1. THE POTENTIAL OF BIONICS IN EMOTIONAL DESIGN

The basic principle of bionic design, the analogy adoption of a biological model to technical products influenced many designers so far. The ability of nature for integrative form and function design is unsurpassed. Hence, bionic inspired technology has proven to be more sustainable, efficient and robust to raise the functionality of technical products. Moreover, besides their functional advantages, many application examples furtherly demonstrate that design inspired by nature often shows to be very attractive to users [1].

In recent times, subjective aspects in product quality become increasingly important to users, too. Indeed, systematic bionic design has mainly been applied to support functional solutions so far. But under the aspect of targeting a sustainable value creation for users, bionic design may also help to better understand and to address the users’ subjective needs in product design. In this contribution, a systematic approach is used to analyze the potential of bionic design in terms of supporting subjective value creation in technical products. Therefore, bionic design analogies are investigated by looking at objective Gestalt characteristics and subjective user impression aspects. In this way, the main idea of emotional bionics can be realized: using nature’s subjective design potential to gain sustainable user satisfaction. The systematic approach is demonstrated in detail by conducting a pilot study with an application example of cats as bionic and cars as technical models.

2. STATE OF THE ART

2.1 Bionic Design and Emotions

Biologically inspired design or bionic design as a discipline investigates structures, processes and design principles of biological systems and transfers them into technical problem solving [1]. Therefore, basic procedures and design principles do exist that are firmly integrated into the bionic product development process [2, 3]. E.g., different computational approaches help to link biological and engineering systems and allow adaptations into different domains. In doing so, they formalize and functionalize design principles in order to support a systematic bionic design [4].

Aside from functional modelling, bionics are also used to source subjective imprints in natural design. Measuring semantics and emotional responses to bio-inspired design has been done e.g. to investigate animal posture [5]. Therein, formal connections between bio-inspired sources and design solutions have been examined. Research shows that there is a correlation of emotional terms and semantic descriptions between bionic and technical models. Also design formalization and computational creativity is applied in bionics research. Therefore, cognitive psychology theories [6] or genetic algorithms [7] are used to generate new design solutions. Especially in the case of bionic design for subjective value creation, the bionic principle has been decomposed to formal models of (visual) perception considered in the context and of aesthetics and Gestalt principles [6]. However, a transfer into systematic design synthesis for user impressions and therefore addressing the subjective

Original Article

Introducing Emotional Bionics to Support Subjective Value Creation in Technical Products

Susan Gretchen ZÖLLER, Tina SCHRÖPPEL and Sandro WARTZACK

Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Abstract: So far, bionic design has mainly been applied to support functional solutions. In recent times, subjective aspects in product quality become increasingly important to users, too. Under the aspect of targeting a sustainable value creation for users, bionic design may also help to better address users’ subjective needs in product design. Therefore, a new methodology is presented. Its first step is the numeric and perception-related investigation of main geometrical criteria in object shape changes between technical solutions and their bionic models. The second step is the identification and utilization of impressions analogies between the two domains. Thus subjective similarities between the product and its bionic model are examined both in geometrical and in impressions respect in order to derive implications for the field of Emotional Bionics. The methodology is explained in detail by applying a pilot study.

Keywords: Emotional bionics, Subjective value creation, Design analytics
value of a product is outstanding. As a result, the user’s subjective expectations towards products following bionic principles may be triggered more effectively.

2.2 Subjective value creation

Subjective value creation can be described as a process that starts with the user getting a specific stimulus, e.g. perceiving the Gestalt of a product, while using the humans’ sensory system like vision, hearing or smell [8]. The perceived information is then used to evaluate the product [9]. Depending on the users’ personal evaluation, the satisfaction to use or the rejection of a product follows. The result of this evaluation process is influenced by dynamic and individual constraints. An important aspect hereby is the alignment of the perceived information to the user’s own personality, i.e. individual values and attitudes [10]. If the perceived subjective quality matches with the personality of a user, user satisfaction is generated [11].

2.3 Product appearance and Gestalt analysis

A product’s overall appearance is mainly defined by its Gestalt (ger. Form, shape), represented by perceptually relevant pattern elements for human vision like lines, edges and more gradual changes in contrast [12, 13]. A computational approach that investigates a product’s Gestalt is presented by Orsborn et al. who use principal components analysis to extract the main visual characteristics of technical products [14]. In doing so, design patterns and user recognition can be investigated. Those computer-aided procedures help to formally analyze user feedback to subjective product experience depending on different design characteristics (e.g. [15]).

2.4 Kansei Engineering and ACADE

Kansei Engineering as form of affective engineering supports the formal interpretation of users’ subjective experience. It links design changes to their impact on user’s subjective impression of a product [16]. An approach that takes these relations between product design changes and user impressions and systematically links them to the individual’s subjective evaluation system is ACADE [17]. It works with specific quantitative impressions profiles (semantic differentials with ratings between opposite word pairs; see also Figure 1) that represent the full spectrum of user attitudes towards a product. They are used to subjectively characterize both the product and the user. In doing so, an overall impressions profile of both is derived. Given the impressions profile of different product variants, a functional connection between the product’s properties and the single impressions is derived. Using the psychological construct of product-personality congruency (section 2.2), an optimal fit between user and product is then achieved, knowing the targeted user’s impressions profile as well as their functional connection towards product properties [18].

Subsuming, bionic principles are not yet used for improving products in terms of subjective quality. Indeed, nature has the potential to do so. Knowing that the Gestalt of a product plays a major role in subjective human perception and therefore for subjective value creation, this contribution introduces a structural approach of emotional bionics. Therein, ACADE as an approach to quantify subjective value for emotional engineering is applied to make subjective bionic design accessible for product design.

3. METHODOLOGY

The aim of the methodology is to generate valuable insights into subjective value creation in the context of emotional bionics. It helps to better understand the relations between bionic models and technical products from a subjective point of view. Therefore, the methodology consists of three main steps, wherein both quantitative and qualitative methods are used to gain analytical (objective) and intuitive (subjective) findings.

For a first analytical investigation, a Gestalt analysis using principal components analysis (PCA) is processed. Therein, the products’ form variation is examined from a numerical perspective. Those areas that show highest Gestalt variation are Areas of Variance (AoV; analysis A).

For the human perception analysis, an image-based questionnaire is used. Thus, users are asked to highlight those parts of the bionic model or technical product that they are mostly focusing on. These are summed up to the Areas of Attention (AoA; analysis B).

Lastly, an impressions analysis is conducted to derive insights into unique subjective qualities of technical solutions and their bionic models. Therefore, ACADE (section 2.4) is applied to get characteristic impressions profiles of the bionic and technical models that can be compared to each other (analysis C).

Building on that, similarities between the product and its bionic model can be examined in two different ways.
First, Gestalt variation and the users’ intuitive design recognition are analyzed to unveil the products’ Areas of Interest (AoI; analysis A+B). Thus it highlights differences between objective design variations and subjective user attention, differentiating subjectively relevant areas from objective changes. Second, with respect to design differences between natural models and technical solutions, the ACADE analysis unveils subjective analogies by comparing the complementary profiles and Gestalt specifics (A+B+C). The combination of all three analyses lastly allows the derivation of design implications that allow systematic Emotional bionic design. Figure 2 shows the systematic procedure of the emotional bionics methodology. To illustrate this approach, an application example of cats and cars is used.

The example will also be used in section 4, where the methodology is applied exemplarily within a pilot study to explain and demonstrate the different methods inside the methodology in detail and again underline the potential of emotional bionics.

4. APPLICATION EXAMPLE

4.1 Pilot study design

To enable a better understanding of the different methods used inside the emotional bionics approach as well as a first validation, a small pilot study is conducted. Therefore, a total of 16 object samples of cats (7) as bionic models and cars (9) as technical models are used as an application example. The human perception analysis and the impressions analysis are realized via survey. Therefore, 20 participants were acquired to answer the questionnaire. As there is no focus on the relation between design variation and user acceptance but only on the investigation of interdependencies between technical and bionic models, no demographic data collection is needed. In the long run, however, a larger study is needed to exclude individual influences by the participants and thus to ensure the validity of the methodology.

As formerly mentioned and indicated in Figure 2, a sample of cats and a sample of cars are chosen for the application example. On one hand, cats have already been used in previous studies due to their natural kinship to humans. On the other hand, cars are common technical objects in daily life that are designed to meet various user needs. The pilot study is conducted to provide a better understanding of the different methods inside the emotional bionics approach as well as a first validation.

Figure 2: Structural Approach of an Emotional Bionics Methodology
bionic models for many successful car designs - only to mention the Ford Mustang or the Jaguar as a brand name here. Therefore, valuable outcomes for the pilot study are expected regarding bionic analogies. On the other hand, very different subjective impressions are expected as big cats as well as cars are often experienced very emotionally differentiated, ranging e.g. from very cute (like a kitten or a VW Beetle) to very dominant (like a lion or a Dodge RAM). Each of these natural models and technical solutions pose a very distinct overall impression. In this sense, variations of both subjects cause very different user impressions that raise the quality of the pilot study outcome.

Within each sample, different characteristic silhouettes of cats and car types were collected. Subsuming there are 6 different cats (a jaguar, a tiger, a leopard, a snow leopard, a cheetah and a lion) and 8 different cars (a family van, a 3-doors and a 5-doors limousine, a station wagon, a SUV, a pickup truck, a convertible and a sports car). To check the validity of the study, a domestic cat and a stretch limousine are additionally admitted. A domestic cat, as an example, should provoke very different impressions to users (like cuddly, clumsy, playful ...) and a stretch limousine is only used for special purposes instead of daily uses. Furthermore, it will be investigated whether the AoA widely differ there. Lastly, these 2D representations are standardized via feet distance (cats) and wheel distance (cars) to generate a comparable database without distortion.

The pilot study is conducted using pictures of the standardized silhouettes of cats and cars and a two-part survey to subjectively characterize these technical solutions and their bionic models. 20 users were firstly asked to encircle those areas within each cat’s and car’s design where they put most attention to (for analysis B). Secondly, they were asked to fill in impressions profiles for each silhouette that base on characteristic semantic differentials like “high-value/simple” or “exclusive/ usual” (for analysis C). Therefore, the ACADE structure was used that comprises a predefined set of opposite word pairs (semantic differentials) to measure users’ subjective product value [18].

In the following, the outlined three analyses as well as their interdependencies and the derivation of possible design implications are presented. First of all, the Gestalt analysis is conducted using PCA (analysis A). It shows that there are differences in the data interpretation, depending on the dimensional reference system (x-axis, y-axis and combined). Nevertheless, some dominating curves appeared in all three dimensions that indicate the designs’ objective Gestalt variation. Contrarily, within the human perception analysis (analysis B), some defined design areas show to be characteristic for users to get their overall impression. Within the impression analysis (analysis C), the survey feedback unveils that there are distinct impressions profiles for each cat and car model. Due to high response consistencies, these profiles seem to be commonly characteristic and give hints to some general bionic clichés in society.

Lastly, an integrated analysis including all three analyses is conducted. Their findings will be reflected and subsumed to general statements regarding Gestalt approaches in the bionic design context of subjective value creation.

4.2 Gestalt analysis

For an analytical analysis of the objects, a PCA is conducted as computational form of Gestalt analysis by strictly following Orsborn et al. [14]. Therein, the geometrically described silhouettes of object variations are analyzed in order to identify the main components of the object’s structure (Figure 3).

First of all, the bionic and technical models are transferred into 2D data models (silhouettes standardized by feet or wheel distance). Herein, an atomization of the 7 cats’ and 9 cars’ silhouettes is processed to represent the objects by Bézier curves and cycles [14]. Each curve or cycle has four control points that are extracted to fully describe the outlines of each object sample. It is ensured that each object contains an equivalent number of control points (total of 40 control points per object for cats and 31 control points per object for cars) so that the input data for cats and cars are similar. Since the silhouettes are 2D representations, each point has an x- and a y-coordinate, which must be given into the PCA separately. Therefore, there are four input data sets: (i) input cats, x-coordinates, matrix 7×40, (ii) input cats, y-coordinates, matrix 7×40, (iii) input cars, x-coordinates, matrix 9×31, (iii) input cars, y-coordinates, matrix 9×31.

![Figure 3: Procedure of the PCA](image-url)
Introducing Emotional Bionics to Support Subjective Value Creation in Technical Products

For the following principal components decomposition, the data is furtherly prepared by norming (mean value subtraction) and standardization. Thereafter, the load matrix with principal components is created, whereas the components are reduced to the only important ones using the Kaiser’s criterion (Eigenvalue > 1) [14]. Initially, the principal components for the x- and y-coordinates are given as separate load matrices. To obtain an integrated view of both dimensions, the load matrices of both dimensions are cumulated. This allows an overall view of both coordinates in combination.

Since only the dominant control points within the components are important, only those points are considered, whose relative weight is part of the top 15% of the absolute value of the considered component. A Bézier curve or cycle is only identified as an essential characteristic of the cat or car if at least 2 out of 4 control points are classified as dominant. Table 1 shows the relevant principal components according to the considered dimension. The top 15% of the individual components are highlighted in grey.

### Table 1: Overlook of relevant principal components

<table>
<thead>
<tr>
<th>Component</th>
<th>X-coordinates</th>
<th>Y-coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>comp. 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>comp. 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>comp. 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4 visualizes the derived PCA results of a tiger. Whereas the analyses of the x- and y-coordinates show high relevance of e.g. the head section of a cat in general, the details can strongly differ, e.g. regarding the cat’s lower jaw or the neck silhouette. The integrated analysis of the x- and y-coordinates show highest numeric deviations in the tail, the chest and the head of the animal. Those areas with highest numeric deviations are defined as AoV.

4.3 Human perception analysis

During the second analysis, the psychological construct of attention is used to get specific information about a users’ design perception. Hereby, attention represents processes of focusing and selection, enabling the separation of relevant against irrelevant information. Accordingly, the user only needs to deal with a small fraction of data which he or she can process much more efficiently than a whole bunch of inputs [8]. The process of attention is hereby strongly dependent on the user’s intend and the task the user must accomplish. This means that users will primarily focus on information that helps to achieve their purpose [19]. In the context of human perception analysis the participants of the survey were asked to encircle those areas they were paying most attention to whilst characterizing the objects by the given impressions (Figure 5 a). Therefore, based on this given task and the knowledge of attention, the encircled areas reflect those parts of the models that evoke the impressions. Additionally, the size and number of these areas are not limited. In this way, object specific information about the users’ design perception is quantitatively gathered. In the end, the feedbacks from every participant for the technical models and their bionic models are cumulated. By superimposing their feedbacks through transparent circular fields, the AoA represent the users’ most recognized design areas of each model as well as the areas that are responsible for the expression of impressions (Figure 5 b)

Summarizing, AoA show high homogeneity regarding the main attention areas for each model throughout the survey feedbacks. Each of it has not more than two focus areas (in the example it’s the head and the tail of the jaguar). Concluding, all provoked impressions may be derived by the same perception areas, widely independent from the single person.

4.4 Impressions analysis

In the third analysis, the individual impressions profiles of each cat and car are gathered using the ACADE procedure [18]. In this sense, the impressions profiles consist of 12 semantic differentials that are rated from 1 to 10 by the participants of the pilot study (Figure 6, axes; e.g. exclusive/usual). The results’ variety of each impression for one single object (like the sports car) is low, showing that both the biological models and the technical models have clear, distinct impressions profiles for a various number of persons. The mean values of all users for each impression are thus aggregated to build the overall impressions profile for every cat and car. In this sense, each of the objects is assigned to a unique impressions profile described by mean value and standard deviation of the return data on users’ impressions. All
Impressions profiles are depicted in Figure 6 (lines), compared per sample. It shows that there is a variation both in composition (structure) as well as in extent (parallelism). Comparing the cats’ to the cars’ impressions profiles, there is equal variance in single impressions values. Mean standard deviations of 2.33 for cats and 2.56 for cars show high variety amongst different object variations. In more detail, the respective profiles show characteristic expressions and the additional check-examples (domestic cat and stretch limousine) succeeded. As an example, a lion was experienced to be highly masculine and strong whereas a cheetah was more female and fragile.

4.5 Emotional Bionic Design
The application example with the three analyses unveiled two main findings that contribute to a systematic emotional bionic design: The first insight affects the source of subjective quality. A comparison of objective Gestalt analysis (analysis A) and human perception analysis (analysis B) shows high differences between actual design changes and user attention (AoV and AoA). The second insight affects the analogy of impressions. Comparing both the bionic models’ and technical solutions’ impressions profiles (cats and cars), the impression analysis (analysis C) shows higher similarities between specific cats and cars than amongst cats’ and cars’ sets themselves. As an example, a lion was experienced to be highly masculine and strong whereas a cheetah was more female and fragile.

Figure 6: Impressions profiles of cats’ (left) and cars’ variations (right) conducted with ACADE [18]

Within the AoA of the cats were more consistent than AoA of cars. Apart from that, both cats and cars show characteristic AoA at the upper head (front) and the tail (back) of the cat (car). On the right of Figure 7, the results from the PCA as Gestalt analysis method are presented. Whereas the head and the tail of the cats remain as highly relevant, the cars’ deviations in the front are not relevant from an objective point of view. The back of the cars, indeed, is also considered as relevant. Concluding, objective Gestalt analysis states only few similarities between cats’ and a cars’ design variation.

Differences in the results of the objective, numeric Gestalt analysis and the human perception analysis effectively show that human attention does not only recognize deviations between a model’s shape and the commonality to other representatives of a group. It also indicates general particularities that may not be considered as being relevant by numeric Gestalt analyses: Comparing objective Gestalt variation to the users’ most attended design areas (analyses A and B), those areas that are perceived most relevant for impressions creation, do not necessarily depend on actual numeric design variation; they are AoI for subjective design.

Figure 7: Comparison of superimposed Areas of Attention (AoA) and Areas of Variance (AoV)
Analogy of impressions: The subjective similarity between bionic pairings. Due to its similar data structure, cats and cars can be compared immediately regarding their characteristic impressions profiles (analysis C). This comparison of both technical solutions (cars) and their bionic models (cats) show the potential of emotional bionics: Whereas each domain shows high variation amongst car or cat types, high similarities between specific cars and cats can be stated.

As highlighted in Figure 8, e.g. a pick-up truck (car) indeed has high impressions similarities with a lion (cat). In the same row, a limousine (car) is similar to a jaguar from a subjective point of view. Contrarily, a jaguar and a lion are perceived very differently and so are a pick-up truck and a limousine: These similarities indicate the bionic potential for the respective pairings.

4.6 Design implications

The insights of the pilot study demonstrate that there are specific geometrical and impressions analogies between technical products and their respective bionic models. Whereas objective Gestalt analysis in itself is not able to unveil design analogies from a quantitative point of view, human perception analysis shows relevant areas that are similar for both the bionic models and the technical solutions. Furthermore, a high similarity of impressions profiles in both models is stated. It shows that subjective bionic and technical counterparts can be assigned and evaluated analytically.

In the bionic design context, studies following up this analytical approach represent an objective way how to align the subjective overall impressions of technical products to their bionic model. First, a characteristic overall impression of a bionic model is concretized using impression profiles (analysis C). In this sense, technical solutions and bionic counterparts can be immediately detected due to their profile similarity; as well as their remaining differences. One of the main benefits of identifying similarities is the possibility to recognize the actual standing of the examined portfolio of technical products and indicate unused bionic potential for the future. If one of the examined products already has high similarity to one of the bionic counterparts in terms of emotional bionics, an attempt to establish an even stronger bond between the technical and bionic model can be made. This may lead to an increased likeability and enthusiasm towards a product. However, it also unveils whether products do not yet have any similarities to bionic models. In this case, the primary aim should be to create such a connection. Product-personality congruency (section 2.2) may help to realize this link as its core idea is to help users identifying themselves positively with a product. Once a target user’s impressions profile is known, the designer is then able to transfer e.g. characteristic lines of a matching bionic model to the product’s Gestalt and thus explicitly address the target user.

The AoA shows which parts of the bionic model are of interest. The pilot study showed that users do not necessarily pay most attention to design areas with highest objective variance (AoV). Indeed, there are distinct areas that are most focused by all users (AoA). In these AoI, the Gestalt of a technical solution can now be systematically aligned to the bionic model. In doing so, characteristic design features determining the appearance of a focused bionic model could be stringently abstracted and integrated into new product design creations. The associative process in bionic design for technical products is thus objectified to a certain stage. Providing objective parameters offers a
way to communicate bionic principles from a subjective perspective to all stages of the product design process. Consequently, subjective bionic associations are systematically deducible. With the information about functional analogies derived by this procedure, designers can now better understand where subjective value is created, what the geometrical drivers of impressions changes are and how analogies to bionic models may be used.

5. EVALUATION OF THE METHODOLOGY

In this contribution we introduced an emotional bionics methodology to support subjective value creation in technical products. A pilot study with 20 participants was conducted to exemplarily apply the methodology and gain first insights of the fragile interplay of the subjective potential of nature and technical products. The pilot study showed a high benefit when it comes to identifying Areas of Attention (human perception analysis) and finding bionic analogies (impressions profiling). The objective Gestalt analysis (principal components analysis) generated a few insights about those areas having the highest numeric deviation but couldn’t generate valuable new findings in terms of the understanding of emotional bionics. With these results, the pilot study is a first small validation of the methodology. Nevertheless, further studies must be carried out to ensure the reliability and reproducibility of insights of the methodology.

6. CONCLUSION AND OUTLOOK: THE FUTURE OF BIONIC DESIGN IN SUBJECTIVE VALUE CREATION

Bionic design affects all areas of product development. As nature is the ultimate origin of all existence and our needs, it is not very surprising that nature is also responsible for our emotional ability and feelings. May it happen consciously or not, everybody tends to evaluate technical products to bionic models as these form the archetypes of our environmental system our evaluation consists of. So far, this “natural potential of attractiveness” was used rather intuitively in the product creation process. Indeed, it is only reasonable to investigate whether an analytical approach to capture relations between bionic models and technical products in the design for subjective value does exist. Subjective value creation has not been payed much attention to so far but is of rising importance. Thus, bionic design may be successfully fostered in this context.

The outlined systematic approach helps to understand analogical processes in bionic design from a subjective point of view and provides systematically derived, reasonable insights. With those, it could be possible to use the design of nature in order to meet the subjective expectations of the users. Especially the concept of attention, as it is mentioned in section 4.2, is important for this matter. It shows that a person filters the information he or she perceives from a product depending on what is relevant or not. In this sense, bionic analogy can only be successful if it triggers attentional related design characteristics. The human perception analysis as part of the introduced methodology helps to identify and focus on the truly subjective relevant parts of bionic and technical models and therefore assist to meet the user’s expectations.

Nevertheless, the complexity of the human feelings, being part of the inconceivable system of Mother Nature, will never be understood completely. So, all efforts made in this direction may rest fuzzy, gathering only fragments of our perception by which we try to understand our being every day.

REFERENCES