A CONCEPTUAL NETWORK APPROACH TO STRUCTURING OF MEANINGS IN DESIGN

Georgi V. GEORGIEV*, Yukari NAGAI*, Toshiharu TAURA** *

*Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, 923-1292, Japan
**Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan

Abstract: This paper proposes the viewpoint of design as a process of ‘structuring of meanings’. This is a framework which is directly related to the synthesis of concepts and to creativity during the early stages of design. In the presented approach three factors – Sum of Meanings, Relatedness by Path and Standard Deviation of Relatedness by Path – assessing meanings are established in connection with results of design. Furthermore, those assumptions are tested in a case study, resulting in a model of the influence of the proposed factors assessing meanings on the evaluation of design. The validity of this model supports the proposed framework. This understanding of the structuring process of meanings and the utilization of the proposed descriptive factors are important considerations towards further support of conceptual design.

Key words: Meaning, Structured Meanings, Factors Assessing Meanings, Relatedness, Concept Dictionary

1. Introduction

Humans respond to the individual and cultural meanings of things [1]. Design as an activity is giving form to the artifacts that solve problems. The problem solved need not be a pressing societal need, but rather any perceived gap in a user’s experience [2].

Design of artifacts as a sense-creating activity, which aims for the products of design to be understandable to their users, is being researched by product semantics. This product semantics approach evolved as a centrality of the meaning building of artifacts [1]. In this approach, the meanings of artifacts are equated with the set of their possible uses, both imaginable by someone and afforded by the artifacts. The users respond to the meanings that artifacts have for them, to what artifacts permit to do with them, the paths they lay out in front of users, and the possibilities they offer. The artifacts mean their “affordances”; the set of their imaginable uses [1] is a view derived from the possibility for different ways of seeing in connection with perception.

Product semantics [3, 4] focuses on the user’s cognitive interpretation of the products to help building the interface of the product by the designer. Furthermore, in this approach, the affordance theories draw attention on the manipulation of the physical properties of the product to regulate the user’s behavior [5]. This product semantics approach emphasizes the interface and functions or acts offered to the user by the designed product, and to thus focused on functional aspects the artifact.

Referring to a more general understanding of the matter, in the framework of this research, we adopt a broader definition of ‘meaning’ as “an abstract idea or mental image which corresponds to concepts”, and it is dynamically structured in the mind [6]. Using this formulation, it should be noted that meanings of the design products usually change depending on the situations, and that these changes are difficult to capture.

Furthermore, in this paper we approach design as a process of ‘structuring of meanings’ which relates directly to the synthesis of concepts and creativity during the early stages of design [7, 8]. By introducing this framework, we seek analysis tools and establish a method for its practical application and testing.

2. Meanings in Design

2.1. Viewpoints on Meanings

Meanings have importance from two viewpoints – the users’ and the designers’ – and this is highlighted in a number of previous researches. For example, Krippendorff [1] discusses the designer’s understanding of the user’s
understanding of the artifact meaning and the disruptions of the artifact interface. Crilly et al. [9] highlight the users’ response as a part of the process of communication, distinguishing between cognitive, affective and behavioral responses. The interpretation of a product is assisted by reference to other products, concepts or entities. The perspective of emotional design [10] indicates that the affect, emotion and cognition have also evolved to interact with and complement one another. This reflects design as aiming at meanings that triggers an emotional response [11] that could be designed into a product in order to communicate with the user at an emotional level.

The difference between words, concepts and meanings are applied to the product in the perspective of the same scale [10]: from behavioral, through affective to the cognitive interpretation. However, the products of design have not a limited interpretation that appears (or makes sense) to the user. From the users’ viewpoint, meanings depend on many factors, situations and conditions – it is dynamically structured in the mind. For the designer, the user’s viewpoint has the greatest significance. The intended meanings should be matched to the resulting ones. Moreover, these meanings have to be viewed in the perspective of the design method. Namely, for the designer the main problem is how to search, choose, compare and evaluate concepts, which are later to be structured and realized as meanings of the artifact. In this perspective, the results depend mostly on the experience and the intuition of the designer [12]. The concept generation process is of a critical importance here. This shows the necessity to match both understandings and need to bridge the knowledge between the two viewpoints by focusing on early conceptual phases of the design.

2.2. Meanings and Semantic Methods in Design

Meanings emerge in the use of language, involving an interaction with artifacts [1]. “In language, artifacts are conceptualized, constructed, and communicated; their meanings are negotiated” (p149). Categorized by the users, the artifacts’ characters, or adjective pairs, can be measured by semantic differential scales. That is reflected in the use of such scales for evaluation in design research.

2.3. Evaluation of Meanings in Design

The product semantics has elaborated use with the semantic differential (SD) method [13] in different research works [14, 4] for evaluation of meanings in design. The SD method is also widely applied in other areas [15]. It describes the product in dimensions of a semantic space. However, the dimensional analysis used by this method is suitable for the user assessment of design products, but insufficient for analysis of meanings and their factors. The SD method and its bipolar characteristics are not extensive enough for the complex nature of meanings, thus requiring further tools and methods for supporting their dynamic nature.

2.4. Semantic Analysis in the Design Process

The importance of language in the design process is highlighted in many research works. Natural language processing tools can be applied in the concept generation process [16, 17], and in the analysis of design team results and performance [18, 19].

2.4.1. Words as Stimuli in Conceptual Design

Chiu and Shu focused on verb stimuli related to concept generation [16]. They clarified how stimuli syntactically relate to other words and phrases that represent ideas. Furthermore, Segers et al. [17] conducted an experiment on the use of word graphs in support of concept design in architecture. The words directly connected to the concepts used as feedback in the design process are proven to help designers – namely to reduce fixation, and to promote new concepts.

2.4.2. Analysis of Performance in the Design Process

The analysis of nouns in previous research indicates that they are associated with the performance of design teams [20]. Noun assessment was shown to be a possible measure of performance in the design process.

Such tools are already used in various approaches of the analysis of design activities. Dong uses latent semantic analysis for studying design team communication [18]. This approach enables the direct measurement of knowledge construction in the design process. The findings help to bridge the gap between shared mental representations of the designed artifact, constructed by designers in the team. Concepts formation is evaluated with computational linguistics tools. The knowledge accumulation is described in a data structure comprised by a set of links between concepts. Outcome analysis and conversation analysis in these cases are performed using the concept database [18] as an analysis tool.

These conceptual design approaches highlight the importance of connected concepts and meanings that are relevant to the design task. In fact, they raise the possibility of applying natural language computational tools to support the conceptual design phase.

2.5. Importance to the Design Method

Not discussing the general idea of meaning, in this research, we shift this approach to another viewpoint. Our perspective on meanings is as they rise in the structure of concepts in human mind – thus structure itself is a meaning (in other words, represents such) for the users. This structuring process relates to the meanings of the designed artifact and thus to the method of design.

We draw attention to the structure and relation among
3. Aim of the Research

The aim of this study is an initial investigation of the structuring meanings in design, with a particular focus on the characteristics of the structured meanings in well evaluated design. Overall, this approach can be considered as an attempt to establish the factors which affect design outcomes. By establishing factors describing these structure characteristics, the goal is to successfully connect such factors to the results of design, in this way being able to support design process. The understanding of the structuring process of meanings is an important consideration towards further support of the early stages of design. Finding factors assessing meanings is to serve as a basis for active and dynamic conceptual design, implemented in a tool for meaning-based support. This leads to the hypotheses of this research:

3.1. Hypotheses

Hypothesis 1: The structured meanings, found in the design, can be described by practical quantitative factors assessing meanings.

Hypothesis 2: A certain structure and certain relations of meanings have an effect on the evaluation of design and become a contributing factor to this evaluation.

3.2. Research Questions

The research questions below are basic to the method and analysis used in our approach. They are as follows:

- Is it possible to define and express factors describing the structured meanings? This question is based on the importance of the relations of concepts which we hypothesize.
- What is the effect of structure and relations between meanings on the evaluation of design in the context of other factors?
- Which factors assessing meanings can have an implication in the design method, regarding the processes of synthesizing meanings and concepts?

3.3. General Method of Meaning Analysis

Understanding of the structure requires factors capable of describing it. The directions are towards description of factor assessing meaning quantity and factors assessing meaning relations in order to evaluate differences and comparison between meanings.

The method is comprised of following steps: establishing such factors assessing meanings, analyzing them for number of examples in a case study and testing them in comparison to factors evaluating qualitatively this example designs.

4. Tools for the Analysis of Meanings

The structures of meanings can be considered as concepts which are operated on by information processing technology based on human knowledge, e.g., a concept dictionary such as WordNet [21]. The WordNet lexical database as a knowledge system is applicable to the search and analysis of concepts, already elaborated in various approaches in design research [16, 18, 19, 17]. The idea of applying WordNet, discussed in this work, is to involve it in the evaluation of relations between concepts, thus as a tool for the evaluation of the structured meanings.

There are different measures of meanings using the WordNet database as ontology of concepts. Such estimations of relations and similarity of concepts [22] are applicable to other domains [23]. By evaluating relations of the meanings, the use of WordNet is expandable into a practical support for design. Connecting an evaluation analysis and humans' understanding in the form of meanings raises such a possibility.

This study was designed to address the needs of a practical description of meanings in the design method. The main tools used the method presented here are:

- The WordNet (version 2.0) lexical network database as a representation of concepts, meanings and conceptual relations [21].
- WordNet::Similarity (version 2.01) for evaluating the relations and connections between meanings. This software module implements a variety of semantic similarity and relatedness measures based on information found in the WordNet [22].

4.1. Factors Assessing Meanings

This research proposes three original factors assessing meanings for the needs of meanings analysis. The first factor is based on an idea for a factor which summarizes meanings. The following two factors are based on an idea for factors which represents relations between meanings.
The approach connects quantitative analysis with meanings. For the actual calculations of the last two factors, the WordNet database and the similarity and relatedness measuring software WordNet::Similarity were used by [22]. The simplest measure among those defined in this database, the concept relatedness by path length [22], was used in our research. Sum of Meanings, Relatedness by Path and Standard Deviation of Relatedness by Path are discussed as factors assessing meanings. They are defined as follows:

The Sum of Meanings $M$ counts the number of all meanings per example. The Relatedness by Path $R$ is defined as the average value (number of relations $n = M!/2!(M - 2)!$ in Equation 1) of all meanings similarities by shortest path in the WordNet database (Equation 2) [22]:

$$R = \frac{1}{n}\sum_{i=1}^{n} S_i \quad (1)$$

Where the similarity $S$ is a real number between 0 and 1 defined as:

$$S(m_1, m_2) = \frac{1}{p} \quad (2)$$

With $m_1$ denoting meaning 1, $m_2$ denoting meaning 2, and where the path $p$ is measured in steps in the WordNet database. Equation 2 is a standard measure in WordNet::Similarity [22]. This mathematical definition of similarity $S$ has a practical interpretation. It closely corresponds to the judgment of semantic relatedness of words by human subjects [22]. Here, the defined factor Relatedness by Path $R$ is derived from the similarity $S$. In this way, it is a measure of the average distance between meanings of a design. The Standard Deviation of Relatedness by Path $\sigma_R$ is defined as the unbiased standard deviation of the Relatedness by Path $R$:

$$\sigma_R = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (S_i - R)^2} \quad (3)$$

The Standard Deviation of Relatedness by Path $\sigma_R$ factor is a measure of how widely values of individual similarities $S_i$ are scattered from its average value $R$. This factor is an addition to the Relatedness by Path factor. The three factors assessing structure have an application in the design method – structuring of meanings.

### 4.2. Procedure of analysis

The actual procedure of the meanings analysis of one design example is illustrated in Figure 1, and is also described below:

The design is characterized by the number of meanings (Stage 1) e.g. the list of meanings – Alliance, Band, Blend, Collection, Communication and so on. The interpretation of meaning relatedness between the example pair of words Alliance and Communication is calculated in the WordNet path (shown in Stage 2). The shortest path is calculated with WordNet::Similarity as Alliance – Connection – Communication, which consists of 3 steps. According to Equation 2, the Relatedness by Path is 0.33. For every example design, a similarities of all meanings is calculated (Stage 3). This is summarized by Equation 1. In this way, the three factors of the investigated design example are calculated (Stage 4). The real value (between 0 and 1) of the factor Relatedness by Path is obtained with this method. In summary, the method incorporates calculations of factors assessing meanings, taking into account the number of meanings and the evaluation of relations among all the meanings.

### 5. Case study

#### 5.1. Data Collection Method

Inheriting the viewpoint of design as meaning-producing, we focus on obtaining practical knowledge for the connection of the meaning factors with the evaluation of design. For a verification of the viewpoint of this research, we conducted a case study of the features of the structured design. We focused on data and a non-fixed interpretation of meanings, namely the relations between concepts in this interpretation. The choice of the case study [1] is derived from the criteria of tight connection with semantic principles (p237). The most explicit meanings-centered design, thus the most analyzable, is the communication design. Thus, in our verification case study we collected data regarding meanings with design examples form this area. In a pilot case study [23] the connections between meanings previous were found to be associated with the impression of design. In research discussed here, a pen-and-paper case study was conducted to answer the questions raised above. The results of this case study are analyzed here to test the constructed hypotheses. The interpretation of the results of the case study is elaborated through structural equation modeling and path analysis.

Specifically in communication design research, meaning has been addressed as design factors [24], and its important role in influencing people's impression has been pointed out. The meanings are regarded as the main tool for the design process [25]. Although the meanings are reported to be connected with design characteristics [15], the connection is thought to be a weak one.

The case study is based on the survey form [26]. We completed the following procedure, in order to verify the effectiveness of the proposed factors assessing meanings:

A questionnaire for the evaluation of factors and indicated meanings was conducted. This questionnaire investigates general assessment factors, including the evaluation and interpretation of meanings for the design examples of logotype symbols. An extensive analysis of gathered meanings as nouns was performed using the WordNet database and the relatedness measures. This analysis investigates the meanings in our examples and to
Figure 1. Procedure used for the meanings analysis of a design example.

test the proposed factors regarding to the first hypothesis. The factors assessing meanings are extracted. The procedure of meaning analysis and factors assessing meanings take into account the differences between the indicated meanings. Furthermore, factors assessing meanings are compared with the evaluation and with common factors for the assessment of symbols.

An interpretation of findings using Structural equation modeling (SEM) [27] was elaborated. The purpose is to build a model which predicts the influence of meanings factors on the evaluation of design. This is investigated in order to contribute second hypothesis. Our assumption is that together with common factors, represented in this study by familiarity and harmony, factors assessing meanings have a strong influence on the evaluation of the design.

5.2. Participants

Eighty-six students in the second year of the engineering design major at the Technical University of Sofia completed a questionnaire for this study. The selection of participants is based on the assumption that all of them already have a fundamental knowledge of the design process, but that they are not practicing professionals. This follows from our opinion that results will be better applicable in further approach of design support. Moreover, this selection is relevant to the general goal of developing a new support method for design through this analysis. All the participants are volunteers, who received no additional course credits for their participation.

5.3. Structure and Procedure

The conducted questionnaire included 60 design examples of logotype symbols in color, and was divided into two parts (Figure 2). The first part included general assessment factors on a 7-point scale, as shown in Table 1. The second part focused on the interpretation of meanings of examples. Every participant assessed 20 examples and pointed out the meanings of 20 other examples. For every participant, the first and second group included different examples in a different order. Parts of the questionnaire included an explanation of the factors under assessment and of the meanings respectively. The examples chosen were from different origins and have different design characteristics. They cover a broad range of successful examples of design of logos in use, highlighting different design characteristics.

5.4. Factors

The general assessment factors chosen are evaluation (further denoted by $E$), clearness ($C$), meaningfulness ($F$), familiarity and harmony. The last two factors are common factors for the assessment of the design in such cases [24, 15]. An analysis of these common factors shows that only a few of them are relevant to meanings. The choice of
familiarity is connected to the creation of meaning, while harmony is a common generalizing factor of, for example, balance, symmetry, Gestalt [24]. The factors known as be influenced by cross-cultural differences are excluded. The factors used in this research, their judgments (as it was explained to the participants prior to filling out the questionnaire) and characteristics are shown in Table 1. The newly added factors are “clearness” and “meaningfulness”. The choice of clearness and meaningfulness was derived from the assumption that both these factors are connected with the interpretation of meaning. Furthermore, among aesthetic general assessment factors, harmony is chosen as the most general one, incorporating balance and symmetry.

6. Results

6.1. General assessment factors

For every example, the average value of every assessment factor is calculated. This means that all 60 examples received scores for the factors evaluation, clearness, meaningfulness, familiarity and harmony. The initial descriptive statistics of the general assessment factors are shown in Table 2.

The familiarity assessment of the examples was relatively low. Compared to all other general assessment factors, the evaluation factor has the smallest standard deviation. This means that participants made a relatively narrower judgment on evaluation than on other factors.

6.2. Interpretation and Factors Assessing Meanings

In the second part of the interpretation of meanings, participants indicated as many meanings as they discovered in the examples that were presented (Figure 2, Part 2). There were no limitations in the meanings to be indicated. Nouns represent the greater proportion among given answers for meanings. For every example, the meanings, including those repeated more than once, are grouped together for further analysis. The meanings that were discovered vary from 31 to 84 nouns. Table 3 presents one example, indicated meanings and factors assessing meanings. The total of 60 groups of indicated nouns are used in the WordNet analysis.

6.3. Summary of Factors Assessing Meanings

From the calculations in the previous step, for every example, three factors assessing meanings were computed: first, the simple sum of discovered meanings per example; second, the relatedness by path, which is the average relatedness between all the meanings of the considered example; and finally, the standard deviation ($\sigma_R$) of the relatedness by path. The summary of descriptive statistics for all examples is also shown in Table 2. The average number of meanings per example is 55.7, and the average relatedness by path is 0.2378. After obtaining meanings (Figure 1, Step 1), for every pair of words the relatedness by path was calculated (Step 2). These measures were grouped into a similarity matrix (Step 3), constructed from every example. This resulted in 961 to 7056 calculated relatedness measures between meanings of words. Then, the average relatedness by path and its standard deviation were calculated (Step 4).

6.4. Correlations between Factors

The first step of this analysis was the evaluation of the correlations between the general assessment factors and the factors assessing meanings. The analysis of correlations showed no strong correlations between factors assessing meanings and general assessment factors (Table 4). The common factors of familiarity and harmony were not significantly correlated to any factors assessing meanings. If we consider the factors assessing meanings, the correlations and significance are higher with “clearness” and “meaningfulness”, and lower with “evaluation”. A model of predictions of factors will possibly provide a better explanation for these results. The commonly approved factors “familiarity” and “harmony” are excluded from the final model, because their correlations are not significant.

Furthermore, in this study, the dependent variable is considered for the evaluation of design, and the independent variables are the factors assessing meanings and other general assessment factors – clearness, meaningfulness, familiarity and harmony. The regression analysis conducted in the next step shows significant correlations also within general assessment factors (Table 5). The correlation matrix shows the Pearson r's and the significance of each r – the effect of factors assessing meanings on the evaluation and general assessment factors. The only correlations that are not significant are those of the sum of meanings with the relatedness factors and with clearness.

6.5. Analysis with Structural Equation Modeling (SEM)

In the next step of the analysis, Structural Equation Modeling (SEM) [27] was used to evaluate the influence of factors assessing meanings on the design evaluation. As a statistical technique for estimating relationships, it is a suitable theory testing [27]. This modeling is an extension of the general linear model and represents relationships among variables using path diagrams.

After regression analysis was performed, a path analysis using the SEM of these factors was conducted, using software AMOS 5. This is a search for direct and indirect effects of the variables on the evaluation. The factor of evaluation is considered as a dependent variable in the path analysis result, as shown in Figure 3.
Table 1. Characteristics of general assessment factors as dependent variables

<table>
<thead>
<tr>
<th>General assessment factors</th>
<th>Evaluation</th>
<th>Clearness</th>
<th>Meaningfulness</th>
<th>Familiarity</th>
<th>Harmony</th>
<th>Sum of Meanings M</th>
<th>Relatedness by Path R</th>
<th>Standard Deviation of Relatedness by Path σ_β</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value of total quality of design –</td>
<td>Easiness to perceive and appearance of design elements –</td>
<td>Creation of meaning and understanding design –</td>
<td>Degree of remembering or impression of that design is seen or with common features</td>
<td>Combination of pleasing elements in design –</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refers to evaluative reaction to the impression created by design in terms of goodness, quality and likeness</td>
<td>Refers to perception clarity and uninterrupted transfer of design intentions</td>
<td>Refers to the degree and success of meaning creation, understanding meanings</td>
<td>Being familiar and with common design –</td>
<td>Involves balance and symmetry of design from a Gestalt perspective of arrangement of elements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modified/ Generalized from previous studies</td>
<td>New</td>
<td>New</td>
<td>Common/ Generalized from previous studies</td>
<td>Common from previous studies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor/ Excellent</td>
<td>Unclear/ Clear</td>
<td>Meaningless/ Meaningful</td>
<td>Unfamiliar/ Familiar</td>
<td>Inharmonious/ Harmonious</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Descriptive statistics summary of average general assessment factors and factors assessing meanings (N=60)

<table>
<thead>
<tr>
<th>General Assessment factors</th>
<th>Evaluation Mean</th>
<th>Clearness Mean</th>
<th>Meaningfulness Mean</th>
<th>Familiarity Mean</th>
<th>Harmony Mean</th>
<th>Sum of Meanings M</th>
<th>Relatedness by Path R Mean</th>
<th>Standard Deviation of Relatedness by Path σ_β Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.45</td>
<td>4.16</td>
<td>4.15</td>
<td>2.99</td>
<td>4.78</td>
<td>55.7</td>
<td>0.238</td>
<td>0.246</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.79</td>
<td>1.05</td>
<td>0.91</td>
<td>1.00</td>
<td>0.87</td>
<td>14.2</td>
<td>0.050</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3. Indicated meanings and calculations of factors assessing meanings of one example

<table>
<thead>
<tr>
<th>Factors</th>
<th>Indicated Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example (No 53)</td>
<td>alliance (2), alliance, anxiety, bending (2), bending, bind, bone, butterfly (5), circle, collision, commitment, connection (3), cylinder, destruction, figure, flexibility, folder, game, harmony, heart, hyperboloid, interaction, joint (2), joystick, motion, necktie, object, plane, plasticity, reflection, ribbon (4), roundness, sandglass, sculpture, spot (2), star, surface, symbiosis, symmetry, thing, touch, unclearness (2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors Assessing Meanings</th>
<th>Sum of Meanings M</th>
<th>Relatedness by Path R Mean</th>
<th>Standard Deviation of Relatedness by Path σ_β Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>54</td>
<td>0.187</td>
<td>0.174</td>
</tr>
</tbody>
</table>

Table 4. Factor correlations between factors assessing meanings and general assessment factors

<table>
<thead>
<tr>
<th>Factor correlations</th>
<th>General Assessment Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>Factors</td>
<td>Sum of Meanings M</td>
</tr>
<tr>
<td>Assessing</td>
<td>Relatedness by Path R</td>
</tr>
<tr>
<td>Meanings</td>
<td>Standard Deviation of Relatedness by Path σ_β</td>
</tr>
</tbody>
</table>

(N=60; ns – not significant; * - p<0.05; ** - p<0.01; *** - p<0.001)

The results of path analysis show the effects of factors on evaluation. Standardized estimates are shown beside arrows. The unobserved variables from e1 to eW2 are error variances.

6.6. Interpretation of the Output Model of SEM

We now explain the validity of the output model. The resulting model has good evaluations according to “global model fit” criteria. The measured goodness-of-fit index (GFI) of the model reaches 0.973 (Figure 3), and the adjusted goodness-of-fit index (AGFI), 0.929. The overall model fit to the data is very good (NFI is equal to 0.98) [27]. Adding more direct effects does not improve goodness of fit indexes. Reducing the direct effects significantly impairs the model fit.

The model reaches a minimum at a chi-square of 4.86 with 8 degrees of freedom and a probability level of .772
The model contains both unobserved (error variances) and observed variables (WordNet factors, factors assessing meanings and general assessment factors). Common general assessment factors of familiarity and harmony do not improve the goodness of the model.

The practical interpretation of the model is based on the direction of the arrows and standardized regression weights besides them (Figure 3). For example, when the $R$ by 1 standard deviation, the $\sigma_R$ increases by 0.87 units. Also, when the $\sigma_R$ increases by 1 standard deviation, the meaningfulness rises by 0.42 standard deviation. Through this mechanism, the influence of factors assessing meanings as predictors of the dependent variable evaluation is made clear. Equation 4 shows the interpretation of the model from Figure 3.

$$E = 0.139C + 0.518F + 0.003M + 3.175R - 4.000\sigma_R + 1.804$$ (4)

Where $E$ is Evaluation, $C$ is clearness, $F$ is meaningfulness, $M$ is the sum of meanings, $R$ is relatedness, $S$ is the deviation of relatedness and where the last term is a coefficient. The result of structural equation modeling clearly shows the influence of the WordNet-based factors assessing meanings on the final evaluation of design. The Sum of meanings factor, the factor of Relatedness by Path and connected to it, the Standard Deviation of Relatedness by Path ($\sigma_R$), are introduced as factors, describing meanings in designs.

These three factors assessing meanings (Sum of meanings $M$, Relatedness by Path $R$ and Standard Deviation of Relatedness by Path $\sigma_R$) are strongly connected to the Clearness and Meaningfulness in our case. The influence of $M$, $R$ and $\sigma_R$ in the model shows the importance of the meaning relations (Figure 3). These relations have both an indirect and a direct influence on the evaluation of design. The model, as a relevant result, confirms the analysis and the factors assessing meanings proposed in the method.

7. Discussion

The discussion that follows is in terms of factors, their importance and applicability in design method. The understanding of design adopted in this research, as a process of ‘structuring of meanings’, shows potential in the proposed method. However, the method, analysis and claims are limited by the case study and require further cases for completing the framework. The second hypothesis is confirmed by the results of the case study, although the effect of the proposed factors assessing meanings is not direct, but mediated by the factors of meaningfulness and clearness. The general significance of the model shows the potential of the described factors assessing meanings. The results confirm the first hypothesis.

The three factors assessing meanings quantitatively describe the structured meanings, found in design. The three presented factors assessing meanings are proven to be valid according to the model. Answering the first research question, the description they provide, is based on quantity and relations among meanings and is relatively simple. Structure and tighter relations between meanings contribute to the evaluation of design in our case study. The causality of the model shows the effect of meanings with certain relations on the design evaluation, with this answering the second research question. Considering the third research question, particularly the relatedness of meanings shows that it can be applied in a design method. This factor is easy to calculate [22] and contributes significantly to the evaluation (Equation 4). There is possibility of application of this factor in a tool for the dynamic suggestion of meanings in conceptual design, enhancing the concept-synthesizing process at that stage [28, 29, 8].

In the perspective of the case study, the findings of the case study reveal a rather complex structure, which the factors of relatedness and its standard deviation suggest. The findings presented here about factors assessing meanings can be interpreted as follows:

The Sum of meanings factor shows that the meaningful design is better appreciated among users. The Relatedness by Path factor reveals that connected meanings of the design receives a better evaluation from the users. The Standard Deviation of Relatedness by Path $\sigma_R$ factor has a different interpretation in the perspective of the above factors. There is a presence of groups or grouping of the meanings. This conclusion applies in the context where these groups are well interconnected. However, the approach necessitates further investigation in different cases and subjects of study.

8. Conclusions

Understanding the role of meaning relations in design gives the product creation process a prospective and applicable tool for advance in this area. By focusing on the network description, the framework of ‘structuring of meanings’ overcomes some limitations of the previous methods; e.g. the limited dimensionality of the semantic differential method.

This paper introduces factors assessing meanings, which are describable, and connects them in a model for the prediction of evaluations of design. The presented model is verified by structural equation modeling. The model describes the causality between factors assessing meanings and general assessment factors. The relevance of the presented model to the collected data is considered to give good results.
Table 5. Regression analysis between factors used in the model

<table>
<thead>
<tr>
<th>Factor correlations</th>
<th>General assessment factors</th>
<th>Factors Assessing Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evaluation</td>
<td>Clearness</td>
</tr>
<tr>
<td>Evaluation</td>
<td>-</td>
<td>0.722 ***</td>
</tr>
<tr>
<td>Clearness</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>Meanings</td>
<td>0.266 *</td>
</tr>
<tr>
<td>Correlation</td>
<td>Sum of Meanings</td>
<td>-0.056 ns</td>
</tr>
<tr>
<td></td>
<td>Relatedness by Path $R$</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Standard Dev. of Relatedness by Path $\sigma_R$</td>
<td>-</td>
</tr>
</tbody>
</table>

(N=60; ns – not significant; * - p<0.05; ** - p<0.01; *** - p<0.001)

In this context, the factors assessing meanings are successfully contributing to the evaluation of design. The elaboration of these factors completes a preliminary model involving meanings in a successful design. The influence of the characteristics of meanings measured directly on the general evaluation of design is significant (Figure 3). The factors assessing meanings which we introduced, and particularly the relatedness, can be involved in an approach to support design process. This factor can be measured and changed dynamically during the conceptual design.

9. Contribution to design support

The early stage of conceptual design is characterized with exploration of concepts on abstract level. Here, the provision of the score of relatedness of meanings can support designers in evaluation of meanings. Moreover, this exploration will be supportable by suggestion of meanings, having greater score of relatedness to the meanings that designers inquire. For example, in the case of design of logotype symbols, designers start search of concepts, which correspond to the design task. The sets of concepts, explored with regard to the idea of logotype symbols, can be evaluated with the factor of relatedness and this information provided to designers. The awareness of relatedness will support and affect designers’ searches and decisions in early stage of design.

Such a supporting approach can elaborate a real-time evaluation of relatedness of concepts in the process of design. With such means, the designer would have the opportunity to structure the concepts along with structuring the form of the design product. The approach of structuring of the design concepts is particularly applicable to areas with the creation of impression meaning, such as product design.

Acknowledgments

We would like to thank Svetla Vassileva, Sofia Anguelova, Minh Le Nguyen and Junya Morita for their help on different stages of this study.

References