



Cambridge University

Botanic Garden

Plants Inspiring Design and Technology Trail

To be able to survive wind, rain, extreme temperatures and high, low or changing light levels, plants need to protect themselves, as (unlike animals) they cannot simply move to shelter. Developing a protective outer layer was key to the early evolution of land plants.

Over time, this protective outer layer has been modified in a wide variety of ways to help different plants survive in challenging environments. The process of evolution has developed some surprising solutions to complex problems, some of which have already inspired innovations such as Velcro. Researchers are investigating plant surfaces as inspiration for new materials.

This trail aims to introduce you to the invisible microscopic world of plant surfaces and the materials some of them are inspiring.

**See an online version of this trail
at www.botanic.cam.ac.uk/design-technology**

Plants Inspiring Design and Technology

At first glance the surface of a plant leaf, stem or petal may look flat but, under a microscope (see images of these at the end of this leaflet), a surprisingly intricate landscape is revealed. Cells making up the surface can be pointed, ridged, jigsaw-like, or a variety of other shapes, and hairs or outgrowths can form delicate structures.

Plants have had millions of years to evolve solutions to the problems they face on a day-to-day basis. Amongst others, these problems involve leaves getting too wet or not getting wet enough, harvesting enough light for photosynthesis, not being damaged by too much light, attracting pollinators and distributing seed. This evolution happens incrementally over very long periods of time: random changes to a plant's genetic code which give it even a tiny advantage over other plants will help contribute to its survival. Plants which survive pass their genes on to future generations and, very gradually, astonishingly complicated structures can emerge.

The field of science devoted to artificially replicating effects from the natural world is called 'biomimetics'. Historically, most research has focused on animals – for example, looking at gecko feet to see how they walk up vertical surfaces, or termite mounds to investigate their air conditioning. But plants are also giving us ideas for new materials and surfaces, and many are now entering commercial production. These are relatively early days, though: there are certainly many other innovative solutions waiting to be discovered. Conserving the world's plant biodiversity is critically important if we are to maintain this natural library of surfaces which have the potential to inspire new materials.

1 *Populus tremula* (Aspen)

Wood has been used in buildings for millennia because it is cheap, easy to work with and readily available worldwide. However, since the advent of skyscrapers and larger buildings, construction work has generally involved steel and concrete because wood lacks the structural properties required to support such large buildings.



Researchers in the Department of Biochemistry have been using similar techniques to those used to investigate plant surfaces to analyse the microstructure of wood. Microscopists at the Sainsbury Laboratory here in the Garden used samples from aspen to better understand how wood is formed. They are now investigating how changing the arrangement of the molecular building blocks in wood might alter its strength, with the aim of seeing more large buildings built out of timber, which is more sustainable than steel and concrete.

See the trail website for more information about this plant.

2 *Arctium minus* (Lesser Burdock)

Burdock is frequently found in neglected patches of ground, where its purple flowers can easily be mistaken for thistles. These flowers develop into 'burrs': seedheads with hooked bracts (modified leaves) that hook onto the fur of a passing animal (or a rambler's socks) to be carried away to colonise another site.



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These hooks were the inspiration for Velcro, one of the first materials based on plant surfaces. In this two-part fastening system, a furry surface mimics the animal's fur, and a hooked surface is comparable to the hooks on the burrs. While the burrs on the plant will fall apart when scratched by the animal, Velcro is strong enough to be pulled apart and refastened thousands of times. The word 'Velcro' is a combination of the French words 'velour' (meaning 'velvet') and 'crochet' (meaning 'hook').

3

Tropaeolum majus (Common Nasturtium)

Plants harvest the sun's energy using the process of photosynthesis, which takes place in the leaves. Dirt on the leaf's surface can block out sunlight, so dirty leaves are less efficient at making energy.



Nasturtium has leaves covered in tiny clumps of waxy tubes. This wax causes water to form beads and run off: the leaf is extremely good at repelling water. The water picks up dirt on the leaves as it runs off, so the leaves are self-cleaning. This is called the 'Lotus effect', because it was first described in leaves of the sacred lotus (*Nelumbo nucifera*); during warmer months you can see a sacred lotus in our glasshouse. Many man-made surfaces take advantage of the 'Lotus effect', including self-cleaning tiles, paints, glass and fabrics, coatings to make microwave antennae less susceptible to rain and snow buildup, and surfaces used for dew harvesting.

4

Hibiscus trionum (Flower-of-an-Hour)

For plants which are pollinated by animals, flowers exist as the plant's advertising display. The colour blue is particularly attractive to insects, but to produce it as a pigment the plant requires specialised conditions within its petal cells (which is why there are not many blue-flowered plants). Flowers such as *Hibiscus trionum* have minuscule ridges in the 'cuticle' (waxy coating) that covers the dark part of the petal, which act rather like the grooves in a CD, diffracting light to give a rainbow effect. With this method, the plant produces a blue halo without having to make any blue pigment. Analysis of other flowering plants revealed that such iridescence is widespread.



Experiments with bees show that they can find iridescent flowers faster than non-iridescent flowers. This discovery may help us breed crop plants which are more efficient at being pollinated. Researchers at Cambridge are investigating how the plant forms these tiny ridges.

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5 *Gazania rigens* var. *uniflora* (Treasure Flower)

Gazania species are popular plants in the daisy family (Asteraceae), grown for their showy petals. Like other members of the family, the *Gazania* ‘flower’ is a collection of hundreds of tiny ‘disc flowers’ in a central group, with a number of further ‘ray flowers’ arranged around the outside, each with an enlarged, asymmetrical petal.

Gazania petals show a microstructure of flat cells featuring tiny folds running from the base of the petal to the tip. The reason for this architecture is unclear, but it is likely to do with water: while the petals overall repel water, causing it to form droplets, the folds cause the droplets to stick to the petal. A water droplet on the petal surface looks spherical, but cannot roll off even when the flower is turned upside down. Structures such as these could be useful in microscopic devices used for collection of very small quantities of liquid. The surface structures would trap the liquid, then guide it in a preferred direction for collection and analysis.



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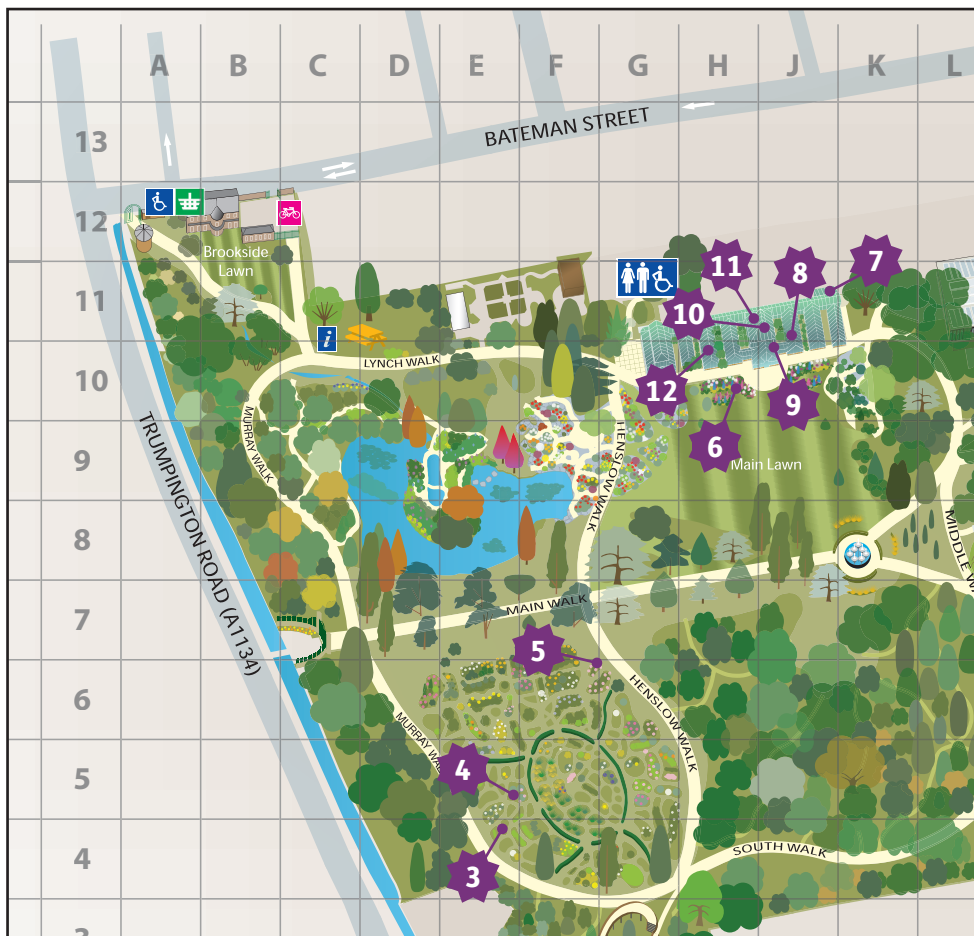
6 *Antirrhinum* spp. (Snapdragon)

Snapdragon flowers are often found brightening up garden borders with their tall spikes of coloured flowers. Their flowers are symmetrical from left to right and feature a lip petal that bees must grip in order to open the flower and access the nectar and pollen inside. Snapdragon petals are covered in cone-shaped cells that make it easier for the bees to hold on. Experiments in the Department of Plant Sciences have shown that bees will fall off mutant plants that lack these conical cells, so it is likely that they have evolved to help with the process of pollination.

Much research is being done today in the area of ‘food security’: working out how to feed a rising global human population. Many of our crops rely on pollinator activity, but global pollinator decline means there will be fewer insects to do the work. Researchers here are investigating the characteristics of crop plant flowers, including the distribution of conical cells on their petals, to help make flowers more efficient at being pollinated.



Plants Inspiring Design and



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Biotechnology and
Biological Sciences
Research Council



and Technology



7 *Salvinia natans* (Asian Watermoss)

The Asian watermoss is an aquatic fern with leaves about the same size as a penny. Like sacred lotus (*Nelumbo nucifera*), water runs off the watermoss leaves, but microscopic analysis shows a completely different mechanism of action: in the watermoss, specialised structures each hold a tiny air bubble. When its leaves are completely submerged, they retain a layer of air over their entire surface.



'Salvinia effect' surfaces have great potential to be used as drag-reducing coatings. A layer of air on the surface of an object moving through water reduces the friction between the two, and a 'Salvinia effect' coating has been shown to reduce friction by over 30%. If applied to ships, such coatings could reduce their fuel use. 'Salvinia effect' surfaces are also extremely good at absorbing oil from the surface of water, and are being investigated as materials to help clean up oil spills.

8 *Nepenthes* spp. (Hanging Pitcher Plant)

Pitcher plants grow on soils that are low in nitrogen, an important nutrient. They gain additional nitrogen from digesting the carcasses of insects that fall into the pitcher and drown in the liquid contained inside. Many pitcher plants make their surfaces slippery, often using waxes on the internal walls of the pitcher. Scientists in the Department of Zoology identified areas in the lip of the plant that have tiny ridges; when these are wet, insects skid off the lip and fall into the pitcher. Slippery surfaces are of interest for the development of medical equipment. Bacteria form 'biofilms' on the surfaces of such equipment and removal is costly or, in some cases, impossible. It has been shown that surfaces inspired by the hanging pitcher plant prevent around 96% of biofilm attachment, and do so for a far longer time than untreated surfaces.



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9

***Tradescantia pallida* ‘Purpurea’** (Purple Spiderwort)

This plant is native to the Gulf Coast region of eastern Mexico. Its leaves display a golden sheen when viewed under direct light. This shine comes from a collection of waxy structures that grow out of the surface of the leaf in a disordered manner. It is this disordered structure that scatters the light and creates the golden iridescence. You can see the colour when shining a phone torch on the leaf. The golden iridescence disappears if the leaves are rubbed, as this removes the waxy layer. In many plants it is thought that waxy structures like these help the plant protect its cells from excess radiation by scattering UV light (high energy and a short wavelength). However, the golden sheen created by the waxy structures in the purple spiderwort is a result of reflectance of longer wavelengths of light near the red end, unlikely to provide a photoprotective effect. The biological function is unknown but is speculated to be either a herbivore repellent or aiding the creation of a hydrophobic surface.



10

Margaritaria nobilis (Bastard Hogberry)

The bastard hogberry is a tree native to Mexico, Central and South America and the West Indies. Its fruit start out green but ripen to a brilliant iridescent blue when they fall to the forest floor.

It is likely that the plant has evolved this unusual colouration because it helps foraging animals see the fruit, which they eat and disperse.

Similar to blue oil fern leaves, plywood-packed fibres of cellulose within the cell walls of the fruit's skin reflect light. Cellulose is not usually iridescent: it is the same material used to make cotton T-shirts and paper. It is not yet known how the plant lays down these cellulose fibres, which is why we are growing it here. When it eventually flowers and fruits, researchers will be able to analyse the ripening fruits to follow the development of the colouration.

Fabrics using cellulose fibres similar to those found in the blue oil fern and bastard hogberry can change colour as they stretch. These fabrics could be used for tension sensors or cutting-edge camouflage. *See the trail website for the amusing tale of how we acquired this plant.*



Nemec / CC BY-SA 3.0

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please return it to the ticket office for others to use.

11

Goeppertia zebrina (Zebra Plant)

The zebra plant is a popular houseplant, with long stems supporting large, striped leaves with an unusual velvety texture. The zebra plant is native to Brazil, where it grows in the understory of tropical rainforests. Its leaves have an even spread of cone-shaped cells on the surface, giving the curious property of lessening splashing of water that lands on the plant. Instead, the water spreads out over the leaf over a few seconds. This spreading may be a strategy to boost evaporation rates, allowing the leaf to dry quickly in the damp forest – wet leaves are ideal breeding grounds for moulds.



There are many possible human uses of surfaces which promote evaporation, and replicates of the leaf structure could be used on windows, mirrors or shower screens. Additionally, the water-conducting properties of the leaf surface may be useful in designing new microfluidic cooling systems.

12

Saxifraga sempervivum (Saxifrage)

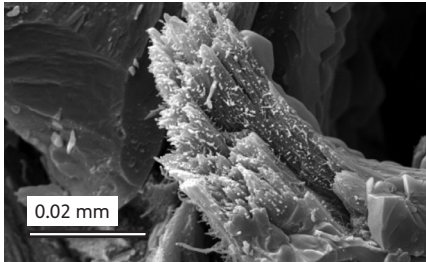
S. sempervivum is an arctic-alpine plant with small succulent leaves that have a protective silvery-white crust on its surface. In a collaboration between the Garden and the Sainsbury Laboratory, scientists sampled *Saxifraga* from the Garden's National Collection and discovered that the protective crust contains the rare mineral vaterite, a form of calcium carbonate.



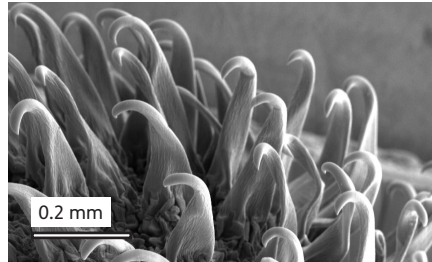
Naturally occurring vaterite is rarely found on Earth. Small amounts of vaterite crystals have been found in some sea and freshwater crustaceans, bird eggs, the inner ears of salmon, meteorites and rocks. This was the first time that the rare and unstable mineral has been found in plants and in such a large quantity. *Saxifraga* were found to be exuding vaterite from 'chalk glands' (hydathodes) on their leaf margins. Vaterite is of interest to the pharmaceutical industry for its use in drug delivery. Other potential uses of vaterite include improving the cements used in orthopaedic surgery and improving the quality of paper for inkjet printing by reducing the spread of ink.

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Electron microscope (black and white) or light microscope (colour) images of surface structures which give the plants their special properties.

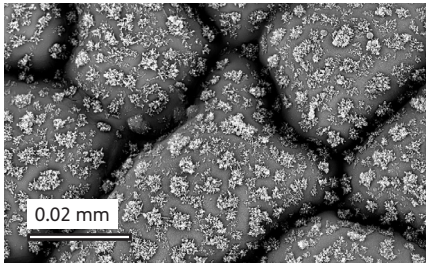


1. Analysis of bundles of fibres in aspen wood helps us understand what gives it its strength.

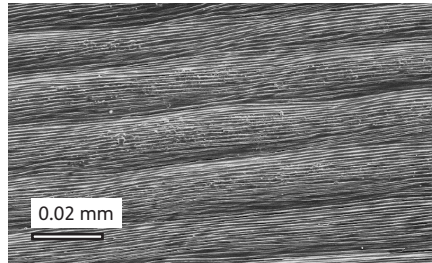


SecretDiac / CC BY-SA 3.0

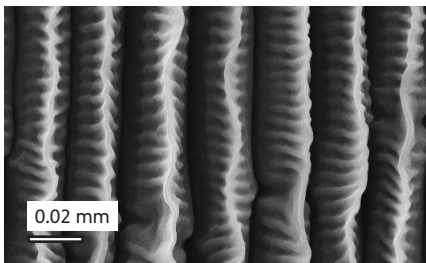
2. Common burdock seedheads have hooked spikes which catch on to animal fur, enabling distribution.



3. Tiny wax tubes on Nasturtium leaves make water form beads which roll off, cleaning the leaf.

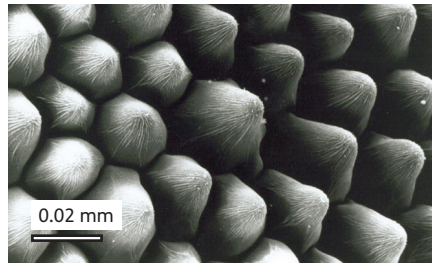


4. Fine ridges on petal surfaces of *Hibiscus trionum* diffract light, forming a blue halo.

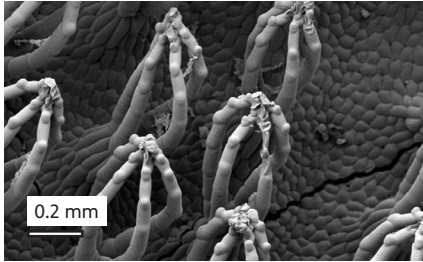


Kerstin Koch, Rhine-Waal University, Germany

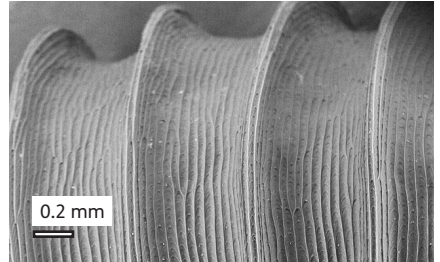
5. Treasure flower petals are ridged, and repel water into drops – but attract those drops!



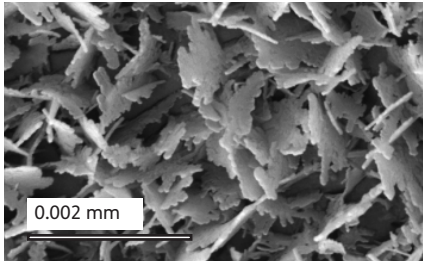
6. Snapdragon petals have conical cells which allow bees to grip them better.



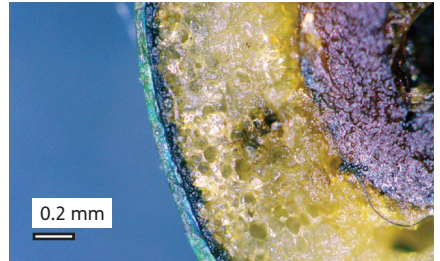
7. Asian watermoss leaves have unusual whisk-like structures which trap air bubbles.



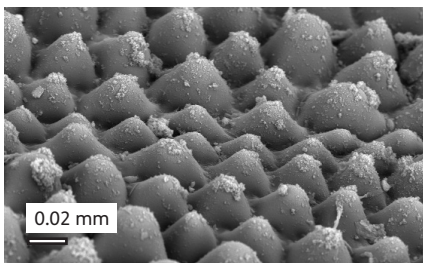
8. The hanging pitcher plant is carnivorous. These ridges make insects lose their grip and fall in.



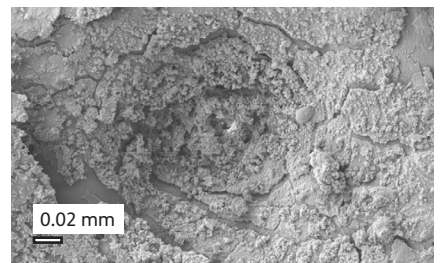
9. Purple spiderwort has waxy structures that create a golden iridescence.



10. The skin of bastard hogberry fruit contains cellulose fibres that make the fruit iridescent.



11. The conical cells on zebra plant leaves let water spread quickly over the leaf surface.



12. Hydathodes (chalk glands) on the leaf surface of *Saxifraga sempervivum* exude the rare mineral vaterite.

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