MEANING STRUCTURE MODELING ON THE DESIGN CONCEPTUAL LEVEL

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ABSTRACT

This paper discusses a new approach to conceptual design. The presented methodology is based on the structure of meanings in the design process. The search and evaluation of meanings form the foundations of developing this structure of meanings. In order to facilitate the use and operation of the meanings, the WordNet lexical database is used. An existing visualization of WordNet is used for the process of meaning search. The WordNet::Similarity software for the measure of the relatedness of meanings in this database is the basic tool used for the evaluation process. The concept of similarity is concerned with the degree of interconnections between different meanings. Such search and evaluation techniques are later on incorporated into our methodology of the structure of meanings to support the design process. The measures of relatedness of meanings are developed as a convergence criterion for application in the evaluation processes. Further on, our methodology for the structure of meanings is used to construct meanings in a given example of shape. All the steps of the design methodology, including the search and evaluation processes involved in developing of the structure of the meanings, are elucidated. This design example is discussed to clarify possible implications of the design methodology. Finally, the paper presents directions for developing and further extensions of the proposed design methodology.

KEYWORDS

Meaning, design methodology, structure of meanings, search for meanings, evaluation of meanings, WordNet

1. INTRODUCTION

1.1. Background

When designers create products, they are taking meanings into consideration. Moreover, people recognize products of design as meanings. Thus far, meanings have been considered to be an important prospective for design, such as product semantics (Petiot, Yannou, 2004; Butter, 1989). In recent times, designers have been increasingly taking into account the important role played by meanings. Therefore, there exist some design supporting approaches that aim to connect design processes with meanings. So far, a sensitive topic on the agenda has been an understanding of the meaning of products. Designs need methods that support meanings incorporated in them, and those methods should have the ability to explicitly operate the meanings.
1.2. Meanings in design

Meanings in design can be approached from two different perspectives—functional application of the design and impressions of the design created in the user. The applied methodologies are also diverse. Both approaches are important to support of creativity involved in design process.

Functional meanings

The following are the meanings based on the functional and physical phenomena of design. Functional meanings are approached through different methodologies and theories.

Ontology is one of the methodologies, used for support of functional meanings in conceptual design. Such methodology is described in Horvath (1998), which focused on the modeling and representation of concepts for the computational support of the design process. The study elaborated on the ontology theory for formalizing the design concepts. This methodology successfully utilized the ontology paradigm in descriptions and the structuring of design concepts.

Moreover, Gero, Kannengiesser’s (2004) design method emphasizes the function-behavior-structure framework and its ontological approach. The representation of design process of this framework involves the interaction of making and seeing. This interaction between the designer and the representation determines the direction of the design process. This approach explores the functional properties and meanings of the designed product.

The methodological approach of Chakrabarti, Bligh, (2001) focuses on the physical descriptions of the design; these descriptions provide the intended functions of the design problem. It involves mapping natural language representations to the function structure and solution concept. This model is transferred to the knowledge-base of mechanical structures. The model proposed in this paper guarantees a search in the entire range of known solutions. Moreover, Sarkar, Chakrabarti, (2007) highlight the role of the exploration of concepts in creativity. The enhancement of this exploration contributes to design creativity from the viewpoint of relations between the design function and natural phenomena.

Impression meanings

On the other hand, the viewpoint of impression meanings of the design is researched from different approaches. These approaches emphasize the user requirements for user-oriented design. These refer to the meanings of the product, based on the impression in the user’s mind, i.e. the user’s cognitive interpretation of the designed product.

The concept of emotional design emerges from such a linkage. Norman, (2004) highlights the interaction between affect, emotion and cognition. An emotional response to a product design that is in agreement and does not conflict with its efficiency is the major attribute for success of a product. Furthermore, Norman, (2004) also associates this viewpoint to the perceived functional use of the products, based on visual impression. This example of the user’s impression of a product design creates meaning for that product.

Another example is the meanings surveyed by the semantic differential method, which is based on work of Osgood, et al., (1957). The semantic differential method focuses on measuring the connotative meanings of designs. Such research was carried out by Hsiao, Chen, (1997), who proposed a semantic recognition and rule-oriented approach for developing a product design. A number of referential products are used to quantify partial contributions to the impression of a product in terms of its image; this is done by using the semantic differential method. The results are implemented in models of products, which can be constructed by first inputting words and their corresponding functions to describe the image of the product under consideration. A new product forms can further be generated from a basic model of the product by regulating the shapes of the components using rules. This approach is based on the assessment reflected to design and not the design process of using meanings.

The product semantics approach has been discussed by Krippendorff, (2006) and Krippendorff, (1989) as impression 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 in shape (Krippendorff, 1989). This approach centered on symbolic associations and meanings and is generated by design features during the process of designing. It establishes the meanings embodied in design in the form of design semantics.
In recent times, both viewpoints—functional and impression—are required by designers, in terms of creative methodology involved in design. However, thus far, there has been no successful application methodology to explicitly process and operate all types of meanings, during designing.

**Issues to be addressed**

It is necessary to have a new user-oriented methodology that focuses on both types of meanings—functional and impression. With aid of this methodology it should be possible to rationally approach support these meanings. For this purpose, it is necessary to elaborate on the explicit representation of meanings that reflect complex human knowledge. Moreover, the methodology should be easily operable by the designer. In addition, in order to support the designers’ creative process, it is necessary to consider the early stages of process.

From the viewpoint of creativity, the exploration, synthesis, search and finding (Finke, 1996; Sarkar; Chakrabarti, 2007; Nagai, Taura, 2006) of new concepts and meanings are critical for design achievements. Creative design entails the creation a new structure of meanings by the designer. Existing methods can not address all these issues in their complexity and are not universally applicable beyond the original designation of methodology.

The early stages of design entail the following requisites:
- Control and construction of meanings
- Explore the meanings search in favor of the choice of the meanings
- Enhance and support the choice of the meanings. Use a systematic approach to meanings on the basis of their evaluation
- Use more complex and objective information concerning meanings; these should be consistent with human knowledge
- Improved designer control over the structure of the meanings

Currently, the search and evaluation of meanings in the conceptual phase of design rely only on ability of the designer. These abilities are not sufficient for an objective search and evaluation of meanings; moreover, they are not entirely effective for conceptual design.

**2. AIM OF THIS RESEARCH**

The present research introduces a methodology with above described features and proposes the structuring of the meanings in the process of conceptual design.

Hence, we term it as the *structure of meanings*. Our approach is based on the notion that the design process can be considered as the *developing structure of meanings*.

The goal of this research is to support the development of this structure in conceptual design. This structure of meanings is achieved by the *search and evaluation* of meanings. In order to propose a method for supporting the design process from the perspective of meaning, we focus on the relations of words enabling those meanings and involve these words in the construction of a network of meaning.

The tool for analysis of meaning relations has two requirements: it should be searchable and should facilitate the evaluations of meanings in it. Quality requirements constitute the number of meanings represented and their interconnections in such network.

**2.1. WordNet database**

Natural language processing provides tools that can be applied for such meaning analyses. WordNet represents knowledge in the form of a structured interconnected concept dictionary that is applicable for design support. The WordNet database satisfies all the basic requirements for a tool to be implemented in such a methodology; it can address and describe both functional and impression meanings. This database covers the requirements mentioned in the previous chapter. The aim of WordNet is to serve as a database system, consistent with the knowledge about the manner in which human beings process language and concepts.

More than 20 years of development WordNet of has resulted in creation of a network database comprising over than 150,000 words and 207,000 word–meaning connections. Words are organized in hierarchies and are interconnected by different kinds of semantic relations. Semantic relatedness refers to the human judgments of relationships between pairs of concepts. It is also used as lexical ontology in computer science (Pedersen, et al., 2004).

The advantages of WordNet as humanly constructed database and having an extended network between concepts are that it is practically useful for searches and evaluations of connections between concepts. Different types and lengths of interconnections are comparable in the network. Thus, it is usable as a structure for connecting concepts and representing
the human mind, not only for linguistic analysis but also as an evaluation tool.

2.2. Concept evaluation tools

Pedersen, et al. (2004) describes the practical application of measures of concepts within WordNet. The measures are domain independent. The developed WordNet::Similarity tool has been used in recent approaches in different domains (Pedersen, et al., 2007). This approach is practically applicable as a concept evaluation tool. It allows the measure of the semantic relatedness and the similarity between concepts found in the WordNet lexical database. This research assumes that meaning structure and relations are applicable as criteria to support of design choices and exploration.

The domain of design support already has some examples in which WordNet has been applied. Restrepo, (2007) uses the semantic similarity approach for contributing to the searches of conceptual designs. Although the work is focused on the conceptual design phase, it has only has an application for comparison with existing designs descriptions.

In a different approach, meanings have been researched as the semantics of product design, and this approach was extended to the view that similarity of language bridges the designers’ knowledge (Dong, 2005). However, this research uses WordNet in a different manner, namely to search for meanings. Moreover, the WordNet::Similarity tool is used for the evaluation of meanings in the methodology of design.

3. DESIGN METHODOLOGY

3.1. Framework of the structure of meanings

This framework is established as a description of application of the structure of meanings in the design process. Basically, in our framework, we distinguish between two domains—shape domain and meaning domain. Additionally, we describe the designer and WordNet database, i.e. either they act independently or they are connected to these domains, interacting with the domains or intermediating interactions between them. We divide the process into the conceptual, emergence, prototyping and detail phases (Figure 1).

In this framework, the design process is presented as a progressive transfer between meanings and shapes. In the initial stages, the meanings are searched, evaluated and expressed (emerged) in shapes; then the prototype of the shape is developed through iterations into the final product. In the twelve stages of this framework of meaning structure (Figure 1), the designer can refer back to any stage of the process. The steps are described as follows:

**Conceptual phase**

At a fundamental level, the designer’s work entails the translation between objectives (concepts or meanings), and the visualization of that concept in a form of a shape. In the first and second stages (Design task and Meanings abstraction) of the conceptual phase, the designer extracts (abstracts) the initial set of meanings (Meaning Set in Step 3) based on the description of design goals.

This set is searched and evaluated with the core design methodology described in the following chapter. With support of this design methodology we achieve the appropriate (improved) meaning structure in Stage 5. The improved structure of meanings from Stage 5 is expressed in the form of a shape in the design prototype in Stage 6.

**Emergence phase**

This phase refers to the emergence or visualization of a shape from the meanings (concepts). The meanings are translated into shapes. Here (stages 7 and 8 in Figure 1), the shape and meaning structure are modeled. The process primarily involves sketching and multiple iterations by the designer.

**Prototype phase**

The structure of the shape is expressed in the design prototype. This phase results in a structured shape (Stage 9, Figure 1), that is again prototyped in multiple iterations by the designer (stages 10 and 11).

**Detail phase**

The meanings are verified and evaluated using approach similar to this used in the conceptual phase. All the details are finalized and the shape is refined.

**Outline of the framework**

By the way of a conclusion, we provide an outline of the framework. It describes the design process as the transition between meanings and shapes. Through this, the framework outlines the important points connected with meanings for the creative design process (Figure 1). This paper focuses on the conceptual phase of design, which is considered as
the most important in design (Finke, 1996). Further, the proposed design methodology focuses on achieving the structure of meanings in stages A-B-C. Using this framework, the methodology supports the effective exploration and evaluation of meanings. This contributes to conceptual exploration and synthesis. The latter is the key to creativity in the design process (Nagai, Taura, 2006).

3.2. Search and evaluation in design methodology

The steps of design methodology described below are part of the structuring the meanings phase of conceptual design in the framework, which is the focus of this study.

Steps

The design methodology uses the following precise procedures for meaning search and evaluation (Figure 2). It corresponds to the stages A-B-C in the framework presented in the previous figure. Stage A involves the meaning set used in the design methodology; Stage B entails building the structure of meaning using search and evaluations and Stage C is the resulting appropriate meaning structure (Figure 2). The steps are:

- meanings set refers to the starting point of initial concepts (meanings) that relate to the design task and abstracted meanings from the task (A)
- Search in WordNet with these meanings (B1)
- Visualization of WordNet as a network neighborhood of searched meanings (example is provided in Figure 3) (B2)
- Designer selects new meanings (concepts) from this neighborhood network (Figure 3) (B3)
- New meanings are evaluated by convergence criterion form WordNet::Similarity (B4)
- If the meanings do not show sufficient convergence criterion, the designer returns to one of the previous steps, i.e. the designer selects new meanings (concepts) or searches using new input (B5)
- The process continues until a good score on convergence criterion is achieved or until the designer decides that the meanings are appropriate (B1–B5). The steps are repeated until an improved and appropriate structure of meanings is attained.

3.3. Search method

The essential aim of the meaning search (B1) is to find more applicable meanings on the ba-
3.4. Evaluation method

The evaluation of meanings (B4) is based on measures implemented in WordNet::Similarity release 2.01. (http://search.cpan.org/dist/WordNet-Similarity/). There exist a number of measures, and the relatedness based on path is the most general one of these. Relatedness by path length is based on the principle of counting edges between concepts (Pedersen, et al., 2007). It is a relatively simple measure in WordNet’s noun hierarchy. Relatedness by path (similarity) can be defined as follows:

\[
\text{Sim}_{\text{path}}(\text{Meaning}_1, \text{Meaning}_2) = \frac{1}{\text{Path}}
\]

The measure results in a number between 0 and 1, evaluating the degree of similarity between the two meanings. Although, it has the relative advantage of simplicity, it is restricted to only nouns and the “is–a” relation.

Our methodology uses this measure for the evaluation criterion (B5) of the set of meanings. Since relatedness (similarity) refers to the degree of similarity between a pair of words, we summarize this relatedness the convergence criterion. Previous research has pointed out that relatedness contributes to evaluation (Georgiev, et al., 2007). The results from this research indicate the significance of relatedness by path for the high assessment of designs. Higher relatedness corresponds to better evaluated designs. The relatedness of meanings is applicable as a comparative criterion between the pairs of meanings. Thus, convergence is the evaluation of relatedness or similarity of a limited set of meanings, as follows:

\[
\text{Convergence} = \frac{\sum_{i=1}^{N} \text{Sim}_{\text{Path}_i}}{\text{Number}_{\text{SimPath}}}
\]

Characteristics

In terms of applicability, the general characteristics and advantages in terms of applicability of our methodology are as follows:

- It directly operates the structure of meanings and explicitly explores meanings.
- It uses WordNet as an explicit and non-tacit representation of the human’s mind. WordNet is a very complex knowledge-based structure that has a broad coverage and is domain independent.
- It implements a criterion that is easy to judge and evaluate criterion.
- It can be calculated and evaluated in real time, during the design process.
- It is conducted at an early design stage.
4. DESIGN APPLICATION EXAMPLE

The practical implications are clarified with design example of the methodology. We focused to the structure of meaning, applied in the graphic design case. The case of communication design is using meanings in easily describable way (Bowers, 1999; Kazmierczak, 2003). Symbols in communication design and brand recognition are regarded as special area of application of meanings, connected with design semantics. These symbols have rich structure of many associations — in this case nouns represent meanings.

4.1. Similarity and convergence criteria

The practical application of relatedness by path (Georgiev, et al., 2007) is implemented in convergence criteria, as described in point 3.4. Support role of convergence criteria is addition in decisions of designer.

The described examples are demonstration of design methodology implications. Further we discuss case trial, which cover difficult meaning inputs from design task. In here presented example, the methodology of and application of meaning criterion in design tasks is described. According to results of the study, if the input meanings in form of keyword set are highly similar, using this approach a little can be done. For that purpose we cover a difficult case of application of the methodology.

4.2. Example

The discussed example focuses on the designing logo for a company, called Relymount, which produces mountain radio transmitters. The aim of the design task is to represent characteristics of the company in the designed shape.

Design task

The design task is analyzed in the first stage of the design process (Figure 1). The meanings conveyed from this task result in five input meanings consideration—Communication, Connection, Radio, Mountain and Durability— to be considered further in the process. This set is directly extracted from the explicit goals of the design. These meanings are decided to be the meaning set, further structured in the design methodology. This case represents the meanings from the design tasks that are not well connected and are too difficult to elaborate.
Design methodology

The next process according to the design methodology is the evaluation of the whole meaning set (B5 in Figure 2). The relatedness and convergence criterion between the five input meanings is shown in Table 1. Note that, each pair of words has different similarities. The calculated convergence score of 0.155 is considered to be relatively low (Georgiev et al., 2007). Hence, the aim is to achieve a better convergence score, while keeping the meanings close to the initial meaning pairs. Next, the steps B1 to B5 of the design methodologies are discussed.

Table 1 Example—path relatedness matrix of meanings for the words Communication, Connection, Radio, Mountain, and Durability

<table>
<thead>
<tr>
<th></th>
<th>Communication</th>
<th>Connection</th>
<th>Radio</th>
<th>Mountain</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>0.5</td>
<td>0.1</td>
<td>0.125</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Connection</td>
<td>0.2</td>
<td>0.143</td>
<td>0.125</td>
<td>0.067</td>
<td>0.091</td>
</tr>
<tr>
<td>Radio</td>
<td>0.1</td>
<td>0.067</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mountain</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>0.091</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Convergence | 0.155

In the next stage, the design methodology continues with the search (B1) and visualization (B2) to help the designer to choose new meanings (Figure 4). This process focuses on meanings and replacements with closer meanings (Figure 4, representing step B3) will give better total convergence of the whole set of meanings.

The visualization of the local WordNet structure for the meanings of the word “radio” is shown in Figure 4 (a). This graph shows different possibilities for substitution of the input meaning. Respectively, the meanings of the words “mountain” and “durability” are visualized on Figure 4 (b) and 4 (c). On the basis of these visualizations the replacement meanings are chosen by the designer. The designer chose not to change Communication and Connection.

As a result of the visualization, it was decided by the designer that the meanings for Radio, Mountain and Durability would be replaced by Wireless, Peak and Continuity respectively. Further evaluating all the replacements, the new convergence score of the set of five meanings is calculated 0.200 (Table 2). As a result, it is higher than the initial convergence score—0.200 > 0.155. The higher convergence will possible give better design results (Georgiev et al., 2007). Using this methodology, the meanings are further developed for better convergence, as shown in Table 2.

Table 2 Example: Path relatedness matrix of the meanings of the words Communication, Connection, Wireless, Peak, and Continuity

<table>
<thead>
<tr>
<th></th>
<th>Communication</th>
<th>Connection</th>
<th>Wireless</th>
<th>Peak</th>
<th>Continuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>0.5</td>
<td>0.1</td>
<td>0.167</td>
<td>0.167</td>
<td></td>
</tr>
<tr>
<td>Connection</td>
<td>0.2</td>
<td>0.2</td>
<td>0.333</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wireless</td>
<td>0.111</td>
<td>0.077</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>0.143</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Convergence | 0.200

Emergence and prototyping phases

The stage after application of the core methodology continues with designer’s search of possible implementations of these meanings in shape (Figure 5). All possible representations meaning – shape at this stage are decided by the designer. Further, these representations are modeled into a single shape through multiple iterations.

The conceptual designs iterations resulted in different prototype layouts of the shape structure, which are shown in Figure 6 (a). The final decided idea sketch by the designer and the layout of final designer’s decision for the shape with the meanings of Communication, Connection, Wireless, Peak and Continuity is shown in Figure 6 (b) and (c).

In every step of design the convergence score is added to the designer criteria and decisions. Designer’s judgment and awareness (appropriateness of choices made) are important for success of this task.

In summary, this example of design methodology discloses application shows search, evaluation and
Radio is replaced (by designer) by Wireless using visualization of the local WordNet structure for the word “radio”.

Mountain is replaced (by designer) by Peak using visualization of the local WordNet structure for the word “mountain”.

Durability is replaced (by designer) by Continuity using visualization of the local WordNet structure for the word “durability”.

Figure 4 Example: Search (B2) and visualization (B3) of WordNet for the meanings of Radio (a), Mountain (b), and Durability (c). The chosen substitutions are Wireless, Peak and Continuity, respectively.

building of meanings structure using WordNet and similarity measures in the WordNet database. These processes of search and evaluation use initial meaning set from the design task and develop this set to form an appropriate meaning structure in the conceptual design phase.

5. CONCLUSION

This research established a framework of meanings that can support different aspects of meanings in design support methodology. It is conducted by a meaning search and the evaluation of the structure of meanings according to criteria. The search and evaluation of meanings are key stages in the proposed design methodology. The structure of meanings—that can be directly operated and developed by the designer—on the design conceptual level is applied. Confirmation of changes and development of the structure of meanings by the designer is done by the presented example.

Figure 5 Example: Possible representations (decided to be developed by designer) of meanings of words Communication, Connection, Wireless, Peak and Continuity in shape (Emergence phase in Figure 1).
The design methodology advantages can be considered to have the following:

- The search for meanings is enhanced in a systematic manner, by using the complex WordNet knowledge database for objective representation of the meanings.
- The evaluations of the designer in terms of meanings are enhanced by the introduction of the convergence criterion, which can be easily evaluated for sets of meanings.
- There is improvement in the designer’s control and in the building of the structure of meanings.

This is an objective approach that is applied in the conceptual phase. As such, it can prevent inappropriate design decisions (e.g. using a set of meanings that will probably result in a design that is not well evaluated) or improve the choice of meanings (e.g. by using a set of meanings that will possibly enhance the evaluation of design).

The described criterion—convergence criterion—serves as an additional judge of the sets of meanings. The convergence criterion provides a qualitative criterion in addition to that of the designer. With the use of WordNet in the search of new meanings that are closely related to the initial meaning, we can achieve a better exploration of the concepts.

The discussed communication design task example is used for verification of the design methodology in terms of features and activities of the designer. The practical developing of the structure of the meanings is done. The example discloses the importance of search and evaluation of meanings in the conceptual phase of design. In this way, the development of this structure supports the efforts of the designer. The methodology is equally applicable to both the design and the redesign tasks. In the example, although the methodology is applied to impression meanings using nouns, it can similarly be applied to functional meanings, incorporating verb or adjectives hierarchies from WordNet. The approach is universal because of its characteristics of consequent search and evaluation of meanings. It is a reflection to the iteration processes of designing.

6. FUTURE WORK

6.1. Integrated support and expanding research on criteria

Considering this methodology, further refinement of the process is required. The steps of search and evaluation of the convergence criterion have not yet integrated into a single system. An improved integrated functionality is required to facilitate easy application in the design conceptual phase.

There is a possibility that other more complex criteria can be described for structure of meanings in WordNet. We will identify such criteria in future studies through the exploration of different measures of relatedness.
6.2. Extension to other design domains

The future aim of this methodology is to support both functional meaning and impression meanings. The possibility for the extension of the methodology, including other hierarchies in WordNet is a factor for the extension to the product design domain. It is not limited to a specific design area or type of design tasks.

This methodology is also applicable to the final stages of the design process, where the judgments for the meanings formed from the prototype design can be incorporated in the final decision.

The support of the product design necessarily involves (and possibly, predominantly focuses on) the verb and adjectives sub-networks of WordNet. It is possible that this extension will reflect on the criteria. Additional research in this direction is needed. Functional meanings can be analyzed by the measures in these sub-networks.

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