint fashion, and later scored one at a time (see 2.3.2).

2.3.1 Part 1 – Concept design

In the first part, participants designed bicycle racks for an urban setting. The design task was chosen on the basis of the expected familiarity of the problem space to everybody and the wide range of different possible solutions. Part 1 was carried out remotely. The participants were informed about the general aims of the study and the procedure via e-mail. The detailed instructions were provided by the researcher via phone or a Skype call, also giving the subjects the opportunity to ask questions. However, communication happened on a need-to-know basis in order to keep the task information as identical as possible for all the participants. The participants completed the first part at their own offices. In the design part, the participants received 20 minutes to design a solution to the given problem. The solution was instructed to contain a sketch of the structure of the solution with information of the functionality and materials of the concept. After finishing, the participants were required to photograph or scan their solutions and send them to the researcher electronically. Each session lasted for a maximum of 30 minutes.

2.3.2 Part 2 – Concept evaluation

The second part was organized in the presence of the researcher typically at the participant's office about seven days after completing the first part. The participants were asked to individually evaluate solutions to the problem presented in the first part, while thinking aloud. All of the sessions during the second part were recorded. Each participant was shown seven concepts, six of which were the baseline concepts designed by the research team. The seventh concept for each pair was the solution designed by the member of the pair in the experimental group. The concepts were presented in a counter-balanced order using the Latin squares method to eliminate presentation order effects. To control the influence of visual presentation and participant's preferences related to the use of color and different drawing styles, the concepts created by the experimental group members were redrawn into a visually uniform format by the baseline concept artist.

Before the evaluations (RT, ST, & CS) were carried out, the participants were provided three practice tasks for thinking aloud (Atman and Bursic, 1998; Chi, 1997; Ericsson and Simon, 1984). After the practice, the concepts were presented one at a time and the subjects were given one minute to familiarize themselves with each. Next, the subjects performed the ranking task (RT), giving the best concept the rank of 1 and the worst rank of 7. After this, the participants evaluated the concepts one at a time on the dimensions of usability, looks and feasibility on a six-point scale ranging from 'extremely bad' to 'extremely good.' This was the scoring task (ST). Finally, the subjects were asked to choose two concepts to be developed further by the City of Helsinki City Planning Department (CS). All of these tasks were to be carried out while thinking aloud. Finally, the participants filled a post-experiment questionnaire. The second part lasted for a maximum of 35 minutes.

2.4 Analysis

The examination of results for this report focused on the qualitative analysis. Although quantitative data was also gathered, it is not reported here. A coding scheme for the protocol analysis was developed (Chi, 1997; Ericsson and Simon, 1984), with an emphasis on the use of decision criteria in the second part of the experiment, which has to do with justifying the dimensions used in ST. The criteria were coded only in RT.

The coding scheme regarding the decision criteria was developed bottom-up according to the emergent data patterns. Three different types of decision criteria were identified: explicit, implicit and *multi-occurrence implicit criteria*. The explicit criteria were gathered from utterances in which the participants explicitly stated they would be using the concepts' performance on given dimensions as criteria. Table 2 shows two instances of how explicit criteria were decided upon in the data. Each successive occurrence of explicit criteria was coded as well.

Table 2. This excerpt shows how subject # 6 established two explicit criteria (space saving and safety) to be used in RT.

Line #	Criterion	Segment
81		so I'd set two criteria to be used here
82	SAF/2	one would be safety from burglars
83	SPA/2	And the second [criterion] would be that it wouldn't take a lot of space on the street

Sometimes criteria were used in an indirect manner, usually occurring as justifications for single ranking decisions, and in contrast to explicit criteria, no explicit justification for their use was ever delivered. These instances were considered as "Implicit criteria." Multi-occurrence implicit criteria (MOIC) is a category of implicit criteria where the criteria occurred multiple times throughout the evaluation and were used in a very similar manner to explicit criteria but never stated explicitly as such (see Table 3 for an example). Three occurrences of a single implicit criterion would grant the status of MOIC.

3 RESULTS

The participants evaluated the concepts and carried out concept selection in three different tasks. None of the participants had previous work experience directly related to the presented design problem. The concepts developed by the subjects during the first phase varied significantly. Some subjects provided highly visual renditions of the possible structure of their ideas, whereas others provided highly verbose descriptions of the concept's functionality with little attention paid to the visual aspects of the idea. All subjects provided a valid solution to the task (with a mean score of 3.69 in terms of validity in the expert assessment). During the second phase of the test, sixteen protocols were collected. On average, over two hundred segments were identified per protocol, but there was great variance between subjects (M = 234.4, SD = 82.2 segments) giving a hint of different levels of verbosity. Statements regarding the practice tasks and the instructions were omitted from the analysis. Some subjects had trouble in verbalizing their thoughts while carrying out the tasks (as suggested by the great variance of segments in the protocols). One subject reported that the concepts' visual features were a driving factor in her evaluations. The positive and negative aspects were automatically highlighted in when she perceived the concepts, making the verbal reporting of the decision process very difficult. However, the majority of participants were able to verbalize their thoughts during the evaluations.

Table 3. An excerpt from the coded protocol of subject # 4. Here the MOIC used on lines 141 and 142 have an effect on the way the concepts are ranked. On line 143 the subject ranked the fan rack better than the frame rack according to their performance on the MOIC.

Line #	Criterion	Segment
140		actually these both are good
141	SPA/1	this [cable wall] solution saves space
142	SPA/1	whereas this frame rack takes a lot of space
143		so I'll put them [concepts] into the following order

3.1 Evaluation strategies

The subjects exhibited a variety of approaches to concept evaluation. Starting from RT, some participants evaluated the concepts in a very analytic manner, thoroughly contemplating the features of the concepts and comparing them to existing solutions in depth. Some subjects, on the other hand, made the decisions in a more intuitive manner – the concepts were merely glanced at and the decisions were made in a swift manner. One participant, for instance, explicitly stated that she would be using quick intuitive pairwise comparisons in the evaluation – a clear evaluation strategy. She modified the order in which the concepts were on the table according to the pairwise comparisons, keeping the best concepts to her left and quickly comparing each concept to the best ones, gradually moving towards right. When a concept of inferior quality was encountered, the assessed concept was placed on its left. This iterative process took her four minutes.

The differences in evaluation styles persisted in ST as well. Some subjects carefully contemplated the scores for each given dimensions, whereas some scored the concepts quickly without further deliberation. What was common for most of the evaluations was the tendency to stick to the same evaluation strategy for all the concepts, evaluating each concept according to the given dimensions in the same order. Deviations from the patterns were rare.

The behavior in CS varied greatly: many of the participants made the decisions quickly by referring to the previous tasks, whereas some went to great lengths to determine the concepts best fit for further development. However, some of the participants used more analytic means where they eliminated concepts from evaluation according to their performance on some aspect. The process was iterative by nature so that even if a concept was initially identified as plausible, it might have been eliminated in light of further evidence. Interestingly, CS yielded some self-contradictory results. In some cases, the participants evaluated some concepts fairly low in both RT and ST (or even the worst of the lot). Regardless, they still chose the very same concepts for further development due to some feature of the concepts.

Although some subjects clearly stuck to an analytic strategy and some to an intuitive strategy throughout the tasks, some intra-subject variation took place from task to task. One participant, for instance, carried out RT and ST in a thorough manner, while only very briefly referring to the previous tasks in making her decision in CS.

3.2 Decision Criteria

The participants used a great variety of explicit and implicit criteria according to which the concepts were ranked (shown in Table 4). 121 segments that contained some use of criteria were identified in the data. All participants used some set of criteria in the evaluations but differences in their use were common. Altogether, the mean amount of criteria used per subject was 7.5 (SD = 3.35). The means for the use of explicit and implicit criteria and MOIC, respectively, were as follows: $M_{explicit}$ = 2.75 ($SD_{explicit}$ = 2.98), $M_{implicit}$ = 2.69 ($SD_{implicit}$ = 2.02) and M_{MOIC} = 2.06 (SD_{MOIC} = 2.32).

Table 4. The use of explicit, multi-occurrence implicit and implicit criteria during RT throughout the protocols.

Criterion	Code	Explicit	MOIC	Implicit	Total	%
Space saving	SPA	8	17	5	30	24.79
Novelty value	NOV	14	3	7	24	19.83
Feasibility	FEA	7	0	10	17	14.05
Safety	SAF	4	3	5	12	9.92
Price	PRI	2	0	7	9	7.44
Usability	USA	4	0	5	9	7.44
Looks	LOO	1	6	2	9	7.44
Simplicity	SIM	2	4	0	6	4.96
Meets requirements	MRQ	1	0	1	2	1.65
Social context	SOC	1	0	1	2	1.65
Design quality	DSQ	1	0	0	1	0.83
Total		45	33	43	121	100
%		37.19	27.27	35.54	100	100

Table 5 demonstrates the distribution of criteria used by the participants. This controls the extensive use of a single criterion by single participants, as was the case of SPA-MOIC, where two subjects shared 11 hits of the criterion. The concept's ability to save space, its feasibility, novelty value, price and usability dominated the evaluations, each criterion being used by 50 per cent or more of the participants.

Table 5. The distribution of criteria use during RT. Each cell indicates the number of subjects using a given type of criterion.

Criterion	Explicit	MOIC	Implicit	Total	% of participants using criterion
Space saving	3	4	4	11	68.75
Feasibility	4	0	7	11	68.75
Novelty value	4	1	5	10	62.50
Price	2	0	7	9	56.25
Usability	3	0	5	8	50.00
Safety	2	1	4	7	43.75
Looks	1	2	2	5	31.25
Simplicity	1	1	0	2	12.50
Meets requirements	1	0	1	2	12.50
Social context	1	0	1	2	12.50
Design quality	1	0	0	1	6.25

All participants used some criteria in the evaluations but differences in their use were common. Table 6 illustrates the distribution of the use of criteria per subject. In some cases, a test subject would clearly set out to evaluate the concepts according to a pre-determined set of explicit criteria. However, she would stop referring to at least some of them and start using a different set of implicit criteria (or MOIC) instead. In fact, as evident in Table 6, some participants relied heavily on MOIC and implicit criteria, their number of uses outnumbering the use of explicit criteria, whereas some employed primarily explicit criteria.

Table 6. The use of different kinds of criteria in the evaluations.

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**Total**	**%**
Explicit	2	7	1	2	0	9	0	0	5	5	6	0	5	0	0	2	45	37.19
MOIC	0	5	0	6	4	3	0	0	0	0	0	6	0	3	3	3	33	27.27
Implicit	1	1	3	2	5	0	4	2	4	4	1	5	0	7	3	1	43	35.54
Total	3	13	4	10	9	12	4	2	9	9	7	11	5	10	6	6	121	100

Six participants did not establish any explicit criteria to be used in the evaluation. Four of these participants did, however, use a MOIC in their evaluation, leaving only two participants who used only implicit criteria. One of these participants (participant #8) reported that having to verbally express one's thoughts during the evaluation was remarkably difficult and used only two implicit criteria. Taking this into account, only one participant (#7) did not use any explicit criteria or MOIC.

4 DISCUSSION

This paper has documented a study of design concept selection as it occurs in a quasi-experimental setting. We utilized verbal protocol analysis during an idea evaluation task to capture different types of decision strategies and discover decision criteria used by the participating professional designers. The results show that designers employ a great variety of different evaluation styles when provided with such a method. Some participants applied a highly analytic approach, whereas some stuck to a quick and intuitive evaluation style, sometimes applying highly novel methods (as described in section 3.1). In general, intuitive evaluations were slightly more common in the experiment, but did not, however, include any clear evaluation strategy or method. However, no dominating style emerged during the experiment. Furthermore, even the analytic evaluations were erratic at times and switches in evaluation style were commonplace.

A common finding in the protocol data was that all subjects independently established evaluation criteria to be used in the ranking task. This simplified the ranking task into approximately one to four easily perceivable dimensions of evaluation. In terms of the number of subjects using explicit criteria, traditional criteria associated with designers' values, such as novelty, feasibility, and usability were most common along with the more task-specific space saving criterion. Surprisingly, in contrast to prior beliefs (e.g. Holm, 2006), aesthetics were not a significant criterion in RT. As industrial design is unquestionably a profession heavily concerned with (among others) the aesthetic qualities of products, asthetics were expected to have some importance in the evaluations. However, only five subjects used aesthetics as a criterion and it was used only nine times in the protocols. Instead of proposing that aesthetics are not a significant factor in concept selection, this finding might be due to the visual uniformity and the sketchy nature of the concepts. When considering implicit criteria, however, the picture is less clear. The same criteria (novelty value, feasibility, and usability) shared a majority in implicit criteria use as well. However, their dominance was not as clear as in explicit use. Expectedly, participants evaluating the concepts in an intuitive manner were more likely to rely on implicit criteria and use them in lesser quantities than others.

Maintaining an analytical approach to evaluation was hard to come by among our participants. As stated earlier (sec 3.2), although some participants clearly stated they would be using a giving set of explicit criteria in their evaluations, they ended up using implicit criteria or MOIC in their evaluations. Usually these cases started with the participant using one of the more popular criteria (e.g. novelty value) as a starting point for the evaluation, but ended up using some of the highly task-specific dimensions (such as safety or space saving) as criteria. These deviations from explicit criteria give hints of the pervasive nature of task-specific criteria when designers are not given, or apparently following, any structured method. It may be in fact due to the explicit criteria getting overridden by features evident in the concepts. When given considerable amount of freedom in the evaluations, a great divergence in the evaluations became evident in the data where some concepts were scrutinized in different quantities and by using different approaches to evaluation. The great divergence in evaluation strategies and criteria, along with internal conflicts and switches in evaluation style, supports the use of structured methods in concept selection. These phenomena might be avoided by using rigid structured methods such as those proposed by Ulrich and Eppinger (2003) or some numerically oriented methods, such as s-Pareto frontier selection (Mattson and Messac, 2005) or

Electre II (Vinodh and Girubha, 2011). These mismatches in evaluations, among other findings, give hints of the pervasive nature of non-normative behavior in concept selection. Finally, in order to give concepts a fair treatment, it is advisable that all designers evaluate the concepts using the same method and criteria. However, it remains and open question how the criteria should be established in any given evaluation.

4.1 Future research

We believe additional research into design decision making has a great potential to contribute to to the practice of design. The problems of rational and normative decision making become evident when dealing with design problems, which are commonly described as ill-defined or 'wicked' problems (Rittel and Webber, 1984; Yang, 2010). As these problems are not clearly formed, rational models of problem solving are not considered to work (Schön, 1983). Hence non-normative behavior in design may be a promising field of study, which may yield results with great significance on design practice. For instance, Beggan (1992) identified a systematic preference of artifacts that people experience as their 'own' over identical artifacts owned by others – a phenomenon for which Beggan coined the term *mere ownership effect*. Additionally, Pierce, Kostova and Dirks (2001) proposed that people start associating themselves with artifacts by spending time with them (or creating them), forming a relation of *psychological ownership*. As conceptual development is a labor-intensive and time-consuming effort, it could be hypothesized that designers will have a special psychological relationship to their concepts, leading to biased behavior in concept evaluation.

Additional research on the use of evaluation criteria in different design problems should be carried out. This would help to discover whether or not the findings are replicable across tasks and, for instance, if there is a natural balance in the use of general and task-specific criteria. Moreover, Ditto and Lopez (1992) identified a tendency of using differential criteria for preference-consistent and preference-inconsistent conclusions. People tend to examine information inconsistent with their preferences more critically than information consistent with their preconceptions and preferences. Furthermore, the quantity of information required to reach a conclusion is asymmetrical, depending on the preference. This phenomenon is closely related to the well-documented confirmation bias (see, e.g., Stanovich, 2006). Now, a similar experimental method as used in the present article should be applied to study whether different kinds of criteria are applied in the evaluation of one's own concepts and others' concepts. A final suggestion for future research is that of biases against creativity. Mueller, Melwani and Goncalo (2012) identified a tendency for people to be biased against creative ideas. Furthermore, creative ideas are sometimes winnowed by purpose in organizations (Amabile, 1998). Regardless of explicitly supporting creative thinking and "out-of-the-box" problem solving, creative ideas are shunned on. This bias could have grave implications on design practice, hence its impact on concept decision making should be mapped.

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