BIOLOGIZING PRODUCT DEVELOPMENT — RESULTS FROM A STUDENT PROJECT

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Biomimeticsbecome a more and more attracting topic in the field of product development. Whereas most literature aims for a codification of biology knowledge in order to make it usable in different forms of databases, this paper focuses on the direct interdisciplinary collaboration. Therefore a student project with biology as well as engineering students was conducted. Based on its analysis, the paper presents requirements for further method improvements in the field of biomimetic design as well as a procedural approach that supports the direct interdisciplinary collaboration.

Keywords: Biomimetics, Biomimetic Design Process, Interdisciplinary Product Development.

1. INTRODUCTION

Since several years a lot of research is conducted in the field of biomimetics to enable the development of biomimetic products. Many factors favor the attractiveness of biologically inspired design, others might lead to problems and challenges. Its multi-disciplinarity e.g. requires experts from two different domains. Furthermore the aim of biological research is the understanding of biological phenomena whereas engineers seek to generate new concepts by using physical phenomena and others. This leads to different methodological approaches. In addition, biological concepts mostly show up multi-functional designs and come up with a very broad portfolio of possible resources such as material and processes [1].

Apart from the discussion about unique characteristics and behavior of biologically inspired products, there is a strong need for methods and models that bring together both fields. For this reason, two different approaches are often mentioned — top-down (problem driven) and bottom-up (solution driven). For the former the technical problem is the starting point. The identification of a biological solution leads to the application of the underlying principle in a technical product. The other way around, a biological phenomenon gets analyzed and further transferred into a technical product [2, 3].

1.1. Situation

The more and the faster new products are required, the stronger is the need to identify and to classify efficiently biological systems with a high technical potential. A wide range of recently generated design methods as well as procedure models try to support this process, see Section 2. Mostly these approaches focus on a formal search in databases and literature. Even the key elements of several procedural models (activities) base on such a kind of search. The shortcomings of these approaches are the need for a strong formalization to make biological principles findable as well as the necessity to identify the worth solutions for an efficient design process. Since the range and the quality of biologically

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inspiring as well as technical solutions vary a lot, an appropriate structuring of any database and choice of literature is of utmost importance.

So far these approaches focus on the (formal) application by engineers and therefore the codification of biological knowledge. But especially an interdisciplinary field like biomimetics needs the analysis of the different approaches both disciplines normally use and a procedure to make both disciplines work together on development projects — thus to integrate biologists into the design process and to attract even those engineers with a small affinity to biology.

1.2. Approach

In order to understand how engineers and biologists work together informally, and thus “naturally”, a student project was set up. The team had to develop a biomimetic bag. For several weeks, both mechanical engineering as well as biology students worked together without any methodological restriction. The students were free to choose their procedure. Of special interest was the question, when and how the biologist was involved. The understanding of the way of collaboration was meant to show how methods of biomimetic modeling could be improved in future.

2. STATE OF THE ART

2.1. Procedural models and methods for product development

Most procedure models begin with a concept design phase that includes the determination of requirements. Through the process the product gets more and more concretized [4, 5]. Since several iterations might be necessary during the development process, most models include the possibility to take a step forwards or backwards.

The VDI-guideline 2206 (Design methodology for mechatronic systems) [6] is one example for the need to identify a common procedure for the collaboration of different technical disciplines. A first design definition phase is followed by a domain-specific design (mechanical engineering, electrical engineering, information technology). Afterwards the system integration assures that properties are met. Missing in this approach is a definition of how different disciplines define their interfaces or which models they use. Furthermore, the focus is on technical disciplines. Engineers most likely use the same or understand relatively fast models that are common in other engineering areas. In contrast, biomimetics needs to bring different models and ways of thinking into the process.

2.2. Procedural models and methods for biomimetic product development

Lots of researchers in the field of biomimetics do research on procedural models as well as specific methods. An approach based on the VDI-guideline 2221 is suggested by Löffler [7]. It consists of the identification of biological idols via setting up analogies and an evaluation of the transferability by using physical similarity laws. Subsequently, the biological solutions are adapted by using rules of variation and combination. In the procedural model of Lindemann & Gramann biological systems that correlate with the target are analyzed until a technical analogy can be detected. As long as no technical solution can be realized, the degree of abstraction as well as the intention is modified and the process is restarted. The biological principles or examples are included through a Checklist of Biological Associations that propose several (limited) biological patterns according to different functions and objects (e.g. change the state of the aggregation — condense — gas — leaf) [8].

Lenau *et al.* propose a procedural model for the biomimetic design, see Figure 1. It consists of five main phases and several sub-stages. These stages are connected through activities both forwardly and backwardly. Several sources are used for the search phase such as Asknature and Google books. Afterwards the identified biological phenomena were structured to have a better starting point for the design phase. Therefore different aspects are addressed on cards: title, photo, phenomena, biological mechanisms, functional principle and a simple sketch to illustrate the principle. In order to identify

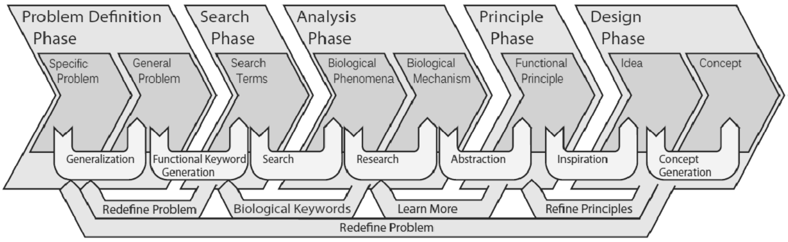

Figure 1. A procedural model for biomimetic design [2].

efficiently keywords and phenomena, Lenau et al. propose to integrate biologists, but confess the need for research on how to do so [2].

Helms *et al.* [1] conducted a student project as well. The authors present the observation results of several projects with small multidisciplinary student teams. The participants were presented to a six step approach before, but worked independently with almost no intervention by the observers during the project. According to the authors, the design process is non-linear and dynamic, but certain steps of a problem-to-solution approach can normatively be identified.

Apart from these general procedures, a lot of methods and models for the solution finding process can be found. They can be divided into three classes: searching in databases, searching in technical literature and using personal knowledge. Databases, accessed by functions, have been introduced by Hill [9], designed as a paper based catalogue, or Löffler [7], implemented as a software. Instead of natural systems, Bruck *et al.* present a database that documents biologically inspired concepts [10]. Sarkar *et al.* [11] suggest to use databases with both biological as well as technical solutions. The benefit of this database is its applicability for problems with a lack of suitable biological solutions. Vincent & Mann [12] suggest enhancing the TRIZ-database with natural systems.

Shu [13] proposes an approach using technical literature, not especially edited for biomimetic product development. They suggest to search a function as well as synonyms in textbooks. The text also gives a further concretization of the biological solution. If fundamental literature such as Purves *et al.* [14] is used, also engineers can understand the texts. Since the books have several scopes, there is a strong need to support the selection of appropriate literature for engineers.

The last strategy is using personal knowledge, as e.g. discussed by Löffler [7]. He suggests to find natural solutions in a brainstorming session.The advantage of this team-based approach is that a group of people comes up with a broader pool of possible solutions, especially if they have a different background regarding education and knowledge.

2.3. Challenges in biomimetic design

Besides the identification of a suitable solution out of the broad range, the interdisciplinary collaboration between biology and engineering design is one of the main challenges of biomimetic design. According to Jordan [15], the reason is a poor interchange of knowledge between biology and engineering design, different profiles of knowledge and language barriers due to different terminologies. Furthermore, biology and engineering design have different purposes. While biology describes existing systems, mainly in an open-ended fundamental research, engineers practice applied research with tangible problems in the context of the development of technical products and systems.

Helms *et al.* [1] observed that the teams in their project used both solution-to-problem or problem-to-solution approaches. The authors end in the extraction of eight main errors that occur during the biologically inspired design process, see Table 3.1..

Furthermore it was shown that within most of the projects, students did not use a function to come to a solution, but a structure. Also the solutions were composed of different sub-solutions which arose during the process when elaborating another solution. The fact that most teams used the solution driven approach led also to a very early fixation on a certain biological structure. Interestingly, some groups

Table 1. Main errors during a biologically inspired design process [1].

Vaguely defined problems	Simplification of optimization problems
Poor problem-solution pairing	Solution fixation
Oversimplification of complex functions	Misapplied analogy
Using "of-the-shelf" biological solutions	Improper analogical transfer

could hardly handle the huge amount of solutions they found whereas others hardly found suitable solution.

3. METHODOLOGICAL APPROACH

3.1. Setting of the project

Since the project was meant to show how both disciplines work together without strict methodological restrictions, the project team was free to choose its procedure and to choose appropriate methods. The students did not have any roadmap to follow. It was up to them to decide which discipline was responsible for which input and based on what information they came to a design decision. Especially they had to find a way how, why and when to focus on certain concepts.

The project team consists of three students. Two of them were studying mechanical engineering. Due to their lectures and work as student research assistants at the institute, they were familiar with classical procedural models and methods in the field of product development. The third student came from the field of biology. In order to gain intentionally an insight that is less influenced by classical engineering approaches, this student had no knowledge about engineering processes. The biology student was very familiar with all different fields of biology and provided a very good overview of lots of phenomena. Especially the student could link possible solutions to each other, e.g. via taxonomy. The missing constraints regarding models and methods included also no hint for any databases. This especially left space for classical literature from both fields that was or is not specifically adapted for the use in biomimetics.

3.2. Procedural requirements

During the creative and evaluative part of the project (for approx. four months), the students met several times with each other as well as with the authors. For their internal meetings they could choose their procedure freely as described above, but were asked to document appropriately. Of special interest were (1) any iterations, (2) unclear vocabulary, (3) associations that arise in one or both discipline(s), (4) used tools such as sketches and (5) homework, i.e. which discipline needed to search for which kind of information and based on what question. During the meetings with the authors, the students needed to explain their procedure. They were asked for their motivation to choose certain solutions and the challenges the single discipline was facing. After the concept freeze all documentation was brought together and the process was discussed. So in contrast to previous studies, see section 2, there was no normative procedure. Main questions were the following:

— Did they have common problems?
— Are there certain question types that do always arise?
— Do the students have a common understanding of the process steps?

3.3. Project task

In order to support the open approach, the research question was widely formulated. The task was to develop a biomimetic bag. Mainly two different functions needed to be addressed: (1) to carry a certain volume and (2) to adapt the volume according to different requirements. During the project, the team narrowed the task as far as it was useful and needed forthe project. A further analysis is given later on. For the authors it was of special interest in which phase of the project as well as based on which information or problems certain solutions were excluded. Due to ongoing research, detailed solutions can not be presented in this paper.

4. FINDINGS FROM THE PROJECT

In the following, the authors' observations during and after the project are described. They are structured according to four main aspects: 4.1 Requirements, 4.2 Functions, 4.3 Solution finding and evaluation. Afterwards main considerations for the generation of a future procedural model are explained (4.4).

4.1. Requirements

During the specification of the product requirements, the biology student emphasizes that organisms in nature carry material, babies or others always symmetrically. Hence the realization or the adaption of contradicting ideas such as a modern shoulder bag is likely not possible through biological patterns.

In addition, the biologist first concentrated on product requirements that do not or only later appear in classical requirements lists, such as impregnation, fastener, correct fit or design. In general, engineers are trained on describing technical systems by measurable specifications. In contrast, the biologist concentrated on specifications that are relevant in her experience. She focused more on customer requirements than on technical requirements. It seems as if new sub categories need to be implemented when aiming for biomimetic design.

4.2. Functions

Some literature proposes the use of functions to connect the knowledge from both disciplines. Even if functions describe a system neutrally, they need to be formulated properly. Several functions are clear to engineers, but might cause irritations on biologists' side. For example it is not clear what "to segment", "to care for" or "to save" exactly mean. Confirmative is nevertheless the fact that both disciplines look for a product description via functions even if they formulate them differently. In future the formulation of functions could be improved by generating aiding tools, since a lot of other tools, see section 2, also include functional descriptions.

Remarkable is furthermore that the biology student mainly looks for and argues with "basic functions" in nature. I.e. that natural organisms normally only answer to a certain kind of challenge. Main natural functions are (1) Food (to ingest, to cater for, to scavenge etc.), (2) Reproduction and (3) Protection/Defense. That means also that several typical challenges classical engineering is trying to answer by natural idols like "save energy" is not answerable per se by biomimetics. A lot of organisms like humans do not act in general energetically efficient. It is therefore necessary to discuss in which areas and to which extent nature can offer solution concepts.

During the design process the main function was divided in sub-categories to focus on. Also Helms *et al.* [1] address the problem of vaguely defined questions. But so far no rule can be formulated of how to do better. After the findings so far, it seems as if only the discussion with biologists enables the identification of suitable functions.

4.3. Solution finding and evaluation

Helms *et al.* [1] mention several errors that are related to the solution finding and evaluating process. According to them, complex functions get simplified too much. In nature e.g. phenomena might require other (possibly negative) functions to execute the favorable one. Moreover designers concentrate on the specific solutions a natural phenomenon provides, without trying to understand the underlying principles properly. These errors did not occur during this project, since the biologists provided the engineers with the necessary information and also intervened when additional or negative functions were not addressed.

Analyzing the project, it is hardly possible to state whether the students focused more on functions, principles and structures. And it seems as if the strict distinction is not necessary as long as the biologist is integrated into the project team. Since a distinction of these elements is already difficult or impossible for classical engineering design, the effort for databases with a strict classification should be put into an easier and more attractive access for the user.

In most cases the final solution concept came from the engineers. This could imply that they could have found the solution also without special biological support. Nevertheless they have a clearer understanding of the underlying principle and probably the solutions have already reached a higher quality level. So to say, biology could be used as a kind of creativity method that increases the motivation. The engineering students confirmed that the possibility to discuss directly with the biology student helped them a lot in a fast evaluation, directed them into more promising directions and deeply increased their motivation. And they did not have the impression to handle either too less or too many solutions — a problem that is often addressed [1]. Even products that in their final version do not obviously show biological principles can be a good example of biomimetics.

During their internal sessions, the students made often use of drawings. Not only to demonstrate a final idea, but also to elaborate together on a solution. Also Lenau *et al.* [2] include a graphic representation of a phenomenon and functional principle solution cards. Future analyses need to identify the way both disciplines draw their ideas to find a common sketching language.

Even though certain solutions were kept alive during the whole process like “skin”, see also [1], it is not very probable that in future any top-five-list of main mechanisms in biomimeticscan be defined. Rather a discussion about the same ideas and the development of a common mental model is important. Several times new ideas came up “thanks” to a misunderstanding.

Finally the students used the database Asknature to compare what solutions they find without the support of the other discipline. Apart from the finding that the large number of possible solutions does not facilitate but rather complicate the process to a certain extent, the (foreign) language was much often a barrier.

The most remarkable advantage of integrating biologists into the process is the faster and more profound evaluation of possible solutions. All kinds of databasescan not substitute the knowledge of a biologist. As mentioned in Lenau *et al.* [2], one of the main problems of biomimetic design at the moment is time. Most results of the databases are either irrelevant or difficult to apply (see dimension, matching with problem, etc.). A further advantage of a direct judgment by a biologist is that at the same time main structures and principles are explained. This can, as seen in Helms *et al.* [1], also lead to other solutions for sub-problems. This again leads to an enormous facilitation of the approach. By involving biologists directly it is not necessary to differentiate strictly between function, principles, structure, mechanisms, etc.

4.4. Requirements for new methods and procedural approaches

Out of the findings come four requirements for a further improvement of methods in biomimetic design. Table 4.1. gives an overview.

In addition, a generic procedural approach is derived, see Figure 2. In contrast to the literature, it strongly emphasizes the direct integration of biologists into the process instead of a formalization of knowledge.

Table 2. Requirements for method improvement in biomimetic design.

In order to integrate positive capabilities from nature into product design, new aspects need to be added to traditional requirement lists, such as design aspects, haptics and wearing comfort.
Biological phenomena are assigned to answer certain basic functions, such as “to protect”. These main functions need to be taken into account (even formulated differently) to allow an appropriate solution finding.
During the discussions, terms like principle, mechanism and structure were used without strict definition and could neither be clearly defined afterwards. Even in traditional design literature the terms are not defined homogeneously. Further methods and especially databases should not be based on a strict (artificial) classification.
Sketches and drawings were used during the whole process. They are a very good tool that enforces both sides to express themselves. To support the biomimetic design, methods like the 6-3-5 method should be optimized.

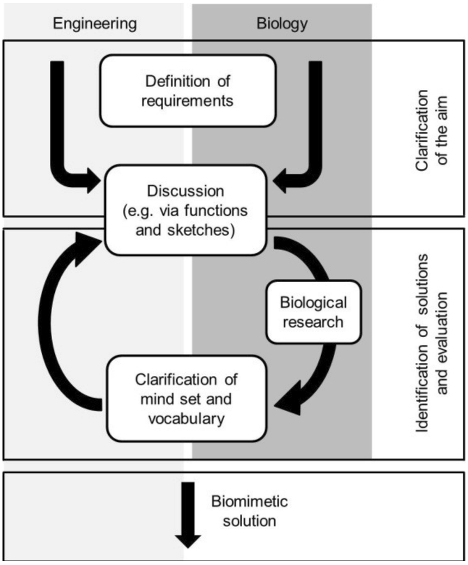

Figure 2. Procedural approach for in interdisciplinary biomimetic design.

Already at the beginning, the biologists are asked to define important requirements for the product — the same the engineers do parallel (see Clarification of the aim). Thus they get early involved and take part in important product decisions by broadening the focus. Once both disciplines have a sufficient idea about the aim, all participants run into a cycle, discussion and clarification, that is supported by a biological research. Since both disciplines are forced to run together through the process, the model allows an evaluation already during the solution finding process. The more often the cycle is passed, the more concrete the ideas get and their quality is increased. Having decided on the favored biological solution, the cycle is left and a traditional product development could be continued. Time as a limiting factor, as mentioned by Lenau *et al.* [2], gets extremely reduced. Especially since constraints in nature, i.e. negative effects of a certain biological phenomenon, are included right from the beginning.

5. CONCLUSION AND OUTLOOK

Since the project team consisted of both disciplines and was able to decide on the procedure on its own, it was possible to identify important differences in their respective procedure. These peculiarities are analyzed to include them in future biomimetic methods and procedures. The project results especially underline the importance of a continuous communication between biologists and engineers. In contrast to any databases, this allows an early and better estimation of product concepts.

Therefore four requirements for a method improvement are formulated. They focus on the integration of new aspects into traditional requirement list such as wearing fit, on functional modeling based on basic biological functions such as protection, on the integration of principles, structures and the like as well as on the optimization of sketching methods. Furthermore a generic procedural model is designed. The model proposes a parallel search phase of both disciplines, followed by a three step cycle for the solution finding and evaluation phase — biological research, discussion and clarification of mind set and vocabulary. For an industrial application, further projects need to show how such biologists might by characterized. Additional student projects should be run to show dependencies of the actual results on the special knowledge of the involved persons. The authors presume that biologists need to be specialized in areas such as biodiversity to run the biomimetic process effectively.

Finally and most important is a discussion with industry about the possibilities to integrate biologists into the development process. The implementation of a database most likely will be more economic than an employment of biologists, but the authors presume that the product development process can be run faster due to a faster and qualitative better generation and evaluation of ideas. Probably external consultants from biology can support first biomimetic development processes. Companies that generally focus on biomimetic design could integrate biologists into the advanced product development, allowing all business units the access to this knowledge.

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