THE ROYAL SOCIETY

Animate materials factsheet: What are they?

What are animate materials?

In the natural world, humans and animals are clearly animate. In a different sense, so are plants and oceans as, although lacking sentience, they move and change, often in response to the environment around them. Rocks can be seen at the other end of a scale of animacy, but even they can take animate form, for example when molten rock or magma reaches the surface in an erupting volcano.

Some natural substances and structures display some degree of animacy due to the action of physical forces such as heat or pressure. Others are more intrinsically animate because of the way they interact with their environment.

Across the scientific world, researchers are developing tools and ideas, many of them inspired by the mechanisms of nature, to create materials that have lifelike properties: in other words, these materials can sense, move, change shape, and adapt to their environment to fulfil particular goals like growing or obtaining nutrients. These materials are referred to as animate materials.

Animate materials created by humans can have their behaviour broken down into three main characteristics, or principles, namely being active, adaptive and autonomous.

ACTIVE

'Active' means that the materials can change their properties or perform actions, often by taking energy, material or nutrients from the environment.

Some examples of 'active' materials currently available are Piezoelectric materials like Quartz crystals that produce an electric current when they are placed under mechanical stress.

Shape-memory alloys such as nitinol (a mixture of nickel and titanium) are another example of active materials. Nitinol can be 'programmed' with a shape while warm. If the alloy is then cooled and bent, when it is reheated, it returns to its original shape. Such materials have been used as strong 'artificial muscles' in robotics, and as components of thermostats.

ADAPTIVE

'Adaptive' means that the materials can sense changes in their environment and respond in a way that maintains or promotes their function, typically with a single predetermined outcome.

Materials include those that overcome typical problems of degradation such as cracks in roads or walls, or scratches on the paint of a car. Lime mortar, used in buildings since the Egyptian pyramids, is an example of an adaptive self-healing material, healing itself by growing new crystals in cracks when water enters and enables lime to react with carbon dioxide in the air.

Self-healing paints are already commercially available and multiple projects are exploring possibilities for self-healing asphalt, concrete and fibre-reinforced polymers used in aircraft.

AUTONOMOUS

'Autonomous' means the materials can automatically 'decide', perhaps through some internal computation, or computation like process, on an appropriate response to signals or changes in the environment from a repertoire of possible outcomes, without being monitored or controlled.

Unlike adaptive materials that have a single response to a specific prompt, such as glasses that darken in response to UV light, autonomous materials show versatility in combining various inputs to generate a suitable behaviour from a diverse repertoire. There currently are no fully autonomous man-made materials in existence.

Do animate materials already exist?

Artificial materials that are fully animate in all three characteristics don't exist at present. As described, there are many examples of materials that have some features that correspond with the definition of either active or adaptive materials, however these materials only represent early branches of animate material development. There is current research that is indicating potential ways to improve and extend the capabilities of these materials and move towards materials that show multiple animate characteristics.

To develop fully animate materials from scratch, researchers need to draw on knowledge from a wide range of separate disciplines. Techniques for making, analysing and testing them will be grounded in the fields of materials science and engineering. However, animate materials will also draw from the expertise of other fields, such as organic and inorganic chemistry, synthetic biology, cell biology and physics.

Image:
Soft robotic hands are able to manipulate fragile objects with dexterity and repair themselves when damaged. © Brubotics (VUB).

What could the future look like?

Animate materials could eventually have a transformative effect on all spheres of life. Buildings could become an active part of local ecosystems, harvesting carbon dioxide from the environment to heal themselves. The walls of buildings could act as bioreactors, using inputs such as light, water, heat, algae, bacteria, nutrients and gases to generate a range of products such as purified water, power, oxygen, recoverable biomass and heat.

Medical implants may be able to interact with our bodies to enhance healing or deliver medicines in appropriate doses in targeted parts of the body. Material goods that reach the end of their useful life could be programmed to separate into their basic components for reuse and recycling.

Clothing may become responsive, becoming more like assistive technology which adapts to changes in people's requirements. New materials are being created that could make clothing or bandages respond to changes in a person's body temperature and detect possible illness.

Robotic-like devices may be developed that are not controlled entirely by some centralised information-processing unit, but instead have a degree of intelligence built into their fabric, resembling the swarming behaviour of some insects and birds.

This could involve the use of soft, responsive materials rather than the hard substances of traditional robotic engineering. These devices might harvest their power from ambient sources rather than needing periodic charging. They could be sent to places to perform tasks that are highly hazardous for humans, such as dealing with radioactive contamination.

Researchers are working to create tiny robotic modules, sometimes called claytronic atoms or 'catoms', that in the future may be able to assemble and disassemble into arbitrarily shaped objects such as a chair.

You can find more information on animate material in the Royal Society's *Animate materials* report: **royalsociety.org/animate-materials**