Preface

This book is based on the hypothesis that evolution created a large variety of fantastic, very efficient lightweight structures as a result of the adaptation to diverse environmental factors, i.e. significant mechanical challenges and the need to build lightly and/or economically.

The focus of this book is on planktonic organisms, where there is good evidence that an arms race between predators such as copepods and their floating prey—diatoms and radiolarians—leads to a large, continuously changing pool of species with individual (defensive) lightweight structures (see Knoll and Kotrc, Chap. 1). Due to a very patchy fossil record, it is impossible to follow the development of feeding tools of copepods to a similar extent—but we do see the results of the arms race: the gnathobases of copepods are not only highly developed in their complex geometries, they also have a sophisticated multi material composition (see Michels and Gorb, Chap. 3).

Diatoms and radiolarians are unicellular organisms and thus restricted to sizes between a few μm and 1 mm. They use amorphous silica as the main building material, which is very convenient as it makes, unlike crystalline minerals, any form possible—even in the size range between a few nm and a mm. The process of biomineralization is initiated by small amounts of organic components and recent research has shown that there is not only one, but a large variety of chemical components involved in this process (Ehrlich and Witkowski, Chap. 4). This makes diatom silica a composite, and an additional structuring of interfaces between organic and inorganic components most likely results in anisotropic, strong material properties. This would be consistent with theoretical mechanics: the best lightweight solutions are a combination of sophisticated structures and composite materials.

The resolution of microscopes with regard to resolving the diatom composite structure qualitatively and quantitatively in 3D is, however, so far unsatisfactory. Layers of silica seem to have a size of 30–40 nm, and the organic layers are even thinner, so that a reasonable material model could not be realized within the project. Although virtually all other structural biogenic materials are also composites, there is one group of organisms, where composites are very common, and which also combine silica with organic materials: higher plants. Especially in equisetales and graminaceae silica structures (phytoliths) are very abundant. Since many publications have already dealt with fibre orientation of wood and plant stems, Keutmann and Speck (Chap. 9) focus on the detection and potential mechanical function of phytoliths in higher plants.

Light weight structures are also an issue in much larger marine organisms, such as echinodermata, especially sea urchins. They use $CaCO_3$ to build their skeletons and have also optimized their mechanical strength to reduce mortality by predation; the selection pressure to build light structures is probably based on their need for mobility and to save energy necessary to build a $CaCO_3$-skeleton. The fossil record is excellent and the geometries of the solitary organisms are less restricted by growth processes than they are in trees or snails. A variety of fascinating typical lightweight principles of sea urchin skeletons are described by Nebelsick et al. in Chap. 8.

Since evolutionary processes have led to fantastic lightweight solutions, especially in diatoms, but are not easily accessible for engineers, Chap. 5 (Kooistra and Pohl) summarizes a variety of interesting principles and gives examples of how they could be applied in the technical world.

Hierarchically organized—fractal—structures are very common in nature. Especially diatom shells are known for honeycomb structures which are interlaced within each other. In other cases they have different stiffening devices such as ribs, honeycombs, and undulations which are combined in different dimensions. This design is advantageous if a massive outer skin, resulting in the best second moment of area, is for whatever reason not applicable. In the case of diatoms, high permeability is required to ensure efficient uptake of nutrients. Other (including technical) reasons could be the need for transparency or a production process.

The combination of complex fractally structured geometries with modern fibre reinforced plastic materials is a highly challenging task, as multiple branchings are the rule and have to be solved. In Chap. 7 by Milwich, an innovative method is described to produce geometrically complex Carbon Fibre Composite (CFC) structures. Mechanical tests revealed very promising properties, e.g. for robot structures. Thus, with the rapid development of production technologies, the near future will see considerable progress in this field.

A highly aesthetic solution for an exhibition pavilion made of thin glass fibre reinforced plastic is described by Pohl (Chap. 6). This ambitious project shows how a combination of lightweight principles from nature, human intuition, and innovative manufacturing approaches can lead to a highly attractive product with the potential for upscaling. In this case, the design aspect is very important and has been successfully realized—visitors of the pavilion were enthusiastic.

An innovative, powerful method which combines several principles of the evolutionary optimization process is the ELiSE method (Chap. 10). It uses the full potential of a synthesis of (a) natural lightweight principles, (b) the innovation strength of ecosystems due to a high biodiversity, and (c) the power of the optimization process. It has thus a higher similarity to the natural process of structure evolution than most other methods used in bionics, but at the same time complies with industrial approaches of product development. An example for this method is given in Chap. 11, where an offshore foundation has been developed on the basis of the ELiSE process.

Most of the chapters contain results of the Helmholtz Virtual Institute Plankton-Tech, which integrated basic research on the biology of lightweight structures with approaches to transfer them to technical structures. We are very grateful for this substantial support by the Helmholtz Society. It is evident that the combination of basic research, applied research and technical realization presented here shows but a snapshot of the increasing tendency to use principles from nature to design clever, environmentally friendly and sustainable technical solutions. I hope it became visible that only substantial effort, dedication, and interdisciplinary cooperation leads to progress in this field and I expect that similar constellations and projects will further improve both our knowledge on fascinating principles in nature and our ability to use them for our own benefit.

2015

Christian Hamm
Bremerhaven
Germany

Springer

http://www.springer.com/978-94-017-9397-1

Evolution of Lightweight Structures
Analyses and Technical Applications
Hamm, C. (Ed.)
2015, XV, 206 p. 121 illus., 82 illus. in color., Hardcover
ISBN: 978-94-017-9397-1