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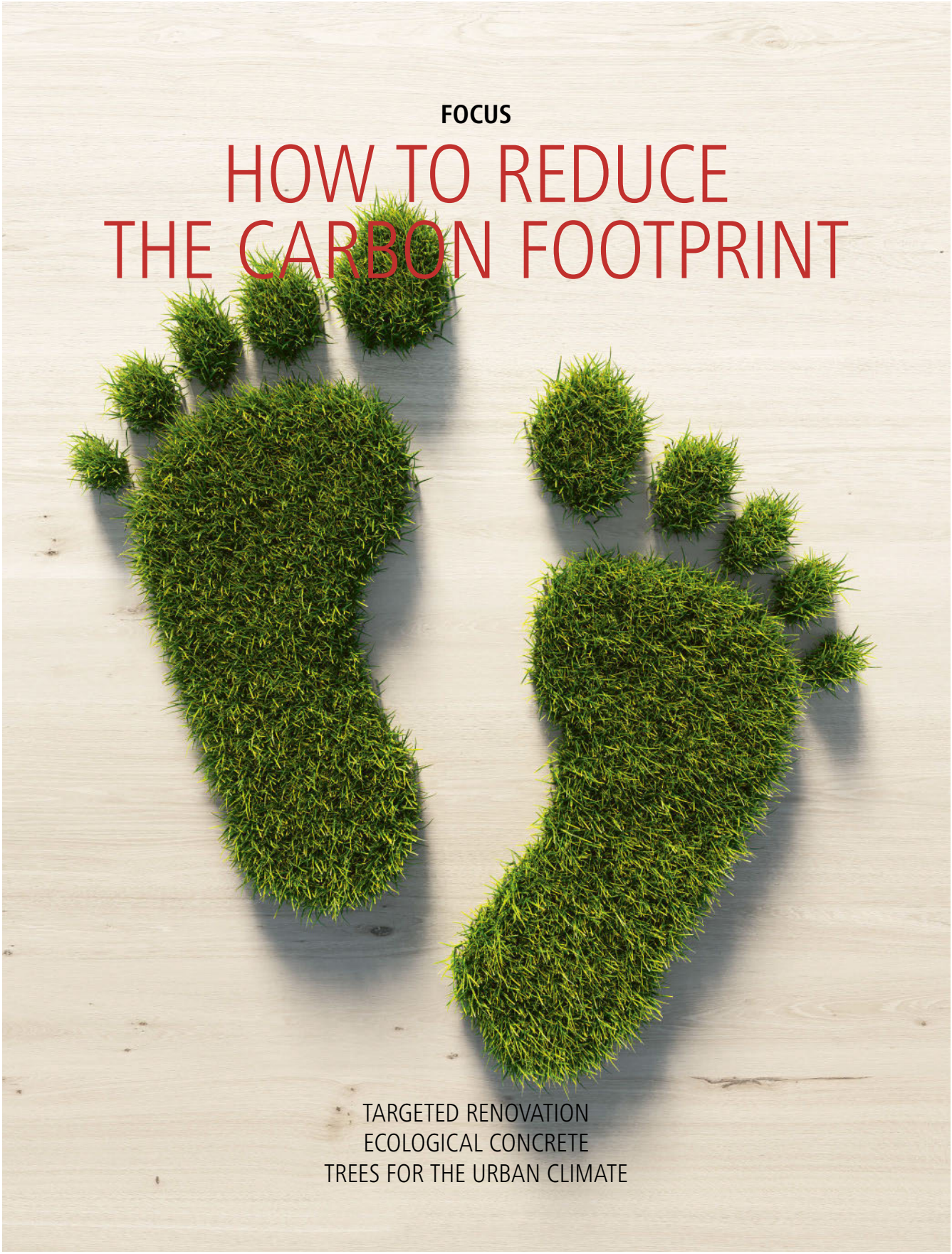

FOCUS

HOW TO REDUCE THE CARBON FOOTPRINT

TARGETED RENOVATION
ECOLOGICAL CONCRETE
TREES FOR THE URBAN CLIMATE

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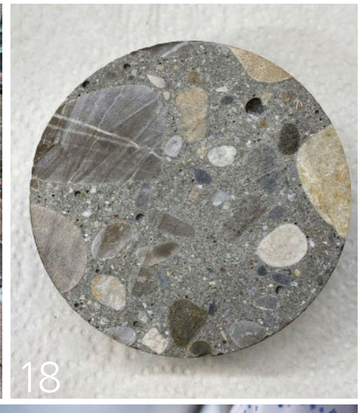
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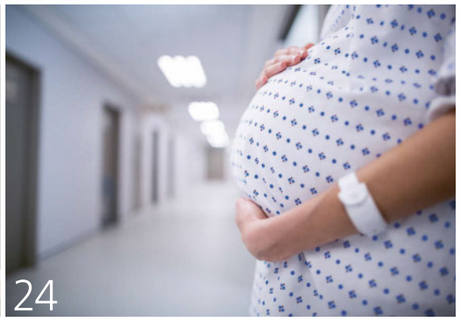
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Reducing the ecological footprint is a goal of numerous Empa research activities.
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OUR FOOTPRINT IS TOO LARGE

Dear reader,

In this issue, we want to take a look at how we can reduce our environmental footprint in various areas. Whether through sophisticated heating and cooling systems that consume considerably less energy thanks to artificial intelligence, innovative building refurbishment or novel cement formulations that cause significantly lower CO_2 emissions. Or is streaming the new way of flying? We have answers to these questions as well.

Because one thing is clear: we cannot go on like this. We simply consume more natural resources than our planet can provide. A glance at the development of Earth Overshoot Day, the day in the year when the demand for certain raw materials exceeds the Earth's capacity to "recharge" its reserves, shows this. In 1970, this day was the end of December – in other words, humans con-sumed globally exactly as much as we "should" have – but this year it was already reached on July 29. So we would need around 1.75 earths to cover our consumption.

And that only if we take global average consumption as a basis. If all inhabitants of the earth would consume as much as Mr. and Mrs. Switzerland, then the end of the rope would already be reached on May 7. So in this country we live as if we had three earths. But we have not. One key to the solution is certainly more efficient, cleaner technologies. Another, perhaps, may be with ourselves.

Your MICHAEL HAGMANN

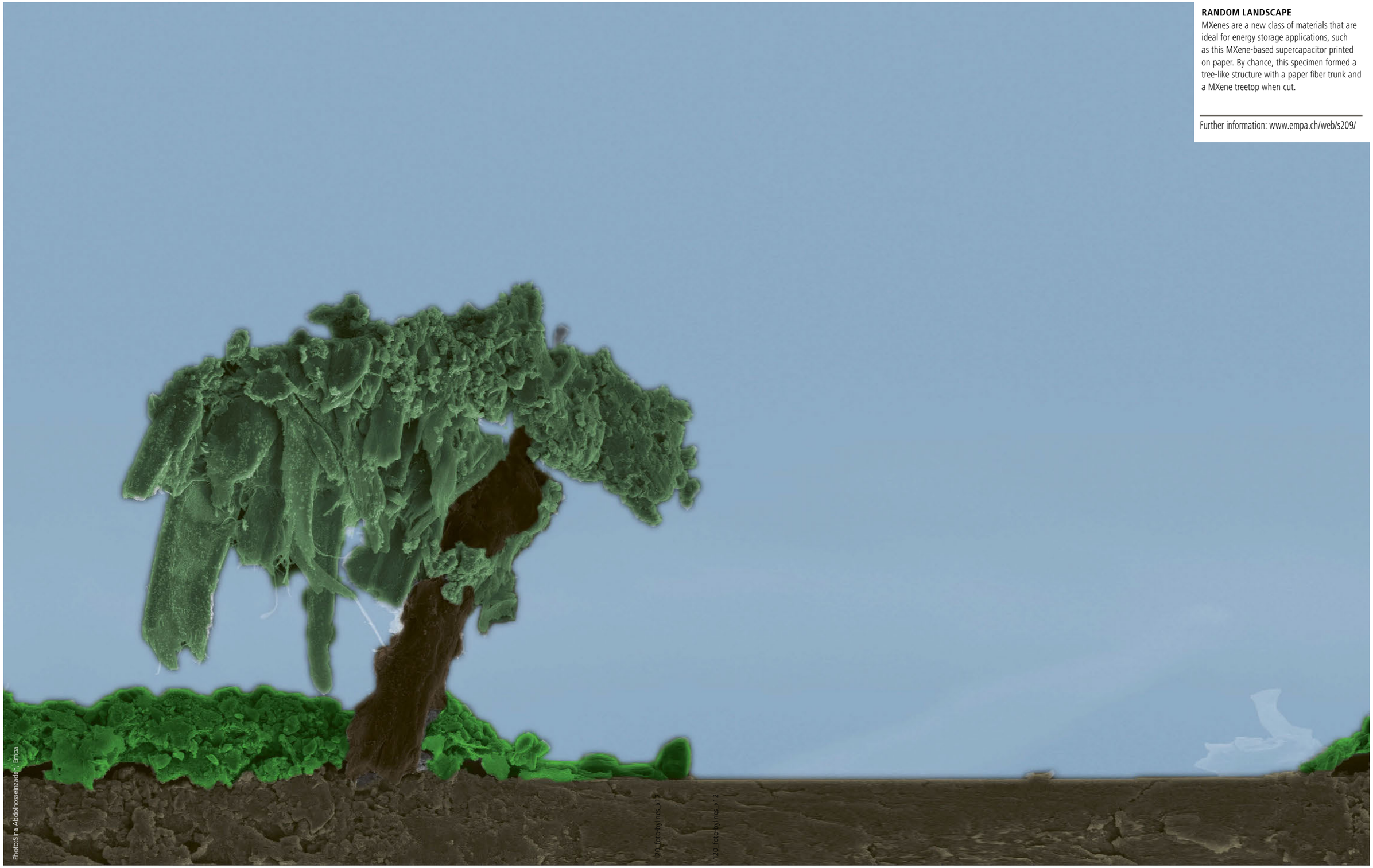


Photo: Sina Abdolhosseinzadeh, Empa

RANDOM LANDSCAPE
MXenes are a new class of materials that are ideal for energy storage applications, such as this MXene-based supercapacitor printed on paper. By chance, this specimen formed a tree-like structure with a paper fiber trunk and a MXene treetop when cut.

Further information: www.empa.ch/web/s209/

THE PATH TO AN ENERGY-EFFICIENT BUILDING PARK

Heating, hot water and private electricity consumption consume large amounts of energy and cause high CO_2 emissions. Energy-efficient renovations of buildings can reduce this consumption – but how is the money best used for which type of building? Empa researchers have investigated this question.

Text: Karin Weinmann

Buildings in Switzerland consume around 40% of the final energy. Heat generation accounts for the lion's share of this. This is not good news for the climate: almost two-thirds of all buildings in Switzerland are heated with oil or gas – making Switzerland the leading country in Europe. Heating alone caused CO_2 emissions of around 15.8 million tonnes in 2018. The good news is that there is huge potential to reduce these emissions without sacrificing living comfort – the magic word is energy-efficient renovation.

The differences in how much energy a building consumes are immense: a poorly insulated building can consume up to 300 kWh per square meter per year, while a building built according to the Minergie standard requires no more than a tenth of that. So renovation it is – but what first? A 1990 renovated apartment building from the 1920s? Or do you prefer the single-family house built in 1975 and still in "original condition"? And ideally, which measure should the money be invested in to achieve the greatest effect: renewing the roof? Insulate the walls? Replace the oil heating with a newer model – or even install a new, more efficient heating system? Replace the electrical appliances? Or would solar panels on the roof be the best option?

There are many possibilities, and the means are usually limited. Also from an economic point of view, it does not make much sense to bring a building that already has good values even closer to the optimum at great expense – while an old building could be made massively more efficient for the same amount. Empa researchers from the "Urban Energy Systems" department headed by Kristina Orehounig have taken a close look at Switzerland's existing buildings in order to find practical answers to these questions. The aim is to identify those measures which, with the optimum use of resources, can avoid as much CO_2 emissions as possible.

ARCHETYPAL BUILDINGS

For their calculations, the researchers grouped Switzerland's buildings into different clusters: by construction period, building type, number of residential or working units and number of floors. They also take into account regional differences – such as solar potential or the need for heating days. This resulted in a set of 1000 archetypal residential buildings – 500 single-family homes and 500 multi-family homes. The data show that the majority of these buildings were built between 1959 and 1994 – and that over 75% use an electric or fossil fuel-fired

RENOVATING
Existing houses can become massively more energy-efficient through renovation.

COSY WARMTH
An important step: moving away from fossil heating systems

Photos: iStock

boiler. For the commercial buildings, a smaller set of archetypes was identified, 45 in all: nine restaurants, schools, hospitals, office buildings and shops each.

The second step was to identify possible measures to avoid greenhouse gas emissions. These include refurbishment of the building envelope, such as additional insulation of roofs, walls and floors, or replacement of windows and doors. Other possibilities are to use more efficient technol-ogies – such as heat pumps – or to use renewable energy, for example by using solar thermal energy, photovoltaics or biomass boilers.

OPTIMUM SOLUTIONS BY YEAR OF CONSTRUCTION

Switzerland has committed itself to reducing its greenhouse gas emissions to a quarter of today's level by 2050. To achieve this goal, according to the Swiss Association of Engineers and Architects (SIA) Energy Efficiency Trail, emissions from the construction and operation of renovated buildings would have to be reduced to 10 kg CO_2 equivalents per square metre per year. Empa researchers used this figure as a basis for calculating how this could be achieved as cost-effectively as possible. Calculated across all building types, this figure is CHF 384 per tonne of CO_2 avoided. However, there are major differences between the individual building types: the most CO_2 per Swiss franc used can be saved by renovating apartment buildings, followed by schools and office buildings.

But which measures are typically necessary for which building category to achieve the targeted CO_2 target? One thing quickly becomes clear: houses that run on electric, oil or gas heating have almost no chance of achieving these values, even if the entire building envelope is optimally renovated. District heating, biomass heating or heat pumps, combined with solar panels and storage solutions, are necessary for almost every year of construction in order to reduce CO_2 emissions to a low level. Only for buildings constructed after 2010, there are exceptions that achieve sufficiently low values even with gas or oil heating.

Once the energy system has been optimised, the next step is to look at the building envelope. The majority of buildings built since 1995 do not require additional insulation. Even with older construction years, it is by no means always necessary to renovate the entire envelope – even in the case of buildings with the worst values from the years 1919 to 1948, this only affects just under one fifth. In around 60% of buildings from this period, it is sufficient to insulate walls and windows better. For buildings from the following period (up to 1979), the most necessary refurbishment is the roof.

If we go one step further and look at all the residential buildings over all the years, there are six measures with which two thirds of the houses could reach the limit of 10 kg CO_2 per square metre and year: Insulate the roof or façade and replace windows, and install photovoltaic systems combined with storage tanks. As far as heating systems are concerned, it is becoming apparent that biomass heating systems or heat pumps are most efficient.

SOLUTIONS AT DISTRICT LEVEL

In a next step, the researchers considered not only the individual buildings, but also district heating in their calculations. While fossil-based district heating systems are usually the most cost-effective solution, they are increasingly being replaced by more CO_2-friendly solutions such as waste heat utilisation, heat pumps or biomass boilers. There are significant differences between rural and urban regions. In urban areas, where the distances between buildings are typically short, district heating systems are a cost-effective way to meet CO_2 emission targets. On the land, building level solutions are preferable.

> "Six measures are enough to achieve the efficiency targets for most buildings"

Overall, the Empa researchers conclude, the potential is indeed enormous: if the proposed measures were scaled up to the entire Swiss building stock, emissions could be reduced by up to 80%, depending on the type of building. The Swiss building sector can therefore make a significant contribution to improving the country's sustainability. ■

Further information on the topic is available at:
www.empa.ch/web/s313

Graphics: Hug & Dorfmüller Design AG

TEST SUBJECT
The "Urban Mining and Recycling" unit in the NEST research building has two student rooms. One of them was equipped with a self-learning heating and cooling control system.

Photo: Zooey-Braun, Stuttgart, Empa

SMART HEAT

Can buildings learn to save all by themselves? Empa researchers think so. In their experiments, they fed a new self-learning heating control system with temperature data from the previous year and the current weather forecast. The "smart" control system was then able to assess the building's behavior and act with good anticipation. The result: greater comfort, lower energy costs.

Text: Rainer Klose

Factory halls, airport terminals and high-rise office buildings are often equipped with automated "anticipatory" heating systems. These work with pre-defined scenarios specially calculated for the building and help save building owners a great deal of heating energy. However, such an individual programming is too expensive for individual apartments and private homes.

Last summer, a group of Empa researchers proved for the first time that it could indeed be much simpler than that: Intelligent heating and cooling control does not necessarily have to be programmed, the system can just as easily learn to reduce costs by itself and based on the data of past weeks and months. Programming experts are no longer necessary. With this trick, the cost-saving technology will soon also be available for families and singles.

The crucial experiment took place in Empa's research building NEST. The UMAR unit ("Urban Mining and Recycling") offers prime conditions for this test: A large eat-in kitchen is framed on both sides by two student rooms. Both rooms are 18 square meters each. The entire window front looks east-southeast towards the morning sun. In the UMAR unit, heated or pre-cooled water flows through a stainless steel ceiling cladding and ensures the desired room temperature. The energy used for heating and cooling can be calculated for each individual room using the respective valve positions.

CLEVER COOLING – THANKS TO THE WEATHER FORECAST

Since project leader Felix Bünning and his colleague Benjamin Huber did not want to wait for the heating period, they started a cooling experiment in June 2019. The week from 20 to 26 June began with two sunny, but still rather cool days, followed by a cloudy day, finally the sun burned over Dübendorf and drove the outside temperature to just short of 40 degrees.

In the two sleeping rooms, the temperature should not exceed the mark of 25 degrees during the day, at night the limit is set to 23 degrees. A conventional thermostatic valve provided the cooling in one room. In the other room, the experimental control system equipped with artificial intelligence (AI) developed by Bünning and Huber and their team was at work. The AI had been fed with data from the past ten months – and it knew the current weather forecast from MeteoSwiss.

GREATER COMFORT WITH LESS ENERGY

The result was crystal-clear: The smart heating and cooling control system adhered much more closely to the preset comfort specifications – while using around 25% less energy. This was mainly because in the morning, when the sun was shining through the windows, the system was cooling the rooms beforehand. The conventional thermostat in the second room, on the other hand, could only react once the temperature went through the ceiling. Too late, too hectic and with full power. In November 2019, a cool month with little sun, lots of rain and cool winds, Bünning and Huber repeated the experiment. Now it was all about heating the two rooms. At the time this issue went to press, the evaluation was still in progress. But Bünning is convinced that his predictive heating control system also collects points here.

The Empa team has already prepared the next step: "In order to test the system in a real-world environment, we have planned a larger field test in a building with 60 apartments. We will equip four of these apartments with our intelligent heating and cooling control system". Bünning is curious about the results. "I think that new controllers based on machine learning offer a huge opportunity. With this method we can construct a good, energy-saving retrofit solution for existing heating systems using relatively simple means and the recorded data." ■

Further information on the topic:
www.empa.ch/web/energy-hub

COZY WARMTH
Conventional thermostats only switch on when it gets cooler. The intelligent controller can heat with foresight and thus saves energy.

Photos: iStock

IS STREAMING THE NEW FLYING?

Streaming consumes enormous amounts of energy and is at least as damaging to the climate as all civil aviation – according to a French study. It is generally underestimated what electronic devices – apart from electricity consumption – actually cause in terms of emissions. But how harmful is our digital consumption really for the environment? Lorenz Hilty, head of the Computer Science and Sustainability Research Group at Empa and the University of Zurich, explains.

Text: Cornelia Zogg

STREAMING
The world's population streams more than a billion hours a day on YouTube alone. This causes a lot of CO_2.

Photo: iStock

By 2050, the federal government wants to reduce per capita CO_2 emissions to 1.5 tons per year. A challenging goal. Because everything we use consumes energy - even if it's less visible than when refuelling our car or air travel, an issue that is strongly represented in the media. The steak that lands on the plate, the heating that keeps our feet warm in winter, or even "bingewatching" on Netflix on a rainy Sunday – everything has its price in the form of CO_2 emissions. Streaming in particular is becoming increasingly discredited. According to the think tank "The Shift Project", our streaming behavior is just as harmful as civil aviation. Should we all get off our screens now?

> "The transmission of a video stream is usually no more energy consuming than illuminating a room"

"That's definitely not necessary," says Lorenz Hilty. Although streaming is the most energy-intensive thing you can do on the Internet, the transmission of a video stream usually generates no more emissions than illuminating a room. An hour of streaming on a flat-screen TV produces 150 grams of CO_2, including data transfer.

THE SUM MAKES THE DIFFERENCE

Considering how much is streamed worldwide, however, the energy consumption is considerable. On YouTube alone, one billion hours of videos are watched every day. According to a study by the University of Bristol, YouTube's global CO_2 emissions are therefore roughly equivalent to those of the city of Glasgow. However, it should also be noted that the benefits are spread across a large part of the world's population: "57 percent of all people today have access to the Internet. 34 percent have a smartphone. But only 3 percent of the world's population can afford to fly at least once a year," says Hilty.

For Hilty, not only consumers are responsible, but also streaming providers. The fact that YouTube continues to transmit music as a video stream, for example, ensures unnecessary data transfer. Similarly, the trend away from the conventional broadcast principle of television (many viewers watch the same programme simultaneously) towards the unicast principle (the data is transmitted individually for each person, i.e. as with Netflix) is responsible for a major leap in the energy consumption of film consumption. And mobile Internet access also costs more energy than stationary Internet access.

DIGITAL IS NOT EQUAL TO ECOLOGICAL

Thus digital sometimes does not mean ecological. According to a study by the Royal Institute of Technology in Sweden, a printed book generates 1.2 kilograms of CO_2. An eBook reader, on the other hand, requires 30 to 40 times as much to produce. Only when you have read 35 eBooks on the reader does it begin to pay off for the climate. In general, software is still a scientifically hardly investigated area with regard to the emissions caused. Hilty also wants to shed light on this. Together with foreign partners, he has developed criteria on behalf of the German Federal Environment Agency (UBA) to assess the sustainability of software products. "The issue was how much energy the software consumes in the end device, but also the transmission of data and servers," says Hilty. Further criteria concern the hardware capacities that have to be kept available for the operation of a software product – and how often they have to be replaced and extended because new versions of the software place higher demands on the hardware. In the case of smartphones and laptops, for example, the production of the hardware causes a greater environmental impact than the power consumption during operation of the devices. The Federal Environment Agency is currently working on using the criteria developed in the study to award sustainable software products the "Blue Angel" eco-label.

RAISING AWARENESS

Sitting in an airplane is still the most CO_2-intensive way to spend time. A single flight from Zurich to New York and back already emits 2.5 tons of CO_2 per passenger, significantly more than the targeted per capita emissions budget for an entire year. According to Hilty, it is therefore not appropriate to introduce regulations for streaming on the Internet. "It's not regulated how long you can keep the light on either." Nevertheless, it would not do any harm if the population were to develop an awareness of how much energy is consumed and where it can be saved. Because CO_2 traps often hide in everyday situations that we hardly notice cause emissions because they happen in distant places. The use of the Internet is one of them. ■

Further information on the topic:
www.empa.ch/web/s506/informatics-and-sustainability-research-isr

1.5 tons of CO_2 – what does that mean?

The Swiss Federal Government wants to limit annual emissions to 1.5 tonnes of CO_2 per person. This quota includes not only private consumption but also all emissions from the production and maintenance of goods. There is not much left! But what do 1.5 tonnes of CO_2 emissions mean for a private individual?

Heating a
20 m²
apartment in an old building or
125 m²
in a house with Minergie standard for one year

8'300 km
driving with an average passenger car

10'000 hours
video streaming

214'300 km
travel by train (5 × around the world)

500 × showers
(approx. 4 minutes per shower)

9'000 km
international flight
e.g. Zurich - Bangkok (single, Economy)

150 kg
of beef
(which is 3 × average annual consumption in Switzerland)

Numbers: FOEN, Swiss Energy Foundation, Empa/UZH

Graphics: Hug & Dorfmüller Design AG

EVERY TREE COUNTS

Is it possible to create cool zones in cities to tackle the more pronounced heat island effects due to climate change? Empa researchers have developed a simulation program that can make detailed predictions about which pavement and which type of vegetation could help. Using the Münsterplatz in Zurich as an example, they have run through such a model calculation.

Text: Rainer Klose

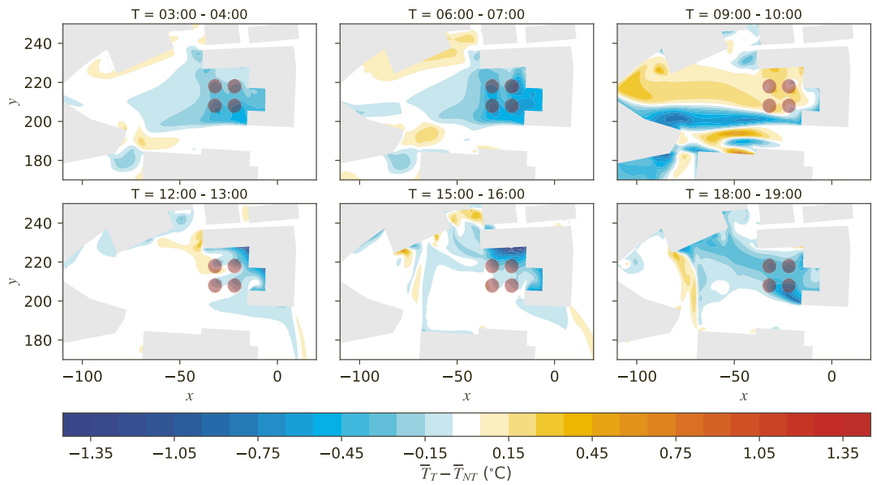
GREEN COOLING
The Münsterplatz in Zurich is a classic heat island. A green area such as the one shown here as part of an art project in the summer of 2019 could help.

Photo: Peter Baracchi

FOUR TREES
The simulation shows how a group of trees on the northeastern corner of Münsterplatz would change the air temperature at a height of two metres – compared to Münsterplatz without trees.

Top right:
In the brown areas the air gets warmer in the morning because the trees change the wind currents.

Bottom:
In the afternoon, the trees shade the facades of the houses and provide considerable cooling. In the evening, the whole square benefits from this cooling effect.



TEMPORARY OASIS
Thanks to soil and grass, the ground cools down more at night and stores less heat during the day.

The heat wave is coming, and it's caught us a couple of times. In the summer of 2015, for example, during the second warmest Swiss summer since weather recordings began. In the cities, the asphalt smoldered, and shadowless squares such as Zurich's Münsterhof became almost impassable.

How do we intend to organize the cooling of our cities in the next 100 years - if climate change starts to hit? Will a bit of city green suffice, distributed according to aesthetic taste? Or can it be a little more specific? Empa – known for its accuracy – has made its first calculations on the Münsterplatz in Zurich.

MAKING CLIMATE CHANGE MORE BEARABLE

Aytaç Kubilay works in the Laboratory of Multiscale Studies in Building Physics at Empa. The department's employees are experts in simulating heat flows in various dimensions - from individual pores in bricks, concrete walls or wood - to entire cities. It is quite clear that such a research group is also concerned with climate change and is considering strategies to make the coming warm period more bearable, especially in cities.

The Empa researcher has chosen Münsterplatz in Zurich's old town for his simulation. A large part of the square is covered with cobblestones, the edge of the Fraumünster church is concreted. There are some cafés and seating facilities, but there are no trees that would provide shade. In addition, the Münsterhof is surrounded by buildings on almost all sides. The facades heat up considerably due to the irradiation of the sun.

GARTENTOR'S ART ACTION

In the summer of 2019, the project of the artist Heinrich Gartentor of the Bernese Oberland showed just how much large part of the population are already longing for a green Münsterplatz. For four weeks, the square was covered by a rough meadow, which had been specially made for the project by a gardener in Aargau. In addition, there were two shady willows from the Baummuseum Rapperswil. Until the campaign ended on 17 September, the city received many inquiries as to whether the meadow could remain permanently installed on Münsterplatz.

Empa researcher Kubilay and his colleagues had nothing to do with Heinrich Gartentor's art action - even if their results point in the same direction. The researchers chose the site to carry out climate simulations that can also be applied to other places and cities. The calculations show that the temperatures on the Münsterhof would be significantly lower if the square was not paved but covered with earth and grass. Overnight, the ground would cool down more and store less heat during the day. The result would be significantly less heating of the surface.

HOW WILL THE COMFORT FACTOR CHANGE?

To find out how the assumed change would affect people, Empa researchers use the Universal Thermal Climate Index (UTCI). This index indicates how high the temperature actually perceived by passers-by is - it takes into account not only air temperature, but also humidity, surrounding surface temperatures, solar radiation and wind speed.

The UTCI is quite similar to the Celsius temperature scale: values from +38 to +46 mean "very strong heat stress", from +32 to +38 it means "strong heat stress", from +26 to +32 it means "medium heat stress", and in the UTCI range from +9 to +26 people feel most comfortable and feel "no temperature stress".

The result: even if only a quarter of the paved area at Münsterplatz were replaced by a different floor covering, the oven would be deactivated in summer. One possibility would be a pavement made of porous bricks, which could be watered and provide evaporative cooling. A grassy landscape would also help - even if it were not permanently wa-tered and dry out at times. The times of day at which the Münsterplatz UTCI index climbs above 32 ("severe heat stress"), would be significantly shorter with alternative floor covering.

PRESENCE OF TREES CREATES A COMPLETELY DIFFERENT CLIMATE

The result would be even clearer if trees were planted on Münsterplatz. Aytaç Kubilay and his colleague Lento Manickathan simulated with their software the effect of four narrow standing trees on the northeast side of the square. "The shade of the trees and at the same time their transpiration cooling would greatly reduce the heat stress," says Kubilay. The perceived temperature would drop by two degrees on large parts of the square. Where the house facades are in the shade, it can even be up to four degrees.

The trees can help cool down the square, but also change the wind-flow field. After the model calculations at Münsterplatz, they want to further refine their simulation in order to enable city planners to make detailed predictions on how climate change can be tackled. ■

Further information on the topic:
www.empa.ch/web/s305

Images: Empa, Peter Baracchi

A RECIPE FOR ECO-CONCRETE

Cement production has to drastically reduce its environmental footprint. Empa researchers are, therefore, working on alternative cement recipes that cause significantly fewer emissions or can even bind the greenhouse gas carbon dioxide.

Text: Andrea Six

IMPROVED CLIMATE BALANCE WANTED
If one ton of conventional cement is produced, around 700 kilograms of carbon dioxide will rise into the atmosphere.

Photo: iStock

It is the most widely used product in the world. Cement is indispensable yet its reputation has become quite tainted in the course of the ongoing climate debate. Mixed with water, sand and gravel, it results in concrete, on which our modern world is built. However, the frugal material is in the limelight primarily because of another property: The production of one ton of cement causes around 700 kg of carbon dioxide (CO_2) that is emitted in the atmosphere. This is less than in the case of, say, steel or aluminum production. But it's the sheer quantity that makes the difference. Every year, we produce around twelve cubic kilometers of concrete worldwide, a quantity that could completely fill Lake Lucerne – every year anew. And the trend is rising.

The share of global CO_2 emissions caused by the cement industry is currently around seven percent. However, this is likely to increase in future, as demand is growing in Asia and increasingly also in Africa, while production in Europe is more or less stable. So it is high time to look for a cement that offers people housing and infrastructure, but still takes environmental aspects into account and can be produced in line with our climate targets. The United Nations Environment Program (UNEP) also calls for the immediate development and use of new cement-based materials that are more climate-friendly and at the same time cost-effective. Empa researchers are thus working on alternative types of cement and concrete that produce less harmful greenhouse gas or can even bind CO_2.

"Cement is traditionally burnt in a rotary kiln at around 1450 degrees Celsius," says Empa researcher Frank Winnefeld from Empa's Concrete and Construction Chemistry lab. Although fossil fuels can be replaced by alternative energies, "with an average degree of substitution of 50 percent with today's technologies, the savings potential is already quite exhausted, at least in Europe," says Winnefeld. However, more energy could be saved by using raw materials that require a lower burning temperature. A promising candidate is CSA cement made from calcium sulfoaluminate. It requires a firing temperature that is 200 degrees lower and emits around 200 kg less CO_2 per ton of cement. But the reduction in greenhouse gas emissions is not only due to the lower firing temperature. A large proportion of the climate advantage of CSA cement is due to the lower amount of limestone in the raw material mix.

> "A CO_2-negative concrete would be a true climate friend."

HUGE DEMAND

Limestone is responsible for the bulk of CO_2 emissions through a chemical reaction during cement production. Thus, reducing the proportion of limestone is an interesting aspect in developing eco-cement. In addition to CSA cement, researchers look at substitute constituents that accumulate as waste materials in other industries.

CONCRETE AND CEMENT

Concrete production is responsible for around 6% of man-made CO_2 emissions globally, in Switzerland even for 9%. In the do-it-yourself sector, concrete is mixed using simple rules of thumb. For example, 300 kg of cement, 180 l of water and 1890 kg of aggregate produce a cubic metre of concrete. The CO_2 emission of the concrete comes largely from the cement content: cement must be burnt at 1450 degrees, whereby mineral-bound CO_2 dissolves from the limestone. Worldwide, 2.8 billion tonnes of cement are produced annually.

These include slag from blast furnaces used in the production of pig iron and fly ash left over from coal combustion. Both products can be mixed with cement to help reduce CO_2 emissions.

But these secondary raw materials cannot meet the industry's gigantic demand. Empa researchers are, therefore, breaking new ground and identifying branches of industry whose residues are still little used. "The metallurgical recovery of precious metals from electronic waste leaves a high-quality slag that can also be mixed with cement in powder form," explains Winnefeld. If the slag's heavy metal content complies with the legal standards, this cement could also be used in Switzerland. The good news is that the sediment of the "urban mine" from the remains of our disused mobile phones and computers will continue to grow in the future. According to Winnefeld, it is also possible to use mineral construction waste for cement admixtures.

The type of additives in cement could even be changed in such a way that the burning process could be completely eliminated. In so-called alkali-activated cement, the components such as slag, ash or calcined clay are animated to the desired chemical reaction by strong alkaline solutions such as sodium silicates. The products of this reaction then combine to form a material whose compressive strength corresponds to that of burnt, conventional cement.

CLIMATE GAS CAUGHT UP IN CONCRETE

The ability to bind CO_2 in concrete instead of releasing it is also an ingenious feature. A CO_2-negative concrete would be a true climate friend. Empa researchers are working on a magnesium-based cement that will provide the basis for this eco-concrete. Resources for the raw material are available in regions where

magnesium-containing olivine is found in the soil. The mineral is mainly found deep in the Earth's mantle. However, if it is transported to the surface by volcanic activity, for example in Scandinavia, it can be degraded. In cement production from olivine, CO_2 is then added to the raw magnesium silicate. And since only part of the material is burnt in a subsequent processing step, overall less CO_2 is produced than was previously consumed. And although the product already bears a catchy name ("MOMS", Magnesium Oxide derived from Silicates), its properties are still largely unexplored.

BETTER CONCRETE
Empa scientist Alexander German is researching components for dioxide-negative concrete. (top)
The ingredients for eco-cement are mixed in the concrete laboratory. (middle)
Magnesium oxide and hydromagnesite give the mortar its white colour. (bottom)

Photos: Empa

GROWING DIVERSITY

To ensure that such approaches do not end up as niche products, but can be produced industrially and cost-effectively, meticulous analyses must show that eco-cement meets the same requirements as conventional products. Many alternative types of cement currently lack the simple recipes for adding new constituents or modifying manufacturing processes without compromising the coveted properties of traditional cement. For as long as the at least equivalent performance of eco-cement cannot be demonstrated beyond doubt, the classic Portland cement, a low-cost and well-characterized building material, will remain the material of choice for civil engineers.

Cement researchers at Empa are currently analyzing chemical mixing ratios and conformity criteria such as the strength and durability of new types of cement, paving the way for approvals that comply with standards. These include investigations on a small and gigantic scale. In addition to chemical investigations, microscopic analyses and thermodynamic modelling, with which the reactions inside cement are investigated, the load-bearing capacity of large components made of different types of cement is also compared. "Industrial processes will have to be optimized, as they are still too expensive in many cases," says Winnefeld. It is clear, however, that alternative types of cement can be used to produce concrete with a comparable or even better durability.

In any case, one development is already emerging: The variety of cement and concrete products will increase in the future. For building material producers, this diversity leads to increased requirements. Moreover, Winnefeld is certain that the use of secondary raw materials would make local solutions more attractive if there were no transport routes, for example because suitable industrial residues are produced near a cement plant. ■

Further information on the topic:
www.empa.ch/web/s308

A MYSTERIOUS HAND

PROGRESSIVE
Metal from all over Europe can be found in the bronze hand.

The bronze hand of Prêles is considered the oldest bronze sculpture of a human body part in Central Europe. It is 3500 years old – found by two private individuals and handed over to the archaeological service in the canton of Berne. Marianne Senn, leading researcher in the field of archaeo-metallurgy at Empa, was involved in the analysis. She found out that the metal was being cast – a technology that was advanced at the time. According to the research team, the metal for the bronze hand comes from the Valais or the French Alps.

www.empa.ch/web/s604/bronzehand-preles

BURNING RUBBER
Most of the micro-rubber in the environment comes from tyre abrasion.

RUBBER IN THE ENVIRONMENT

Tire abrasion lands as micro rubber mainly in soils and waters and to a small extent in the air. The amount of these particles in our environment is anything but small, as Empa researchers have now calculated. A total of 200,000 tons of microrubber have accumulated in the last 30 years – most of them in the five meters to the left and right of roads. Most of the microrubber, however, ends up in the sewage treatment plant or is recycled together with old asphalt. The rubber is harmless to the human organism. The proportion of tyre abrasion in the fine dust inhaled is also in the low single-digit percentage range at locations close to traffic.

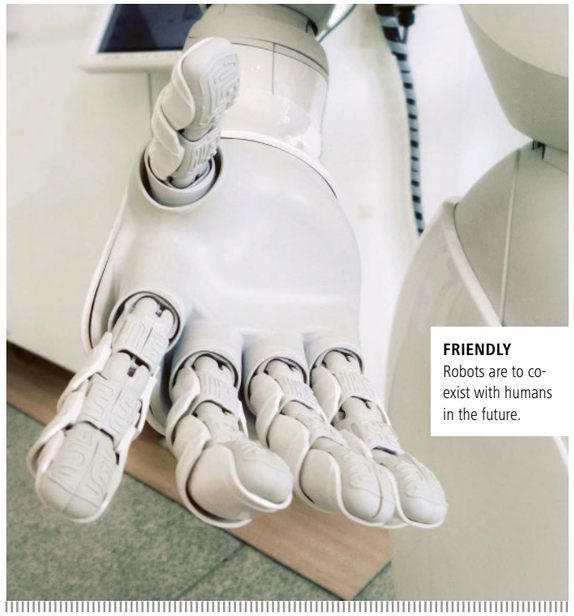
www.empa.ch/web/s604/mikrogummi

Photos: P. Joner (Archäologischer Dienst des Kt. Bern), Unsplash

NETWORKED ROBOT RESEARCH

Empa is on board the Swiss National Science Foundation's National Centre of Competence in Research (NCCR) Robotics. Under the direction of ETH Zurich and EPFL, the Universities of Berne and Zurich and the "Istituto Dalle Molle di Studi sull'Intelligenza Artificiale" in Lugano are also involved. Robots are being developed to improve the quality of life of individuals and benefit society. With this multidisciplinary NCCR, Switzerland should continue to be at the forefront of international robotics research.

www.nccr-robotics.ch



FRIENDLY
Robots are to co-exist with humans in the future.

QUIET
Large-format atomic crystal structures swallow sound.

DAMPING LOW TONES

A team of Empa acoustic researchers has succeeded in building macroscopic crystal structures that use internal rotation to attenuate the propagation of sound waves. The method makes it possible to design very light and stiff materials that can also "swallow" low frequencies particularly well.

www.empa.ch/web/s604/phononischer-kristall

Photos: Empa, Unsplash

SAVE DIAGNOSIS FOR MOTHER AND CHILD

Preeclampsia is a particularly dreaded pregnancy complication that threatens the lives of mother and child. A correct diagnosis, however, is currently time-consuming and, in many cases, inaccurate. The Empa spin-off "MOMM Diagnostics" is developing a fast and precise test that provides diagnostic certainty and at the same time saves healthcare costs.

Text: Andrea Six

RELAXED
MOMM Diagnostics develops a new test that offers pregnant women precise and rapid certainty.

Photo: iStock

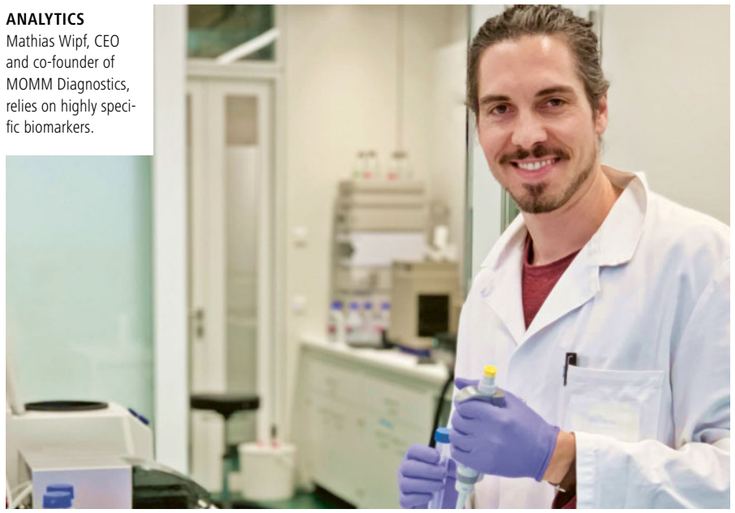
Nausea, swollen hands or shortness of breath sound like typical symptoms that pregnant women have to deal with. However, these unspecific symptoms can also be signs of a disease in progress. Preeclampsia often gradually creeps up as a general discomfort and goes widely and unnoticed – until mother and child suddenly become a medical emergency, which in severe cases can even lead to death. In Switzerland, around two percent of all pregnant women suffer from the condition; each year around 500,000 children and 76,000 mothers die worldwide.

As dangerous as the complex clinical picture is, its cause is still unclear. Pathological changes to the blood vessels, blood pressure regulation and internal organs can lead to premature births, organ failure and, ultimately, even to the death of mother and child. In its early stages pre-eclampsia can be slowed down with simple treatments such as aspirin and magnesium. However, it is difficult to diagnose preeclampsia swiftly and reliably – until now, that is. The Basel-based company "MOMM Diagnostics", a new Empa spin-off, is developing a simple and precise test that provides certainty within minutes.

OPTIMAL TREATMENT

At present, two physical changes, which are both consequences of the disease, are the common diagnostic criteria for pre-eclampsia: If the mother's blood pressure rises and certain proteins are found in her urine, the likelihood for pre-eclampsia is high. The problem is: The two symptoms could also be linked to other conditions and thus lead to unnecessary hospitalizations or even false treatments. What's more, if the mother really suffers from preeclampsia, blood circulation and kidney function will already be affected at the time of diagnosis. This is where the "MOMM Diagnostics" assay comes in. "We are analyzing two very specific biomark-

ers in the maternal blood," explains Mathias Wipf, CEO and co-founder of the company. With a highly sensitive immunoassay, the two markers are detected in tiny concentrations of several picograms per milliliter using antibodies. The specificity and sensitivity of the test are significantly higher than those of the current clinical diagnosis.



ANALYTICS
Mathias Wipf, CEO and co-founder of MOMM Diagnostics, relies on highly specific biomarkers.

TINY BIOSENSOR

And the elegant thing about it is that the tiny biosensor for detecting the markers is printed on a paper strip. A drop of blood from the mother's finger is enough to detect the molecules. "Basically the system resembles a pregnancy test," says the researcher who developed the biosensor in Empa's "Transport at Nanoscale Interfaces" lab. "However, the results are analyzed electronically." This is another advantage of the new test: The paper strip can be evaluated with a compact reader. Since pregnant women regularly go to medical check-ups anyway, the test can be carried out in the gynecologist's practice and there is no need to ship blood samples to a specialized diagnostics lab. This saves valuable time – time, in which treatment can already be started.

> "The test has the potential to avoid unnecessary hospitalization. It could ease the burden on the healthcare system."

STRESSFUL FALSE ALARM

Another benefit of this rapid screening method should not be underestimated: The expectant mother is spared the long wait for a lab result, and there is no uncertainty as to whether the preventive referral to hospital corresponds to the threat to her state. Because a false positive result of the conventional test, which only turns out to be false alarm a few days later, can sometimes cause a great deal of anxiety, which one would like to spare pregnant women.

Markus Hodel, Head of Obstetrics and Fetomaternal Medicine at the Kantonsspital Luzern, is often confronted with patients suffering from preeclampsia. He welcomes the development of the new MOMM test. "This allows us to individually assess the risk of the expectant mother at an early stage," says Hodel. In addition, the monitoring of high-risk pregnancies and the adequate treatment of patients can be optimized. "Since the test also has the potential to avoid unnecessary hospitalization, the burden on the healthcare system could be reduced," says the clinician. Previously, patients were admitted to hospital as a precaution if the results of the conventional test were considered suspicious. However, a study involving Hodel's team now shows that a sensitive test, such as the new MOMM biosensor technology, which can be carried out directly at the gynecologist's practice, has significant savings potential. In Switzerland, savings of around two million Swiss francs in healthcare costs could be achieved annually if a "point-of-care" test, or POC test for short, were to be used by a gynecologist.

LARGE MARKET POTENTIAL

In the US, the technology is already patent pending. Mathias Wipf and his team are currently developing a prototype; close cooperation is planned with CSEM in Neuchâtel and the University of Applied Sciences Northwestern Switzerland. The Empa spin-off, founded in 2018, is supported by a "FET Innovation Launch Pad", an EU funding program for start-ups in the field of "Future and Emerging Technologies". And from 2020, new investors can join the start-up company. The biosensor POC test is expected to be ready to hit the market by 2023. Due to the large market potential, Wipf expects double-digit million sales figures already within the first five years. The location for research, development and production in Basel is expected to grow to 25 headcounts. ■

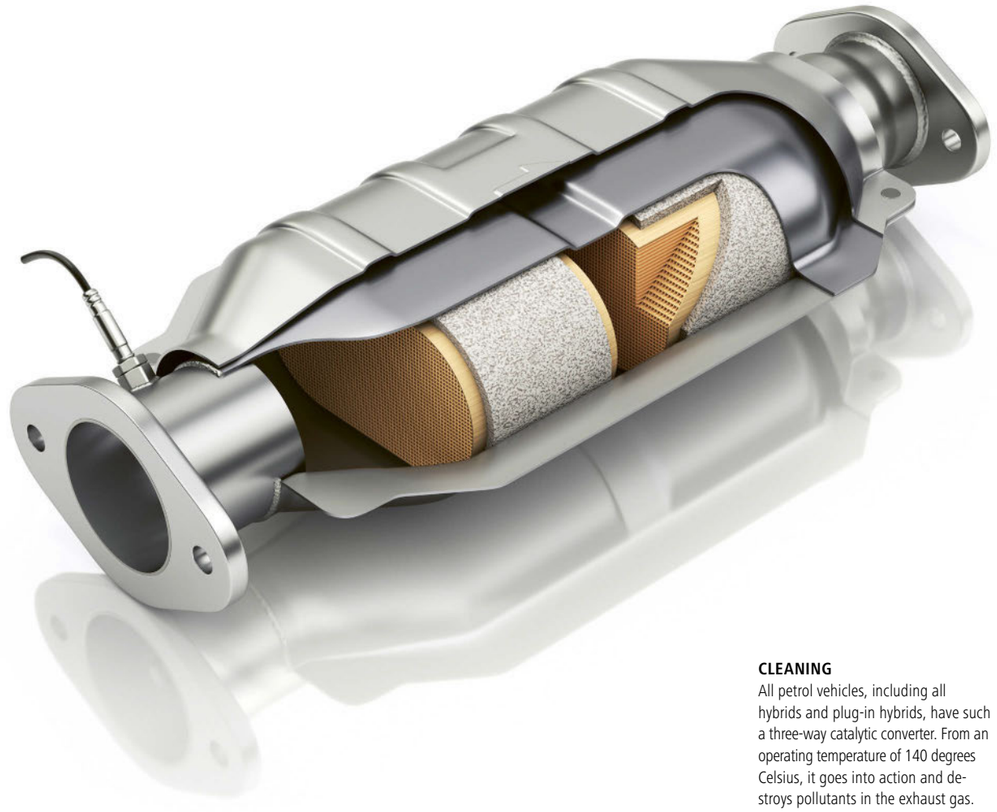
Further information on the topic:
www.mommdiagnostics.com

Photo: Empa

THE COLD-START DILEMMA

With hybrid cars and plug-in hybrids, cold starts occur more frequently when the internal combustion engine stops and the electric motor pushes the car through town. How quickly can the catalytic converter be preheated so that it can still clean exhaust gases well? What would be the method of choice? A team of Empa researchers is investigating.

Text: Rainer Klose



CLEANING
All petrol vehicles, including all hybrids and plug-in hybrids, have such a three-way catalytic converter. From an operating temperature of 140 degrees Celsius, it goes into action and destroys pollutants in the exhaust gas.

Phorto: iStock

From January to September 2019, almost 17,000 hybrids and plug-in hybrids were redeemed in Switzerland – an increase of 60 percent over the previous year. These cars can drive a few kilometers through the city electrically. They only need the combustion engine on the outskirts of the city when the driver accelerates onto the motorway or country road. The problem here is that the engine makes a cold start at high revs and engine load – quite differently than was previously the case.

Can exhaust gas purification keep up with this? Can the catalytic converters that we have been using since the 1980s be used in such cases? Viola Papetti and Panayotis Dimopoulos Eggenschwiler have calculated this with a specially developed mathematical model. And they offer recommendations on how catalysts could be preheated in the future.

ONLY A HOT CATALYST WORKS

During a cold start, the engine pushes hot combustion gases through the cold catalytic converter. The catalytic converter must gradually warm up in order to develop its chemical cleaning effect. As long as it is cold, carbon monoxide, nitrogen oxides (NOx) and unburned hydrocarbons penetrate unhindered into the outside air. The good emission values of modern Euro 6 vehicles are only achieved with a warm catalytic converter. The differences are drastic: in the first 5 minutes after a cold start, a vehicle emits more pollutants than a 1000 km, non-stop, drive with a warm engine.

CHEMISTRY AND HEAT EXCHANGE IN THE CATALYTIC CONVERTER

For their model calculations, the researchers chose a typical catalytic converter for a 2.0-litre petrol engine. Using the OpenFOAM simulation program, they computed how the hot exhaust gases heat up the ceramic honeycomb of the catalyst and the catalytic cleaning layer known as the "washcoat". At first, the catalyst is only "heated" by the hot gases, then the heat gradually penetrates the ceramic and the sheet metal shell of the catalyst. A little later, the chemical reaction sets in: the pollutants are chemically decomposed on the washcoat. They provide additional heat.

> "Only at 140 degrees Celsius will the catalyst start to work well"

MINUTES PASS WITHOUT EXHAUST GAS CLEANING

The researchers' model computations start on a winter day at minus 13 degrees Celsius. Nothing happens in the first 30 seconds of a car journey. Then the first quarter of the catalyst begins to heat up. After one minute, warming begins in the second quarter; only two minutes after starting the engine does the third quarter warm up. It takes a total of three and a half minutes for the catalytic converter to heat up to three quarters and clean all of the engine's exhaust gases at 140 degrees Celsius.

SCENARIO FOR HYBRIDS AND PLUG-IN HYBRIDS

The researchers repeated the model calculation for a hybrid car. Suppose the catalytic converter had already been warm once and has now cooled down in stop-and-go traffic because the car was on the road powered only by its electric motor. The "cooled" catalytic converter still has a residual temperature of just under 90 degrees; in this case, too, it is only fully heated after three minutes.

Finally, the researchers simulated a cold start on the entry of a motorway – a typical szenario for plug-in hybrids that can run on battery power to the edge of town and then accelerate. Here is the catalytic converter minus 13 degrees cold, but twice the amount of exhaust gases are flowing through. With the plug-in hybrid, the catalytic converter is warm enough after 90 seconds to clean all the exhaust gases, because the stronger exhaust gas flow heats up the catalytic converter faster, and the chemical reactions start earlier and more strongly.

PREHEATING POSSIBLE?

The bad news: even the most modern plug-in hybrids emit toxic pollutants for minutes after each cold start. This could become a problem over the next few years if the EU continues to tighten its emissions regulations. The problem can only be solved if the catalytic converter is heated up as soon as the combustion engine starts. Or even better: before it starts. How could that work?

"I see three possibilities," says Empa researcher Dimopoulos Eggenschwiler. "The engine could be used to produce hotter exhaust gases, which would cost additional fuel. One could also use the hybrid battery in the cars to preheat the exhaust gases electrically. And the washcoat of the catalytic converter could be preheated with the aid of microwave radiation so that the chemical reaction starts faster." The question remains: which method costs the least energy?

The researchers have also computed this: When cold starting in the city, it is more efficient to preheat only the exhaust gases. A cold start on the motorway would cost too much energy because of the large amount of gas. Here it is worthwhile to preheat the washcoat directly. "In the end, only a combination of all methods produces the best results," says Viola Papetti, who carried out the simulation computations.

HOT
A hot rear silencer on the underbody of a car. So far, only engine heat has been used to clean exhaust gases. In the future, we could preheat catalytic converters electrically to avoid pollutants during cold starts.

Photo: stock

USEFUL COMPUTATION METHOD FOR ELECTRIC CARS

"And there is one more thing", says Panayotis Dimopoulos Eggenschwiler at the end of our conversation. "We can also apply our calculation method to battery electric vehicles."

The Empa researchers' simulation program can in fact not only calculate the heat distribution in the exhaust tract of a combustion engine, but also that in a lithium-ion battery. This makes the tool perfectly suited to optimizing the cooling technology of electric cars – also during charging. Good rapid charging systems can only be realised with optimum temperature monitoring and cooling. ■

Further information on the topic is available at:
www.empa.ch/web/s504

Photo: Robert Stürmer / Empa

CREATIVE
Merging machines with the intelligence of life:
Mirko Kovac, Director of the new Materials and Technology Center of Robotics.

"Digital intelligence alone is not enough to enable spontaneous reactions to the environment in all its unpredictability"

VERTICAL TAKE-OFF

Mirko Kovac is heading the new Materials and Technology Center of Robotics of Empa and Imperial College London. Together with his team, he develops drones and flying robots, which are supposed to help autonomously with building maintenance, for instance. And incidentally he is kicking off a revolution: he wants to build "living" machines.

Text: Andrea Six

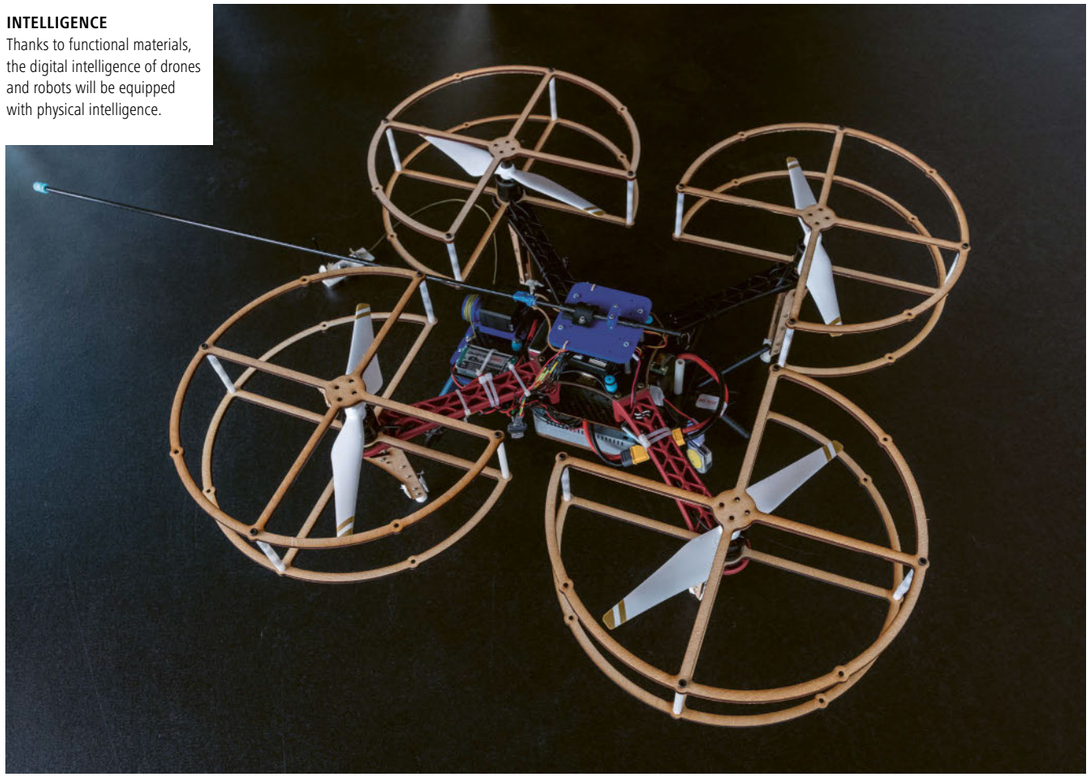
The man actually loves machines. And life, too. And now he intends to merge both. Mirko Kovac is developing robots and drones that, thanks to their biological properties, can merge the digital intelligence of computers with the physical intelligence of biological systems. Driven by the vision of a society, in which people are assisted by machines to a degree that corresponds to a real "cohabitation", he has been head of the newly established Materials and Technology Center of Robotics in Dübendorf since last year. Currently, a flight arena for drones, which could be used to maintain buildings, for example, is being built in the joint center of Empa and Imperial College London. With his team, Kovac wants to advance the area of infrastructure robotics so that applications can be developed for dams, tunnels, wind turbines or offshore facilities.

An urgent current problem: Workers working on scaffolding or at great heights, for example, are exposed to an enormous risk of accidents. Drones that work safely and efficiently even in danger zones or in places that are difficult to access could provide human specialists with useful support in these tasks.

DRONES IN THE KITCHEN

"We will develop and validate such applications in our new flight arena," explains the researcher. Kovac, who also heads the Center of Excellence for Infrastructure Robotics Ecosystems at Imperial College, already operates a complementary flight arena in London. In addition to Empa's expertise in materials science, another unique feature of the conditions at Empa is the existing test site for his developments: The NEST research building on the Empa-Eawag campus.
Here, the drones and robots are to be

USEFUL
The drone researcher is convinced that robots can make a meaningful contribution to society.



INTELLIGENCE
Thanks to functional materials, the digital intelligence of drones and robots will be equipped with physical intelligence.

Photo: Robert Stürmer / Empa

MIRKO KOVAC

CARREER After studying mechanical engineering at ETH Zurich, Kovac received his doctorate from the Laboratory for Intelligent Systems at EPFL in Lausanne. He then worked as a postdoctoral fellow at the Harvard Microrobotics Laboratory at Harvard University in Cambridge, USA.
SCIENCE Mirko Kovac has headed the Materials and Technology Centre for Robotics at Empa since December 2018. He is also Director of the Aerial Robotics Loboratory at Imperial College London and Royal Society Wolfson Fellow. His research focuses on the development of flying and soft robotic solutions for digital infrastructure systems.

observed at work and optimized in a real-world environment. The modular innovation building NEST is particularly suitable for observing the "ecosystem" of man and machine, as it is by definition subject to a permanent rebuilding process, so that the robots can expect a multitude of possible tasks. "We have the opportunity to investigate the interactions between robots and humans in reality," says Kovac. How it is to cooperate with a robot, or whether or not a drone interferes in the kitchen, can be studied in real-life everyday situations, which, at the same time, can be analyzed scientifically.

Kovac, who after completing his degree at ETH Zurich and his doctoral thesis at EPFL worked all over the world in robotics research, among others at the renowned US universities Harvard and Berkley, considers Switzerland a strong location that is rightly called the "Silicon Valley of robotics". The density of research institutions and the diversity of expertise are pleasingly high by international standards. He is sure that Switzerland can be at the forefront, especially in the area of the intersection of materials science and robotics.

The researcher wants to trigger nothing less than a revolution. While classical robotics has dealt with sensor technology and the control of a machine by a computer, Kovac wants to go further. "The pure digital intelligence of a computer is not enough to develop applications that can spontaneously react to the environment in all its imponderability," he says. A physical intelligence, through intelligent materials and structures, makes a machine a being that can be integrated into society. Functionalities based on nature and biological materials will ultimately enable the construction of biohybrid robots.

THE BIOLOGY OF THE MACHINE

The fusion of machines with "bios", ancient Greek for life, is for Kovac – within certain limits – a declared goal and not a taboo. He is by no means interested in creating a chimera of animal and robot, but rather in equipping mechanical aids with certain characteristics of life, especially the ability to interact with their environment. "The robots and drones should be able to react intelligently, autonomously and robustly to their environment," he explains.

Since childhood Kovac, now 39, has been fascinated by what holds machines together at their core. "As a child, I disassembled Swiss watches because I had to find out where the "heart" of the watch beats," he says. At the same time, he was fascinated by the highly specialized abilities of animals to live perfectly adapted in their ecological niches. This childlike fascination has grown out of the mechanical engineer's realization that "living" machines can be developed through inspiration and creativity if organic or biologically inspired, smart materials and structures are combined with sensor technology and computing capacity. Kovac is convinced that this creativity is fostered by a strong, multidisciplinary team of scientists who not only do their research in a focused, but at the same time in a networked and broadly holistic manner.

At Empa, Kovac and his team are now developing robots and drones that are supposed to have completely new capabilities thanks to "soft" functional materials. This makes it possible, for example, to carry out autonomous inspections of components or quickly contain damage, for example in the event of pipeline leaks. He is not only cooperating with his colleagues at Imperial College, but also with Swiss experts through Empa's participation in the National Center of Competence in Research (NCCR) "Robotics – Intelligent Robots for an Improved Quality of Life" led by ETH Zurich and EPFL. He is aware that a topic such as the coexistence of humans and robots can trigger both concerns and enthusiasm in society. "It is one of the tasks of research to critically question results and communicate real risk assessments to decision-makers," says Kovac. Even his love of machines cannot stop him from doing so. ■

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

CELEBRATING INTERDISCIPLINARITY

ADVANCING
Empa's doctoral students present the wide range of research topics at the annual symposium.

On November 28, Empa St. Gallen organized the annual Empa Doctoral Symposium. Following the theme "Science Cocktail: Mixing Disciplines to Drive Innovation", the event began with an inspiring speech by Professor Neil Alford of Imperial College London and continued with lectures and poster presentations showing the diverse work of Empa PhD students. Congratulations to Oliver Braun and Rimah Darawish for winning the Best Lecture and Poster Award respectively.

AWARD FOR CFRP PIONEER

On 18 September, Urs Meier, former director of Empa in Dübendorf and expert for carbon-fibre reinforced plastics (CFRP) in civil engineering, received a prestigious award for his services – the "SAMPE Fellow Award". This award is presented in recognition of outstanding contributions in the fields of materials and processes.

www.empa.ch/web/s604/sampe-fellow-award

DISTINGUISHED
The "SAMPE Fellow Award" 2019 went to Urs Meier.

Photos: Empa

NEST AT SWISSBAU 2020

In 2020, NEST will again be present at Swissbau. Together with its partners, NEST is inviting visitors to Swissbau Focus for exciting workshops on the topics of "Energy in the neighbourhood" and "Resource-efficient, loop-friendly construction". The NEST team will also be present at various events during the fair and at the stand (F07) in Hall 1.0 South. Swissbau will open its doors from 14.–18. January 2020.

WORKSHOPS

INTELLIGENT JUGGLING WITH ENERGY
Tuesday, 14 January 2020, 13:45–14:45
Basel Exhibition Centre, Hall 1.0 South, Swissbau Focus, Room 2

NUTRIENT CYCLES IN BLUE-GREEN ARCHITECTURE
Thursday, 16 January 2020, 15:00–16:00
Basel Exhibition Centre, Hall 1.0 South, Swissbau Focus, Room 3
In collaboration with Eawag

CONSTRUCTION IN THE CIRCULAR ECONOMY
Friday, 17 January 2020, 13:15–14:15
Basel Exhibition Centre, Hall 1.0 South, Swissbau Focus, Room 4
In cooperation with eco-bau

PLANNING AND REALITY – A DEVIATION WITH CONSEQUENCES?
Friday, 17 January 2020, 14:15–15:45
Messe Basel, Hall 1.0 South, Swissbau Focus, Room 1
In cooperation with SCCER FEEB&D and SIA

nest.empa.ch/swissbau

EVENTS
(IN GERMAN)

16. JANUAR 2020
Tagung: Immissionsmessungen von High-end bis Low-cost
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/nabeltagung
Empa, Dübendorf

2.–7. FEBRUAR 2020
Tagung: Atomic, Cluster and Surface Physics
Zielpublikum: Wissenschaft
https://sasp20.empa.ch
St. Moritz

7. FEBRUAR 2020
Kurs: Elektrochemische Charakterisierung und Korrosion
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/korrosion
Empa, Dübendorf

6. MÄRZ 2020
Kurs: Tribologie
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/tribologie
Empa, Dübendorf

11. MÄRZ 2020
Kurs: Neue Trends in der Fügetechnologie
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/fuegetech
Empa, Dübendorf

Details and further events at
www.empa-akademie.ch

THE PLACE WHERE INNOVATION STARTS.