Bionic Lightweight Design

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Nature has come to a range of advanced lightweight principles due to evolution. These principles can serve as models for innovative concepts of technical constructions. A corresponding expansion of the established procedure of lightweight designs to principles of nature leads to a variety of innovative lightweight construction concepts, expanding the potential for highly effective constructions.

What is bionics / biomimetics

Mimetic (μίμησις (mīmēsis), 'to imitate') is defined as copying or simulating movements, forms and further characteristics in such a way that biomimetics implies foremost the imitation of a biological system. The term bionic contains the greek syllable 'bion' (βίος) for 'an independent, individual organism' and the English ending '-ics' associated to 'science, art, study, knowledge of or skill in'. In addition, the term bionics is also known and used in the interdisciplinary field of biology 'bio' and electrics '-ics' and describes the development of electro-mechanic implants.

However, the international DIN ISO standard ISO 18458:2015 "Biomimetics -- Terminology, concepts and methodology" announces the term "biomimetics" to describe the method and idea to learn from nature for technically improvements and developments. Nowadays, several products have been developed and optimized inspired by biological models and their principles: The Velcro®-System, fluid repellent surfaces (e.g. Lotus-Effect®) and even planes are probably the best known and used biomimetic product examples. Additionally in the automotive industry, besides lightweight design improvements, cars have been optimized in different other aspects. Examples for these innovations are bumpers which are inspired by nuts, streamlined shapes adopted from fishes and the car finish using the "butterfly-effect".

But this is just the beginning of the biomimetic renaissance! With new manufacturing possibilities such as additive manufacturing, advanced robotics and composite materials many more biological effects are realizable. One good example is the so called "Fin-Ray-Effect®": Discovered, analyzed and implemented – this is the way of working for biomimetics – by Leif Kniese, this principle has not just inspired products for grippers and robotics but also the daily belongings like the normal mop bucket (Vileda®).

Biomimetic is not just an upcoming trend; it has been used successfully since decades and centuries. Due to new technologies, today we have the chance to learn from nature in a highly systematical way. Since a lot of biological information is already available and with the abovementioned opportunities of the new manufacturing technologies, this is one way to manage the rising pressure to innovate.

2 Systematical lightweight design process
The basic procedure for the design of technical lightweight structures is described by available tools such as guidelines and design manuals. A methodological technique for the design of structures is e.g. described in VDI guideline 2221 and 2222. When designing a lightweight and functional structure, typically materials are substituted and already existing constructions are changed and optimized, thus saving time and development costs. However, this approach leads to solutions that are characterized by the initial structure and have in consequence a low potential for innova-

tive, possibly more appropriate, solutions, which are a prerequisite for significant improvements of already existing technical solutions.

1. Boundary conditions
2. Concept
3. Drafts
4. Manufacturing documents
5. Prototype
6. Validation
7. Approval

Fig. 1 Systematic lightweight design process (Klein B. , 2001)

To the development of good ideas with an innovative problem solving character great importance should be attached. Although the methodology is well described (see Fig. 1), the conceptual design (Step 2) for an entirely new and therefore unknown lightweight solution is very difficult in the early stages of development and takes about 30% of the time of a complete development project. In addition, to the necessary basic idea of a new design, the engineer faces the fact that lightweight structures can be solved for specific technical tasks with very different geometries, materials and construction methods. Since the possible combinations of all variations are very numerous, their evaluation is difficult at the outset.

In summary, it can be said that the established process of constructing lightweight solutions includes the critical step of developing the concept, which is currently mostly achieved through experience and through existing structures. The contrary exists in nature, where a huge knowledge about the potentials and construction principles of lightweight structures can be found. Nature can serve as an endless source of inspiration for lightweight constructions.

The VDI guideline 6220 for Bionics describes the search for ideas in nature as a screening process and identifies him as the central step on the way to an invention. It is characteristic of this approach that it is time-consuming and unsystematic. Special expertise is required and limited access to knowledge sources makes the conversion of bionic methods difficult.

Hence, the established process of constructing lightweight designs (Klein B. , 2001) has to be adapted for bionic lightweight solutions. The most relevant step is the concept development, which has to be extended for the entry of knowledge about the biological lightweight models. For this purpose there is an interaction required between the engineer and another knowledge repository, which provides the construction, constructive basic elements and load characteristics of biological models. An efficient interface is required that allows the engineer to access the knowledge of nature and to pick a suitable biological model. Evaluation criteria that reflect the mechanical behavior and the load characteristics of biological construction methods should be present in the knowledge storage (Maier, Schulz, & Thoben, Verfahren zur funktionalen Ähnlichkeitssuche technischer Bauteile in 3D-Datenbanken, 2012).

In addition to the identification of an appropriate biological model, the implementation of biological principles to technical drafts must be clarified. Biological models usually form overall, robust constructions, since the load cases in nature can not be anticipated in general. The constraints defined in a lightweight construction project are the contrary - very accurately known - and require specialized constructions, to ensure an optimal lightweight solution. It is necessary to recognize the operating principles behind the constructions of nature to understand them. Only then a suitable abstraction can be performed (Maier, Siegel, Thoben, Niebuhr, & Hamm, 2013).

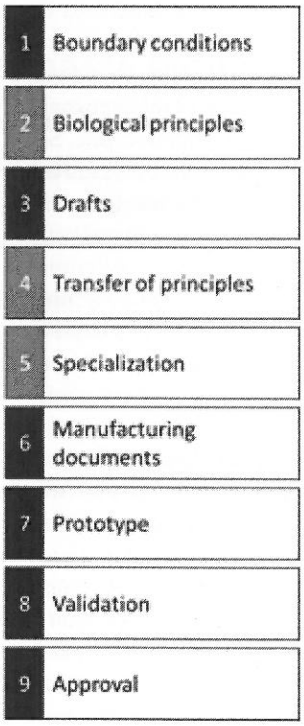

Fig. 2 Systematic bionic lightweight design process (Maier, Niebuhr, Hamm, & Thoben, 2015)

For the implementation of a systematic bionic lightweight design process, the classical procedure will be expanded (see Fig. 2). The step 2 is supplemented with a knowledge repository, which holds usable biological models for the engineer. A similarity search based on active surfaces allows the automatic detection of the respective most suitable biological model for any technical load. A simple structure review with the help of a dimensionless, lightweight-characteristic value extends the knowledge store to an important function for the evaluation of structures with regard to their lightweight potential. The abstraction process of natural building methods to technical lightweight constructions is necessary for the transfer of biological building methods (Step 4). It can be systematized by performing a combination of topology optimization within the geometries of biological models. Finally, the specialization of the bioinspired constructions to the technical loads can be achieved by parametric optimization in step 5.
The extension of the classical design methodology to the lightweight knowledge of nature allows powerful, lightweight designs, which are characterized by a high degree of innovation.

Darwin, C. (1928). The Origin of Species. Mundus Publishing.

Jiao, H., Zhang, Y., & Chen, W. (2010). {T}he {L}ightweight {D}esign of {L}ow {R}{C}{S} {P}ylon {B}ased on {S}tructural {B}ionics. Journal of Bionic Engineering, 7(2), 182-190.

Klein, B. (2001). Leichtbau-Konstruktion: Berechnungsgrundlagen und Gestaltung (5., überarb. Aufl. ed.). Braunschweig: Vieweg.

Liu, K., & Jiang, L. (2011). Bio-inspired design of multiscale structures for function integration. Nano Today, 6, 155-175.

Ma, J., Chen, W., Zhao, L., & Zhao, D. (2008). {E}lastic {B}uckling of {B}ionic {C}ylindrical {S}hells {B}ased on {B}amboo. Journal of Bionic Engineering, 5(3), 231-238.

Maier, M., Niebuhr, N., Hamm, C., & Thoben, K.-D. (2015). Eine Konstruktionsmethodik des bionischen Leichtbaus. Lightweight Design, 34-39.

Maier, M., Schulz, J., & Thoben, K.-D. (2012). Verfahren zur funktionalen Ähnlichkeitssuche technischer Bauteile in 3D-Datenbanken (Vol. 12). Springer-Verlag. From http://dx.doi.org/10.1007/s13222-012-0086-6

Maier, M., Siegel, D., Thoben, K.-D., Niebuhr, N., & Hamm, C. (2013). Transfer of Natural Micro Structures to Bionic Lightweight Design Proposals. Journal of Bionic Engineering, 469-478.

Milwich, M., Speck, T., Speck, O., Stegmaier, T., & Planck, H. (2006). {B}iomimetics and technical textiles: solving engineering problems with the help of nature's wisdom. American Journal of Botany, 93(10), 1455-1465.

Nachtigall, W. (2008). Bionik: Lernen von der Natur. C. H. Beck oHG.

Xing, D., Chen, W., Zhao, L., & Ma, J. (2012). {S}tructural bionic design for high-speed machine tool working table based on distribution rules of leaf veins. Science China Technological Sciences, 55(8), 2091-2098.

Zhao, L., Ma, J., Chen, W., & Guo, H. (2011). Lightweight Design and Verification of Grantry Machining Center Crossbeam Based on Structural Bionics. Journal of Bionic Engineering, 8, 201-206.

Zhao, L., Ma, J., Wang, T., & Xing, D. (2010). Lightweight Design of Mechanical Structures based on Structural Bionic MEthodology. Journal of Bionic Engineering, 7, 224-231.