Opening up new biological perspectives on light weight technical structures

Both natural organisms as well as technical structures have to cope with the same physical boundary conditions. This makes studying plants, animals and other natural organisms so exciting as their solutions to a specific problem may be quite different from a standard engineering approach. In Biology the terms material and structure often completely blend as apparent in the common construction principle in using hierarchical structuring which make structure and material almost inseparable.

In our modern world the importance of reducing weight is constantly growing due to the amount of energy which can be saved. In this field nature offers a vast reservoir of ideas as building light weight is one common natural principle.

For new light weight impact protection materials the largest of all citrus fruits *Citrus maxima* presents an ideal role model as it is able to withstand impact at velocities of up to 50 km/h ($\sim$ 32 mph) and to dissipate considerable amounts of kinetic energy [1]. Its protective peel is composed of an open-pored cellular foam consisting of cellular material, cellular fluids and mostly air. The volume fraction of air to fluid/solid shows a gradual increase from an additional closed-pored layer on the outside of the fruit. Further, vascular bundles are present throughout the whole thickness of the peel.

As all these structural elements compose a rather complex protection layer the challenge lies in reducing this complexity to an amount where technical manufacturing becomes feasible. Currently parts of the structure are being transferred to metal foams in a bottom-up process [2,3], which implies an in depth analysis of the biological role model. Metal foams are of special interest to the automotive industries due to their low density. Changing the manufacturing material to polymers will also allow a transfer of the viscoelastic properties and will extend the field of application to helmets and other body protection wear in the future.

[1] Thielen, M., Schmitt, C. N.Z., Eckert, S., Speck, T., Seidel, R.: Structure – function relationship of the foam-like pomelo peel (*Citrus maxima*) – an inspiration for the development of biomimetic damping materials with high energy dissipation. Bioinspir. Biomim. 8 (2013).

[2] Fischer, S.F., Thielen, M., Loprang, R.R., Seidel, R., Fleck, C., Speck, T., Bührig-Polaczek, A.: Pummelos as concept Generators for biomimetically-inspired low weight structures with excellent damping properties. Advanced Engineering Materials / Advanced Biomaterials, 12, pp. B658-B663 (2010).

[3] Martone, P.T., Boller, M., Burgert, I., Dumais, J., Edwards, J., Mach, K., Rowe, N.P., Rueggeberg, M., Seidel, R., Speck, T.: Mechanics without muscle: biomechanical inspiration from the plant world. Integrative and Comparative Biology, 50(5), pp. 888-907 (2010).