Repelling water and dirt: superhydrophobic biological surfaces and biomimetic innovations

Life evolved over the last 3.5 billion years: a continuous process of mutation and selection – or trial and error. Today we know of some 1.8 million different species – but assessments indicate the existence of over 10 million species. All organisms interact physically as “solids” with their gaseous and liquid environment. As boundary layers, surfaces play the crucial role in interactions. Thus it is no surprise that organisms evolved a stunning diversity of most complex and usually multifunctional structured surface architectures.

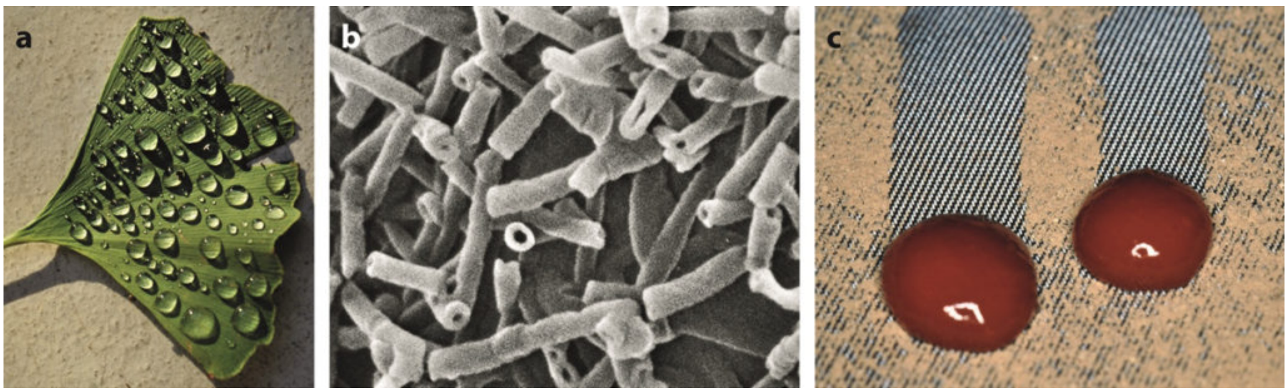

Fig. 1. (a) Gingko trees with water repellent leaves exist unchanged since the Jurassic Period. Their extreme water repellency is similar to the Lotus (b) a result of a dense layer of nonacosan-10-ol crystals covering the leaves, each tubule with a diameter of 110 nm. (c) Dust-contaminated surface of a superhydrophobic biomimetic textile cleaned by rolling tomato ketchup drops. (Source: Barthlott et al. 2016).

Living organisms have a lot to teach us, information that can then be applied to technology. *Biologically inspired design* is as old as mankind: from the prehistoric paintings in caves to modern polymer chemistry, which by definition is based on biological role models. Some mechanical examples of biologically inspired design are Icarus in Greek mythology or Leonardo da Vinci’s devices.

As a science *Biotechnik,* today better known as *bionics* or *biomimetics,* arose between 1800 and 1920. One fundamental innovation was the construction of the first electric battery based on the electric ray by Alessandro Volta in 1800, as well as the construction of airplanes by Otto Lilienthal in the 1890s. We keep forgetting: a modern Boeing or Airbus is based on bionic ideas. In the 1960s the field of cybernetics introduced the terminology “bionics” and “biomimetics”, the modern terms used today.

Surprisingly late, materials scientists became aware of biological *surfaces*. Their functions and interactions are often highly complex and difficult to analyze: *"God made solids, but surfaces are the work of devil"* (Wolfgang Pauli). In our paper we focused on superhydrophobic surfaces. We analyzed around 20.000 different species, plus non-biological surfaces over more than four decades (survey in: http://link.springer.com/article/10.1007/s40820-016-0125-1).

Superhydrophobicity refers to extreme water-repellency. Surprisingly, no evidence for lasting superhydrophobicity in non-biological natural surfaces exists - but it is one of the most noticeable characteristics of many plants and animals. Some 250 million square kilometers of superhydrophobic plant surfaces exist on our planet.

In 1976 and 1997 we described the self-cleaning *Lotus Effect* and its possible biomimetic applications. We showed that a hierarchical structuring of the surface in combination with a hydrophobic chemistry is responsible for the water-repellent and self-cleaning characteristics. This has led to a rapid advancement in surface technologies; subsequently the term superhydrophobictiy was coined. Biologically inspired products have gained an astonishing and rapidly increasing market share in the last decades. Assessments provide estimations of US $425 billion for the 2039 U.S. GDP for all bioinspired technologies, including biotechnological products. Bionics and biomimetics (or even the misleading term "biomimicry") are buzzwords in marketing. They are increasingly used for products and processes that are non-bionic: they are termed *parabionic,* pretending to be bionic but having neither a bionic function nor a bionic origin.

Fig. 2. (a) Leaf of the Giant Salvinia with a water droplet on the egg-beater shaped hairs, Salvinia has perhaps the most complex surface in plants; the upper surface of the leaf stays dry when submerged in water due to its ability to retain an air-layer. Air layers also reduce drag between a solid and water by up to 30%.If this technology were applied to each transport ship worldwide, it could lead to a saving of about 3% of the total worldwide fuel consumption and significantly reduce emissions. (b) Modern dragonflies have very thin stable and superhydrophobic wings. (c) The fossil Meganeura with its light-weight wings spanning around 70 cm is the largest insect that ever existed. It lived about 360 million years ago during the wet and moist Upper Carboniferous Period and could not have flown without superhydrophobic wings. (Source: Barthlott et al. 2016).

Biological evolution is a slow process that occurs over millions of years. It works by undirected processes and thus tries all constructional possibilities - the vast majority of mutations are detrimental and will disappear. These are million years of research and development that can be used for technical engineering: materials scientists have a goal of designing and fabricating a particular product within a limited time frame. Another crucial difference between evolutionary design and the design process an engineer uses, there is always a specific target that must be reached. Unlike nature, an engineer is not always free to use the unimaginable in their design process: this is the second crucial difference to biological evolution. The current dramatic loss of biodiversity also means the loss of biological role models for technical applications. They should be treasured as inspiration for future technology: another intrinsic value of biodiversity.

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