Empa Quarterly

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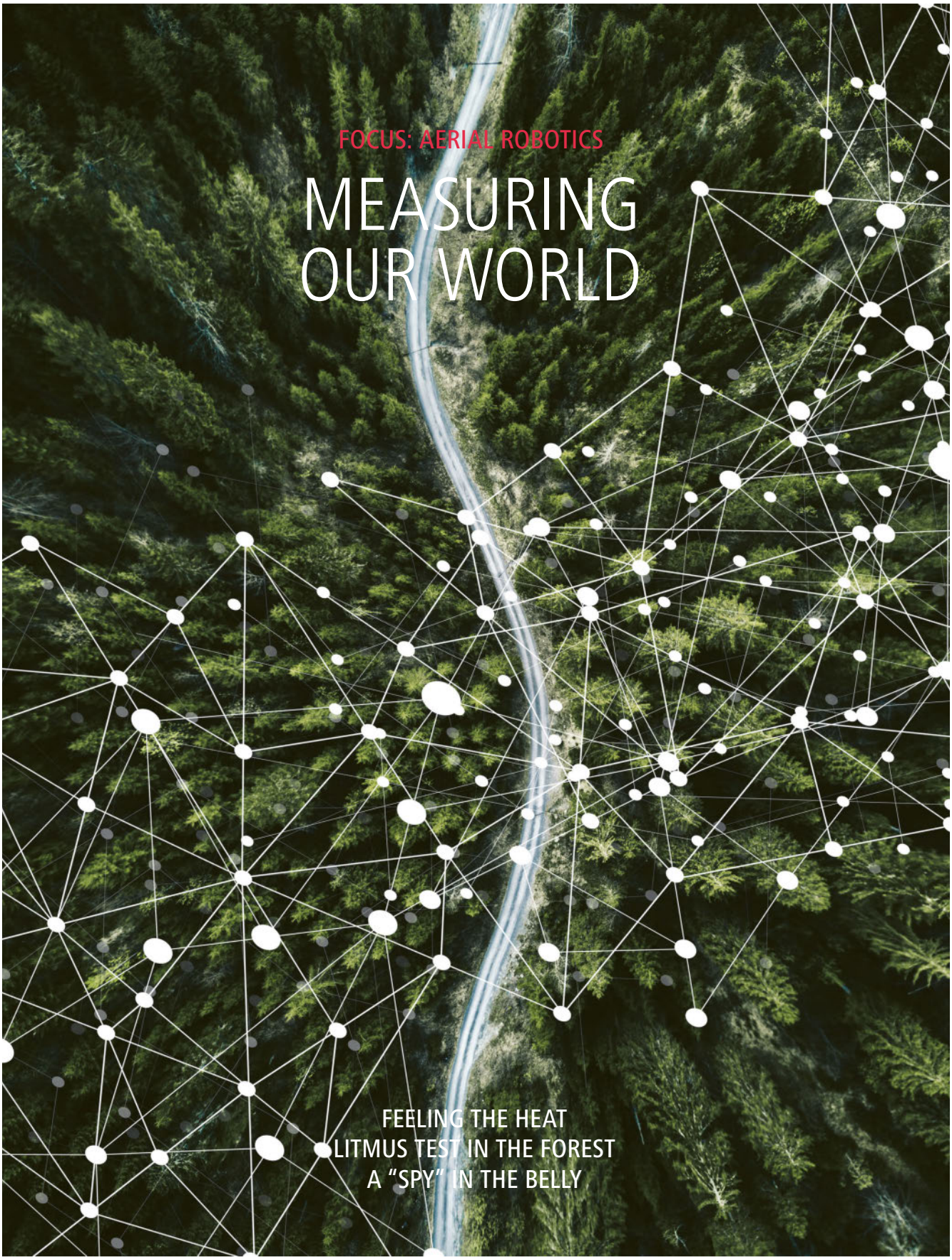

FOCUS: AERIAL ROBOTICS

MEASURING OUR WORLD

FEELING THE HEAT
LITMUS TEST IN THE FOREST
A "SPY" IN THE BELLY

www.empaquarterly.ch

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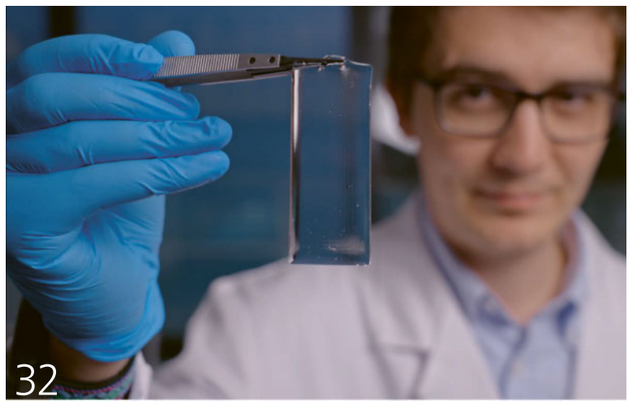
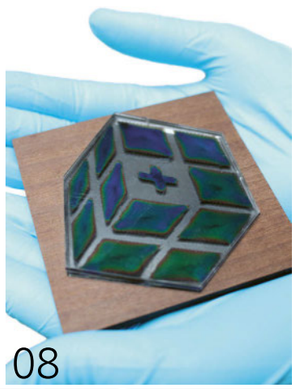
[FOCUS: AERIAL ROBOTICS]





Photos and illustrations: Empa (4), Schwarz Pictures

[COVER]

Measuring what we need to protect: The drones of Empa's Sustainability Robotics Laboratory can observe nature far less intrusively than any human. Some of them even dissolve into the environment without a trace once their work is done.
(See p. 24.)
Image: iStock, Empa

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OUTSOURCING CRITICAL THINKING? NOT A GOOD IDEA!

Dear Readers,

The world around us is getting smarter: packaging, cars, houses, text and image processing programs – aka ChatGPT, Midjourney and the like. So is it time to sit back and relax while Artificial Intelligence (AI) is doing the work for us? Hardly; our brain's performance depends on constant training. And as fascinating as the computer-generated products might be, there are also downsides. After all, AI not only helps us to understand our world better; it can even be used to create alternative realities – see Deepfakes.

We should thus ask ourselves: Where does AI bring real advantages, and where should we be vigilant? Do we understand our new "toy" well enough to let it loose on the world without manual? No AI, no matter how smart, can take these considerations off our shoulders. So we would do well to keep our thinking organ fit in the future – despite all the conveniences that ChatGPT and Co. undoubtedly offer.

What does all this have to do with Empa? For one thing, we are developing autonomous robotic systems and the materials to build them, so that drones can take on various tasks that are hazardous for humans, such as remote infrastructure monitoring, environmental observation and firefighting – as the Focus section in the current issue illustrates. On the other hand, we regularly investigate the pros and cons of new technologies and explore the diverse interactions between humans and autonomous systems in the planned DroneHub in NEST.

Enjoy reading!
Your MICHAEL HAGMANN

A SHOCKING HORROR (BIO-)FILM
Hygiene is taking a back seat in this horrendous community: The bacteria in this scanning electron micrograph have formed a lively partnership at the root of a tooth (beige). The rod-shaped bacteria (green) and cocci (yellow) cover the tooth root and its openings for the blood vessels. This biofilm tenaciously attaches itself to the teeth with the help of a sugar-containing matrix. Depending on the composition of the microbial community, the biofilm causes tooth decay and inflammation at the tooth root. Empa researchers are investigating the mechanisms of these successful communities and are developing biomedical materials to keep the pathogens at bay.

Further information on the topic is available at:
www.empa.ch/web/s404

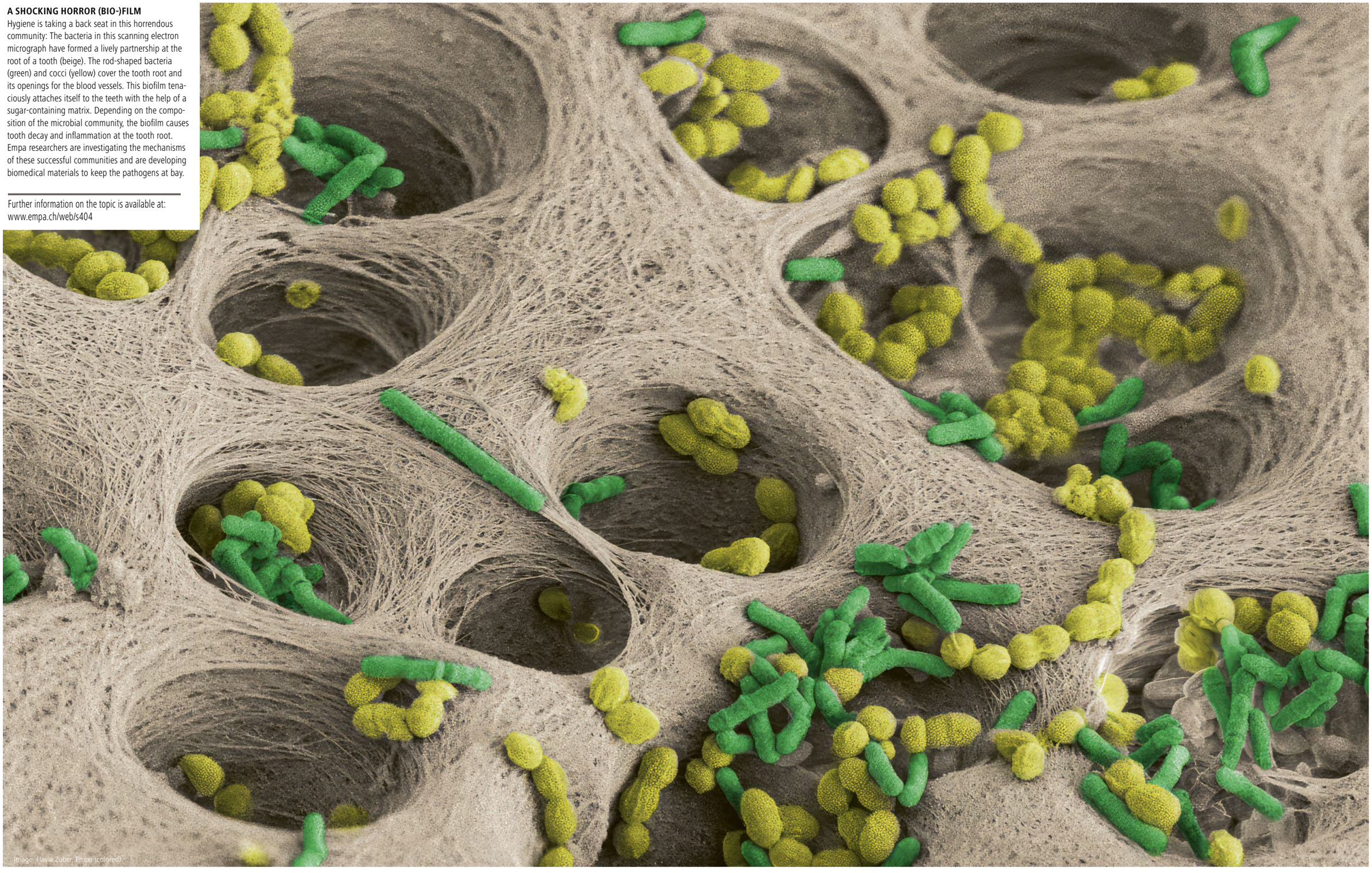


Image: Flavia Zuber, Empa (colored)

A CHILDREN'S BOOK FOR A SUSTAINABLE FUTURE

FOR THE FUTURE
Schoolchildren and researchers will work together to design a children's book on circular economy.

Climate crisis, loss of biodiversity, growing mountains of waste, dwindling resources: Our (one and only) home planet is in deep crisis. Research tells us what we need to do in order to build a sustainable society: limit resource consumption, circulate materials in the technosphere, and provide renewable energy for sustainable materials cycles. However, the conditions, pathways, and opportunities are not very tangible. In order to change this, Empa researchers sought out unusual collaboration partners: schoolchildren. Supported by the St. Gallen University of Teacher Education, they want to work with primary schoolchildren to develop visions for a sustainable future and compile them in an illustrated children's book. The Swiss National Science Foundation (SNSF) is supporting the project as part of its Agora program, together with the household appliance manufacturer V-Zug and the trade association SWICO.

www.empa.ch/web/s506

MEET EMPA'S BRIGHT MINDS

MEET THE PEOPLE
The new video series "Bright Minds" provides insights into the personal journey of Empa researchers.

Developing game-changing solutions for society's most pressing challenges is tough. Empa scientists take on that task – and deliver. High time to put the limelight on the faces behind the novel materials and technologies developed at Empa: A new video series – "Bright Minds: Bold Ideas. Smart Materials." will give you insights about a researcher's personal journey and their path to discoveries all the way to the translation of research in practical applications. The videos also reveal how interdisciplinary teamwork at Empa is advancing innovation. "Bright Minds" will launch in May 2023, with Mirko Kovac and Evgeniia Gilshtein, Empa's Sustainability Robotics experts, taking center stage.

www.empa.ch/bright-minds

Photo: Pixabay, Graphic: Empa

NEW TECHNOLOGY REVOLUTIONIZES THE ANALYSIS OF OLD ICE

FROZEN HISTORY
The 1.5 million year old ice contains bubbles of ancient air, making it an important climate archive.

The Beyond EPICA – Oldest Ice project, a European consortium that includes the University of Bern, aims to analyze 1.5 million year-old Antarctic ice to gather data about Earth's climate history. Such ice cores are a key climate archive. They contain air bubbles, which will allow scientists to directly measure historical greenhouse gas concentrations. However, such measurements are far from trivial. 15,000 to 20,000 years of climate history are compressed into just one meter of ice. Together with the University of Bern, Empa researchers have developed a new method to accurately analyze the ancient ice. The team led by Lukas Emmenegger, head of Empa's Air Pollutants/Environmental Technology laboratory, developed a new laser spectrometer that can measure greenhouse gases on a sample of just 1.5 milliliters of air.

www.empa.ch/web/s503

NOVEL COMPUTER COMPONENTS INSPIRED BY HUMAN BRAIN CELLS

Researchers at Empa, ETH Zurich and the "Politecnico di Milano" are developing a new type of computer component that is more powerful and easier to manufacture than its predecessors. Inspired by the human brain, it is designed to process large amounts of data fast and in an energy-efficient way. The novel component, known as a memristor, is based on halide perovskite nanocrystals, a semiconductor material known from solar cell manufacturing. The researchers manufactured the thin-film memristors at the Thin Films and Photovoltaics laboratory and investigated their physical properties at the Transport at Nanoscale Interfaces laboratory, both at Empa. Based on the measurements, they successfully simulated a complex computational task that corresponds to a learning process in the visual cortex of the brain.

www.empa.ch/web/s207

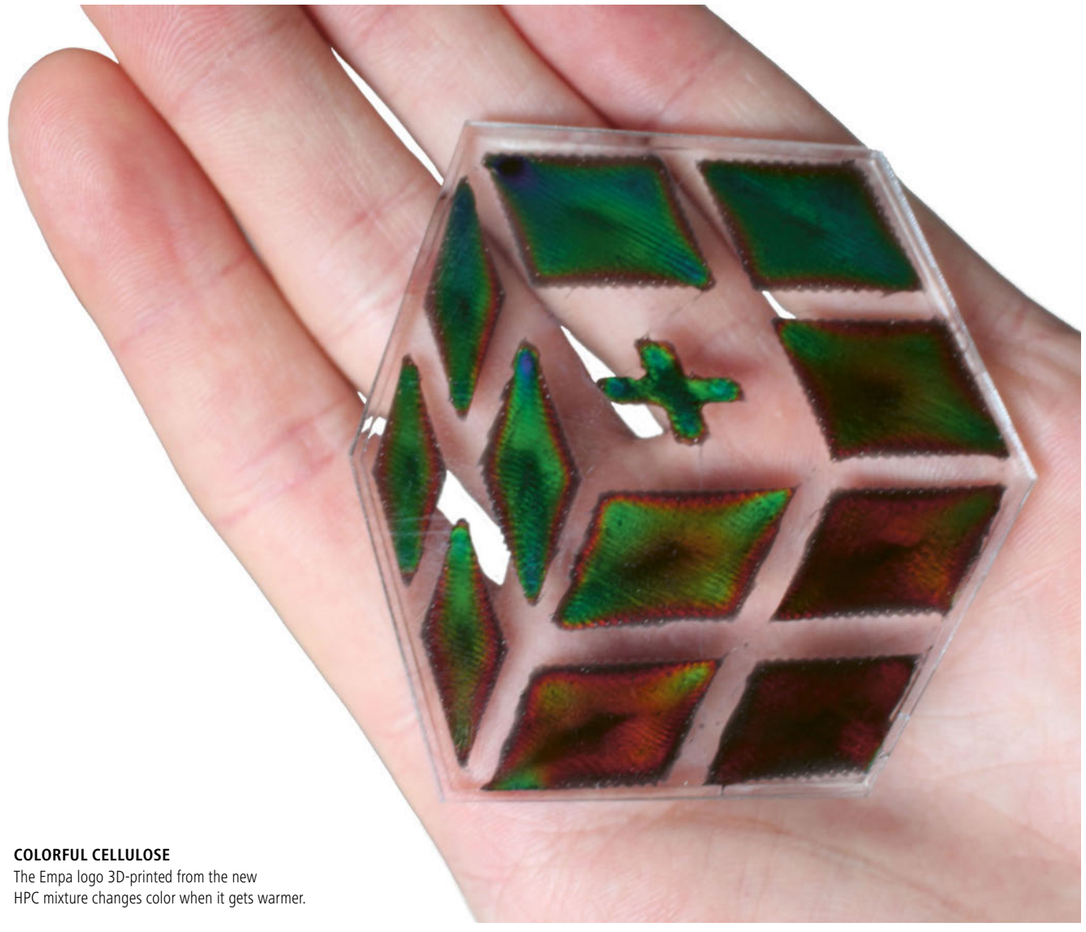
UNMATCHED PERFORMANCE
As of now, no computer can match the energy efficiency of the human brain.

Photo: PNRA/IPEV, Illustration: iStock

THE CHAMELEON EFFECT

Is it possible to 3D print biodegradable sensors and displays? Researchers from Empa's Cellulose & Wood Materials laboratory have developed a cellulose-based material that allows just that. The mixture of hydroxypropyl cellulose with water, carbon nanotubes and cellulose nanofibrils changes color when heated or stretched – without the addition of any pigments.

Text: Anna Ettlin



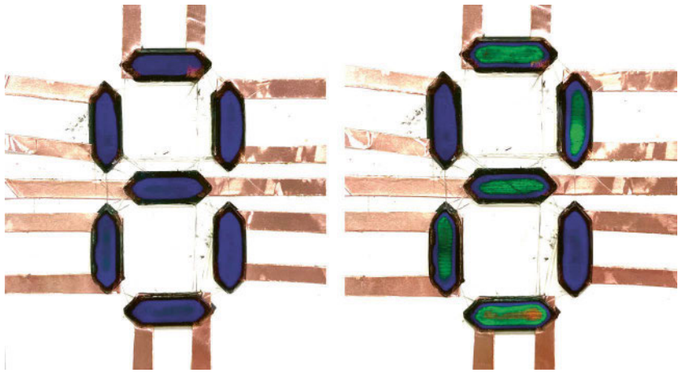
COLORFUL CELLULOSE
The Empa logo 3D-printed from the new HPC mixture changes color when it gets warmer.

Photos: Empa

An elastic material that changes color, conducts electricity, can be 3D printed and is also biodegradable? That is not just scientific wishful thinking: Empa researchers from the Cellulose & Wood Materials laboratory in Dübendorf have produced a material with these exact properties on the basis of cellulose and carbon nanotubes.

The researchers started with hydroxypropyl cellulose (HPC), which is commonly used as an excipient in pharmaceuticals, cosmetics and foodstuffs, among other things. When mixed with water HPC is known to form liquid crystals. These crystals have a remarkable property: Depending on their structure – which itself depends on the concentration of HPC, among other things – they shimmer in different colors, although they themselves have no color or pigment. This phenomenon is called structural coloring and is known to occur in nature: Peacock feathers, butterfly wings and chameleon skin get all or part of their brilliant coloration not from pigments, but from microscopic structures that "split" the (white) daylight into spectral colors and reflect only the wavelengths for specific colors.

The structural coloring of HPC changes not only with concentration but also with temperature. To better exploit this property, the researchers, led by Gustav Nyström, added 0.1 weight percent carbon nanotubes to the mixture of HPC and water. This renders the liquid electrically conductive and allows the temperature, and thus the color of the liquid crystals, to be controlled by applying a voltage. Added bonus: The carbon acts as a broadband absorber that makes the colors deeper. By incorporating a small amount of cellulose nanofibers into the mixture, Nyström's team was also able to make it 3D printable without affecting structural coloring and electrical conductivity.



BIODEGRADABLE
The display consists of seven electrically conductive segments that change color when a voltage is applied.

SUSTAINABLE SENSORS AND DISPLAYS

The researchers used the novel cellulose mixture to 3D print various potential applications of the new technology. These included a strain sensor that changes color in response to mechanical deformation and a simple seven-segment display. "Our lab has already developed different disposable electronic components based on cellulose, such as batteries and sensors," says Xavier Aeby, co-author of the study. "This is the first time we were able to develop a cellulose-based display."

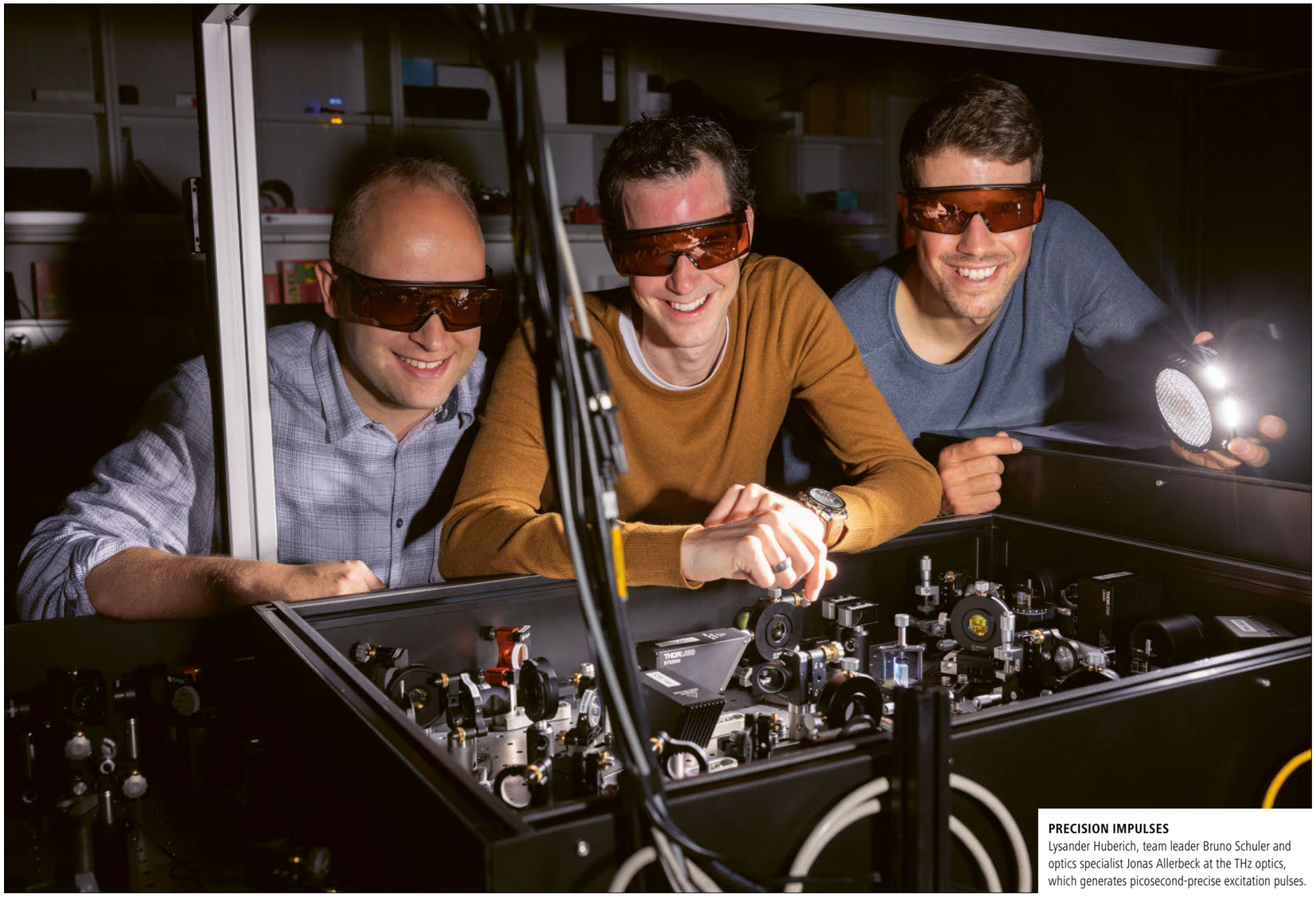
In future, the cellulose-based ink could have many more applications, such as temperature and strain sensors, in food quality control or biomedical diagnostics. "Sustainable materials that can be 3D printed are of great interest, especially for applications in biodegradable electronics and the Internet of Things," says Nyström, head of the laboratory. "There are still many open questions about how structural coloring is generated and how it changes with different additives and environmental conditions." Nyström and his team aim to continue this line of work in the hope of discovering many more interesting phenomena and potential applications. ■

Further information on the topic is available at: www.empa.ch/web/s302

MASTERS OF DEFECTS

Bruno Schuler and his young team are embarking on an ambitious research project: He will selectively generate defects in atomically thin semiconductor layers and attempt to measure and control their quantum properties with simultaneous picosecond temporal resolution and atomic precision. The resulting insights are expected to establish fundamental knowledge for future quantum computers.

Text: Rainer Klose



PRECISION IMPULSES
Lysander Huberich, team leader Bruno Schuler and optics specialist Jonas Allerbeck at the THz optics, which generates picosecond-precise excitation pulses.

Photo: Gian Vaitl, Empa

The term molybdenum disulfide may sound familiar to some car drivers and mechanics. No wonder: the substance, discovered by US chemist Alfred Sonntag in the 1940s, is still used today as a high-performance lubricant in engines and turbines, but also for bolts and screws. This is due to the special chemical structure of this solid, whose individual material layers are easily displaceable relative to one another. However, molybdenum disulfide (chemically MoS_2) not only lubricates well, but it is also possible to exfoliate a single atomic layer of this material or to grow it synthetically on a wafer scale. The controlled isolation of a MoS_2 monolayer was achieved only a few years ago, but is already considered a materials science breakthrough with enormous technological potential. The Empa team now wants to work with precisely this class of materials.

The layered structure of individual atomic layers makes this material interesting for physicists in search of base materials for next-generation nanocomputers. MoS_2 – and its chemical relatives called transition metal dichalcogenides (TMDs) – are one of the main "shooting-stars" in a whole range of two-dimensional (2D) materials. TMDs are 2D semiconductors and have a direct band gap, but only as a single layer, making them particularly attractive for ultimate miniaturized integrated circuits or optical detectors. The robust quantum mechanical properties of 2D materials are also being ▶

intensively explored for use in quantum metrology, quantum cryptography, and quantum information technology.

But not only the base material matters, but in particular also the ability to manage defects in there: Analogous to chemical doping of "classical" semiconductors in integrated circuits or foreign ions in solid-state lasers, atomic defects are "like the icing on the cake," especially in 2D materials, Schuler said.

ATOMICALLY THIN QUANTUM COMPUTERS?

The Empa researcher wants to characterize atomic defects in TMDs using a novel type of instrument and investigate their suitability as so-called quantum emitters. Quantum emitters form the interface between two worlds: electron spin – the quantum mechanical analogue of the electron torque – which is suitable for processing quantum information, and photons, i.e. light particles, which can be used to transmit quantum information over long distances without loss. 2D materials offer the great advantage that the relevant energy scales are much larger than for 3D materials, so it is expected that the technology can be used above cryogenic environments – ideally even at room temperature. In addition, the defects have to be located on the surface of the 2D material, making them much easier to find and manipulate.

But first, the defects in the two-dimensional MoS_2 layer have to be detected and their electronic and optical properties have to be investigated precisely. Precise, in this case means that the location under investigation is explored to the accuracy of one angstrom. For comparison: 1 angstrom is to a meter what 4 cm is to the distance Earth-Moon (400,000 km). And the snapshot used to record the electronic excitation of the quantum dot must be accurate down to one picosecond (ps) – 1 ps

> "In this project, we are observing things for the first time that no one has seen before."

is as small of a fraction of a second as 2 days are compared to the age of planet Earth (5 billion years). These ultrashort and atomically precise measurements then provide a very detailed picture of what dynamic processes are occurring on an atomic scale and what factors are affecting those processes.

AN APPARATUS MADE OF TWO HALVES

The apparatus in which the experiments will take place is already located in a room in the basement of Empa's laboratory building in Dübendorf – where the floor is the most stable. "We have invested over a year and a half of preparation and development work to complete our experimental setup," Bruno Schuler explains. "In October 2022, we connected the two halves of our system and were able to measure lightwave-induced currents for the first time. The principle works! A huge milestone in the project."

The two halves that Schuler's team will now work with are, on the one hand, a scanning tunneling microscope (STM). An ultrathin tip is used to scan the atomic surface of the sample. The scientists will position the tip at a defect site, i.e., a vacancy or a "foreign" atom in the structure.

Then the second half of the system, which Schuler's colleague Jonas Allerbeck has set up, comes into play: A 50-watt infrared laser sends ultrashort laser pulses onto a nonlinear lithium niobate crystal. This generates a phase-stable electromagnetic pulse in the terahertz frequency range. This pulse is only a single oscillation of light long and can be split with special optics into a pair of pump and probe pulse – both of which follow each other with variable delay and can measure the electron dynamics in a stroboscopic manner.

AN ELECTRON "JUMPS" ONTO THE DEFECT SITE

The two pulses are then sent into the STM and directed to the probe tip. The first pulse detaches an electron from the tip, which "jumps" onto the defect site of the two-dimensional MoS_2 layer and excites electrons there. "This can be either an electric charge, a spin excitation, a lattice vibration or an electron-hole pair that we create there," Schuler explains. "With the second pulse, we then look a few picoseconds later at how our defect site responded to the excitation pulse and by that we can study decoherence processes and energy transfer into the substrate."

In this way, Schuler is one of only a few specialists in the world to combine picosecond-short time resolution with a method that can "see" individual atoms. The team makes use of the intrinsic localization of states in the 2D material system to hold excitations in one place long enough to be detected. "The ultrafast lightwave scanning probe microscope enables fascinating new insights into quantum mechanical processes at the atomic scale, and 2D materials are a unique materials platform to create these states in a controlled way," says the Empa researcher.

AN ERC STARTING GRANT

Bruno Schuler and his team, the optics specialist Jonas Allerbeck and PhD student Lysander Huberich, who works on the scanning tunneling microscope, are supported by funding from the European Research Council. The ERC Starting Grant supports particularly talented young scientists – the Champions League of the European research community. Schuler brought the best prerequisites with him: He studied physics at ETH Zurich and specialized in his doctorate at the birthplace of scanning tunneling microscopy, the IBM research laboratory in Rüschlikon. As a postdoc and later as a group leader at the Lawrence Berkeley National Lab in the US, he conducted his first research on 2D materials and coordinated an international research team.

He now wants to use this experience to strengthen and further develop Empa as a research hub for quantum nanotechnology. "We have the privilege of breaking new scientific ground with this project and observing things for the first time that no one has seen before," Schuler says. At Empa, Bruno Schuler's research group is part of the nanotech@surfaces lab lead by Roman Fasel. The internationally renowned group conducts research on quantum effects in low-dimensional organic and inorganic nanostructures, which could form a basis for next-generation quantum computers. ■

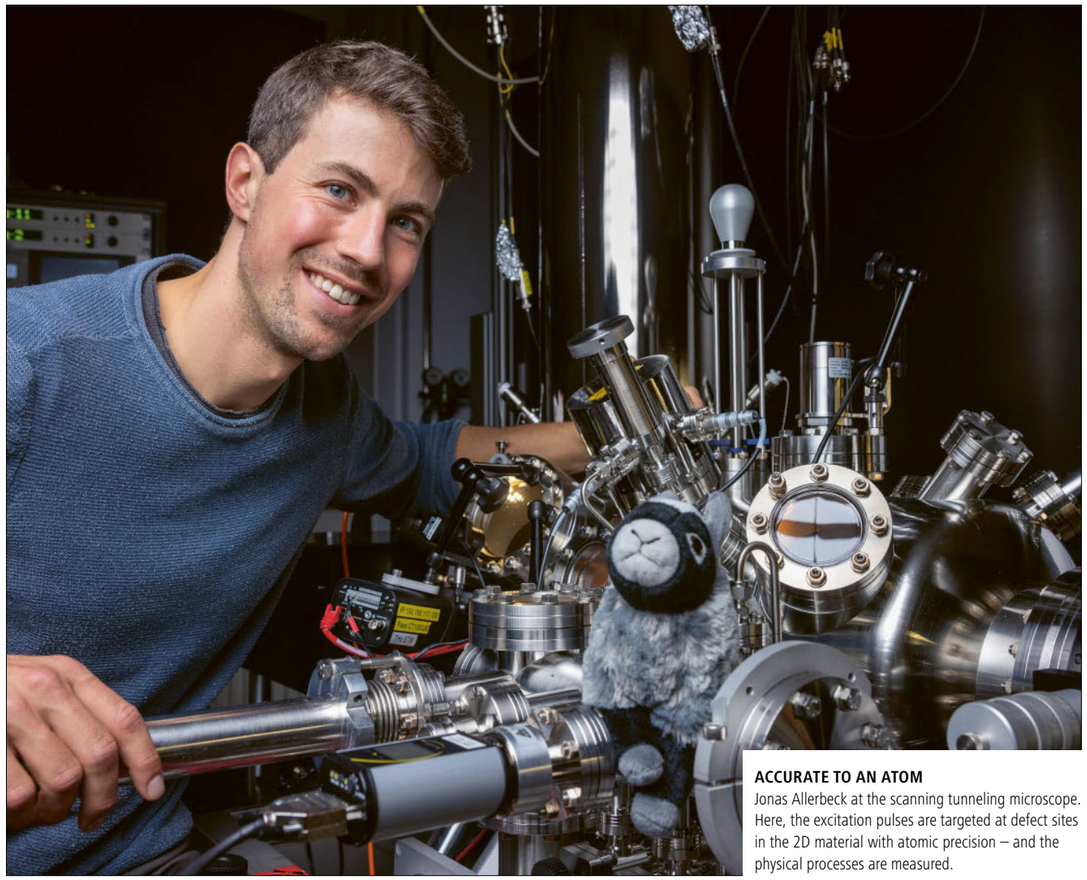


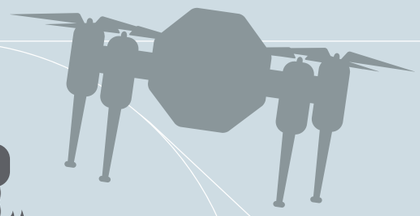
Photo: Gian Vaitl, Empa

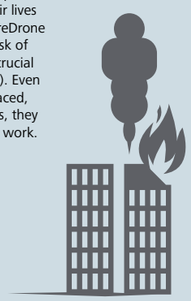
ACCURATE TO AN ATOM
Jonas Allerbeck at the scanning tunneling microscope. Here, the excitation pulses are targeted at defect sites in the 2D material with atomic precision – and the physical processes are measured.

Further information on the topic is available at:
www.empa.ch/web/s205/2d-quantum-materials

A drone for every occasion

An entire drone universe is being developed by researchers at Empa's Sustainability Robotics lab in collaboration with the Aerial Robotics Laboratory at Imperial College London. These drones can not only fly, they can also swim, dive and support firefighters. Thanks to biological inspired properties and smart materials, the sustainable robots will combine the digital intelligence of computers with the physical intelligence of biological systems. Whether in fire, water, earth or air – these drones are always in their element.

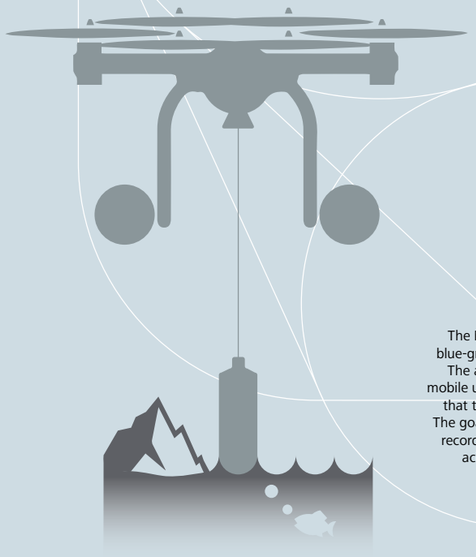




Fire

Untamed bushfires or burning buildings – the destructive power of fire is gigantic. Facing it means firefighters risking their lives time and again. Thanks to heat-resistant materials, the FireDrone can examine a fire source at close range without the risk of damage. The flying robot can provide firefighters with crucial information to optimize their response strategy (page 16). Even where destroyed buildings need to be repaired or replaced, drones can play a role: As a swarm of cooperative robots, they can 3D print structures on site and support construction work.

More information



Water

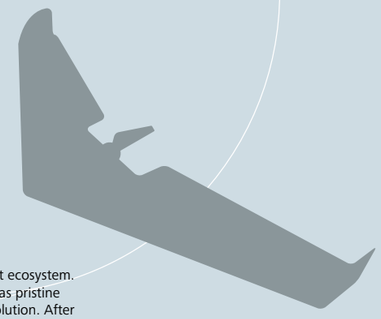
The MEDUSA drone helps predict the occurrence of toxic blue-green algae or monitor water quality in mountain lakes. The aircraft is capable of landing on water and releases a mobile underwater capsule, equipped with camera and sensors, that takes water samples from depths of up to ten meters. The goal is to gather information on global climate change by recording data on water temperature, currents, salinity and acidity even from regions that are difficult to access.

More information

Air

New inspection drones explore the condition of infrastructure such as wind turbines and bridges from the air. For stationary measurements over a longer period of time, they can settle on site and operate in a more energy-efficient manner. The ProteusDrone made of flexible and intelligent materials is currently being developed for complex environmental conditions. It will be able to change its shape – similar to the sea god Proteus from Greek mythology who is considered a master of transformation. This should allow the drone to be used in difficult environments such as the Arctic. It uses the element of air not only to fly, but also to sail on the surface of the water. A true quick-change artist, the ProteusDrone will even learn to dive.

More information



Earth

The condition of the soil is an important indicator of the health of the forest ecosystem. To ensure that data can be analyzed even from inaccessible regions such as pristine forests, the bio-glider (page 24) serves as a sustainable and cost-effective solution. After taking its measurements, it is decomposed by soil microbes. The bio-glider is supported by a flying robot à la Robin Hood: The drone, which is equipped with sensor arrows, can provide environmental data from higher up in the forest. It fires its sensor arrows precisely into the trunks, from where the sensors can determine the temperature, air quality and moisture content of the environment. In the future, it will also monitor pest infestations, forest fires, the impact of human activity on the forest and the behavior of wild animals.

More information

Graphic: Empa

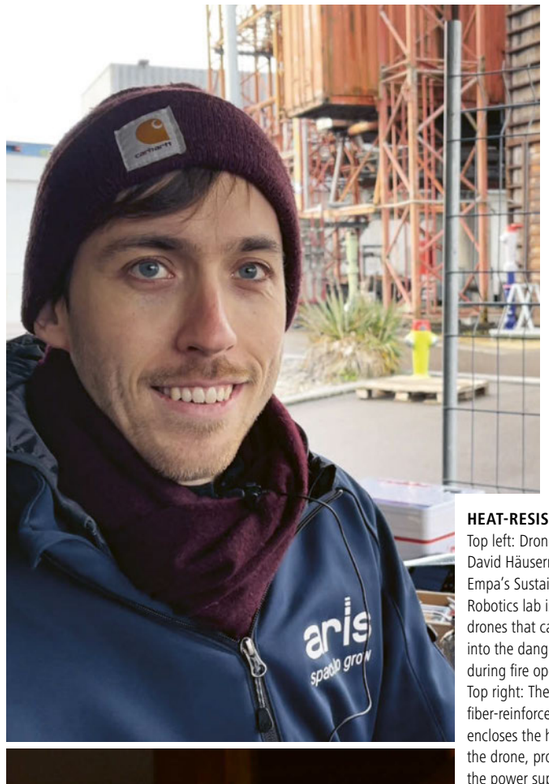
FLYING FIRE-FIGHTER

Empa researchers are developing a heat-resistant drone that can analyze the source of danger at close range in the event of a fire. This allows firefighters to optimize the strategy of a high-risk operation before entering the danger zone.

Text: Andrea Six

Photo: Empa

FIERY FLIGHT
At the test site of the Andelfingen Training Center of the Canton of Zurich, the FireDrone can demonstrate its capabilities in as real a situation as possible.



HEAT-RESISTANT
Top left: Drone researcher David Häusermann from Empa's Sustainability Robotics lab is developing drones that can fly right into the danger zone during fire operations. Top right: The glass-fiber-reinforced aerogel encloses the heart of the drone, protecting the power supply and electronics from heat. Bottom: Thanks to its insulating jacket made of aerogel, the FireDrone can collect and forward data from the scene of a fire during a fire mission, even in extremely hot conditions.

Photos: Empa

Where others rush out, they have to go in: Firefighters put themselves in dangerous situations during rescue operations – sometimes right in the midst of a sea of flames. Last year, Swiss fire departments were called out for around 12,660 fire-fighting missions. Since temperatures in a burning building can reach lethal levels of around 1,000 degrees Celsius, it is essential to avoid any unnecessary risk. Flying robots could support such missions: Empa researchers are currently developing a heat-resistant drone that can provide initial data from the hot spot. Based on this information, the men and women of the response team can optimize their strategy before venturing into the inferno.

TOO HOT FOR NORMAL DRONES

"The extreme heat generated by a fire is too great for conventional drones," says Empa researcher David Häusermann of the Sustainability Robotics lab in Dübendorf. Close to the fire, the frame melts and the electronics give up. "More than aerial photos of the fire site from a safe distance are not possible with commercial drones," Häusermann says. The researcher's goal, therefore, was to develop a drone that could withstand the heat and thus provide fast and accurate data from the center of the hot spot.

ULTRA-LIGHT AND TOUGH

Häusermann worked with firefighters to determine the requirements of a drone in a fire mission and set out to find a material that could protectively surround the heart of the drone – the motors, batteries and electronics. He found what he was looking for with colleagues from Empa's Building Energy Materials and Components lab: The researchers led by Shanyu Zhao and Wim Malfait were able to synthesize an insulating material that can withstand high temperatures and thus make the drone more fire-resistant.

SUITABLE FOR SPACESUITS

The material in question is an aerogel, an ultralight material consisting almost entirely of air-filled pores enclosed in a hint of polymer substance. In this case, the materials researchers chose an aerogel based on a polyimide plastic. Polyimide aerogels are also being researched by NASA, for example, for the insulation of space suits. However, Shanyu Zhao did not rely on polyimide alone to synthesize the aerogel: The composite material consists of polyimide and silica and is also reinforced with glass fibers. "Laboratory analyses have shown that this comparatively fire-resistant material is particularly well suited for use in drones," says aerogel researcher Zhao.

FLIGHT INTO THE INFERNO

The prototype of the FireDrone has already performed well in initial tests at Empa's flight arena in Dübendorf. The flight characteristics and controllability of the drone, which is around 50 centimeters tall, were excellent even with an aerogel insulation jacket. The design was convincing in this "dry run".

However, whether the aircraft would also pass the test of fire had to be demonstrated by tests under conditions as real as possible, which are typical of a fire operation. The Empa team was able to use such a real-life scenario on the training grounds of the Andelfingen training center. While Stefan Keller, training coordinator for the fire department of the Canton of Zurich's building insurance, and the training center's logistics crew lit a gas fire in an oversized metal bowl, the drone pilots steered their device right into the inferno.

The result: The FireDrone prototype survived several test flights. Satisfied, drone researcher Häusermann takes stock: "Even after several flights, the electronics of the FireDrone are undamaged and ready for further tests." A next step would now be to test the FireDrone in a fire, which, unlike the comparatively clean gas flame, shows a strong soot development.

In future, the FireDrone could, for example, film with a thermal imaging camera or transmit sensor measurements on gas and smoke properties, which would allow a better risk assessment. Firefighting expert Stefan Keller is also impressed by the results: "If a drone makes the initial reconnaissance of the situation, we don't have to send firefighters into the danger zone immediately. For us, this progress is enormously interesting." ■

Further information on the topic is available at:
www.empa.ch/web/s799 // www.empa.ch/web/s312

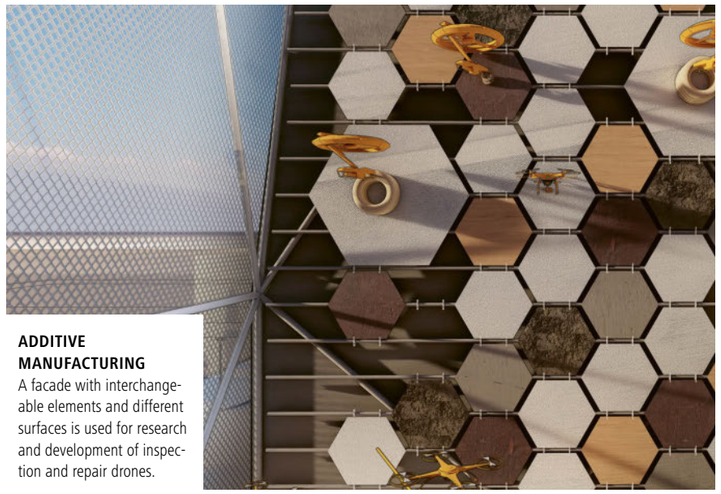
MAN AND MACHINE
In the DroneHub at NEST, the course is to be set for the future coexistence of humans and drones together with industry.

AN AVIARY FOR DRONE RESEARCH

Illustration: Empa

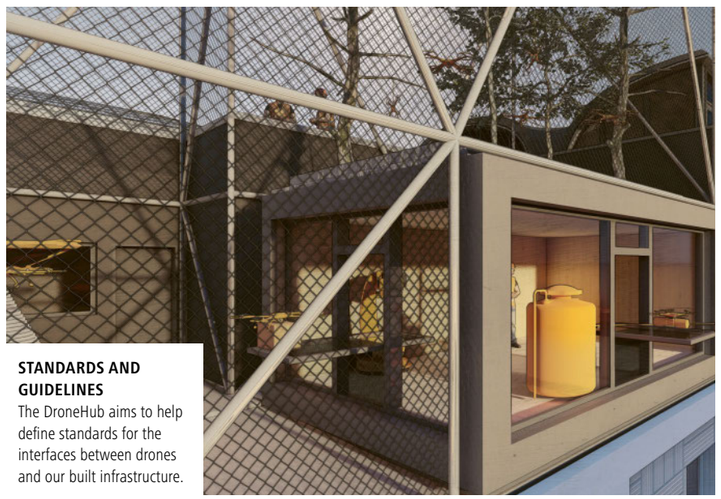
They maintain and repair buildings, observe natural phenomena and transport goods: Drones and robots could play a major role in our lives in the future. With the DroneHub, a kind of aviary is to be created in the NEST research and innovation building on the Empa campus in Dübendorf, where Empa researchers will explore and further develop the interaction of drones, infrastructure and natural habitats together with industrial and academic partners.

Text: Stephan Kälin



ADDITIVE MANUFACTURING
A facade with interchangeable elements and different surfaces is used for research and development of inspection and repair drones.

ROBOTIC ENVIRONMENTAL SENSING
A biosphere environment is used to test sensor and drone technology made from biodegradable materials.



STANDARDS AND GUIDELINES
The DroneHub aims to help define standards for the interfaces between drones and our built infrastructure.

In the same way that our immune system protects the human body, drones will in future maintain our buildings and infrastructure. They will detect damage and carry out repair and maintenance work on their own. This is how drone researcher Mirko Kovac paints the picture when he talks about his vision for the interaction between autonomous flying robots and our built environment. The comparison with biology and the human body is no coincidence: As head of Empa's Sustainability Robotics Lab and director of the Aerial Robotics Lab at Imperial College London, Kovac and his team draw inspiration from nature for their research. This results in drones that dive in and out of the water like waterfowl and take to the skies in seconds, or drones that attach themselves to walls and ceilings and rappel down thin threads like spiders. Or entire swarms of drones are being created, inspired by a colony of bees, that can build in a division of labor while flying and with 3D printing processes. At the same time, researchers are working on bio-hybrid flying robots that biodegrade in nature after their work is done, leaving no traces behind.

Such and other drone systems are developed and tested today in the flight arenas at Empa in Dübendorf and at Imperial College London. To complement this and to make the development conditions even more realistic, an aviary is now to be built on the NEST research and innovation building that can be used as a permanent outdoor test environment for various applications. "With the DroneHub at NEST, we also want to better understand the needs of industry in particular and incorporate them into our research," explains Kovac, and therefore explicitly invites interested companies to collaborate.

Illustrations: Empa

3D PRINTING ON THE FLY

The DroneHub is a kind of cage with a height of up to 11 meters and a volume of 1000 cubic meters. It consists of a tube construction and a mesh and will be located on the top platform of NEST – between the two existing units DFAB HOUSE and HiLo. When completed, the DroneHub will provide test environments for three research fields: On the north side, an experimental facade dominates the picture. The wall is fitted with interchangeable elements with different surfaces and is used to develop drones that can carry out inspection and repair work in the vertical. This includes aerial 3D printing processes – in technical jargon, Aerial Additive Manufacturing. "The drones can detect and repair cracks, for example, without the need for elaborate scaffolding or endangering the safety of people," Kovac says.

> "We need rules and technological standards to integrate drones into everyday urban life."

Having drones on standby at all times increases the speed, at which damage can be repaired – minimizing potential infrastructure outages. "This can be very relevant, especially for energy facilities such as wind turbines or dams," says the drone expert. The fact that the DroneHub is an open air facility, but at the same time embedded in a building structure, means that realistic conditions prevail with regard to wind and weather and the resulting turbulences.

A BIOSPHERE FOR ENVIRONMENTAL SENSING

The second research field focuses on the interaction between drones and nature. Today's climate research relies on sensor and monitoring data from the environment. "Drones are perfect data providers – especially in impassable and wide-ranging areas. They can place targeted sensors in nature and read the data with regular flights," explains Mirko Kovac. The important thing is that the sensor and drone systems themselves have no adverse impact on the environment (see page 24). And that is precisely what the DroneHub is all about: In a naturally designed environment with trees and forest floor, tests can be carried out with biodegradable drone and sensor materials. Part of this biosphere will also serve as a greenhouse for bio-hybrid robot structures – for example, for components for drones made of biodegradable and re-growing materials.

RULES FOR A COEXISTENCE OF MAN AND MACHINE

For the third research area, the DroneHub is to be supplemented with interfaces to the outside world. "If we imagine a future, in which drones are naturally integrated into everyday urban life and robots and humans coexist, then we need rules and technological standards for this," explains Kovac. This starts, for example, with the landing sites on or near buildings that drones are to approach autonomously – or with charging stations, at which transport drones independently refuel energy for the next flight. In the DroneHub, the researchers will develop and establish technical guidelines for such interfaces between buildings and flying robots – and help to ensure that a coexistence of man and machine does not remain science fiction. ■

GREATER ZURICH AREA ASSUMES LEADING ROLE IN DRONE RESEARCH

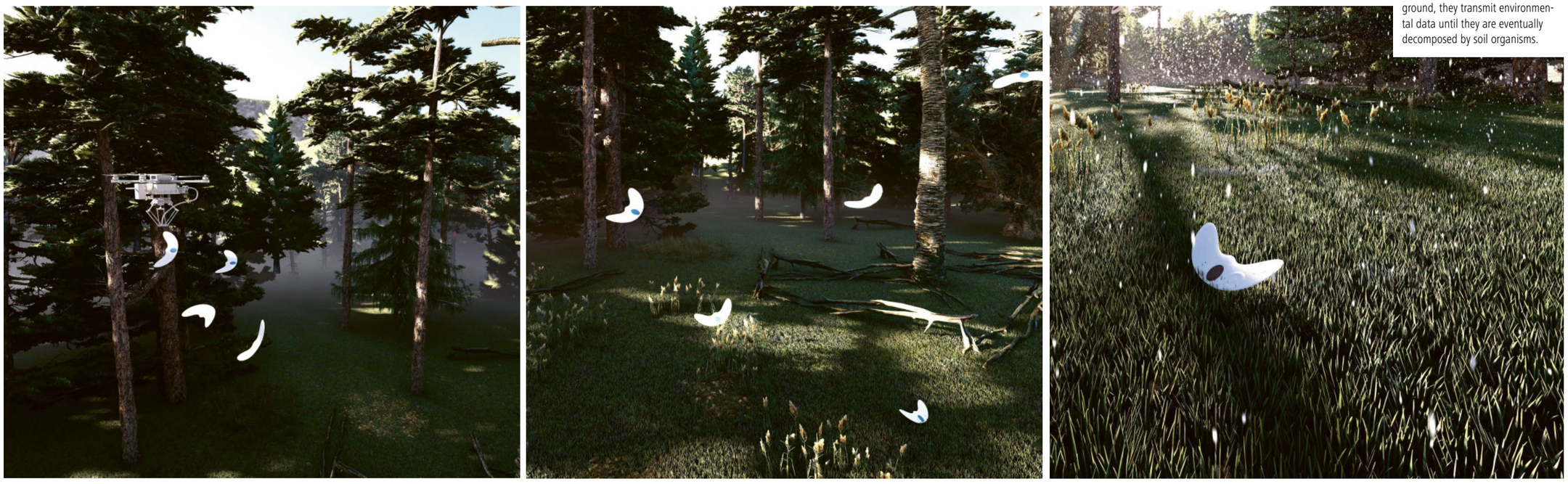
Empa's drone research has strong national and international links – including collaborations with EPFL and Imperial College London. In addition, drone activities will also develop at the nearby Zurich Innovation Park in the coming years. Funded by the cantonal digitalization initiative, a test infrastructure for autonomous flight and vehicles is being created under the leadership of the University of Zurich, the Zurich University of Applied Sciences (ZHAW) and the Zurich University of the Arts (ZHdK). The long-term goal of the recently launched project, called LINA, is to establish a certification body for commercial drones. Empa researchers are in exchange with LINA to promote complementary activities and make the Greater Zurich area a true hotspot for Swiss drone research.

Further information on the topic is available at: nest.empa.ch/drone-hub

DELICATE, DILIGENT, TRANSIENT

Their task is to monitor the condition of ecosystems, for instance in the forest floor – and crumble to dust when their work is done: bio-gliders modeled on the Java cucumber, which sails its seeds dozens of meters through the air. Empa researchers have developed these sustainable flying sensors from potato starch and wood waste.

Text: Andrea Six



SUSTAINABLE SENSORS
Bio-gliders are dispersed over a forest by a drone. When they reach the ground, they transmit environmental data until they are eventually decomposed by soil organisms.

Illustrations: Empa

Alexander von Humboldt, Charles Darwin and Ernest Shackleton set out on years of arduous voyages of exploration to gather spectacular, previously unknown impressions. Today, the pioneers of modern environmental observation are to be succeeded by faster, contemporary data collectors that record important eco-parameters in real time and without any risk. Empa researchers at the Sustainability Robotics laboratory in Dübendorf are therefore developing low-cost, sustainable sensors and flying devices that can collect environmental data in an energy-efficient, close-meshed and autonomous manner even in inaccessible areas, so-called bio-gliders. The ingredients: potatoes, some wood waste and a dyer's lichen.

LITMUS TEST IN THE FOREST

Like leaves tumbling to the ground in autumn, they sail silently to the forest floor: bio-gliders with built-in sensors. Yet the "bio" label applies to the slender flying devices in two ways: They are inspired by biology, as they are modeled on the flying seeds of the Java cucumber, yet they are also biodegradable. Once a drone has released the smart sensor seeds, they report data on, say, soil moisture and acidity until they eventually decay and become one with the forest floor. Empa researcher Fabian Wiesemüller and Mirko Kovac's team from the Sustainability Robotics lab want to use the data from the smart seeds to monitor the condition of the forest soil and its biological and chemical balance. A first sensor is now used to measure the pH value with a classic litmus test. Here, the lichen-derived dye reacts to acid with a color change from purple to red. "The color change of the sensor on the forest floor is then registered by a drone flying over the area," Wiesemüller explains.

A SENSOR IN FULL BLOOM

To ensure that the sensor is protected until it is used and only collects data at the crucial moment, it is covered by a protective film. This is a tricky "contra hood" that releases the sensor as soon as rain falls: during work breaks, it assumes a robust protective posture. As soon as the sensor is to start its operation, however, the protective film reacts very sensitively. If rain or humidity is in the air, it opens like a flower. Together with Gustav Nyström's team from Empa's Cellulose & Wood Materials laboratory, the researchers developed this protective mechanism based on nanofibrillated cellulose from wood residues, which was processed with gelatin to form a fine polymer film that reacts to atmospheric moisture. Once the rain clouds have cleared, the polymer bloom closes after about 30 minutes until the next cycle of duty. To ensure that the "blossom" opens symmetrically, the polymer film is also coated with a very fine layer of shellac, a natural resin-like substance excreted by plant lice. It prevents the polymer material from expanding unevenly when exposed to moisture.

ON THE WINGS OF A … POTATO

The transport vehicle for the biosensor is a glider whose material consists of conventional potato starch, comparable to edible paper. This means that the glider can simply be printed out and pressed into the shape of the Java cucumber seed. Including the sensor, the glider weighs just 1.5 grams and has a wingspan of 14 centimeters. "The biologically inspired design is intended to enable the glider to descend for as long as possible," says robotics researcher Wiesemüller, explaining the choice of glider geometry. In the drone flight arenas at Empa in Dübendorf and at ▶

BIOINSPIRED ROBOTS

They are to repair buildings and measure environmental pollution in inaccessible regions – for these tasks, the artificial helpers are to be inspired by nature. The biologically inspired flying objects still have a lot to learn from their role models in order to be able to act independently in a complex environment. After all, nature has had hundreds of millions of years to perfect the characteristics of living creatures. For the biodegradable sensor glider, the Empa researchers took the Java cucumber, Alsomitra macrocarpa, as their model. The Asian liana lets the wind disperse its seeds that are equipped with transparent wings. Like the original, the smart sensor seeds have a wingspan of 14 centimeters. Instead of the seed at its core, the bio-glider carries a sensor for collecting environmental data.

Imperial College London, Wiesemüller was finally able to optimize the flight behavior and stability of the first prototypes. In the flight arena, the bio-glider manages to achieve a glide ratio of 6. This corresponds to a horizontal distance of 60 meters when the glider takes off from a height of 10 meters.

When the ultralight measuring device reaches the ground, a race against time sets in. While the sensor measures the pH value every time it rains, nature gets to work on it. After seven days under laboratory conditions, soil organisms have already decomposed the wings. After another three weeks, the sensor falls apart. This is how the natural components of the bio-glider find their way back into nature. According to Wiesemüller, the acid sensor is only an initial proof-of-concept that will be followed by other types of sensors that can determine the condition of trees, water and soil in real time.

DUST TO DUST

Currently, the researchers are going one step further. Their goal is to record the effects of climate change on different habitats using completely biodegradable sensor drones. In the spirit of "digital ecology," such robots will allow for accurate predictions of the state of the environment and appropriate preventative measures, and then decompose into their parent materials in nature. So far, not all parts of such environmental drones are available in high-quality biodegradable versions. Empa researchers are now working in interdisciplinary teams on flying drones with an environmentally friendly framework based on highly porous cellulose and gelatin materials. The findings from the bio-glider project are also being incorporated here. ■

Further information on the topic is available at:
robotics.empa.ch

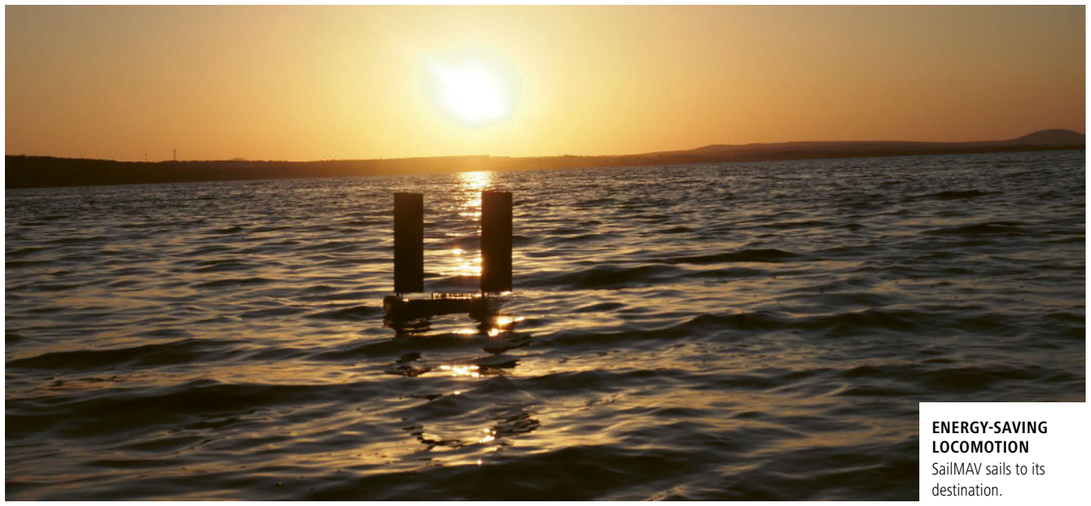
SENSOR FLOWER
The protective film of nanocellulose over the sensor opens like a flower as soon as it comes into contact with moisture – and the sensor can start its work. Right: Model flying seed of Java cucumber (top) and smart Empa glider with sensor (bottom).

Photos: Scott Zona, Empa

FRIENDLY VISITOR

The SailMAV drone can fly and sail on water due to its foldable wings. Its special design also allows it to record wildlife behavior, as animals do not perceive the drone as a hostile intruder.

Text: Andrea Six



ENERGY-SAVING LOCOMOTION
SailMAV sails to its destination.

Photo: Empa / Imperial College London

Gliding along quietly and still getting to your destination – research can be that simple. The ultralight SailMAV drone flies to remote waters and sails there quietly, saving energy. In this way, the small flying robot (Micro Aerial Vehicle, or MAV) can collect data on the biodiversity of, say, a remote alpine mountain lake or an Arctic fjord. "Water birds or mammals on the shore are not disturbed by SailMAV, so the drone can make unbiased statements about the effects of climate change on the state of the ecosystem, for example," explains André Farinha.

Farinha is one of the drone's developers, a team of researchers from Empa's Sustainability Robotics Laboratory in Dübendorf and the Aerial Robotics Laboratory at Imperial College London. Their challenge: to teach the sailing drone to fly, even though the design specifications for movements on the water and in the air are contradictory. Says Farinha, "We were finally able to optimize the aerodynamic properties after mathematical modeling and building a few prototypes so that SailMAV can actually sail on the water like a catamaran and fly with its wings wide open."

To enable the small drone to manage the change of location from one body of water to the next, it folds the sides of its three-part high-performance wing into a horizontal position within two seconds, giving it a wingspan of just under a meter. Farinha's team constructed the flying robot from polymer foam with a tenth-of-a-millimeter-thin carbon shell and coated it with a water-repellent nanoparticle layer.

As a result, SailMAV weighs just 520 grams. Under lab conditions, the fast and agile drone makes the transition from water to air in just a few seconds and within a distance of less than ten meters.

The researchers are now working on ensuring that SailMAV can also do this under real-world conditions in wind and weather. In future, SailMAV will also be equipped with more complex sensors that will allow the inconspicuous bird friend to fly and sail autonomously. ■

Further information on the topic is available at:
robotics.empa.ch

ACCELERATING RESEARCH

The “Empa Zukunftsfonds” seeks private donors for outstanding research projects that are not (yet) supported elsewhere. For example a project from Empa’s Surface Science and Coating Technologies laboratory: With the support of the Helmut Fischer and Anni Walther Foundation the researchers aim to accelerate the development of multifunctional thin films, which could be applied in electronic devices or high-performance optics.

Text: Lars Sommerhäuser, Sebastian Siol

Experiments in ultra-high vacuum deposition systems are often time-consuming and expensive. But what if, instead of 50 experiments, you only had to perform one – and yet still got 50 different material samples? And what if you could automate the characterization of these samples and have the results immediately available for evaluation in a database?

EFFICIENT
Sebastian Siol tests 45 different material samples in one go.

The Coating Technologies Group around Sebastian Siol is pondering these very questions. The answer is obvious: It would be possible to develop novel thin film materials and coatings much faster. For a few years now, Siol’s group has been building the infrastructure to make this dream a reality. In a project funded by the Helmut Fischer and Anni Walther Foundation, this technology is now being further expanded and used for the development of multifunctional ceramic thin films.

The “Empa Zukunftsfonds”, Empa’s fundraising unit, established a first contact with the foundation, which shares the interest in research on multifunctional coatings: The donor has been developing intelligent solutions in the field of film thickness measurements on different materials for 70 years. The foundation therefore agreed to finance a dissertation on this topic and also to expand the group’s infrastructure for automatic characterization to include a hardness tester for thin films.

Research into multifunctional thin films is highly complex and time-consuming, as coatings today have to meet increasingly stringent requirements. At the same time, the number of layers is to be reduced. To achieve this, researchers often have to simultaneously optimize several properties that are difficult to combine, for example in coatings with high hardness and low reflection.

But back to Sebastian Siol’s dream. Through so-called combinatorial thin film development, his team fabricates layers with controlled gradients using special deposition processes. In this way, large parameter ranges are covered in a single experiment, for example with regard to processing temperature or chemical composition. The resulting layers are subsequently analyzed automatically.

Accelerating research by this kind of high-throughput technologies are key to future materials development. Computers are now predicting new materials with promising properties at an ever increasing rate. However, it is challenging to fabricate and study each one individually. A comprehensive infrastructure for combinatorial materials development could speed up this process significantly. Thanks to funding from the Helmut Fischer and Anni Walther Foundation, the Empa team is a big step closer to this ambitious goal. ■

Further information on the topic is available at:
www.empa.ch/web/s208

Photo: Empa

TRANSLUCENT BRICKS

Glass bricks have long been popular in architecture for bringing more light into buildings. Until now, however, they have not been suitable for load-bearing walls and have not insulated well. An Empa team has now developed a translucent glass brick with good insulation properties thanks to aerogel, which can even be used for load-bearing elements. This makes it possible to build aesthetic, translucent walls that reduce the need for artificial lighting inside the building.

Text: Remigius Nideröst

Glazed construction elements are a popular method in architecture for letting light into a building. This allows for better use of environmentally friendly daylight, and less artificial lighting is needed. To maximize this advantage, however, the glass elements should preferably be used to construct entire walls for the building envelope, which requires that the elements have effective thermal insulation and can bear a certain load – a combination that has not been available on the market in this way until now.

BOTH REQUIREMENTS MET: HIGHLY INSULATING AND TRANSLUCENT

Silica aerogels are high-performance thermal insulation materials that are becoming increasingly popular in the construction sector. The most common are opaque insulating mats and plasters. Back in 2017, Empa researcher Jannis Wernery and his colleagues from the Building Energy Materials and Components department had the idea of integrating the insulating material directly into a building brick and presented a new type of brick filled with aerogel, the so-called "Aerobrick". Thanks to its excellent thermal insulation, this brick saves heating costs – without the need for an additional insulation layer applied to the masonry.

However, aerogel can also be virtually transparent, which makes for a translucent, insulating building system. To take advantage of this and further improve the insulating performance of the "Aerobrick", Wernery, Michal Ganobjak and Co. developed a novel modular component based on float glass and silica aerogel granules that combines both properties – it is translucent and insulating: the aerogel glass brick.

The glass bricks filled with translucent aerogel granules allow the construction of aesthetically pleasing and even load-bearing façade elements that enable a significant amount of daylight to enter. The Empa researchers achieved this combination of strength, insulation and light transmission by using offset spacers between the glass panes within the glass brick, which ensure static stability with minimal heat transmission.

The glass brick has a measured thermal conductivity of 53 mW/(m·K) and a compressive strength of nearly 45 MPa. This is the highest insulating performance of any brick found in the technical literature, let alone on the market. Additionally, it comes with the property of light transmission.

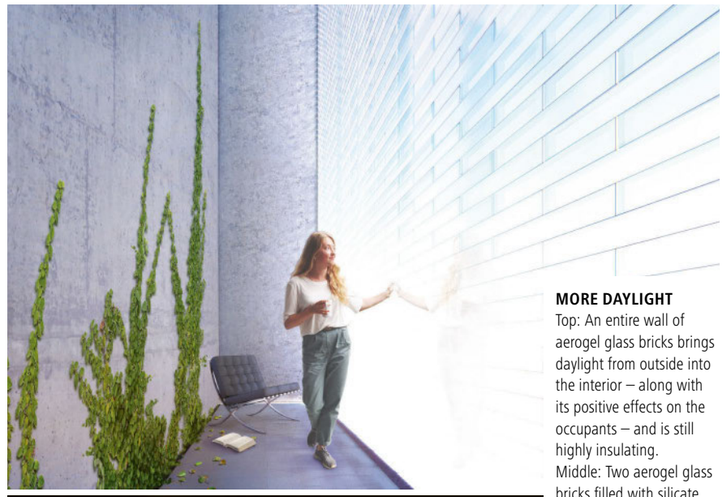
MULTIPLE APPLICATIONS IN VIEW

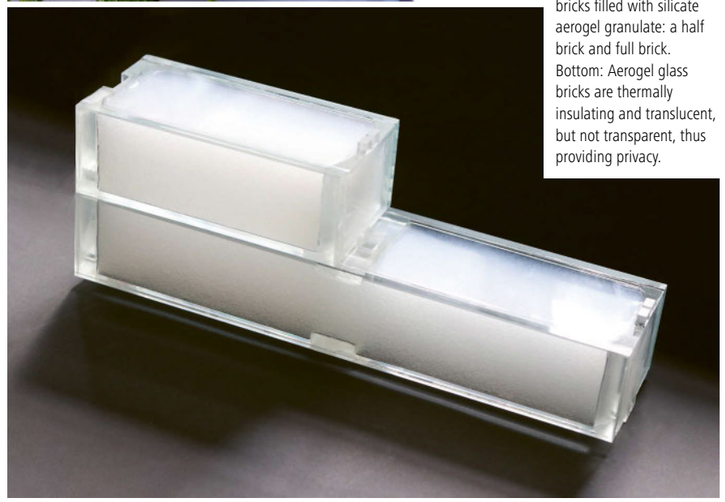
The aerogel glass brick is suitable for applications in which there are simultaneous requirements for high daylight penetration, glare protection and privacy protection, such as in offices, libraries and museums. An important aspect is that a building envelope made of such glass bricks couples the inside of the building with the outside in terms of daylight. This can have a positive effect on the circadian rhythm of the building users. Possible applications include

- Rooms that should not have a line of sight to the outside, for example for reasons of privacy, security or to avoid disturbances, but should still allow diffuse daylight into the interior, such as libraries, galleries, museums, foyers, offices, stairwell cores, gymnasiums, multi-purpose halls, residential buildings or art workshops
- Spaces where daylight is necessary for a healthy circadian rhythm, such as dormitories, hospitals and sanatoriums, as well as zoos, stables and animal breeding facilities, and even greenhouses
- Places where maximum daylight is to be brought in and space is to be saved, such as in densely built-up urban quarters with high-rise buildings and many city apartments
- Architectural elements such as Trombe walls in solar architecture, courtyards or atriums that generate heat from infrared radiation from sunlight

An analysis of material costs shows that the insulating glass brick can be quite competitive in such applications. The glass brick thus offers architecture new design possibilities for more daylight in buildings – both for new buildings and renovations. The researchers have now filed a patent application for the aerogel glass brick and are looking for potential industrial partners.

The project is supported by the Velux Stiftung, Project No. 1,440 for the development of a highly insulating translucent glass brick for diffusive daylighting. The project idea was developed with support from the Horizon 2020 Research and Innovation Program of the European Union under the Marie Skłodowska-Curie Actions, contract number 746,992. ■





MORE DAYLIGHT
Top: An entire wall of aerogel glass bricks brings daylight from outside into the interior – along with its positive effects on the occupants – and is still highly insulating.
Middle: Two aerogel glass bricks filled with silicate aerogel granulate: a half brick and full brick.
Bottom: Aerogel glass bricks are thermally insulating and translucent, but not transparent, thus providing privacy.

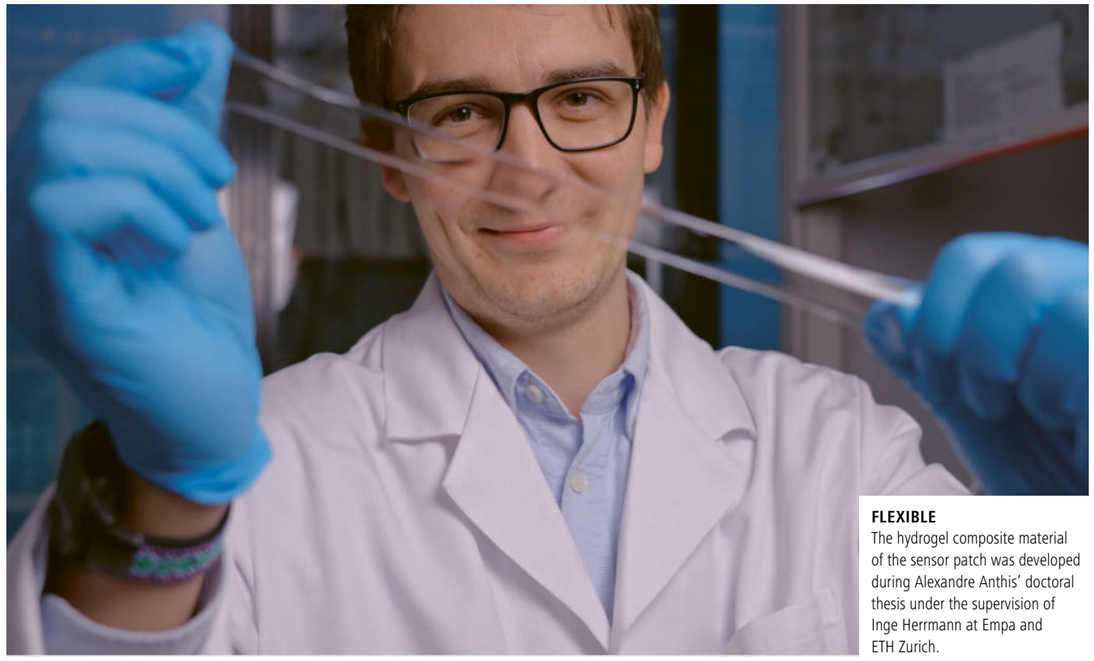
Photos: Empa

Further information on the topic is available at: www.empa.ch/web/s312

A "SPY" IN THE BELLY

To ensure that wounds in the abdominal cavity remain tightly closed after an operation, researchers at Empa and ETH Zurich have developed a patch with sensors. The polymer patch reports dangerous leaks at sutures in the gastrointestinal tract and closes the sites automatically. The team recently published their findings in Nature Communications.

Text: Andrea Six



FLEXIBLE
The hydrogel composite material of the sensor patch was developed during Alexandre Anthis' doctoral thesis under the supervision of Inge Herrmann at Empa and ETH Zurich.

Photos: Empa

After an operation in the abdominal cavity, there is one special concern: leaks at the sutures where the contents of the digestive tract could escape into the abdominal cavity. "Even today, such leaks represent a life-threatening complication," explains Empa researcher Inge Herrmann, who also holds the professorship for Nanoparticular Systems at ETH Zurich. The idea of sealing sutured tissue in the abdominal cavity with a patch is not new. The problem, though, is that clinical success varies depending on the particular tissue that is stuck together. This is because the plasters, which are made of protein-containing material, dissolve too quickly when they come into contact with digestive juices. As part of a long-term collaboration, Inge Herrmann and Andrea Schlegel, a surgeon at the University Hospital Birmingham, therefore pursued the idea of developing a resistant intestinal patch that can indicate leaks at an early stage using sensors.

TEACHING THE PATCH TO "SEE"

The team led by Herrmann and Alexandre Anthis from Empa's Particles-Biology Interactions laboratory in St. Gallen and ETH Zurich's Nanoparticle Systems Engineering laboratory first developed a hydrogel polymer patch that prevents highly acidic digestive juices and germ-laden food residues from escaping from the intestinal tract and causing peritonitis or even life-threatening sepsis.

But the researchers wanted to go one step further: "Surgeons told us that although they do have a close eye on the surgical area during the operation, however complicated it may be – once the abdominal cavity is closed, they are 'blind' and may not notice leaks until it is too late," says Anthis. So to help the hydrogel patch learn to "see," the team worked with hospitals in Switzerland and international research partners to develop a solution: The patch was equipped with sensors. The researchers recently reported on this novel technology in the renowned journal Nature Communications.

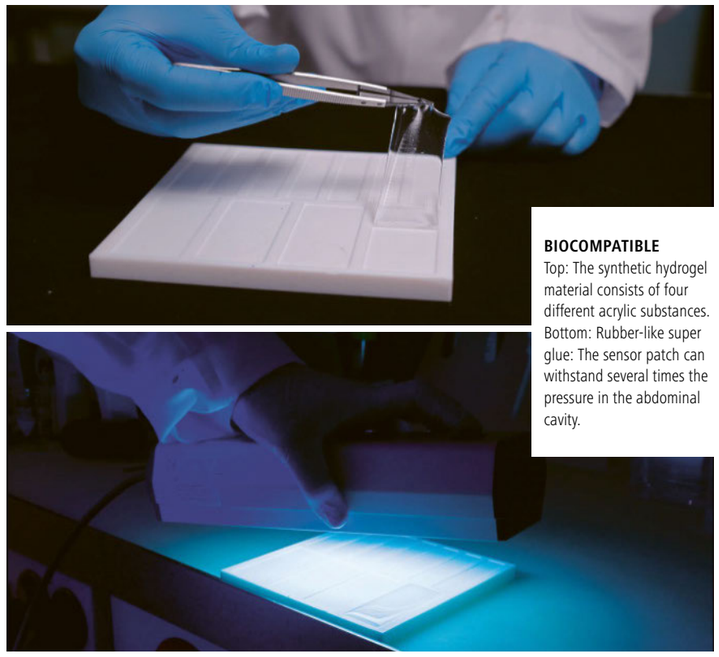
BIOCOMPATIBLE SUPER GLUE

The novel material achieves its ability to "see" by reacting sensitively to changes in pH and to the presence of certain proteins in the vicinity of the wound. Depending on the location of the leak, the reaction takes place within minutes or a few hours. Until now, healthcare professionals had to rely on a physiological reaction of the patient or lab tests that occur much later – both of which may provide a clear indication of a leaking seam way too late.

The sensor patch, on the other hand, makes it possible to detect digestive fluid leaking from a wound due to its composite structure. For instance, acidic gastric juices react with the sensor material, causing minute gas bubbles to appear in the matrix of the patch. The bubbles can then be visualized using ultrasound. "The patches can be equipped with customized sensors for different locations in the digestive tract," Anthis explains. Furthermore, the patch can even release drugs, such as antibacterial agents, if needed.

In addition, the material achieves the necessary properties for wound closure: a stable bond to the mucosa, the formation of networks, stability to digestive juices and waterproofness. In this way, the low-cost, biocompatible super-adhesive, which consists largely of water, could not only reduce the risk of complications after abdominal surgery, but also shorten hospital stays and thus reduce healthcare costs. "The intestinal patch project is already attracting a great deal of interest from the medical community," Herrmann reports.

Now, she says, the task is to drive the application of the clinically relevant innovation in practice. ■



BIOCOMPATIBLE
Top: The synthetic hydrogel material consists of four different acrylic substances. Bottom: Rubber-like super glue: The sensor patch can withstand several times the pressure in the abdominal cavity.

AWARDED YOUNG RESEARCHER

The research team is currently founding the start-up company Veltist. As a spin-off of ETH Zurich and Empa, the future biomed company aims to develop and bring to market materials that will contribute to optimal wound closure and improved healing in surgery, thus helping to avoid the dreaded complications of sepsis or peritonitis. In addition to the MaP 2022 Award from ETH Zurich for the best dissertation in the field of Materials and Processes, Alexandre Anthis also received one of the coveted ETH Pioneer Fellowships as well as the Empa Research Award 2021.

Further information on the topic is available at:
www.empa.ch/web/s403

DISTINGUISHED VISITORS FROM KOREA

WELCOME
Empa Directorate member Pierangelo Gröning welcomes Jong-Ho Lee at Empa.

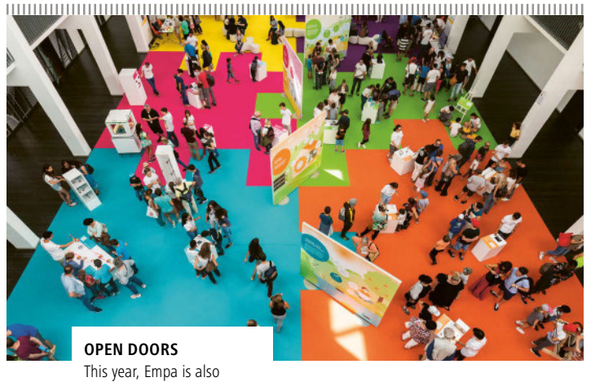
The Korean Minister of Science and ICT, Jong-Ho Lee, visited Empa in January 2023, accompanied by representatives from his ministry and from various Korean research institutions. Empa Directorate member Pierangelo Gröning welcomed the delegation and spoke with the guests about the potential of novel materials and increased cooperation between Switzerland and Korea. The visit also included lab tours, for example at the Laboratory for Joining Technologies and Corrosion led by Lars Jeurgens.

www.empa.ch/web/empa/general-management

EMPA VISITS LAUSANNE

On 29/30 April, the "Portes ouvertes" will take place at EPFL. Empa, as a research institute of the ETH Domain, will be present at the open lab days in Lausanne with several research topics. In lectures, demonstrators and at exhibition stands, Empa researchers will be showing solar cells of the future, environmentally friendly electronics, Advanced Manufacturing technologies and new approaches to reducing noise pollution from rail and air traffic, among other things.

www.epfl.ch/campus/events/fr/evenements/evenements-publics/portes-ouvertes



OPEN DOORS
This year, Empa is also represented at EPFL's "Portes ouvertes".

Photos: Empa, Jamani Caillet EPFL

EMPA AT THE POWERFUEL WEEK

INTERFACE
Christian Bach at the Powerfuel Conference 2022

A secure energy supply, clean mobility and industrial applications thanks to hydrogen technologies and synfuels: This is the motto of the Powerfuel Week 2023, which will take place from 13 to 21 May at the Swiss Museum of Transport in Lucerne. The event is conference, trade fair and exhibition all in one and aims to communicate and promote innovative technologies at the interface between research, industry and politics. As a member of the advisory board Empa supports the implementation of the Powerfuel Week, among other things, by providing advice and expertise. In addition, Empa researcher Christian Bach, head of Empa's Automotive Powertrain Technologies lab, will speak at the Powerfuel Conference on May 16 about the current state of research on synthetic fuels.

powerfuel.ch

FIRST SME INNOVATION DAY IN ZURICH

KICK-OFF
Carmen Walker Späh starts the event.

On 30 March, the first Zurich SME Innovation Day took place at the Innovation Park Zurich in Dübendorf. The keynote speeches, workshops and discussions revolved around topics such as digitalization and sustainability as well as innovation promotion and technology transfer. Empa was represented with an info booth. NEST Managing Director Reto Largo and Markus Kasper from Empa's technology transfer team talked to participants about how to transfer new knowledge from research to industry as efficiently and fast as possible.

kmu-innovation.zuerich/anlaesse/zuercher-kmu-innovationstag

Photos: Quade & Zurfluh AG, Alessandro Della Bella

EVENTS
(IN GERMAN AND ENGLISH)

11. MAI 2023
Workshop: Introducing Empa's Virtual Lab
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/virtual-lab
Empa, St. Gallen

15. MAI 2023
Topical Day: Imaging and Image Analysis XIV
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/imaging
Empa, Dübendorf

22. – 26. MAI 2023
Konferenz: 38th International Conference of the Polymer Processing Society
Zielpublikum: Wissenschaft und Industrie
www.pps-38.org
Empa, St. Gallen

31. MAI – 02. JUNI 2023
Konferenz: 2nd Aerogel Industry-Academia Forum
Zielpublikum: Industrie und Wissenschaft
aia-forum.empa.ch
Empa, Dübendorf

14. JUNI 2023
Symposium: 1st Swiss Symposium on Materials Chemistry 2023
Zielpublikum: Wissenschaft
matchem23.scg.ch
Empa, Dübendorf

14. JULI 2023
Technology Briefing: Einsatz von Laubholz im Tragwerksbau – Chancen und Herausforderungen
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/technology
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Details and further events at: www.empa-akademie.ch

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