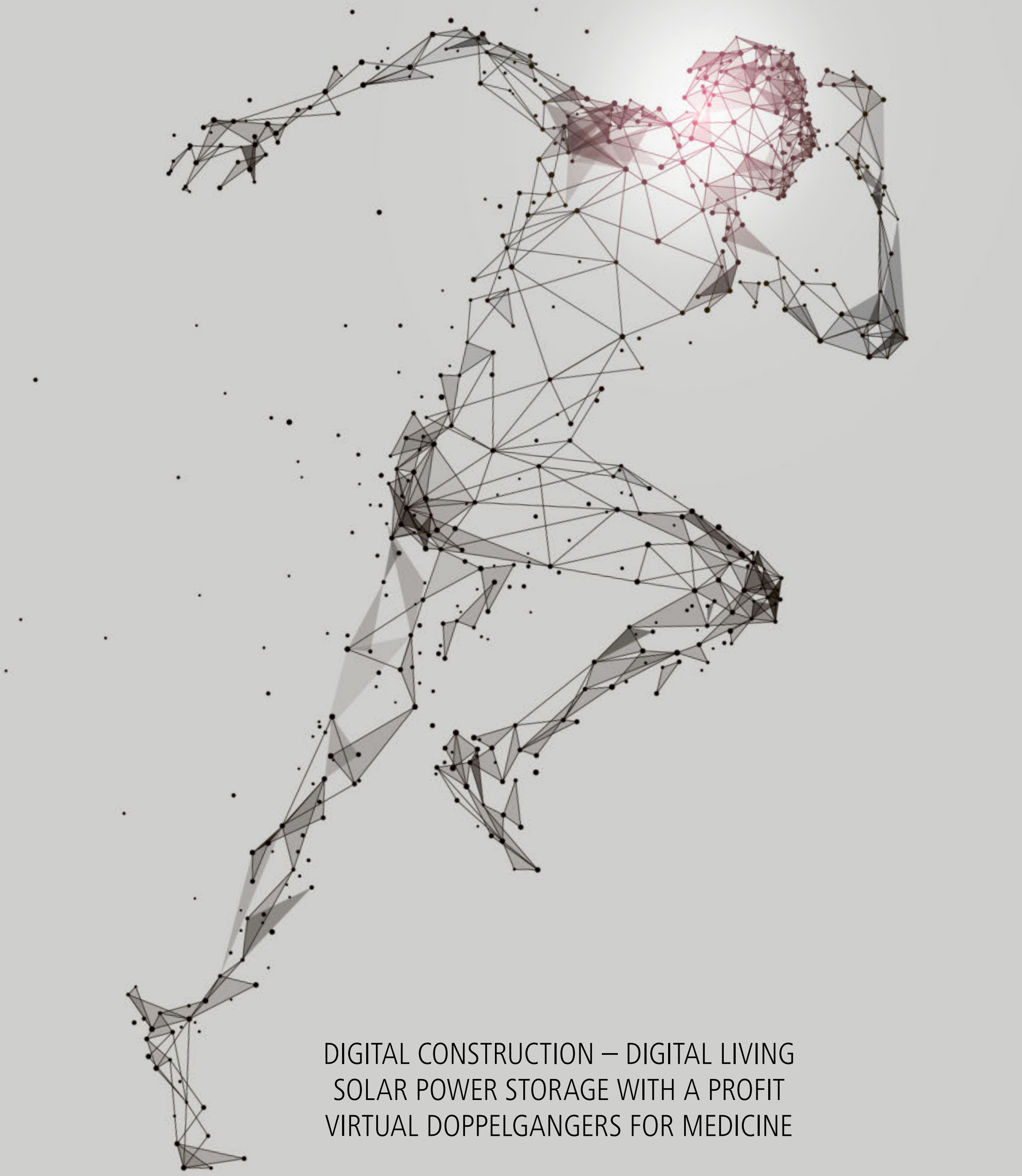
Empa Quarterly

RESEARCH & INNOVATION II #64 II MAY 2019

FOCUS

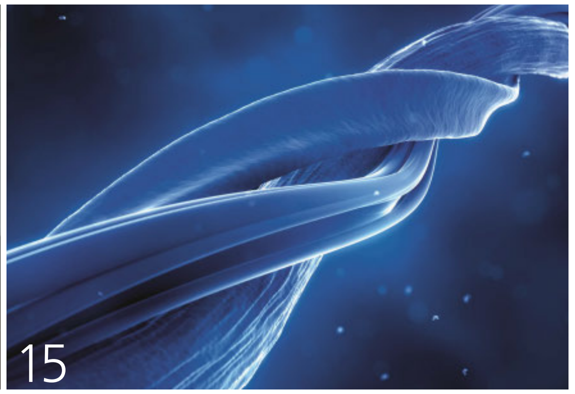
DIGITALIZATION



DIGITAL CONSTRUCTION – DIGITAL LIVING
SOLAR POWER STORAGE WITH A PROFIT
VIRTUAL DOPPELGANGERS FOR MEDICINE

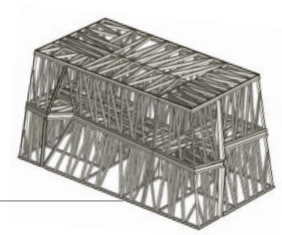
[CONTENT]

[FOCUS: DIGITALIZATION]



Photos: Roman Keller, Empa, shutterstock, Markus Mallaun, Lufthansa

Photo: istock/Getty Images, Grafik: NCCR Digital Fabrication



[COVER]

The digitization of all walks of life is unleashing terrific dynamics. Find out in this issue how Empa helps our society prepare for the future.
Photo: istock/Getty Images

Empa Social Media

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PACKAGING MATTERS

Dear readers,

In times of increasing overstimulation and ever shorter attention spans, first (usually visual) impressions are becoming increasingly important. And although at EmpaQuarterly we primarily focus on "inner values" – i.e. convincing content –, for once we also spared a thought for design. And you, dear reader, are holding the result of these musings in your hand: a research magazine with a contemporary look that – hopefully – meets your approval.

Focused on the essentials, visually powerful with a fresh look, and concise – this is how we want to keep you abreast of new ideas, concepts and innovations from our labs in future. But the proof of the pudding is in the eating: We are extremely eager to hear your opinion on the "new" Quarterly. What do you like, what less so, what is missing? Please let us know all of this and much more via redaktion@empa.ch. We can't wait ...

Speaking of packaging: Another change concerns the shipment of our magazine. So far, you received it wrapped in plastic foil. This is a thing of the past – at least for domestic shipments (and hopefully soon throughout Europe, too – we're working on it). From now on, the Quarterly will reach you at home "unplugged", as it were, which enables us to save about 80 kilograms of plastic waste per year. A drop in the ocean, granted, but you've got to start somewhere. We look forward to your feedback and hope you enjoy our new magazine!

Yours, MICHAEL HAGMANN

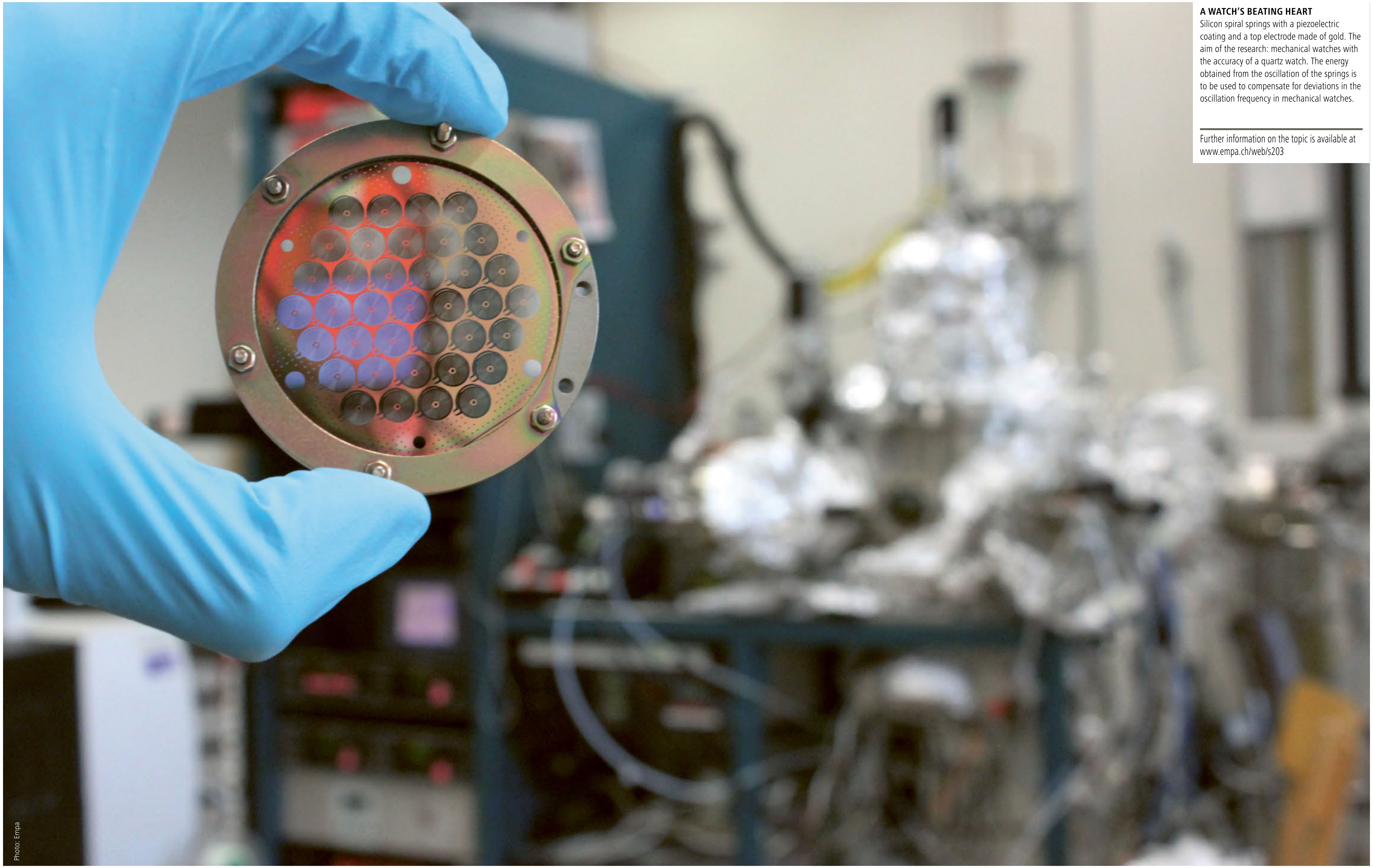


Photo: Empa

A WATCH'S BEATING HEART
Silicon spiral springs with a piezoelectric coating and a top electrode made of gold. The aim of the research: mechanical watches with the accuracy of a quartz watch. The energy obtained from the oscillation of the springs is to be used to compensate for deviations in the oscillation frequency in mechanical watches.

Further information on the topic is available at www.empa.ch/web/s203

ARCHITECTURAL ICON
DFAB HOUSE, three stories high, is situated on the topmost platform of NEST.

STYLISH INTERIOR
DFAB HOUSE will house four short-term residents who will share the living spaces.

BUILDING DIGITALLY, LIVING DIGITALLY

DFAB HOUSE has officially opened today on the NEST building of Empa and Eawag in Dübendorf. It is the world's first inhabited "house" that was not only digitally planned, but also – with the help of robots and 3D printers – built largely digitally. The construction technologies were developed by ETH Zurich researchers in collaboration with industrial partners.

Text: Stephan Kälin, Photos: Roman Keller

A delicate concrete ceiling – cast in 3D-printed formwork – and a curved concrete wall created by a construction robot characterize the architecture of the living room, whose aesthetics are remotely reminiscent of the film sets of the Swiss artist HR Giger (the creator of "Alien"). Upon saying a specific command, the blinds open as if by magic and the kettle prepares water for tea. What sounds like a science fiction film is reality in Dübendorf: today, the smart and largely digitally planned and built DFAB HOUSE opens its doors.

FROM LABORATORY TO ARCHITECTURAL APPLICATION

The three-story "house" is located on the uppermost of three platforms at NEST. On this modular research and innovation building of Empa and Eawag, researchers, together with industrial partners, can test new construction and energy technologies under real-life conditions. NEST consists of a central building core, to which various building modules – so-called units – can dock. For the construction of the DFAB HOUSE unit, researchers from eight professorships at ETH Zurich, within the framework of the National Center of Competence in Research (NCCR) "Digital Fabrication", in collaboration with industrial partners, have for the first time transferred several novel digital construction technologies from the laboratory into real-world applications. The aim of digital technologies is not only to make planning and construction more efficient, but also more sustainable. For example, the digitally ▶

DFAB HOUSE: FACTS & FIGURES

DFAB HOUSE is a demonstration project that shows how digital manufacturing processes can revolutionize the way we design and build. Six independent innovation objects illustrate these possibilities.

1 IN SITU FABRICATOR

The In situ Fabricator is a context-aware mobile construction robot for fabricating building elements directly on construction sites. Its integrated on-board sensing and computation system is developed to enable autonomous repositioning procedures, localization of the end effec-tor and the adaptation of fabrication data according to unforeseen material behavior – without the need for external measurement devices.

Days spent building on site: 22
Total building time: 125 hours

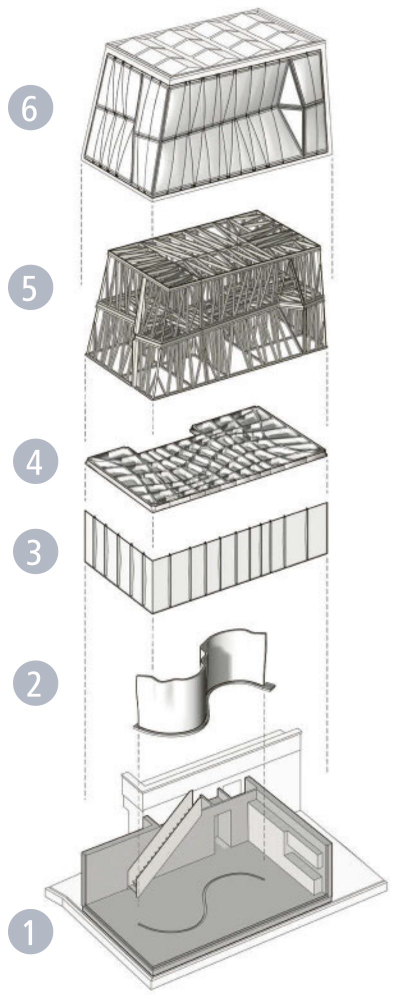
2 MESH MOULD

The Mesh Mould combines formwork and reinforcement into one robotically fabricated construc-tion system. As such the In situ Fabricator robot builds up a 3D mesh structure which acts as both formwork and structural reinforcement. Specially developed cement mortar is then poured into the mesh structure and trowelled off by hand, allowing the unique shape of the load-bearing wall.

Length of wall: 12 m
Height of wall: 3 m
Total number of welding knots: 22,300

3 SMART DYNAMIC CASTING

Smart Dynamic Casting enabled the production of 15 bespoke reinforced concrete mullions. Each mullion was produced by digitally controlled slip-forming, by which self-com-pacting concrete is fed into a flexible formwork that shapes the concrete as it hardens. This technique allows each mullion to be individu-ally produced in the most suitable geometry for the load-bearing requirements for their exact location.



Graphic: NCCR Digital Fabrication

Number of concrete mullions: 15
Volume of concrete per mullion: 23 litres
Time to slip-form one mullion: 4 hours

4 SMART SLAB

The Smart Slab showcases a new generation of a radically optimized digital building processes from design to fabrication. It uses large-scale 3D sand printing to automate and optimize the most labor intense process in concrete construction: fabricating the formwork. The 295 unique 3D-printed formwork parts fully enable the plasticity of concrete to create a free-form, highly optimized building compo-nent featuring intricate ornamental structures which create a rich architectural experience.

Area: 78 m^2
Max. Cantilever: ~4 m
Weight: 15,7 t (~65% reduction)
On site assembly: 4 days

5 SPATIAL TIMBER ASSEMBLIES

An innovative robot-based fabrication process which uses the dual robot system in ETH Zurich's Robotic Fabrication Lab (RFL) to prefabricate timber frame modules for the upper floors of DFAB HOUSE. By using the robots, the timber can be cut, held and positioned reference-free in space, based on the computer layout, allowing for novel and complex geometries.

Precision of beam placement: under 1 mm
Maximum weight of timber beams assembled by the robot: 55 kg
Number of beams in DFAB HOUSE: 487
Number of modules: 6
On site installation time: 12 hours

6 TRANSLUCENT FAÇADE

Aerogel granules are inserted and stabilized between specially developed membrane panels through a novel process. The result is a thin and double curved lightweight façade system with su-perinsulation properties that enables light to enter the building through the entire wall.

Thickness of façade: 80–120 mm
Percentage of energy saved: U-Wert 0,165

planned floor slab of DFAB HOUSE is statically and structurally optimized in such a way that considerable amounts of material can be saved compared to a conventional concrete slab. The tech-nologies also open up new design possibilities. For instance, the two upper residential floors are characterized by wooden frames, which were fabricated with the help of two construction robots and arranged in complex geometries. "The architectural potential of digital fabrication technologies is immense. Unfortunately, these technologies are still scarcely used on construction sites. With the DFAB HOUSE, we are able to test new technologies hand in hand with industry and thus accelerate the transfer from research to practice," says Matthias Kohler, ETH Professor of Architecture and Digital Fabrication.

> "The architectural poten-tial of digital construction technologies is huge."

AN INTELLIGENT HOME

In June, the first residents, academic guests from Empa and Eawag, will move into DFAB HOUSE. At DFAB HOUSE, they will live in an intelligent home. A consortium of companies led by digi-talSTROM has installed the first smart home solutions in DFAB HOUSE, which are based on the manufacturer-inde-pendent digitalSTROM platform. These include intelligent, multi-stage burglar protection, automated glare and shading options, and the latest generation of networked, intelligent household appli-ances. However, DFAB HOUSE is smart not only in terms of home electronics, but also in terms of energy manage- ▶

BUILDING WITH ROBOTS enables new timber const-ruction geometries.

DIVISION OF LABOR
Humans and robots are working closely together on DFAB HOUSE – both on the building site and in prefabrication.

Photos: NCCR Digital Fabrication, Daniel Sanz Pont, Roman Keller

ment: Photovoltaic modules on the roof supply on average one and a half times as much electricity as the unit itself will consume, while an intelligent control system coordinates all consumption and en-sures that no load peaks occur. Two start-up ideas, accompanied by researchers from Empa and Eawag, are helping to save additional energy: On the one hand, heat from waste water, which would otherwise be lost, is recovered directly in the shower trays via heat exchangers, and on the other hand hot water flows from the pipes back into the boiler when not in use instead of cooling in the water pipes. This method not only saves energy and water, but also reduces the risk of bacteria growing in the pipes.

"Thanks to the constructive dialog between scientists and experts, visionary ideas were realized in practice."

LEARNING FROM EACH OTHER

The sixth unit in the NEST research and innovation building is a good example of how cooper-ation between researchers and industry can produce forward-looking solutions. "In implementing a construction project like DFAB HOUSE, traditional construction methods meet new concepts of the digital world. The path from the digital drawing board to an actual building has challenged both scientists and experts from industry. Through a constructive dialog, something truly visionary can now be put into practice; hopefully it will soon be used broadly in the construction industry," says Empa CEO Gian-Luca Bona. ■

Further information on the topic is available at nest.empa.ch/dfabhouse

"IF WE DON'T SEIZE THIS OPPORTUNITY, OTHERS SURELY WILL"

Empa CEO Gian-Luca Bona on the opportunities and risks of digitalization – and the question as to how a materials research institute needs to gear itself up for this future

Interview: Oliver Schneider, Photo: Nicolas Zonvi

Which IT project at Empa do you find the most fascinating?
It's hard to say as we're working on so many exciting projects – starting with nanotechnology, where we are studying the material properties of just a few atoms in chemical reactions, all the way to IT projects such as our Energy Hub Demonstrator, ehub.

What is the ehub project all about?
We want to find out how neighborhoods or entire city districts can be modeled with respect to their energy flows. We do this by recording data and then making predictions, for instance, as to which renovations would be ideal from an energy perspective. The project is closely linked to the Federal Council's Energy Strategy 2050, where we're working towards an optimum use of renewable energies and minimizing our CO_2 emissions.

When one thinks of Empa, digital technologies do not immediately spring to mind. How important is IT for you?
Ever increasingly. This is linked to the fact that today Empa is a research institute for materials science and technologies – and materials are the basis for each and every new IT solution. So when we do materials research, we participate in the development of digital technology and try to apply that technology to research right from the start.

At Empa, robots build houses and drones perform maintenance on them. How far are we from a fully automated building site?
We'd like to show how all the steps from the drawing board to the final product and ultimately its maintenance and operation can be realized with the help of digital technology. To this end, we work with various research institutions, especially ETH Zurich. In doing so, not only have we experienced the potential of building with robots, but also the difficulties. One challenge, for example, is to coordinate the different fields. A lot is going on here at the moment, and we'd like to bring our materials knowhow to the table to realize the construction and maintenance of the future.

Digitalization and automation not only have upsides; they are also contentious. There is talk of unemployment and the loss of professional identity. What's your take on this?
I see a huge opportunity in automation. If we don't seize this opportunity, others surely will and will push us out. But I'm also well aware that stonemasons, for instance, might perceive the technology as a threat. Their job description will change. All classic professions are becoming more demanding in terms of technical knowledge. But that doesn't have to be a disadvantage: At 60, a construction worker would no longer have a broken back, but three retraining courses on his CV.

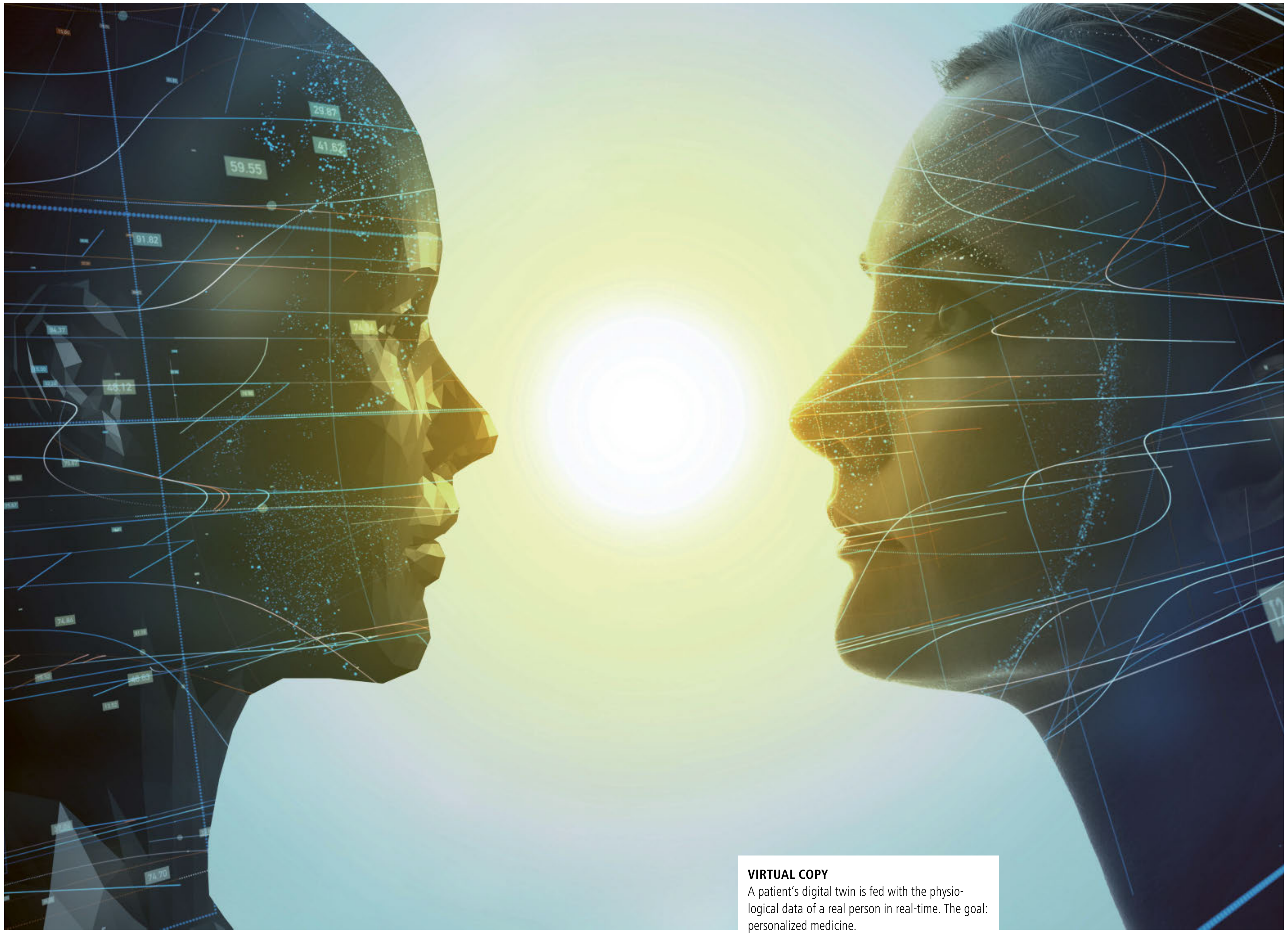
How does Empa want to help shape Switzerland's digital future?
As a materials research institute, we want to open up to the digital environment by making our expertise available on platforms, an approach we call "open innovation". What's more, we keep on developing and investing in the fields of big data, artificial intelligence (AI))and machine learning, for example. International cooperation is especially important here. We need to exploit this potential. Cutting oneself off isn't the answer. ■

Reprint courtesy of www.netzwoche.ch. bit.ly/2I1gPZZ

SEND YOUR AVATAR TO THE DOCTOR

Virtual doppelgangers could one day revolutionize medicine: Empa researchers are developing a digital twin, which should facilitate the development of personalized therapies. The goal is for these avatars to demonstrate how a pain sufferer or a diabetic needs to be treated individually. In doing so, the digital twin also enables a personalized prognosis for the treatment process.

Text: Andrea Six



VIRTUAL COPY
A patient's digital twin is fed with the physiological data of a real person in real-time. The goal: personalized medicine.

Photo: shutterstock

Humans are surprisingly individual. We differ greatly in our eating habits or in our film tastes. When it comes to disease, however, you would be forgiven for thinking we are all the same. There is one painkiller for everyone to treat headaches or insulin injections for all diabetics. For some time modern medicine has known that this is not strictly true and coined the term "personalized medicine". Depending on the age, lifestyle or genetic make-up, a person responds very differently to certain therapies. And as human beings are a living system that changes its habits, goes on vacation or suddenly gets a cold, medical treatments need to be extremely flexible. This is where the idea of a virtual doppelganger comes into play, which is fed with the real patient's physiological data in real time. This medical avatar could one day revolutionize medicine.

Empa researchers are already developing a digital skin twin, which should enable pain sufferers and diabetics to be treated in an optimal way. "Using an in silico doppelganger, we're able to respond to individual patients much more precisely," explains Thijs Defraeye from Empa's "Biomimetic Membranes and Textiles" lab in St. Gallen.

The project that had just been launched is funded by the Novartis Research Foundation and the Competence Center for Materials Science and Technology (CCMX). The goal is to administer medicines such as painkillers and insulin via the skin using intelligent fibers and membranes while sensors simultaneously gage the patient's vital signs. Based on the data, the digital twin makes predictions regarding the individual dosage and monitors the success of the treatment. By the same principle, in the next step the doppelganger might be used to check the healing progress of demanding wounds. With this in mind, Empa researchers have already devised a smart bandage with an integrated sensor.

> "Using an in silico doppelganger, we're able to respond to individual patients much more precisely."

Defraeye and his team are looking to merge two innovative research fields for the development of the digital twins: non-invasive drug administration via the skin using a transdermal bandage, and controlling and predicting the course of treatment using real-time modeling. In this respect, it is particularly shrewd as the skin, our largest organ, offers a large, suitable surface area to channel substances up to a certain molecular size into the body. However, the dosage with conventional therapeutic plasters is virtually uncontrollable as some of the active agent can still be released from the skin layers and get into the body, even if the plaster has long since been removed. Current systems, which provide feedback by measuring the drug level in the ▶

patient's blood, for instance, can only determine whether the dosage might have been too high or too low in retrospect; predictions on the actual need for medication are still pie in the sky.

FEEDING THE TWIN WITH DATA

A digital twin fed with data from non-invasive sensor systems attached to the skin, by contrast, enables the precise and personalized dosage of the active agents. The computer modelling of the digital doppelganger also factors in the patient's skin characteristics. After all, the active agent will be absorbed differently depending on where the plaster is attached to the body or whether the drug is administered to a sun-tanned athlete, an elderly lady with pale, papery skin or a soft-skinned newborn. Thus the drug dosage can be controlled precisely thanks to a tailored, time-dependent rate of expulsion from the bandage because the system looks into the future, not back. "As an extra benefit, we expect to be able to reduce the dosage – of painkillers, for instance – to such an extent that the patient is supplied with just the right amount," says Defraeye.

In other research fields, virtual representatives have been a hot topic ever since NASA's Apollo 13 mission. Doppelgangers were used in simulations to bring the crew of the stricken spaceship safely back to Earth. Today, digital twins exist in aircraft design, vehicle manufacturing and building maintenance, for example. "In medicine, people dream of complete in silico doppelgangers, which predict how a person will age or how an artificial joint will wear in the body," says Defraeye. However, we are still a long way from this becoming a reality. The novel system consisting of intelligent plasters and real-time simulations is, therefore, a crucial step into an as yet little researched area with enormous potential, the Empa researcher explains. At the same time, the personalized digital twin for the transdermal administration of drugs takes us a step closer towards human avatars.

For the development of the digital twin in the healthcare sector, Defraeye has successful research results to build upon: In the food technology sector, he has already developed digital twins of different fruits as part of an ongoing project funded by the Swiss National Science Foundation (SNSF). In order to monitor the cooling chain from the producer to the retailer in real-time and be able to control it in future, the

> "In medicine, people dream of complete in silico doppelgangers."

researcher made biophysical twins of apples, mangos and other fruits that behave in exactly the same way as their natural counterparts in terms of their thermal properties and that act as sensors. The corresponding "fruit spy" accompanies the real fruit on its journey to the supermarket and transmits data to the digital twin, which adjusts the cooling in the truck, for instance. In this case, the virtual fruit is based on a three-dimensional CAD model of an apple or a mango combined with corresponding multiphysical simulations.

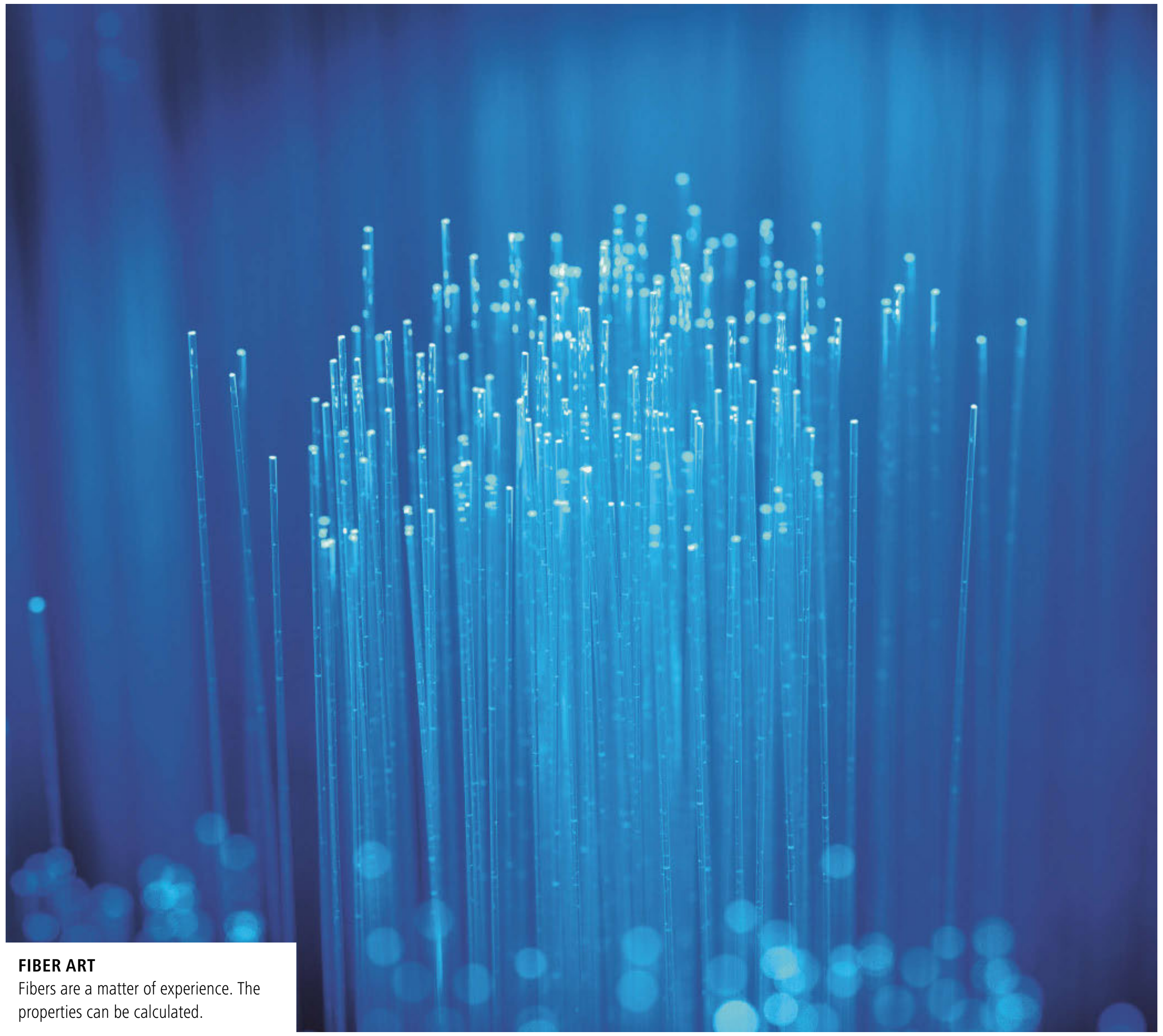
For the transdermal treatment avatar, the Empa researchers will program a complex multiphysical skin model, which is fed with data from sensors on the skin. Biophysical twins of the person, dubbed manikins, are used as helpers for the development of the sensors. Based on the information from the sensor-covered mannequins, physiological values and reactions of a real patients can be estimated, such as changes in skin temperature or perspiration rate. The manikins and a linked-up computer model are already an established system at Empa for simulating human physiological responses. The system will now be used to set up the considerably more complex digital human doppelgangers, which are governed by a vast number of variables. "After all, not only does the virtual twin have to respond to changes; it also needs to predict drug dosage safely and individually," says Defraeye. ■

EMPA'S SIMULATION NETWORK

Back in 2016 simulation experts from several fields of research joined forces to form the "Empa Modeling & Simulation Group". They share simulation software, bounce ideas off each other about strategies, and regularly invite guest scientists to give talks. The goal is to solve computationally challenging problems in physics, chemistry, materials science and engineering, ranging from the nanoscale to the environmental arena.

www.empa-akademie.ch/multiscale

Further information on the topic is available at www.empa.ch/web/s604/nanoreaktor



FIBER ART
Fibers are a matter of experience. The properties can be calculated.

Photo: istock/Getty Images

HOW TO PROGRAM MATERIALS

Can the properties of composite materials be predicted? Empa scientists have mastered this feat and thus can help achieve research objectives faster. This leads, for instance, to better recycling techniques and electrically conductive synthetic materials for the solar industry.

Text: Rainer Klose

Ali Gooneie simulates on his computer what holds the world together right at its very core: atoms, molecules, molecular chains and bundles – then lumps and fibers, which emerge thereof. With his calculations, the Empa researcher can also explain properties we can feel with our fingertips: smooth and rough surfaces, flexible and rigid materials, heat-conductive substances and insulators.

Many of these properties have their origin deep inside the materials. Metal or wood, plastic or ceramics, stone or gel – all of these have been examined many times before. However, what about composite materials? How do the properties of such materials come about and how can they be altered in a desired way? A tedious trial-and-error approach in the lab is no longer sufficient in today's fast-paced research; nowadays, you need computer-assisted predictions to be able to decide quickly which experimental path you will have to take.

Gooneie is one of many computer simulation experts who work in various research labs at Empa. He studied polymer technology at Amirkabir University of Technology in Tehran and did his doctorate at the University of Leoben in Austria. "Although after my engineering degree I immersed myself ever deeper in the world of physics formulae, I never lost touch with the real world," he says. "For me, simulations are not an end in themselves. I use them to explain the effects we observe in materials."

PAST AND FUTURE
Ali Gooneie looks at a sample from his most recent research project: electrically conductive polymers. The first calculations for his next project are sketched out on the blackboard.

Photo: Empa

WHAT DOES A HAIR FEEL LIKE? AND WHY?

In order to understand what exactly Gooneie is calculating, it is worth considering a biological polymer composite fiber material we all know very well: hair. Freshly washed, it feels soft and flexible. When it is dry, it crackles like electricity; and when wet, it squeaks like rubber. We can cut it, pull it out, singe it, perm it, bleach it and blow-dry it. But where do all these properties come from?

Hair consists of individual amino acids, which combine to form long-chain proteins known as keratins. These long keratin molecules bond to form threads and fiber bundles. A complex made of cell membranes cements these fiber bundles together. These fiber bundles are encased by several layers of dead horn scales lying staggered on top of each other like the scales of a pinecone. Therefore, the properties of hair would be inexplicable if only the basic chemical building blocks – the amino acids – were considered. Understanding the overarching structure is crucial.

So let us, in our minds, zoom out of the chemical structure and see the molecules only as globules, which are connected like on a pearl necklace. Now the picture is no longer determined by chemistry, but by the collisions and friction effects of these pearl chains. Experts use coarse mathematical models for their calculations.

Eventually, we arrive in a dimension that we can see and feel: the millimeter range, where hair is considered a homogenous material – the fine structure is no longer important. The material's macroscopic properties can be described and predicted using the "finite element method".

DETAILED UNDERSTANDING OF FIBERS

Until only a few years ago, there was no such multidimensional approach in the polymer composites sector. With his research at the University of Leoben, Ali Gooneie had refined this approach, which made him a perfect fit for Empa. The simulation expert moved to St. Gallen and is now conducting research in Empa's Advance Fibers lab led by Manfred Heuberger.

One of Heuberger's research goals is to refine synthetic fibers – an economically important topic: These days, around two thirds of all fibers used worldwide are produced synthetically. A synthetic fiber is considerably more than a fine plastic filament. They only become "fibers" if their molecular structure comprising small crystals and aligned molecules is geared towards the desired properties – such as flexibility or firmness. Only if the fiber structure is known from the nanometer to the micrometer scale can the properties of the product be set specifically during processing.

CONDUCTIVE POLYMER COMPOSITES

Gooneie has already overseen several projects. For instance, one was aimed at embedding carbon nanotubes (CNT) in a polyamide matrix. At the right dosage, CNTs can give a synthetic material electric conductivity – which makes this material interesting for the photovoltaics industry, for example. But what is the perfect amount of nanotubes to be mixed in? Should the tubes be the same length or would a mixture of lengths provide better results?

So far, it has been common for composite researchers to narrow down and solve the problem at hand with a series of experiments. Ali Gooneie, however, tackles the problem from a theoretical angle and uses his multi-dimensional simulation methods. The solution he came up with: A mixture of CNT with different lengths yields electrical conductivity the fastest. Ultimately, he succeeded in predicting the way, in which the nanotubes are arranged in the polymer – irrespective of the speed, with which the processing takes place.

At the same time the calculations were carried out, the researchers got their first experiment going: In a hot extruder at 245 degrees Celsius, they mixed nanotubes in various proportions into

"For me, simulations are not an end in themselves. I use them to explain the effects we observe in materials"

the polyamide matrix. It turned out that an admixture of 0.15 percent by weight yielded the best results in terms of electrical conductivity. Hand in hand with lab experiments, applied mathematics provided an elegant solution to the problem.

GENTLE PET RECYCLING

Simulation calculations can also achieve a lot in recycling projects. The Swiss collected almost 48,000 tons of PET bottles in 2018. From this, industry gained 35,000 tons of recycled PET. The synthetic material is highly sought-after as it is mechanically resilient, air and gas-tight, and can withstand high temperatures. However, PET cannot be recycled an unlimited number of times. If the material is remelted too often, chemical reactions take place within the material: The molecules oxidize, cross-link and form lumps, and the material becomes viscous and translucent.

An additive called DOPO-PEPA could change all this. In fact, the material is a flame retardant developed by Empa researcher Sabyasachi Gaan, also in the Advance Fibers lab. Now the researchers want to explore whether it can also serve as a lubricant and preservative for PET recycling. Gooneie began by estimating whether DOPO-PEPA can be mixed into PET at the intended temperature at all. Then he calculated how the pearl necklace of PET molecules would move in the melt, how the DOPO-PEPA molecules would squeeze between them, and when an equilibrium would appear in the mixture.

The result: An admixture of a few percent of DOPO-PEPA is already sufficient to allow recycled PET to flow well. Thanks to higher mathematics at Empa, recycling will soon run much more smoothly. ■

Further information on the topic is available at www.empa.ch/web/s402

3D-PRINTED IMPLANTS

PRECISION
Additive manufacturing (AM) is a complex task. It takes expertise in materials, the production process and the post-processing of the printed parts.

3D printing is finding its way into industrial manufacturing. This technology and the increasing digitalization of design and manufacturing processes – keyword "Industry 4.0" – will also play a central role in medical technology in the future. A new technology transfer center in the canton of Solothurn will help to transfer know-how from science to industry – and at the same time accelerate research.

www.empa.ch/web/s604/m4m

HOW SAFE IS GRAPHENE?

TINY
Graphene has been hailed the material of the future. But is it safe for humans and the environment?

Graphene is considered one of the most interesting and versatile materials of our time. The application possibilities inspire both research and industry. But are products containing graphene also safe for humans and the environment? A comprehensive review, developed as part of the European graphene flagship project with the participation of Empa researchers, investigated this question. It turns out that further research is needed to predict the relationship between the graphene structure and its activity.

www.empa.ch/web/s604/graphene-safety

Photos: istock/Getty Images, Empa

Photos: www.jungfrau.ch, www.bruag.ch

SCIENCE AT DIZZYING HEIGHTS

Since its inauguration in 1931, the Jungfraujoch High Alpine Research Station has been open to scientists from all over the world. It thus established Switzerland's reputation as an international host country with excellent research facilities. For this pioneering spirit, the European Physical Society (EPS) and the Swiss Academy of Sciences (SCNAT) honor the research station with one award each as a historical site of physics and chemistry. Empa has been conducting research on the Jungfraujoch since the 1970s. The measuring station on the Jungfraujoch analyses the spatial distribution and trends in our atmosphere, ecosystems and oceans and provides valuable data for the development of global emissions.

www.empa.ch/web/s604/top-of-europe-auszeichnung

COLD
Empa is monitoring air quality on the Jungfraujoch at an altitude of 3,450 meters since 1972.

FIREPROOF
Laser-cut ornaments made of wood adorn hotel lobbies and cruise ships.

NON-TOXIC FLAME RETARDANT

Together with BRUAG Fire Protection AG, Empa specialists have developed a new flame retardant for wood and wood-based materials. The colorless additive, which can be easily mixed with coatings and cellulose materials, opens up new applications for wood processing companies.

www.empa.ch/web/s604/eda-dopo-reach

PEAK POWER
Solar energy is produced during the day. How can it be stored?

Photo: Empa

FOR HOME AND GRID

Solar systems on the roofs of residential buildings often produce energy precisely when the residents can't actually use it. Stationary batteries enable this energy to be utilized in the evening, at night or on a rainy day. A research project at Empa is investigating whether the use of stationary batteries makes economic sense for the consumer while at the same time offering advantages for energy suppliers.

Text: Karin Weinmann

An increasing number of Swiss roofs have solar panels on them. This poses challenges for grid operators. After all, on a sunny day vast amounts of electricity can suddenly flow into the grid. If the grid is not built to withstand this surge, in the worst-case scenario it can even collapse. One possibility to prevent this kind of blackout would be to expand the grid infrastructure to withstand far greater maximum loads. However, this leads to considerably higher costs.

One alternative would be to prevent the grid from being inundated with large amounts of electricity. This would mean temporarily storing "surplus electricity" that had been produced locally. But is it worth the effort for the operators of the roof systems? What are the storage options? And can the power grid actually be stabilized in this way?

Empa researcher Philipp Heer set about exploring these questions. For his project, he used real measurement data from the local power and heat supplier Glattwerk in Dübendorf and studied two battery types: lithium ion batteries and salt water batteries of the sodium nickel chloride type, also known as ZEBRA battery (see box). In computer simulations, Heer calculated 160 different scenarios, varying both battery sizes as well as the entire system, which may be based on one central or several decentralized battery storage devices.

> "Batteries that are optimized for multiple targets at the same time achieve 15% higher yield."

PROSUMERS AND DISTRIBUTORS

There are two parties with different interests. On the one hand, the grid operators: These companies run power grids in the mid and low-voltage range in order to distribute electricity to the consumers. In Switzerland, there are around 650 grid operators, which, taken together, maintain a grid covering around 200,000 kilometers. Their goal is to minimize the risk of a blackout on the grid, without having to expand the grid to accommodate a maximum load that can only be expected from time to time.

On the other hand, there are the consumers who simultaneously produce electricity themselves – referred to as prosumers. Their objective is to minimize their energy costs. This means that the self-produced electricity is supposed to be consumed when energy costs are high. As the feed-in tariffs are currently very low compared to the reference tariffs, it is hardly worth it for the prosumer to feed the generated electricity into the grid.

How can stationary batteries now be used in such a way that both sides stand to benefit? Imagine a sunny day: The photovoltaic systems provide power during daytime, i.e. when many residents are not at home. Feeding the electricity into the grid has drawbacks – for both sides: Consumers need to purchase the electricity in the evening again at a higher price, and grid operators have to expand their network to be able to accommodate the surge of electricity. If the self-produced electricity is stored temporarily in local batteries, on the other hand, prosumers can consume it in the evening "for free" – thereby relieving the pressure on the grid.

SHARING ECONOMY FOR BATTERIES

Of course, batteries are not without disadvantages. Their efficiency is not 100%. Overall, the average energy consumption on the entire grid, therefore, increases if battery storage devices are being used. In order to increase the battery's usefulness for all parties, it would thus make sense to optimize the battery controls to accommodate the different interests of the stakeholders, instead of merely maximizing cost savings for the individual prosumer. In the worst-case scenario, all prosumers would fill their batteries with surplus PV electricity until they are fully charged at midday, for instance – and then suddenly all feed the electricity into the grid at the same time. The grid operators would then experience another peak in fed-in energy.

Optimized battery controls would charge the battery precisely when more power is added to the grid than is drawn from it. And this pays off: "Our simulations reveal that batteries that are optimized to accommodate the combined control objectives achieve a yield that is 15% higher than those, which are only optimized in favor of a single stakeholder," explains Heer. Small, decentralized batteries can already be worth it for both parties – but larger, shared storage systems could carry even greater advantages.

VERIFYING SIMULATIONS

In order to see whether the results of the simulation also prove to be true in reality, Heer and his team are now planning on testing battery controls that have been optimized in this way in a real system. To this end, they use Empa's energy demonstrator, the Energy Hub, or ehub for short. The different NEST units act as prosumers, which produce and consume differing quantities of energy. Both a salt water and a lithium ion battery are on hand for the tests. "If the simulation results prove themselves in reality, the local grid in Dübendorf could also serve as a pilot project," says Heer. ■

THE ZEBRA BATTERY

The salt water $NaNiCl_2$ battery, also dubbed ZEBRA battery, was developed in Pretoria, South Africa, in 1985. ZEBRA is an acronym of the project's name, "Zero Emission Batteries Research Activity". The batteries are based on raw materials, which are available in abundance compared to other battery technologies, such as lithium ion batteries. They are operated at temperatures of around 300 degrees Celsius.

Further information on the topic is available at www.empa.ch/web/energy-hub

EMPA ZUKUNFTSFONDS – RESEARCH FOR TOMORROW

Mobility without limits, a growing need for energy, health and performance into old age, a comfortable living environment – how can all these requirements be satisfied if, at the same time, we want to treat the Earth with care and pass it on to our children? The answer lies in the development of innovative technologies and novel materials, which enable us to shape our future in a sustainable and prosperous way, and make it worth living in. This is precisely what we set out to do at Empa. Our researchers develop solutions to the challenges of our time. To achieve this, they have to push the boundaries of science and technology and constantly venture into new territory. In doing so, we help boost the international competitiveness of Switzerland like no other research institution in our country.

Since 2001, Empa has regularly issued what are known as "International Research Calls", where Empa researchers with new, highly innovative project ideas can apply for funding. Many of these ideas have spawned exciting new technologies, which would not have come about if it weren't for this initial financial support. With additional donations, the number of funded projects could be increased and promising ideas given the opportunity to be realized. With this in mind, Empa launched the Zukunftsfonds and is setting up professional fundraising. The Zukunftsfonds awards funding donated to Empa by companies, foundations and private individuals for a good cause. Thanks to this additional funding, we are able to support research projects that do not (yet) receive any funding: pioneering ideas, which may one day make a key contribution towards a more sustainable world.

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Empa
Zukunftsfonds

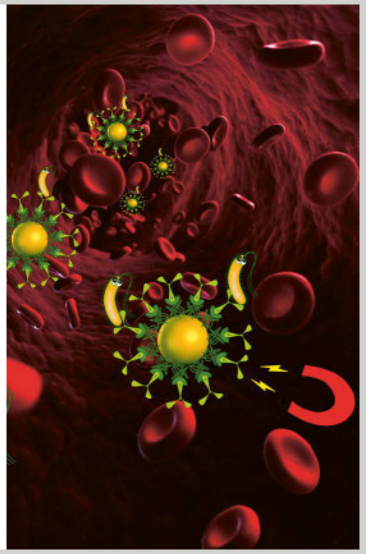
Further information on the topic is available at www.empa.ch/zukunftsfonds.

Photos: istock/Getty, Empa, Eawag

PROJECT EXAMPLE 1

Zeroing in on sepsis

Sepsis is a life-threatening infection that has spiraled out of control and affects as many as 15,000 people a year in Switzerland; one in every three cases is fatal. It is difficult to treat sepsis patients as the pathogen is often hard to detect. As a result, the therapeutic measures are frequently unspecific antibiotics, the excessive use of which is one reason for the increasing resistance to them. Backed by the Novartis Foundation, the project is investigating a new possibility to treat sepsis. It involves using magnetic nanoparticles to directly remove microbes circulating in the blood. This should one day enable pathogenic bacteria to be removed from the patients' blood and to be classified quickly and efficiently, such that a targeted antibiotic treatment can swiftly be initiated.



PROJECT EXAMPLE 2

Improved water filters

Every year, hundreds of millions of people fall ill after drinking polluted water; millions even die as a result. Although clean water is often available in bottles, only the wealthier parts of the population can afford it. For what is known as the "basis of the population pyramid", affordable and reliable methods are necessary to remove pathogens safely from drinking water. Although conventional filters can easily remove bacteria and small organisms, these filters do not work for viruses, which are over 50 times smaller than bacteria. The project's goal is to develop new, specially coated materials, which can capture harmful viruses when integrated in the water filter. The project was made possible by a private donation.

PROJECT EXAMPLE 3

Customized vibration damping

Macroscopic crystal structures can cushion undesirable vibrations or filter noise – without any electronics or electricity. They are lighter and more solid than conventional damping materials, and can even be tailored to the intended purpose. A research project industrial companies have barely ever tackled. And this is why it was funded by the Empa Zukunftsfonds: Are there materials that boast a high mechanical load-bearing capacity, but are still capable of damping sound and vibrations due to their inner structure? After three years of research, proof was finally at hand: Such materials really do exist. Possible applications for these "phononic crystals" include noise reduction in vehicle construction and mechanical engineering, but also earthquake proofing for entire buildings.

COOLING WITH THE SUN

Can you cool with waste heat? Sure. A Swiss research project involving Empa, which ended in November, demonstrated this in an impressive way. Now a large-scale EU project is starting: industrial cooling – thanks to the Spanish sun.

Text: Rainer Klose I Graphic: Hug & Dorfmüller Design AG

Every now and so often heating something up is unavoidable. Potato soup or risotto, tomato sauce or chocolate pudding – all unfeasible without heat. A small proportion of the heat ends up in the stomach, while the remaining majority (inadvertently) warms the surroundings. If we think outside the kitchen, we soon spot the next waste heat suspects: If our laptop gets that warm, just imagine how much more heat an internet provider's server park must produce. We like to have hot showers and let the warm water go down the drain; it's exactly the same story at the launderette around the corner. Then we head out the door and start our car: Its engine converts more than three quarters of the energy contained in gasoline into (waste) heat – and only the smaller proportion into the desired propulsion.

Thus far, all this thermal energy has been lost. This is now bound to change. A pan-European research consortium is starting to "collect" waste heat. A team from Empa is also on board.

Matthias Koebel first became interested in collecting heat through the THRIVE project ("Thermally driven adsorption heat pumps for substitution of electricity and fossil fuels"), a Swiss research project initiated by IBM Research Zurich. The lab in Rüschlikon asked itself a simple question: Can anything useful be done with the vast amount of waste heat from a large computer center? Is the energy perhaps sufficient to actively cool this data center? The IBM researchers called in a series of Swiss materials and systems specialist as partners: ETH Zurich, the University of Applied Sciences Rapperswil (HSR), the School of Business and Engineering Vaud (HEIG-VD), the Paul Scherrer Institute (PSI) – and Empa. The goal was to develop an adsorption heat pump that converts waste heat into cooling capacity.

> Koebel's team succeeded in developing a new absorption material that is three times more powerful.

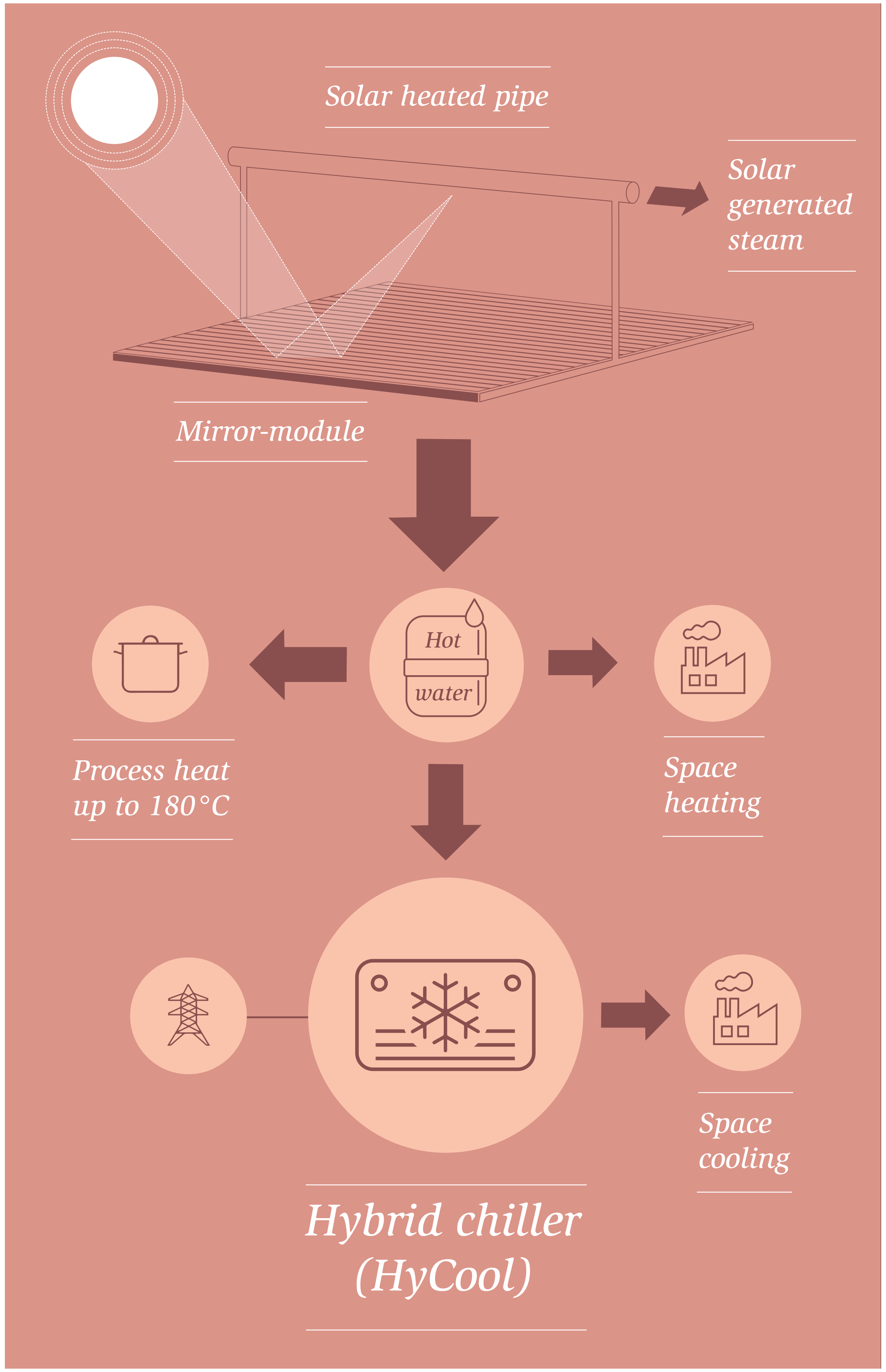
Adsorption heat pumps use heat to generate cooling capabilities. In the plant's cool zone, water evaporates and provides cooling. The water vapor is captured by an absorber material in the warm zone. Once the absorber material is saturated, it is dried again with heat from outside and is available for another cooling cycle.

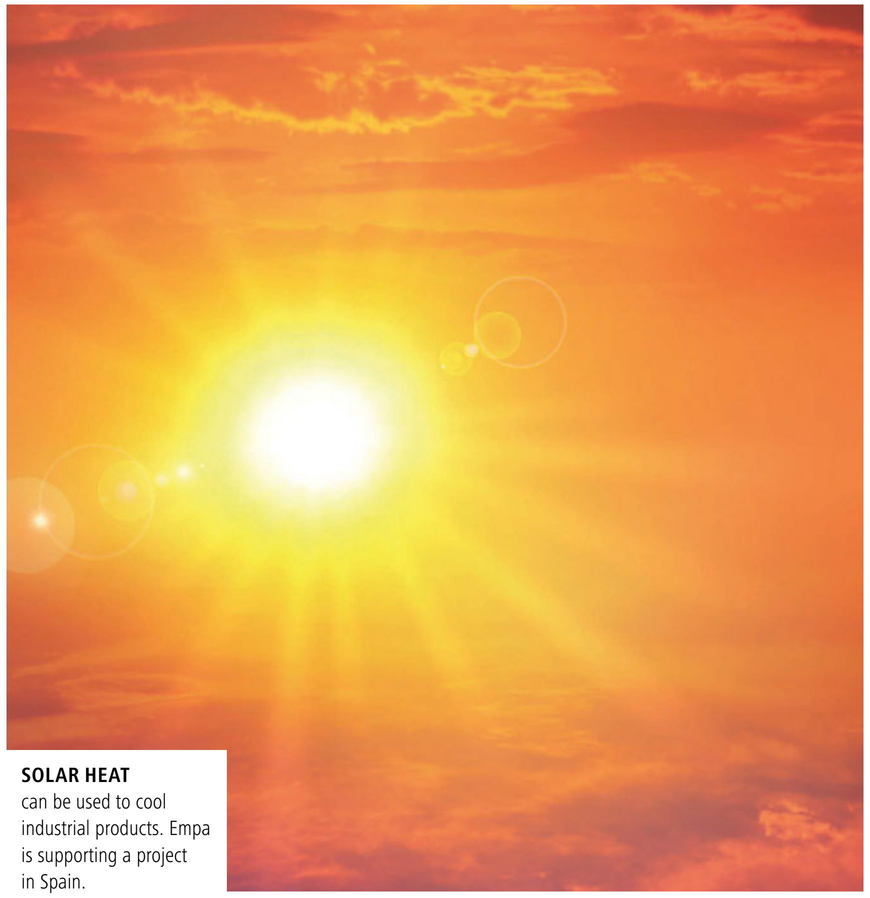
PROTOTYPE OF COOLING SYSTEM

In November 2018, after 47 months in the making, the project drew to a successful close. Within the scope of THRIVE, the HSR researchers initially made a research heat y ten times more powerful. This would be sufficient to air-condition a detached house in Southern Europe in the summer.

Adsorption heat pumps, however, are not just useful to cool individual houses or server parks; they could also improve the efficiency of district heating grids, as the researchers from HEIG-VD calculated. If in future they were to be used for the stationary heat supply, this would result in energy savings of four to nine percent, and another three to six percent in the industrial waste heat sector, according to calculations by PSI researchers. Koebel's team succeeded in developing a new absorption material with a cooling output that is over three times higher than the initial material at the start of the project.

The Empa researchers are now looking to build on this newly developed material. "We developed a porous ▸





SOLAR HEAT can be used to cool industrial products. Empa is supporting a project in Spain.

carbon sponge that is able to absorb a vast amount of water thanks to its micropores, which makes it just the ticket for adsorption heat pumps," Koebel explains. The material is made from synthetic resin by way of pyrolysis. "This method enables us to tailor the material to the intended purpose."

CUSTOMIZABLE FOR ANY PURPOSE

This means it will be possible to adapt adsorption heat pumps for different purposes in the future. For instance, a wood pellet heater generates higher temperatures than the flow of waste heat in a large kitchen. In order to convert the available heat into cooling capacity as efficiently as possible, the heat pumps' absorber material needs to be tuned to the heat source and

> "We have developed a porous carbon sponge that is just the ticket for adsorption heat pumps."

the desired cooling level, too. "We start by defining the suitable material based on material parameters and then manufacture it," says Koebel.

Thanks to this expertise, the Empa team is now involved in a new EU research project called HyCool, which was launched in May 2018 and will run for three years. The goal: The aroma manufacturer Givaudan and the Spanish food producer Bo de Debò would like to cover their cooling needs for their production plants solely with the aid of waste heat and solar power. This will involve combining the absorption heat pump with a conventional one to produce what is known as a hybrid heat pump – which consumes additional electricity but is extremely flexible.

SOLAR COOLING FOR SPANISH READY MEALS

The heat required for cooling is to be generated on the roof of a Spanish factory near Barcelona. A 400-square-meter field of mirrors focuses sunlight onto a pipe, where water vapor is produced to provide the necessary cooling capacity via the absorption heat pump. In the same way, the factory receives process heat of up to 180 degrees Celsius and heat of up to 65 degrees for the hot water supply and to heat the factory in the wintertime.

We will still need to warm things up in the future. We just have to learn to be much more careful with the waste heat we produce. Saving fossil fuels also means avoiding wasting energy by making better use of waste heat at an industrial level. ■

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

Photo: istock/Getty Images

THE WOOD MAGICIAN

The new head of Empa's Cellulose & Wood Materials lab, Gustav Nyström, has taken everyone by surprise by setting unconventional goals. However, paper batteries and nanocellulose sensors have one main objective: to help solve fundamental, socially relevant questions.

Text: Andrea Six I Photos: Markus Mallaun

▶

When Gustav Nyström sees a tree, he sees more than just a biological marvel. "A tree is a great example of how functionality, structure and beauty come together in nature and evolution," says the new head of Empa's Cellulose & Wood Materials lab. For him, the trunk, leaves and roots are also a source of novel materials, which enable a wealth of potential new applications. And the fact that forests cover roughly one third of Switzerland and provide a sustainable, readily available resource is what makes wood so fascinating for Nyström.

REBUILDING WOOD

In times of climate change, the researcher is convinced that we should rely on CO_2-neutral raw materials. And thus he is in line with the current creative minds who design skyscrapers and even bikes made of wood. Nyström also wants to maximize the potential wood harbors as a raw material by equipping it with completely new properties. If wood becomes electrically conductive or magnetic, or if its structure is modified with the aid of microorganisms, for instance, innovative composite materials can be developed for novel applications.

Nyström is focusing on the pressing problems of our time, such as energy storage, and endeavors to find solutions based on new materials. These include batteries made of sustainable raw materials, which degrade on their own in the environment, but also drinks bottles made of wooden components – buzzword plastic waste. With this in mind, his team is developing wood-based polymers and cellulose particles in combination with proteins, which should one day replace problematic everyday objects such as plastic bottles or transparent packaging film, without polluting the oceans in the form of garbage islands. For Nyström, lemonade in cellulose bottles and foils made of environmentally friendly polymers is not just wishful thinking, but an absolute necessity.

GUSTAV NYSTRÖM

CAREER Following his physics degree at KTH Royal Institute of Technology in Stockholm and at Darmstadt University of Applied Sciences, the Swedish-born scientist completed his doctorate in organic electronics and paper-based energy storage at the University of Uppsala in Sweden in 2012.
SCIENCE Before joining Empa, Nyström was a lecturer and senior scientist at the Department of Health Sciences and Technology at ETH Zurich. The 38-year-old has been running Empa's Cellulose & Wood Materials lab since March 2018.

"As a researcher, I want to understand the relationships between these kinds of new high-performance materials. But above all I want my work to contribute to a better future," says Nyström. One of his new projects at Empa is a battery ... made of paper. "Certain structures in wood can be used to store energy," he explains. The Swede's PhD thesis in Uppsala had already focused on energy-saving nanofibrils made of natural cellulose.

DRINKING BOTTLES MADE FROM WOOD

Nyström is focusing on the pressing problems of our time, such as energy storage, and endeavors to find solutions based on new materials. These include batteries made of sustainable raw materials, which degrade on their own in the environment, but also drinks bottles made of wooden components – buzzword plastic waste. With this in mind, his team is developing wood-based polymers and cellulose particles in combination with proteins, which should one day replace problematic everyday objects such as plastic bottles or transparent packaging film, without polluting the oceans in the form of garbage islands. For Nyström, lemonade in cellulose bottles and foils made of environmentally friendly polymers is not just wishful thinking, but an absolute necessity.

He is convinced that the diversity of his team is an essential ingredient in his recipe for success. For instance, he sets great store by having experts from as many different disciplines as possible in his team. It might sound unusual that, as a physicist, he is proving successful in his present research field. Surrounded by chemists, wood scientists and biophysicists, however, the thinking is always flexible and, above all, critical. And only in this melting pot of disciplines can creativity thrive.

The same goes for the researchers' backgrounds. "I appreciate the international nature of our team," says Nyström. "The researchers bring interesting experiences to the table, and we benefit from the fact that different topics are taught in a different style at foreign universities." Nyström himself studied in Sweden and Germany. But this wasn't his childhood dream: "I grew up in the country. When I was a boy, I wanted to become a fisherman. I had no concept of what a 'professor' was." Today, he describes himself as creative, focused and, above all, well organized. "I have three young children. I have to find practical and consistent solutions to strike a good balance between the time I spend on my career and with my family and to be able to cope with my hectic everyday life."

> "Instead of solving the hardest puzzle in the world, sometimes it might be about inventing an easier puzzle."

Moreover, he believes the success of a team is also based on the openness, with which it communicates. "Creativity can only thrive if thoughts and information are shared and challenged." If everyone is reluctant to risk sharing his or her ideas, no new projects will ever come about.

AT EYE LEVEL WITH CANADA

Ultimately, new composite materials should be created in Nyström's lab based on wood and cellulose, the development of which is rooted in all areas of the research field. Proteins from wood pathogens such as fungi, nanocellulose made of algae or fireproof wood – Nyström sees a huge potential precisely in the interplay between different research approaches. "Excellent research can mean finding a piece in the puzzle for a highly complex problem," he says. "However, I find it shrewder to find simpler solutions that could potentially help more people. Instead of solving the hardest puzzle in the world, sometimes it might be about inventing an easier puzzle." And this is precisely why Nyström appreciates combining basic research with industrial applications at Empa. "Internationally, Switzerland is competing with heavyweights like Canada or the US in cellulose and wood research. And we're right up there with them, too." ■

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

INNOVATIONS FROM SWITZERLAND FOR SWITZERLAND

SOUNDS
While the body of a Stradivarius lasts forever, the fingerboard is prone to wear and tear. Tanja Zimmermann, Member of Empa's Board of Directors, reveals an alternative to tropical wood musicians will love.

Guests from business, politics and science met with researchers from the ETH Domain on the occasion of the World Economic Forum in Davos. Federal Councillor Guy Parmelin welcomed some 60 guests. Researchers from ETH Domain then presented projects from their research. Tanja Zimmermann, member of Empa's directorate and head of the Functional Materials department, brought along a special violin: Modified Swiss sycamore maple, which offers the characteristics of ebony – sustainable and completely legal. In the future, this should not only prevent overexploitation in the tropics, but also increase the value of the renewable Swiss raw material.

www.empa.ch/web/s604/empa-at-wef

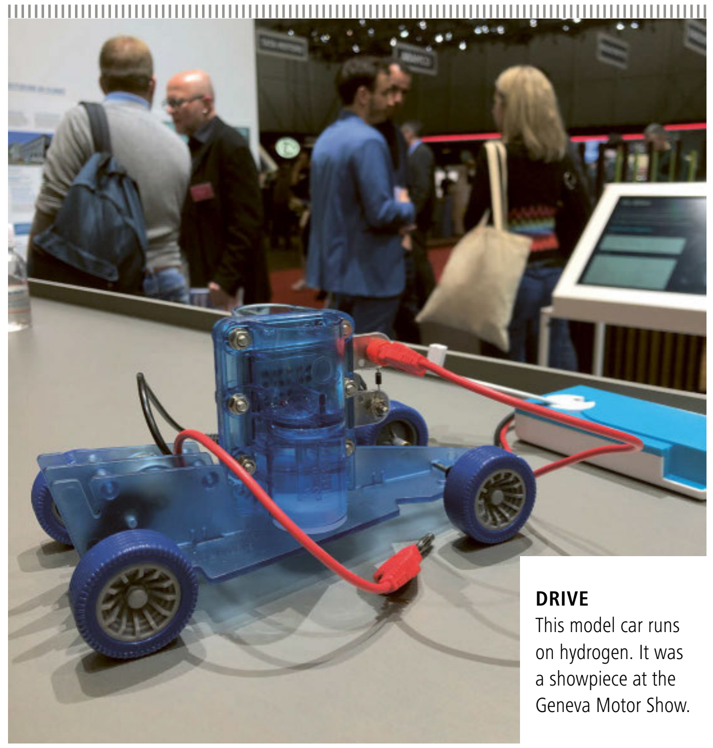
MATERIALS
Swiss textile innovations wow designers in Shanghai.

EMPA AT DESIGN SHANGHAI

Design Shanghai is one of Asia's top design events and takes place every spring. At this year's exhibition, "New Materials and Applications", Empa presented its innovations in the field. These included Sonowood, the Swiss alternative to endangered tropical wood; gold-coated fibers and fabrics; optic fiber sensors; and intelligent textiles. Felix Moser, CEO of Swissnex China, represented Empa as a guest speaker at the event and showcased the Swiss achievements to the audience.

www.designshanghai.com

Photos: Empa (3)



DRIVE
This model car runs on hydrogen. It was a showpiece at the Geneva Motor Show.

THE FUTURE OF MOBILITY IS DIVERSE

From March 6th to March 17th, Empa presented the various ways in which we can gradually replace fossil fuels at the Geneva Motor Show, Hall 6: It is not only electric cars that can be operated with sustainably generated electricity from the sun, wind and hydroelectric power. This electricity can also be used to produce hydrogen, which can be used very efficiently in fuel cell vehicles. But even gasoline and diesel vehicles can run on sustainably generated electricity. To do this, electricity must first be converted into hydrogen and then – in a further step using CO2 from the ambient air – into synthetic fuel, so-called e-fuels. "The mobility of the future is a major challenge. In addition to technical innovations and changes, we also need to change people's behaviour," says department head Brigitte Buchmann. "This is why all new forms of mobility are so important. In order to master the changeover, we have to develop various paths further and not rely on a single technology."

www.empa.ch/web/s604/gims-2019

EVENTS
(IN GERMAN)

23. MAI 2019
Topical Day: High-Performance Multiscale Modeling
Zielpublikum: Wissenschaft
www.empa-akademie.ch/multiscale
Empa, Dübendorf

24. MAI 2019
Kurs: Elektrochemische Charakterisierung und Korrosion
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/korrosion
Empa, Dübendorf

13. JUNI 2019
Kurs: Folgen der Miniaturisierung in der Elektronik
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/emin
Empa, Dübendorf

26. JUNI 2019
Kurs: Elektrochemische Charakterisierung und Korrosion
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/korrosion
Empa, Dübendorf

3. JULI 2019
Energie und Dekarbonisierung – zwischen Forschung und Praxis
Zielpublikum: Industrie
www.empa-akademie.ch/energie
Empa, Dübendorf

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

THE PLACE WHERE INNOVATION STARTS.

Empa
Materials Science and Technology