A method for the evaluation of meaning structures and its application in conceptual design

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Abstract: In this paper, we discuss the relations between the viewpoints of users and designers. The main issue in design is that the user’s and designer’s viewpoints do not integrate well. In this study, we integrate the user's viewpoint into our new proposed design methodology by applying a meaning-based framework in conceptual design. This methodology introduces a user-derived evaluation of 'structure of meaning elements' (SoME) as part of the user’s viewpoint into the particular design phase. Furthermore, we test the proposed design methodology in a case study. The results outline the feasibility of the framework. This study reveals details of how concepts are formed in design and how concept formation can be achieved using design methodology. The significance of this study for science and practical application lies in the proposed integration of the user-derived evaluation of SoME as a step in the design methodology.

Keywords: user’s viewpoint; designer’s viewpoint; design method; design creativity; conceptual design; meanings; search; evaluation; meaning elements; meaning structures; semantic network; evaluation tool; design support.

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1 Introduction

In this paper, we discuss the relations and the differences between user’s and designer’s viewpoints, which, in other words, is the stance adopted by the user and designer, respectively, towards artefacts.

1.1 User’s and designer’s viewpoints – main issue

A number of studies have investigated the user’s viewpoint towards designed artefacts (Krippendorff, 2006; Petiot and Yannou, 2004; You and Chen, 2007) with the aim of incorporating the findings in developing methodologies for designing artefacts (Boess and Kanis, 2008; Horvath, 2008; van Rompay, 2008). This is to aid efforts in integrating the user’s viewpoint into the designer’s viewpoint. The main issue here is that the user’s and designer’s viewpoints do not integrate well (Boess and Kanis, 2008; Krippendorff, 2006).

In many practical cases, this integration is not achieved. In engineering design, the evaluation is too far distant from design methodology. The product and industrial design also lack such mutual integration. Further, this integration appears to be difficult and seems to pose as a long-term problem. The aim to understand the user’s viewpoint is evident in many research efforts; however, the proposed solutions are considered to be incongruent with the design methods (Demirbilek and Sener 2003; Hsiao and Chen, 1997; You and Chen, 2007).

In this paper, we propose the integration of a part of the user’s viewpoint into a design methodology and we test the methodology in a case study. Our approach is oriented towards conceptual design. The paper is structured as follows. Section 2 defines the main problem. Section 3 discusses the limitations of the existing research with regard to the observed problem. Sections 4 and 5 introduce the goal and method of the research. Sections 6 and 7 introduce the proposed design methodology and the case study testing of the methodology. Finally, Sections 8 and 9 discuss the methodology and the issues in the research to be resolved in the future.

2 Definition of the problem

After pointing out the main problems with regard to the user’s and designer’s viewpoints in the previous section, in this section, we focus on the problem and discuss a possible approach in connection with the design methodology (Figure 1). As shown in Figure 1, the user’s viewpoint has to be integrated into the designer’s viewpoint and then conveyed in the design methodology.
A gap exists between the viewpoints of the user and designer. Furthermore, it is very difficult to convey the user’s viewpoint in the design methodology. This is quite evident in areas such as conventional engineering design, where the methods for taking the user’s viewpoint into account are not able to directly connect with the design methodology (Pahl et al., 2007). The main problem can be summarised as how the user’s viewpoint needs to be integrated into the design methodology. A possible approach to this problem is to integrate a part of the user’s viewpoint directly into the design methodology, thus bridging the gap between the two.

Figure 1 Problems with regard to the user’s and designer’s viewpoints in design methodology (see online version for colours)

3 Research on user’s and designer’s viewpoints

In this section, we discuss the user’s and designer’s viewpoints and the limitations of the previous studies.

3.1 Previous approaches

Different methodologies investigate the user’s viewpoint or user’s personal preferences. These methodologies quantitatively express the user’s viewpoint in the form of evaluations. An example of such a methodology is the semantic differential (SD) method, based on the work of Osgood et al. (1957). The SD method focuses on the evaluation of the connotative meanings of designs. Research based on this method has been carried out in different studies. For example, Hsiao and Chen (1997) proposed a semantic recognition and rule-oriented approach for developing a product design.

The user’s viewpoint has been studied as the meaning that an artefact has for the user. Such approaches, where the focus is on the user’s viewpoint, are product semantics (Boess and Kanis, 2008; Butter, 1989; Krippendorff, 1989) and affordances (Boess and Kanis, 2008; van Rompay, 2008; You and Chen, 2007). Product experience bridges product semantics and affordances from the perspective of the user’s apprehension towards the product. Boess and Kanis (2008) focus on instrumental and denotative product use; they opine on the consideration that designers can integrate the users’ attribution of meaning with regard to product use into their design methodology. They also outline the problems of product semantics and affordance approaches. For example, clearly identifiable affordances or semantics cannot be designed reliably in real world situations. This view is based on the assumption that the meaning is made in an interaction and not prior to it. In other words, the situatedness of the product use is central.
Studies on product expression discuss relationships between the concrete (product’s actual features) and the symbolic (product’s perceived expression) (van Rompay, 2008). Van Rompay demonstrates an interactional, embodied approach to product expression. The insights allow designers to relate the abstract and difficult notions to their own experiences while translating the idea into form.

The impression-based meanings of a design have been researched using different approaches. These approaches emphasise the user’s requirements for a user-oriented design. This refers to the user’s subjective interpretations of the product based on his/her personal impressions, that is, the user’s cognitive interpretation of the designed product.

The emotional design approach manifested from this impression-based perspective. Crilly et al. (2004) highlight the users’ responses as a part of the communication process, distinguishing between cognitive, affective and behavioural responses. Norman (2004) highlights the interaction between affect, emotion, and cognition. An emotional response to a product design that agrees with its efficiency is a major attribute for a product’s success. Norman also relates this view with the perceived functional use of the products from the perspective of visual impression. This approach foresees design as a trigger of emotional response (Demirbilek and Sener, 2003) and it could be used to design a product in order to communicate with the user at an emotional level.

The product semantics approach, proposed by Krippendorff (1989, 2006), focuses on the user’s subjective impression of the product’s meanings. This approach takes into account the relationship between the user’s cognitive models and the perceivable features of the concerned product. By a sequence of activities, semantic considerations are incorporated into the design process. Some of the activities include establishing the semantics to be communicated, outlining the attributes to be expressed, and searching for the manifestations to project the semantic considerations with regard to shape (Krippendorff, 1989). This approach is centred on symbolic associations and meanings and is governed by the design features during the design process.

3.2 Conceptual design

Most of the aforementioned approaches focus on the main design stages or problem-solving perspective. The problem solved by the design need not be a pressing societal requirement, but rather a perceived gap in a user’s experience (Ulrich, 2007). In recent times, studies focusing on creativity (Dorst and Cross, 2001; Jin and Li, 2007) have shifted their focus on the processes of concept generation. These processes include concept processing and combination, which are typical in the early stages of design.

Different design theories define ‘concept’. For example, general design theory (GDT), which has its basis in an axiomatic and mathematical approach to the design process, proposes a design paradigm to represent how humans operate to produce a new entity from the attributes of the existing entities (Yoshikawa, 1981). In GDT, the entity concept (natural and artifactual objects) is modelled as an element, and the abstract concept (function and attribute), as a class (subset of elements); these concepts are used as design knowledge in topological space. Furthermore, GDT defines the design process as a mapping from function space, where the design requirement is described, to attribute space, where the design solution is sought. Studies on GDT have derived numerous theorems that can explain the characteristics of design knowledge and the design process (Tomiyama and Yoshikawa, 1987).
Galle (1999) proposes the design paradigm as a manifestation of a design representation. Designing itself is defined as the production of design representations; the latter notion – design representation – is analysed in the context of the artefact production process. The definition of ‘design representation’ is formulated in terms of human agents and their actions and ideas, that is, ideas of things or actions intended to exist and occur in the future.

The ontological approach is widely adopted in the field of design in order to conceptualise and obtain knowledge in the domain. This approach is used to support functional meanings in conceptual design. Such a methodology has been described by Horvath (1998), who focuses on the modelling and representation of concepts for computational support in the design process; Horvath elaborates on the ontology theory for formalising design concepts.

Computer-aided innovation is a systematic approach to improve designer creativity and problem-solving capabilities (Cascini, 2004). For example, such tools manage functional models as product representation techniques. Semantic processing technology is already being used for enriching the knowledge bases of such systems.

Shah et al. (2000) and Shah and Vargas-Hernandez (2002) implemented the objective measures of idea effectiveness. They developed outcome-based metrics from the point of view of both design and cognitive psychology, thus contributing to the identification of key ideation components of design methods.

The foundation and taxonomy of questioning strategies in design constitute the driving forces for the evolution of meanings in the design process. Aurisicchío et al. (2006), Eris (2004), and Wang and Zeng (2009) deal with questions about meanings in design, the relationship between meanings and design, and ways of representing the meanings. For example, Eris shows a class of ‘generative design questions’ (GDQ), which are characteristic of design thinking. The conceptual duality between these questions and decisions are deeply ingrained in the design process. The developed question-centric design thinking model illustrates the integration of the user’s requirements into design concepts through GDQs (associated with divergent thinking) and the integration of those concepts into design decisions through deep-reasoning questions (associated with divergent thinking) (Eris, 2004).

However, these methodologies suffer from poor connectivity with the design methodology; this gives rise to the question of how this gap in the design methodology can be addressed. We can summarise the main problem as follows: the methods that take the user’s viewpoints into account cannot be integrated into the design methodology (they are often contradictory). What accounts for this gap? The user’s viewpoints have various limitations. The following are some of the factors contributing to the problem:

- The approaches for obtaining the user’s viewpoint use methods that are different from those used in design methodologies.
- The methods for obtaining the user’s viewpoint cannot achieve their purpose in a timely manner vis-à-vis design methodologies.
- The user’s viewpoint is from a top-down perspective, while the designer’s viewpoint is from a bottom-up perspective. One can say that they are for a different order of understanding (Krippendorff, 2006).

By analysing the highlighted shortcomings of the existing approaches, a summary of the problematic areas and possible approaches can be outlined. One possible approach will
facilitate the integration of the user’s and designer’s viewpoints at the design level in the form of the user-derived evaluation methodology, rather than integrate the user’s viewpoint into that of the designer.

The evaluation is necessary in order to correctly ascertain the aspects of the designed artefact. In particular, the evaluation is done with methods different than those used in the design methodology.

3.3 The study’s approach

The importance of conceptual design lies in the aspect of idea generation and the fact that the idea can be viewed as a ‘prototype creation’ (Coyne et al., 1990) in industrial design or an ‘original design’ (Pahl et al., 2007) in product design. In the field of engineering design, as the design processes are represented in a sequential model (Pahl et al., 2007), the early phase of the design process – the original design at the conceptual level – is the most creative part in the design process. Many recent studies have focused on conceptual design and concept formation (Mougenot et al., 2008; Segers et al. 2005).

The initial conceptualisation in design allows the integration of the evaluation from the user’s viewpoint because of the following reasons:

1. the concept formation in the conceptual design stage allows flexibility in the ideas regarding the design concept
2. the processes in conceptual design predefine further design endeavours.

Therefore, the approach of this study focuses on concept formation in conceptual design.

If the evaluation method (from the viewpoint of the user’s evaluation) is integrated into the design process we will be able to clarify the gap between the user’s and designer’s viewpoints. That is to say, we will be able to bridge the gap by including the evaluation as a step in the design methodology.

4 Research goals

In order to propose a design methodology for bridging the user’s and designer’s viewpoints for conceptual design; we need to explore what the implications are of integrating the user’s evaluation in the design process.

The aims of this study are twofold:

1. to propose a design methodology that integrates user-derived evaluation in conceptual design
2. to test in a case study the proposed design methodology for conceptual design.

5 Research method

In this section, we integrate the user’s viewpoint into the design methodology by applying a meaning-based framework in concept formation at the conceptual design stage.
5.1 Framework of concept formation

‘Meaning’ can be defined as what an artefact represents for the user. In more particular terms, the meaning element is the most basic part of the meaning. The ‘structure of meaning elements’ (SoME) is the relation between the various meaning elements of an artefact. Therefore, the meaning of the artefact includes meaning elements and the SoME (see Figure 2).

In this study, we explore concept formation as the process of building the SoME. The framework of this study is built on the idea that the design can be conceived as the creation of the SoME by the designer. This is a dynamic process which leads to the creation of the SoME. This framework corresponds to the concept formation process in conceptual design.

Figure 2  Understanding conceptual design as the creation of the ‘SoME’ using the example of a beetle car (see online version for colours)

In this paper, we refer to the term ‘concept’ as a design concept with an abstract notion. The framework of meaning elements is derived from the understanding of ‘notion’ as ‘an abstract idea or mental image, which corresponds to some distinct entity or class of entities, or to its essential features, or determines the application of a term (especially a predicate), and thus plays a part in the use of reason or language’ (Gärdenfors, 2000). It should be pointed out that the SoME of an artefact is perceived as the ‘meaning’ of the artefact as a whole. A set of single meaning elements are put together in a way that it forms a particular whole meaning of an artefact. In other words, during the conceptual design, the meaning of the artefact – a beetle car in this case – is structured from the meaning elements of ‘car’, ‘friend’, ‘ladybug’, and ‘cute’ to the meaning elements of ‘eco’, ‘difference’, ‘car’, and ‘happy’, and the structure of the latter constructs the meaning of the whole entity, that is, ‘beetle car’. The whole meaning of the artefact can be represented as ‘a different car that is ecological and which makes me happy’. The conceptual design is a process of exploration and evaluation of the meaning elements as a part of the SoME. The conceptual design results in a design concept with a structured meaning in the form of the beetle car.

This framework refers to the SoME in a sense that is different from the structure of meaning discussed by Osgood et al. (1957). While Osgood et al. refer to the structure of meaning as the way these meanings are mentally represented and hierarchically
connected, the framework of the SoME in this study refers to the way meanings (meaning elements) are mentally represented and structured in conceptual design.

5.2 Semantic network tools

Nevertheless, the process of structuring non-structured meaning elements into a whole design concept and its meaning should be clarified. This can be done through a semantic network method. In this framework, we need tools to create effective abstract representations in the form of concepts. These concepts represent meaning elements derived from or expressed in the designed product. However, words can represent meaning elements at the lexical level. Moreover, concepts and words can be represented by semantic networks.

The concept of semantic networks originates in the field of psychology [Boden, (2004), p.107]. Semantic networks depict human memory as an associative system wherein a single idea can lead to many other ideas. As computational structures, these networks represent the field of meaning and can be used to model conceptual associations (Boden, 2004).

In the domain of design support, there already exists research in which the concept of semantic network has been used. Segers (2004) uses a semantic network, that is, WordNet (Miller et al., 1990), to understand how words contribute to the enhancement of creativity and help break the designers’ mental fixations in the early stages of architectural design. The feedback provided by the semantic network was found to be useful for increasing the number of ideas and concepts generated by a designer. Word graphs (Segers et al. 2005) showed the effectiveness of language stimuli for idea generation in design.

Chiu and Shu (2007, 2008) investigate a different aspect and use a language-based stimulus method for concept generation. Their work discusses verb-based stimuli in different engineering design situations and their role in concept generation. These studies have proven the importance of semantic networks in the stages of conceptual design.

In a different approach, semantic network was used to analyse and evaluate the ‘language of design’ in design team conversations (Dong, 2006). The results showed high accuracy with regard to human evaluations and were also effective for conducting analysis in real time. This study shows the potential of a natural language processing approach in analysing the performance of a design team.

A tool that analyses and evaluates the meaning elements in design should have two requirements: it should allow searches and facilitate the evaluations of meaning elements. The tool used in the aforementioned studies, WordNet (Miller et al., 1990), represents knowledge in the form of a structured interconnected semantic network dictionary that can be used for design support. The WordNet database satisfies all the basic requirements for the implementation of a tool that uses such a methodology.

5.3 Evaluation from the user’s viewpoint in design methodology

Existing studies (Georgiev et al. 2010) have used an approach towards the user’s viewpoint which was developed on the basis of considered discovery of meaning in design examples. The 86 participants indicated all the meanings they could derive from the provided design examples. A seven-point scale, ranging from ‘poor’ to ‘excellent’, was used independently by each participant to evaluate the design examples.
The indicated meanings were explored as meaning elements. The evaluation scores and the meaning elements were further analysed. The results of the path analysis showed that the average degree of relations between the meaning elements, measured with a semantic network, positively contributes to the evaluation of the design example. In other words, the closer the relations between the indicated meaning elements are, the higher is the evaluation of the provided design examples. This result gives the idea for the integration of an evaluation into the design methodology. This average degree of relations between the meaning elements is described as the main evaluation method in the next chapter of this study.

We are now posed with the question of how these findings can be used to develop a new design methodology. This study addresses this question. Further, we develop a design methodology for implementing the findings and defining it as the SoME.

The SoME represents the process of constructing the meaning in conceptual design. Studies have observed the implementation of exploration (search) methods in conceptual design (de Vries et al., 2004; Segers et al. 2005). The original idea of the current research is to complement the exploration method with evaluation, which is based on the user’s viewpoint.

5.4 Exploration and generation of meaning elements

The exploration of meaning elements can be enhanced by the use of concepts with similar meanings. Conceptually connected words, for example, word graphs, facilitate the exploration and idea generation in conceptual design (de Vries et al., 2004).

The generation of concepts is based on the relation between the hierarchy and processing of concepts. The hierarchy of concepts represents human judgement with regard to why those concepts are judged as dissimilar. For instance, the similarity of concepts has an effect on the generation of new concepts (Wilkenfeld and Ward, 2001; Wisniewski, 1997).

6 Design methodology

In this section, we propose a design methodology for conceptual design by integrating user-derived evaluation.

From the viewpoint of creativity, the processes of exploration, synthesis, searching and finding (Finke, 1996; Nagai and Taura, 2006) of meaning elements are critical for design achievements. For the purpose of clarifying these processes we refine the ‘Geneplore model’ of Finke (1996), as shown in Figure 3.

The model represents creative design process regarding meaning elements, adding the perspective of design methodology. The processes of generation and exploration are related to the processes of the search, judgement and evaluation of meaning elements. The components of the ‘Geneplore model’ are shown in italics. Generation and explorations are related by focusing or expanding concept processes and are restricted by the constraints of the design task.

Thus far, the search and evaluation of meaning elements in the conceptual stage of design are dependent solely on the ability of the designer. Often, these abilities are not sufficient for an objective search and evaluation of meaning elements; moreover, they are not entirely effective for conceptual design. Therefore, support for the designer’s
personal thinking process is essential. The processes involved in the aforementioned model need to be elaborated in design methodology.

**Figure 3** Model based on the ‘Geneplore model’ (see online version for colours)

Source: Developed from Finke (1996)

### 6.1 SoME – framework considerations

Here, we describe the proposed design methodology of the SoME adopted during conceptual design, which is the focus of this study.

**Figure 4** The steps in the developed design methodology which focuses on meaning elements (see online version for colours)

The design methodology employs the following procedures for the searches and evaluations of meaning elements (Figure 4). Stage A involves the set of meaning elements derived from the design task; Stage B entails building the SoME using searches and evaluations; and Stage C involves the generation of the SoME. The steps are as follows:

- deriving the set, which is the starting point of the initial meaning elements that relate to the design task and the abstracted meaning elements from the task (A)
- performing searches with these meaning elements by using a semantic network (B1)
- visualising a semantic network of related ‘searched-for’ meaning elements (example is provided in Figure 5) (B2)
• the designer selects new meaning elements from this neighbourhood network (B3)
• evaluating new meaning elements based on the average degree of relations between the meaning elements (convergence) (B4)

6.2 Search method

The basic aim of the search for meaning elements (B1) is to find more applicable meaning elements on the basis of those of the input, which is judged by the designer. The semantic network WordNet release 2.1 (2006) is used for the exploration of meaning elements associated with the concept that was initially subjected to the search. The result of the WordNet search facilitates the designer’s choice of meaning elements and his/her search for an adequate meaning element or concept.

Figure 5 Visual representation of the semantic network for the word ‘meaning’ (see online version for colours)

Such a search can be conducted by using the Visuwords 2.02 (2008) visualisation (B2) of WordNet, as shown in Figure 5. This search is limited to the representation of the network neighbourhood of the word; that is, the search is limited to words that are directly connected to the word that is initially typed into the search field. Nodes represent words (meaning elements) and the different connections represent different dependencies between the words. The designer judges and selects the meaning elements from this visual representation that are evaluated with the help of the method described in the next section.

6.3 Evaluation method

In order to deal with the SoME, the degrees of relation and convergence are adopted as the factors of the structure. We further describe these proposed objective measures.

The process of evaluating the SoME (B4) is based on the measures implemented in WordNet::Similarity software release 2.01 (2006). Similarity by path is the most general, and it is based on the principle of counting the edges between concepts (Pedersen et al., 2004). It is a relatively simple measure in WordNet’s noun hierarchy. Similarity can be defined as follows:
The similarity $S$ is a real number between 0 and 1 as defined in equation (1). With $m_1$ denoting meaning 1 and $m_2$ denoting meaning 2, the path $p$ is measured in steps in the WordNet database:

$$S(m_1, m_2) = \frac{1}{p}$$  \hspace{1cm} (1)

The measure evaluates the degree of similarity between two meaning elements. Although it has the advantage of being relatively simple, its use is restricted to nouns and ‘is–a’ relations.

Our methodology uses this measure as the evaluation criteria (B5) of the set of meaning elements. Since similarity refers to the degree of similarity between a pair of words, it can be used as a comparative criterion between the word pairs. Thus, convergence, $R$, can be defined as the evaluation of the similarity of a limited set of meaning elements, defined as the average value [equation (2)] of all meaning similarities, $S$, by the shortest path in the WordNet database ($n$ is the number of meaning relations between individual meaning elements):

$$R = \frac{1}{n} \sum_{i=1}^{n} S_i$$  \hspace{1cm} (2)

This research uses the semantic network WordNet to search for meaning elements and the WordNet::Similarity tool for evaluating the degree of relations between the meaning elements. WordNet is used as an explicit complex knowledge-based representation of the human mind. The convergence is adopted as the objective measure of the SoME.

In order to understand the processes, we investigate the applicability of the proposed methodology in conceptual design. To break down the process into its basic elements, we need to focus on the simplest processing activities associated with the meaning elements.

7 Case study

The case study was carried out as a test of the proposed design methodology.

7.1 Method of the case study

The method used in our study comprised the following steps:

- Conducting an observation study on the SoME using the methodology described above. A ‘within-subject design’ with a single subject was used with the aim of conducting an in-depth analysis to identify the features of the subjects’ activity. The variables include measurements taken continually from the subject.
- Evaluating the steps and results of the SoME process and the further use of the SoME in the conception process. The goal is to integrate this structuring process into the designers’ thinking process.

The case study uses language stimuli, without displaying pictures, because language stimuli are used in the idea generation process in design (Chiu and Shu, 2007; Segers et al. 2005). The process begins when the subject is assigned the word pairs and then tasked
to design a new concept; the combined words are considered to enhance the creative ideas in design. For example, Wilkenfeld and Ward (2001) used language stimuli based on experimental techniques for eliciting mental imagery in creative invention tasks. The approach is based on creative cognition (Finke, 1996). The conceptual stage of design is associated with the cognitive models of similarity judgements and idea generation. From the viewpoint of creativity, the concept creation phase in design is considered as a core process of design thinking.

One designer who had graduated from engineering design major and worked in the field of engineering and machine design for three years participated in the experiment. We focused on the SoME in conceptual design, while elaborating on meaning elements derived from nouns. We used meaning element pairs with different degrees of relations.

7.2 Procedure

The procedure was as following:

- The designer was provided with instructions and training on how to use the system (20 minutes).
- Each task was explained to the participant (five minutes for the explanation of each task).
- Four design sessions were carried out in the presence of a guide. Each design session lasted for a maximum of 25 minutes; this involved the participant using the system and a sketch conception session.

All the sessions were video and audio recorded for further analysis.

7.3 Conceptual task

The instructions provided to the participant were as follows.

Design a product or come up with a creative idea by doing the following:

- Use the word pair (different for every session).
- Use the system to explore these words to help develop your idea or design. You can make as many choices as you like and can perform as many searches as you desire. On request, you will be provided with feedback (evaluation) on the idea.
- Verbalise your design process as much as possible; in other words, state your ideas and choices. Write down and describe your idea in detail using sketches and comments.

The input meaning element pairs (word pairs) are shown in Table 1. The selected pairs had different degrees of relations. We took two such pairs from the results of the analysis carried out in other studies (Georgiev et al. 2010), while the other two were taken from Wilkenfeld and Ward (2001). The pairs ranged from being highly similar (‘computer’–‘ski’) to highly dissimilar (‘violin’–‘sea’). The order of the sessions was as numbered in column 1 of Table 1.

The word pair in Session 1 was helicopter–blanket (Wilkenfeld and Ward, 2001). The resulting design was described as follows: ‘Helicopter cargo net can be made as a blanket using tangled threads and knots. It is easy to produce and very strong’ (Figure 6).
Table 1  Similarity measures of the meaning element pairs used in the case study

<table>
<thead>
<tr>
<th>Meaning element pairs</th>
<th>Convergence (value of similarity measure by path range: ~0–1)</th>
<th>Classification of degree of relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4  Computer–ski</td>
<td>0.2</td>
<td>High</td>
</tr>
<tr>
<td>3  Cat–piano</td>
<td>0.1429</td>
<td>Intermediate</td>
</tr>
<tr>
<td>1  Helicopter–blanket</td>
<td>0.1</td>
<td>Low</td>
</tr>
<tr>
<td>2  Violin–sea</td>
<td>0.0769</td>
<td>Very low</td>
</tr>
</tbody>
</table>

Figure 6  Sketches of the conceptual designs in the four sessions
The word pair in Session 2 was violin–sea (taken from the results of an earlier analysis (Georgiev et al. 2010). Idea at the early stage of design: ‘Wave-shaped chin rest’. The resulting design: ‘Design of a wave-shaped violin with different elements also shaped like a wave’ (Figure 6).

The word pair in Session 3 was cat–piano (taken from a previous analysis, Georgiev et al., 2010). Idea at the early stage of design: ‘Tale-shaped note holder’. The resulting design: ‘Cat-shaped educational table for kids. Have keys that play explanations for different aspects of cats’ behaviour, habits’ (Figure 6).

The word pair in Session 4 was computer–ski (Wilkenfeld and Ward, 2001). Idea at the early stage of design: ‘Programmed practice for skiing or snowboarding’. The resulting design: ‘Ski device for an impaired person, controlled by a computer. Person is in a bobsleigh-like seat and is using a computer to direct the ski’ (Figure 6).

The results were analysed as follows. The designer’s process in the four cases is outlined in Table 2. The meaning elements indicated in bold were used in the evaluation, and the meaning elements shown in italics were attributed by the designer and were independent from the system.

### Table 2  
Analysis of the process

<table>
<thead>
<tr>
<th>Meaning element pairs</th>
<th>Main steps involved in finding meaning elements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ski ➔ Water ski ➔ Wedel ➔ Ski/Disabled</td>
</tr>
<tr>
<td>3 Cat–piano</td>
<td>Cat ➔ Whip ➔ Sound</td>
</tr>
<tr>
<td></td>
<td>Piano ➔ Piano ➔ Keyboard ➔ Key</td>
</tr>
<tr>
<td></td>
<td>Holder</td>
</tr>
<tr>
<td>1 Helicopter–blanket</td>
<td>Helicopter ➔ Vane/Cargo</td>
</tr>
<tr>
<td></td>
<td>Sky hook ➔ Hook</td>
</tr>
<tr>
<td></td>
<td>Blanket ➔ Shield</td>
</tr>
<tr>
<td></td>
<td>Blanket ➔ Net</td>
</tr>
<tr>
<td>2 Violin–sea</td>
<td>Violin ➔ Chinrest ➔ Chin</td>
</tr>
<tr>
<td></td>
<td>Shape ➔ Shape</td>
</tr>
<tr>
<td></td>
<td>Sea ➔ Wave</td>
</tr>
</tbody>
</table>

Table 3 provides a quantified summary of the processes involved. The analysis of the results is provided in Table 4. The resulting design ideas were evaluated by two experts on the criteria of practicality and originality (the first is concerned with actual use rather than theoretical possibilities, and the second is concerned with the quality of being new and original and not derived from something else) (Table 4). This method has been used in other studies as well (Finke, 1996).

Using the degree of relations calculated in Table 4, Figure 7 shows a comparison between the convergence of the initial and resulting designs with regard to the meaning elements. A lower convergence of meaning elements in the initial designs resulted in a higher convergence of the various meaning elements in the proposed design. The difference between the convergence of the task and that of the resulting designs is greater with the lower convergence of the meaning element pairs of the tasks.
Table 3  Summary of processes

<table>
<thead>
<tr>
<th>Meaning element pairs</th>
<th>Total time (to the final idea)</th>
<th>Number of words explored (unique words)</th>
<th>Number of accepted ideas (rejected ideas)</th>
<th>Number of requested feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Computer–ski</td>
<td>26 (17)</td>
<td>15 (10)</td>
<td>2 (2)</td>
<td>1</td>
</tr>
<tr>
<td>3 Cat–piano</td>
<td>21 (20)</td>
<td>10 (7)</td>
<td>2 (4)</td>
<td>2</td>
</tr>
<tr>
<td>1 Helicopter–blanket</td>
<td>10 (9)</td>
<td>6 (6)</td>
<td>1 (1)</td>
<td>0</td>
</tr>
<tr>
<td>2 Violin–sea</td>
<td>17 (7)</td>
<td>5 (4)</td>
<td>2 (1)</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4  Analysis of results

<table>
<thead>
<tr>
<th>Meaning element pairs</th>
<th>Originality of the idea (evaluated by experts on a scale of 1–5)</th>
<th>Practicality of the idea (evaluated by experts on a scale of 1–5)</th>
<th>Task (initial) convergence of meaning element pairs</th>
<th>Convergence of immediate meaning elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Computer–ski</td>
<td>2</td>
<td>4.5</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>3 Cat–piano</td>
<td>4.5</td>
<td>4.5</td>
<td>0.1429</td>
<td>0.2</td>
</tr>
<tr>
<td>1 Helicopter–blanket</td>
<td>1.5</td>
<td>3.5</td>
<td>0.1</td>
<td>0.1429</td>
</tr>
<tr>
<td>2 Violin–sea</td>
<td>3.5</td>
<td>3.5</td>
<td>0.0769</td>
<td>0.1667</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meaning element pairs</th>
<th>Convergence of rejected design ideas (if applicable)</th>
<th>Convergence of resulting design idea</th>
<th>Change (task and resulting)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Computer–ski</td>
<td>0.2</td>
<td>0.15</td>
<td>−0.05</td>
</tr>
<tr>
<td>3 Cat–piano</td>
<td>0.1667</td>
<td>0.2</td>
<td>+0.057</td>
</tr>
<tr>
<td>1 Helicopter–blanket</td>
<td>-</td>
<td>0.3333</td>
<td>+0.233</td>
</tr>
<tr>
<td>2 Violin–sea</td>
<td>0.0769</td>
<td>0.25</td>
<td>+0.173</td>
</tr>
</tbody>
</table>

Figure 7  Convergence of the meaning elements of tasks and the resulting designs in four sessions (see online version for colours)
8 Discussions

8.1 Proposed design methodology

In this study, we integrated a method of user-derived evaluation of the SoME in the design methodology. This new methodology bridges the gap between the user’s viewpoint and the design method. The user-derived evaluation is integrated as a part of the design methodology in conceptual design. Therefore, the originality of this study lies in the basic ideas about the proposed integration of the user’s evaluation as a step in the design methodology.

8.2 Case study

The case study tests the proposed design methodology in conceptual design. The conceptual design was tested as the SoME and led to successful design concept formation. The case study is limited in terms of the number of formed concepts and elaborated tools. However, as a test, the methodology allowed the formation of the design concept with the aid of an integrated user-derived evaluation. The design methodology is feasible as a tool for computer-aided concept formation.

8.3 General discussion

The case study reveals the processes of the SoME through the use of a semantic network database and the measures of the relations of meaning elements. In these key stages, the designer deals with the meaning elements in an explicit and systematic manner. The designer creates the SoME at the design conceptual level. In other words, the design process is expressed as a process involving the building of a structure from related meaning elements.

The dissimilar concepts are regarded as being connected to creativity (Finke, 1996; Nagai and Taura, 2006; Wisniewski, 1997). Thus, the methodology might aid the exploration process involved in the creativity by providing feedback on the convergence.

The utility of the existing visual representation is limited by its general features. On two occasions during the sessions, the designer reported that the graph contained too much information. Therefore, excluding some of the information might improve the exploration process. Adding features that stimulate the processes in conceptual design (providing suggestions by comparing the shapes of the two meaning elements and using ‘shape of’ constructions, e.g., ‘cat shaped piano’) can positively influence the design. However, the results indicated that the evaluation was successfully integrated into the design methodology.

There are certain differences between this study and other related ones. Segers et al. (2005) showed that word stimuli affect designers in the early stages of architectural design. Word graphs were evaluated as being helpful in breaking the designers’ mental fixations and enhancing creativity. In our study, we used pre-designated word pairs along with word graph generation.

Chiu and Shu (2007) focused on verb stimuli in predefined tasks. Verb stimuli have been successfully used to solve functional problem statements. In another study, Chiu and Shu (2008) showed that conceptual stimuli with opposite relations played a role in solving functional problems. Thus, we can state that verb stimuli contribute to functional
problem-solving tasks. Action concepts also play an important role in the creative design process (Nagai et al., 2006).

Breaking down the process into its basic elements allowed us to focus on the simplest processing activities associated with the meaning elements. In other words, we can correspond the view that the SoME as congruent with basic theories of creative design, for example, GDT (Yoshikawa, 1981). Our study defines only the meaning elements and the relationships between them, but not the task, which is why we focus on nouns. Various studies have outlined the importance of the conceptual processing of nouns for the generation of creative ideas in the early stages of design (Finke, 1996; Nagai and Taura, 2006; Wilkenfeld and Ward, 2001; Wisniewski, 1997). For example, the analysis of nouns in existing research indicates that nouns are associated with the performance of design teams (Mabogunje and Leifer, 1997). Noun assessment was shown to be a possible measure of performance in the design process.

9 Conclusions and open issues

This study introduced a formal approach to explore and evaluate the SoME in conceptual design. This approach integrates an evaluation from the user’s perspective into the design methodology intended for conceptual design. The results increase the possibility of aiding the designer in constructing the SoME. Furthermore, these results provide suggestions for the development of a support method that focuses on the conceptual design process. Such a support system can aid the formation of concept of the design by providing dynamic feedback of meaning elements with intended SoME. This approach facilitates the understanding of the underlying creative processes at the conceptual design stage. The creation of meaning structures complements our knowledge of the role of dissimilar concepts for the creativity of the created design concepts, by adding a viewpoint not only in the initial stages but also to the processes appearing in the particular design phase. This is a step towards our comprehension and enhancement of creative processes in the early design stage.

The significance of this study for science and practical application lies in the proposed integration of the user-derived evaluation as a step in the design methodology. This study reveals details of how concepts are formed in design and how this can be achieved with design methodology. The approach is not limited to a specific area of design or a certain type of conceptual design task.

However, this initial exploration of the SoME in conceptual design (the design phase from the beginning to the formation of the concept of design) needs to be further investigated, and the tools involved in this process need to be further developed. The proposed method has several foreseeable limitations with regard to the complexity of the designed artefacts and SoME involved. First, the approach is only applicable to the design of relatively simple artefacts, that is, in the case of non-interrelated SoME; therefore, the scale of the SoME has a limitation. Further, the approach of the SoME is a restrictive one. It is possible that humans in real design situations are more dynamic.

Further research needs to be conducted to develop an extensive research method and to provide support to designers with regard to both functional-based and impression-based meanings, which are not based solely on nouns. Furthermore, the support of product design necessarily involves (and considering its functional aspect,
possibly, should focus on) the role of verbs and adjectives in the formation of design concepts.

References


