Faszination **Forschung**

TUM Research Highlights
Technical University of Munich
The Science Magazine
September 2023 | Edition 30

Biophysics: Flows Govern how Veins Adapt

Global South – Five Exemplary Research Projects
Biomathematics – Defeating Diseases with Artificial Intelligence
Geoinformatics – Urban Simulations Provide Answers for the Future

ISSN 18653022

Nominal charge
EUR **9.00**

Dear TUM friends and associates,

Artificial intelligence (AI) is changing many aspects of our day-to-day lives – often without us even noticing it. As ChatGPT makes AI accessible to all, growing numbers of people are waking up to the potential of this disruptive technology.

Africa, the continent of the future, is producing AI innovations with extraordinary dynamism. However, in addition to technological factors, it is also vital to consider ethical aspects. In Ghana, Prof. Christoph Lütge is bringing AI experts together to examine issues surrounding responsible and just AI, even in the development stage. This is one of the research topics we explore in the focus on Global South displayed in this issue of Faszination Forschung.

Prof. Andrea Winkler is developing a cost-effective blood test to diagnose tapeworm infections, which are the cause of around a third of all epilepsy cases in Tanzania. Prof. Frank-Martin Belz and his team are working to assess how establishing sustainable power supplies in rural regions of Africa influences start-up activities and the knock-on impacts on family and village structures.

Water, energy and food are scarce resources – and are closely linked. For example, water and energy are essential for producing food. Prof. Jörg Drewes and his team have adopted a circular approach in their efforts to make Leh, a small town in the Himalayas, less dependent on external water supplies.

The Amazon absorbs vast quantities of carbon dioxide, thereby acting as a brake on global warming. In an international project, Prof. Anja Rammig aims to find out how much CO_2 the rainforest can absorb in future in order. Its goal is to make climate models more reliable. Will the rainforest simply grow faster with more CO_2 available? Or might other factors curb its growth?

In addition to this focus on collaborative research projects in the Global South, this issue of Faszination Forschung presents further insights into exciting research underway at TUM. Prof. Karen Alim is fascinated by the physics of flows and strives to understand the dynamics of networks ranging from the human bloodstream to the veins in leaves and the nutrient supply pathways in a mushroom culture.

Meanwhile, Prof. Thomas Kolbe is asking ambitious questions: “Could solar thermal technology be used to heat the water in residential buildings in Munich? How about using district heating or heat pumps to heat the apartments themselves?” His geodata-based semantic city models simulate the potential energy savings.

Working at small scales, Prof. Eva Weig is taking giant leaps forward by developing nanostrings that can be made to vibrate like a guitar string. Although this is still basic research at this stage, potential applications have already been identified. For example, the nanostrings could be applied as ultra-sensitive sensors or as temporary storage in quantum computers.

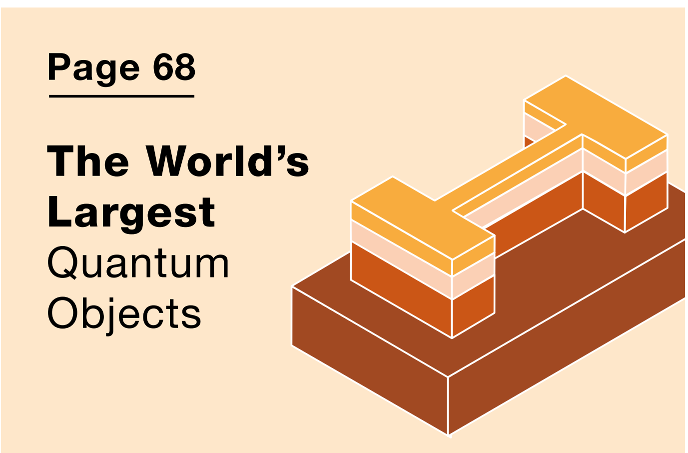
I would also like to take this opportunity once again to congratulate our Leibniz Award winner, Prof. Fabian Theis. This issue of Faszination Forschung details how he combines mathematics, AI and biosciences to analyze how a person’s cells function depending on factors such as their age, sex, lifestyle and different diseases.

I hope you enjoy reading this issue and benefit from new insights and fresh inspiration!

Yours sincerely,

Thomas F. Hofmann, President

Picture credit: Astrid Eckert/TUM



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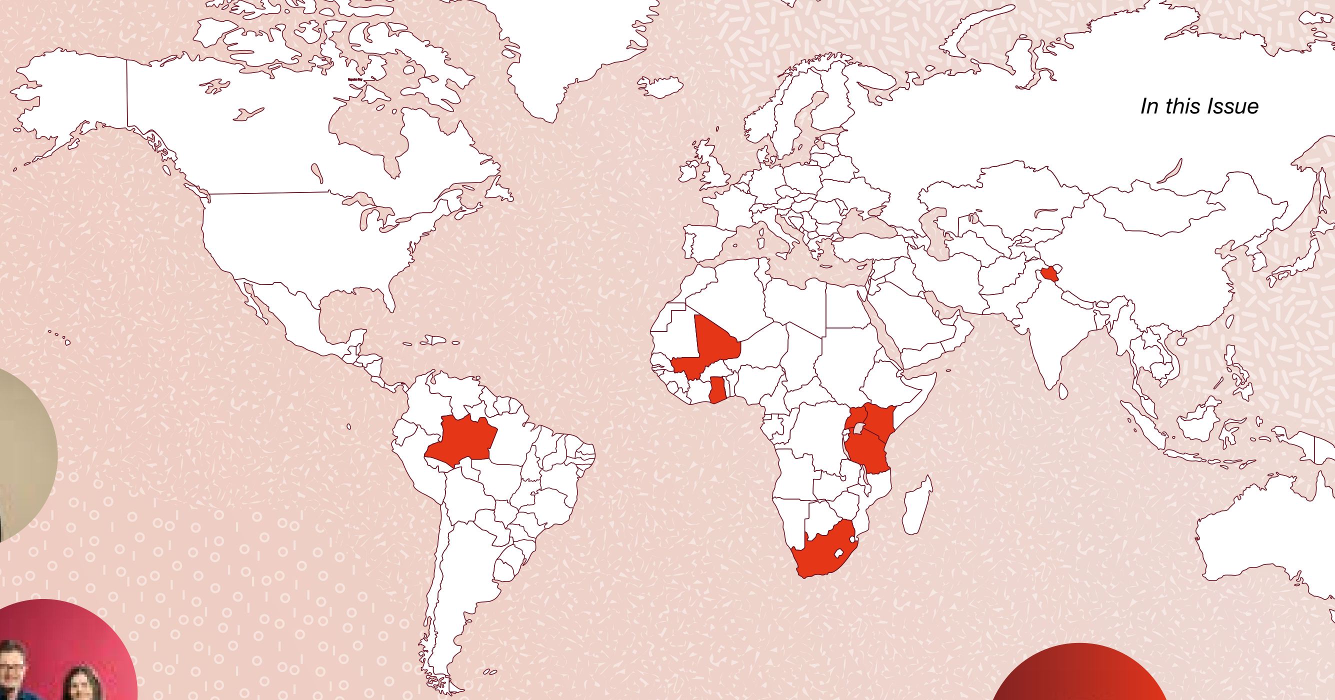
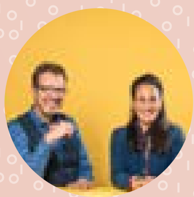




D	**German edition available as a PDF here:**
	www.tum.de/faszination-forschung-30

Picture credits: Astrid Eckert/TUM, Stefan Woidig, Stephan Rumpf, Juli Eberle; Graphics: ediundsepp (source: TUM)

Flows Govern how **Veins Adapt**

The physics of flows shapes living networks. This applies to the human circulatory system, to vein structures in leaves and to the tubes making up fungal networks. Prof. Karen Alim, a biophysicist at TUM, and her team are investigating how exactly flows cause veins to adapt and grow. The end result could be new therapies against pathological changes in blood vessels that are based on purely physical principles.

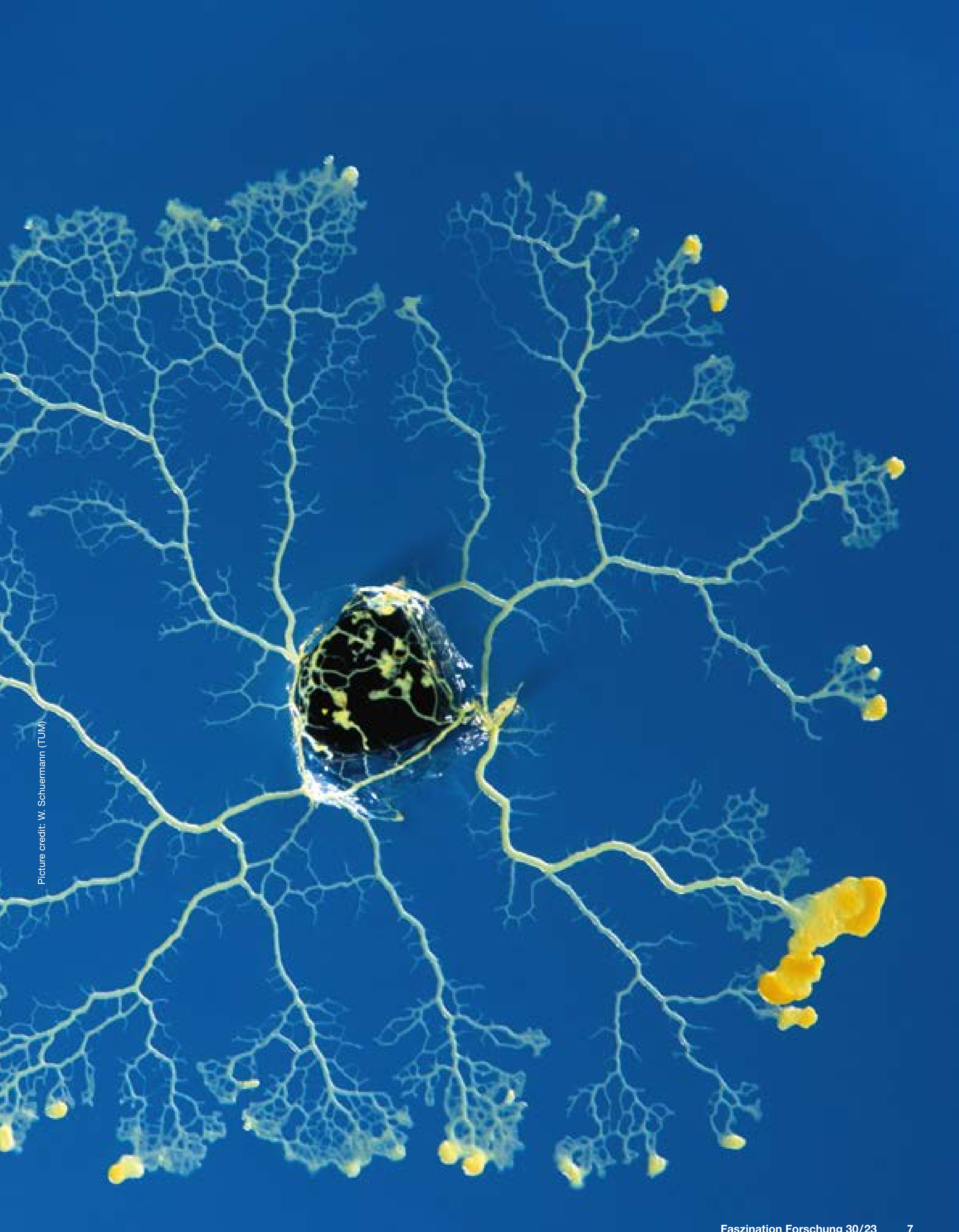
Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Ströme regeln Wachstum von Adern

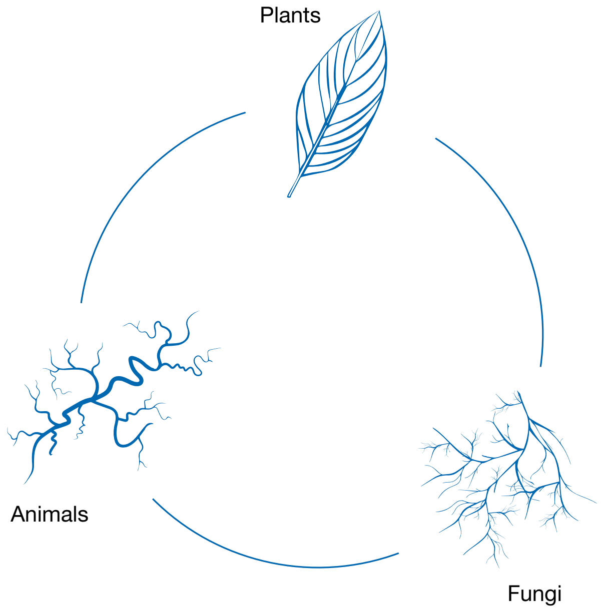
D

Die Physik der Strömungen hat einen fundamentalen Einfluss auf die Entwicklung von Netzwerken – auch auf das komplexe Netzwerk aus Blutgefäßen. Prof. Karen Alim, Biophysikerin an der TUM, untersucht mit ihrem Team, wie genau Strömungen Adern veröden und neu bilden lassen.
Doch die Analyse der Blutströme direkt in Tier oder Mensch gestaltet sich sehr schwierig. Daher blickten die Forschenden auf die Versorgungsbahnen vom Schleimpilz der Art *Physarum polycephalum*. Hier gelten die gleichen physikalischen Prinzipien wie im Blutkreislauf. Das Ergebnis: Neben der Scherrate – einem Wert für die unterschiedlichen Geschwindigkeiten einer Strömung – entscheidet auch die gesamte Netzwerk-Architektur über das Schicksal einzelner Adern.
Nun untersucht Alim auch kleine Netzwerke aus menschlichen Gefäßzellen mit einem Biochip. Zeigt dieses Chipmodell, wie man Adern gezielt vergrößern oder veröden lassen kann, könnten auf rein physikalischer Basis neue Therapien gegen krankhafte Veränderungen von Blutgefäßen entstehen. □

Link
www.bpm.ph.tum.de



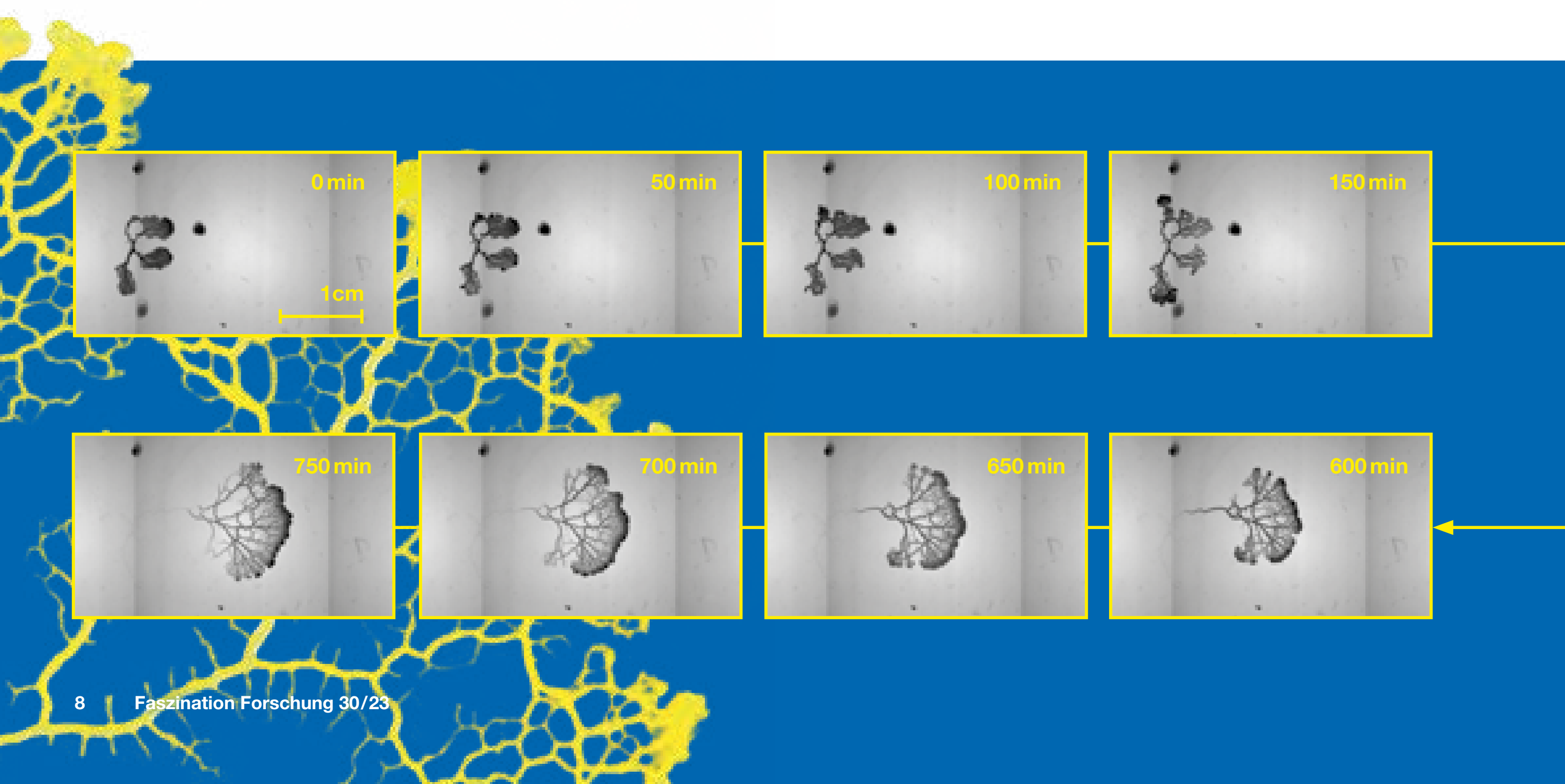
Picture credit: W. Schuermann (TUM)

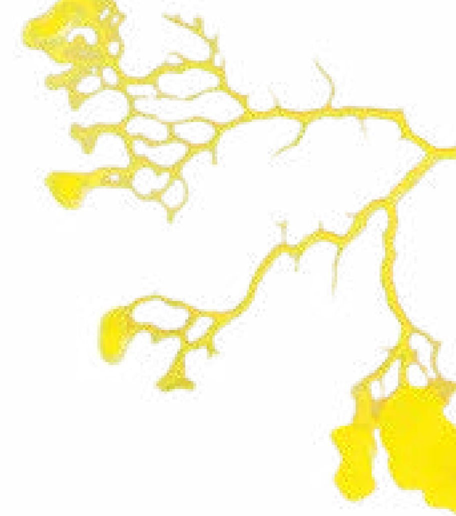


Living tubular networks are a fundamental building block of life. They form the vessels pervading us as well as transport veins in leaves. They also exist in pure form as the body plan of fungi and slime molds.

Every day, the human heart beats around 100,000 times – fairly slowly when we're sitting down and very fast when we're running. Although this hollow muscular organ weighs only 300 grams, it pumps up to 7,000 liters of blood through centimeter-wide arteries to ultra-fine capillaries measuring just micrometers across. This complex network of veins and arteries is constantly reorganizing itself, with some blood vessels vanishing and new ones forming. It is precisely this continuous process of growth and decay that TUM biophysicist Karen Alim and her team are working to understand in more detail. Ultimately, a blood vessel's fate is determined not solely by behavior, environment, nutrients and toxins. The physics of flows also plays a fundamental role in the organization of these networks.

"A network reorganizes itself as soon as blood flows through it," says Alim. In living systems and physical systems, there is always a drive to achieve the maximum possible benefit – in this case, an optimal circulatory system – with the least possible effort. However, scientists are still in the dark about many of the finer details of the relationship between blood circulation and blood vessel dynamics. This means that physicists need not look to the vastness of space or peer into the smallest quantum structures to make new discoveries. Even close at hand, in our own bodies, there are still unexplained processes whose cause and effect can be deciphered using the language of physics. "We have an opportunity to play Newton here," says Karen Alim, referring to the field of biological physics she loves so much. "In my youth, for example, I was fascinated by the lotus effect. It inspired me to examine more closely the multifaceted techniques and mechanisms at work in nature."





It all lies in the physics

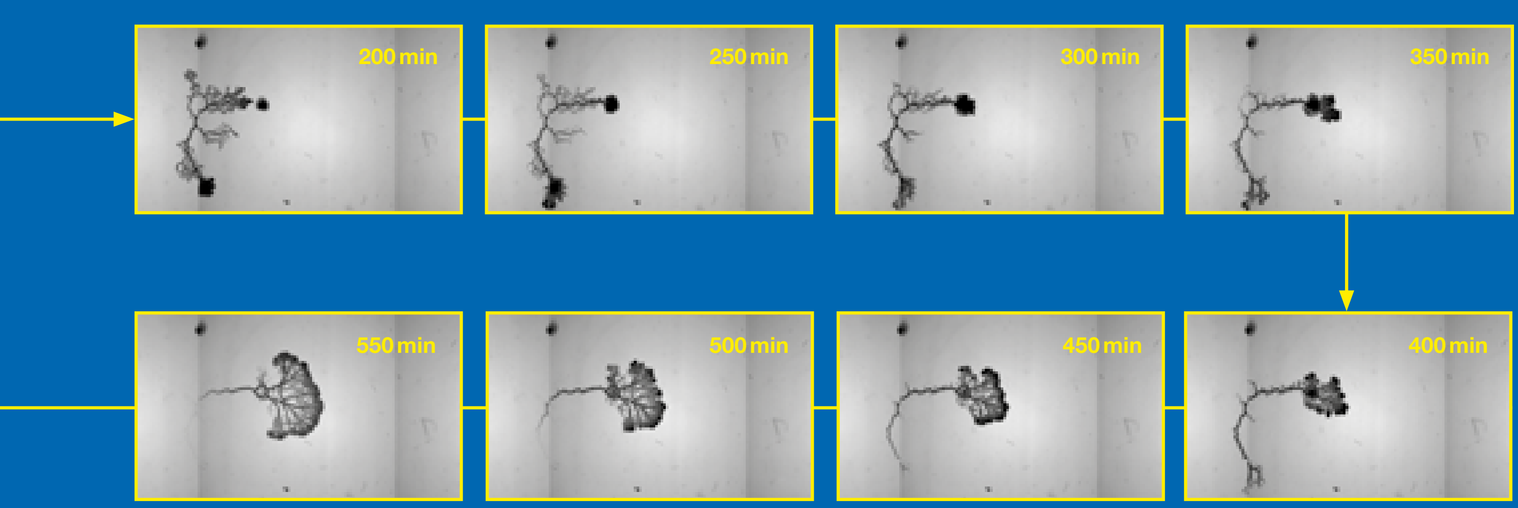
Just as legend has it that a falling apple inspired in Isaac Newton the idea to describe gravity, so observation and experimentation today remain the foundation of models and generally accepted theories. Yet these fundamental methods are extremely difficult to implement when it comes to analyzing blood flows in detail, whether in humans or in animals. “However, similar networks form in many organisms – from animals to plants to fungi,” says Alim. She is well aware of the significant differences in their biology. “That means it’s not their genetic code but rather physics that explains the dynamics within the networks, from the human circulatory system to vein structures in leaves to the supply pathways through a fungal network.”

The general validity of physical principles is what presented Karen Alim’s interdisciplinary team of around 12 researchers with an ideal organism for their experiments: a slime mold of the species *Physarum polycephalum*. This single-celled organism – genetically classified as between animals and plants – builds an ever-changing network of supply lines. In its cytoplasm, nutrients and signaling substances flow through a flat, two-dimensional network of tubes, or veins, measuring just micrometers wide. The TUM scientists pressed the slime mold between a glass slide and a wafer-thin cover. “It grows quite happily there and we can observe and measure the flows using a microscope,” says Alim. ▷

“We have an opportunity to play Newton here.”

Karen Alim

Picture credit: K. Alim (TUM), Graphics: ediundsepp (source: TUM)

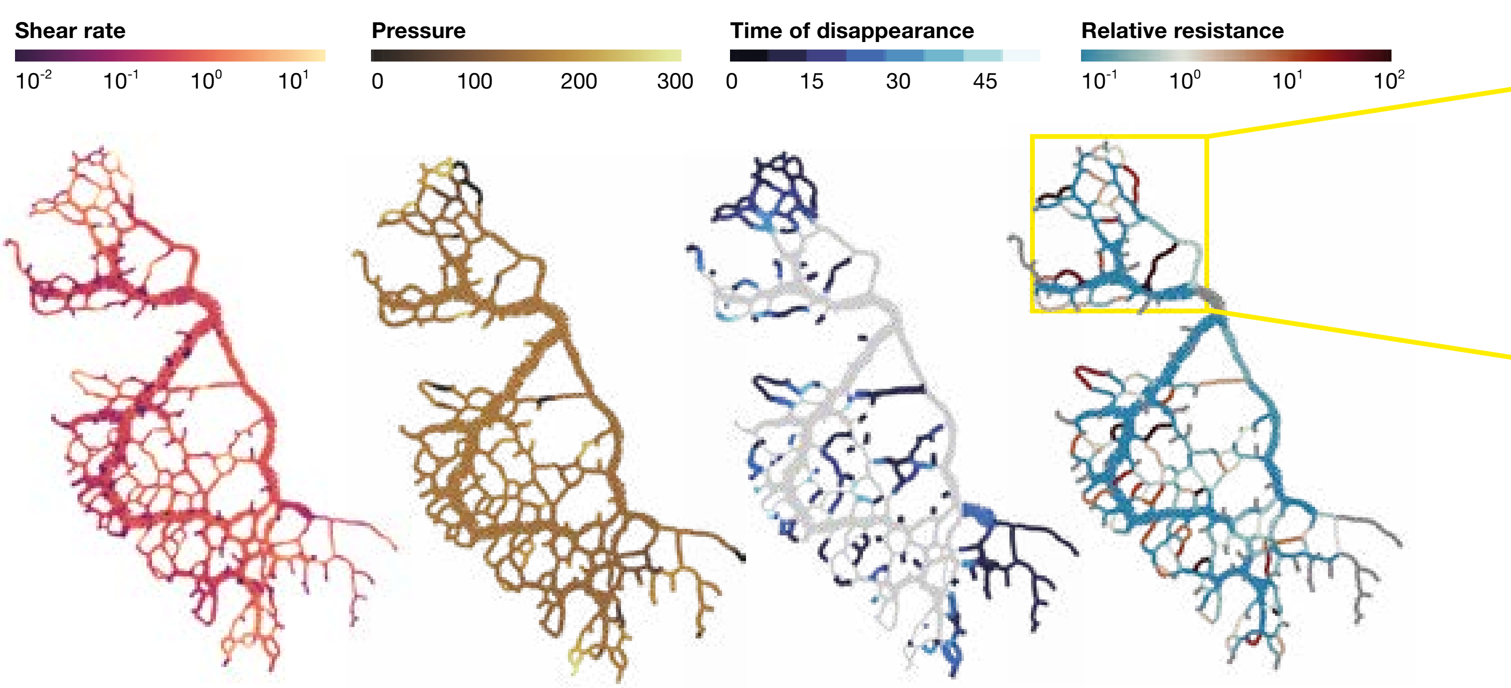


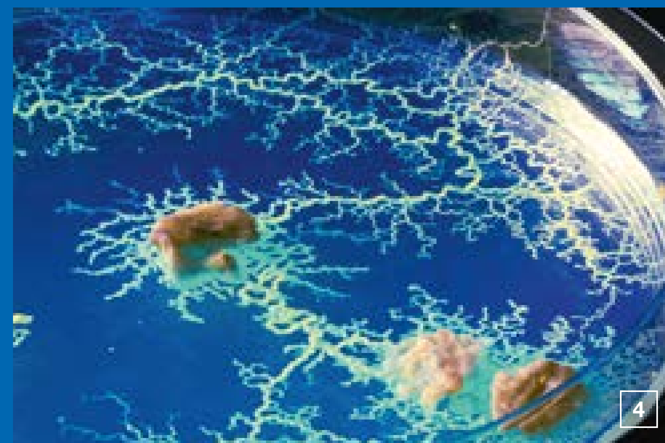
To her surprise, the slime mold did not behave at all as expected. “Initially, we thought that shear rate alone was responsible for the growth of veins in slime mold,” says Alim. In simple terms, shear rate describes the different speeds of a flow through a tube. At the edges, the fluid is subject to frictional forces that slow it down, while the fluid in the center is undisturbed and moves more quickly. A low shear rate with weak shear forces should therefore cause a slime mold vein to shrink until it eventually vanishes, while high shear rates should promote vein growth – or at least, that was the assumption until now. Alim’s measurements, however, did not line up with this

Graphics: ediundsepp (source: TUM); Picture credit: Stefan Woidig

△

Alim’s laboratory cultures the slime molds in liquid. [1] For an experiment, the scientists take a small amount and centrifuge it. [2] From this, they pick up the single-cell mold (plasmodia) and spread 3–4 drops on the Petri dish. [3] The growth of the mold is observed under the microscope. [4] The slime mold aligns its network according to food sources – in this case, oat flakes.





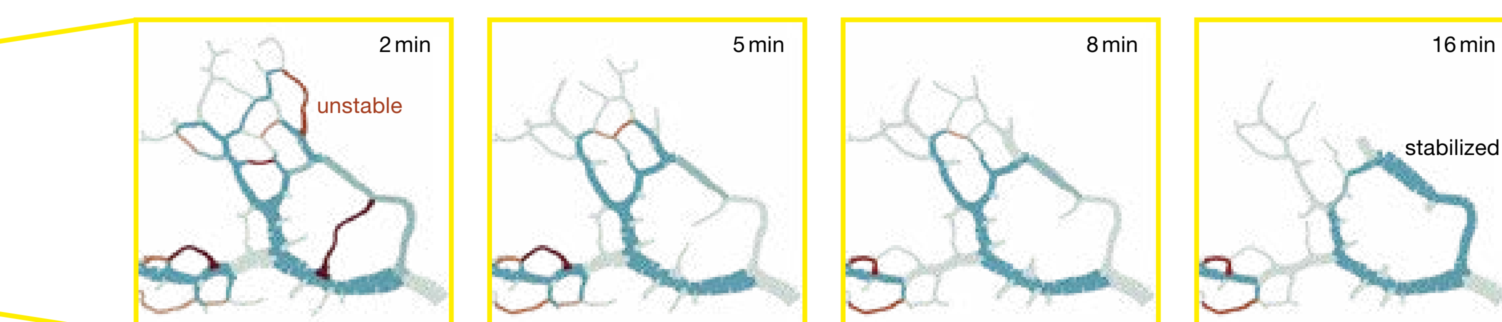
expectation. Despite having identical shear rates, only some of the measured veins shrank, while others remained unchanged. “This parameter alone – shear rates and shear forces – simply does not provide a sufficient explanation,” says Alim. There had to be another factor at play to explain the behavior of the veins in the network.

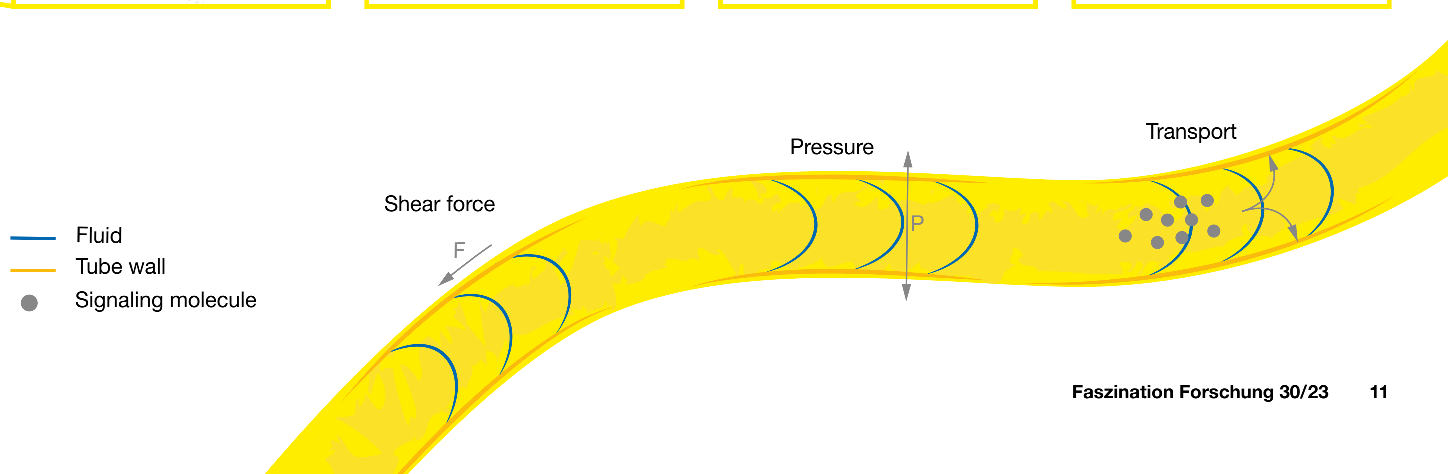
By conducting many more observations – always accompanied by modeling based on complex flow equations – Alim and her team examined the vein behavior in ever-greater detail. Rather than looking solely at individual veins, the scientists considered the network as a whole. This wider focus ultimately delivered the solution. ▷

▽

Shear force, but also pressures and concentration gradients, determine whether veins grow or shrink. But the network architecture, i.e. the condition of neighboring veins, also has an effect. Thus, growing or shrinking veins also influence the network surrounding them.

Time series of network reorganization





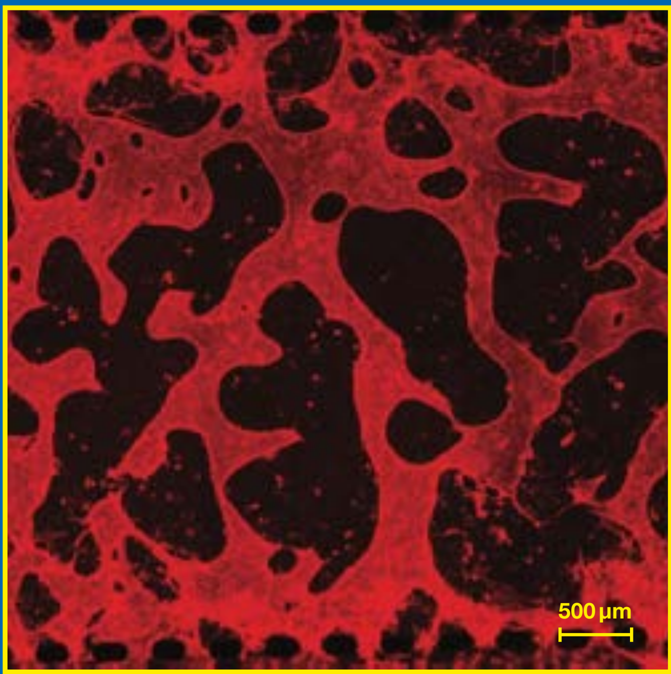
Karen Alim and her PhD student study the growth of a slime mold in the optical microscope.

“The entire network architecture [...] has an impact on each individual vein.”

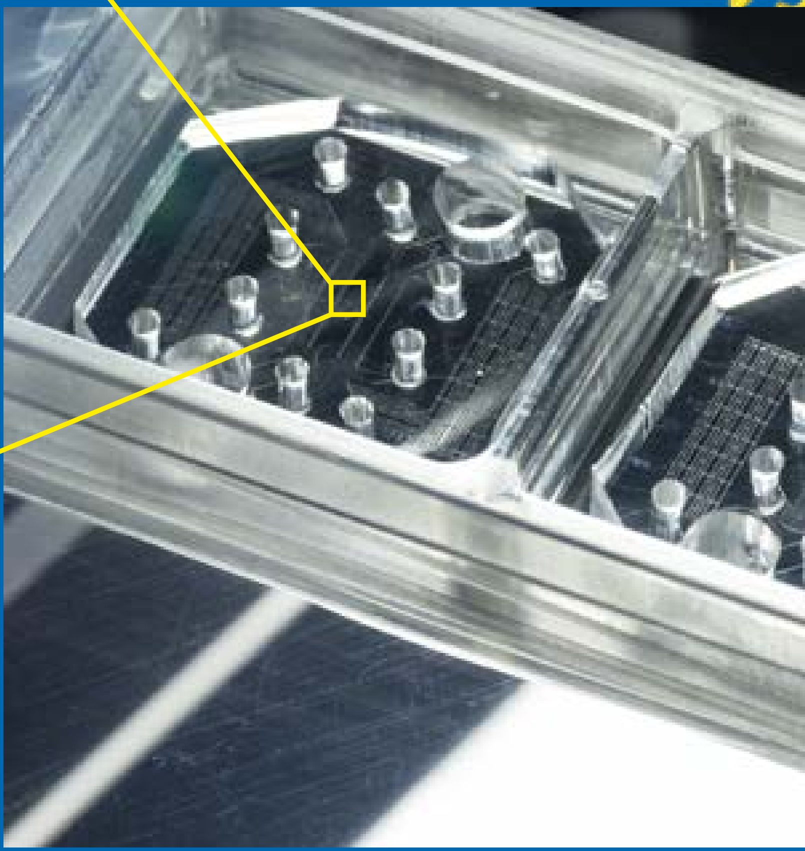
Karen Alim

Picture credit: Stefan Woidig

“The entire network architecture, with all its adjacent larger and smaller pathways, has an impact on each individual vein,” explains Alim. This means, for example, that a small vein would vanish if there was a larger vein nearby. However, if a small vein was surrounded by only other small veins, they would all be maintained. The network’s responses were not immediate and always involved a delay of several minutes. It was this delay that made it so difficult to identify the influence of the network architecture on a single vein. “There is a good explanation for this delay: the cells need some time to react,” says Alim.
The shear rate of flows and the overall network architecture are therefore the decisive factors in the growth or shrinkage of individual veins. Alim is convinced that the same also applies to the blood vessels in humans and animals. In more complex organisms, however, it likely takes considerably longer for networks to reorganize, potentially several hours. With this in mind, Alim is ▷



Experiments to program the growth of blood vessel networks (above) with the help of a biochip (right). A medium containing cells that form human blood capillary systems is deposited into the chip cavity. The cells and their network in the chip can be fed and controlled by perfusion flows.

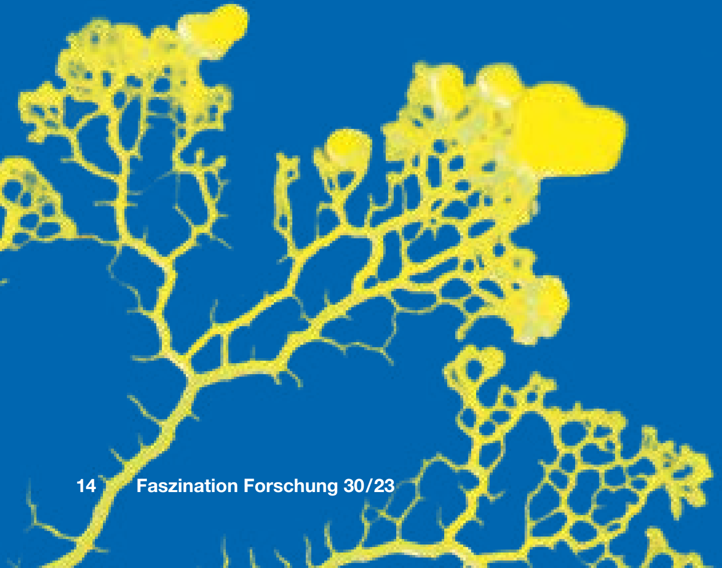


currently planning further experiments using a form of biochip as an observation device. On the surface of the chip, human vascular cells build small networks – like rudimentary artificial circulatory systems. Observing what happens and modeling it could help to explain the behavior of blood vessels. “We hope such chip models will effectively enable us to learn how we could program blood vessels, in other words, deliberately increase or shrink them,” says Alim.

“If we knew the conditions under which blood vessels grow and shrink, there would be plenty of potential applications,” says Alim. In the not-too-distant future, these insights could be used to develop new treatments for pathological changes, including blocked blood vessels. By the same token, these techniques could be applied to deliberately weaken newly formed blood vessels supplying nutrients to a dangerous tumor. “That would be wonderful confirmation that medical progress can be achieved not only in the field of biology, or in chemistry where researchers are looking for new active ingredients, but also through physics,” says Alim. ■

Jan Oliver Löfken

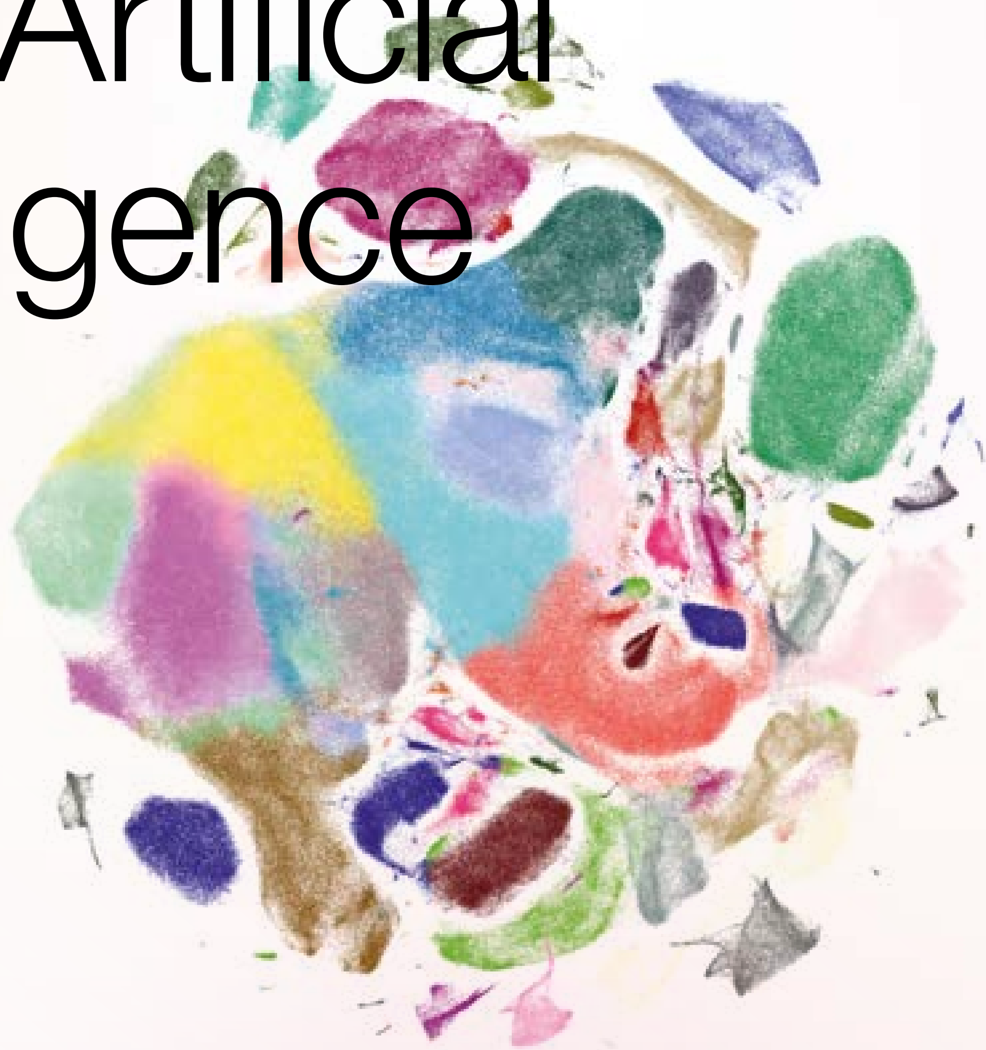
Picture credit: Stefan Woidig



Prof. Karen Alim

has been fascinated by biophysics since she was a child. She studied physics at the University of Karlsruhe, LMU Munich and the University of Manchester. Following her doctorate in theoretical physics (at LMU), she took up a postdoctoral research position at Harvard University before being appointed head of the Biological Physics and Morphogenesis research group at the Max Planck Institute for Dynamics and Self-Organization in Göttingen. In 2019, Alim accepted a professorship in biophysics at TUM and, thanks to a Starting Grant from the European Research Council (2020), has since furthered her research into flows in biological circuits, from fungal networks to the human circulatory system. She is also Vice Dean for Diversity and Talent Management at TUM School of Natural Sciences.

Defeating Diseases with Artificial Intelligence



Picture credit: Mohammad Lotfollahi; Graphics: ediundsepp/midjourney

Modern biomedical research methods generate vast quantities of data. Identifying patterns within this data and drawing the right conclusions are tasks simply beyond human abilities. Instead, researchers turn to computers – and mathematicians like this year's Leibniz Award winner, Prof. Fabian Theis, who feels equally at home in both worlds: computer sciences and life sciences.

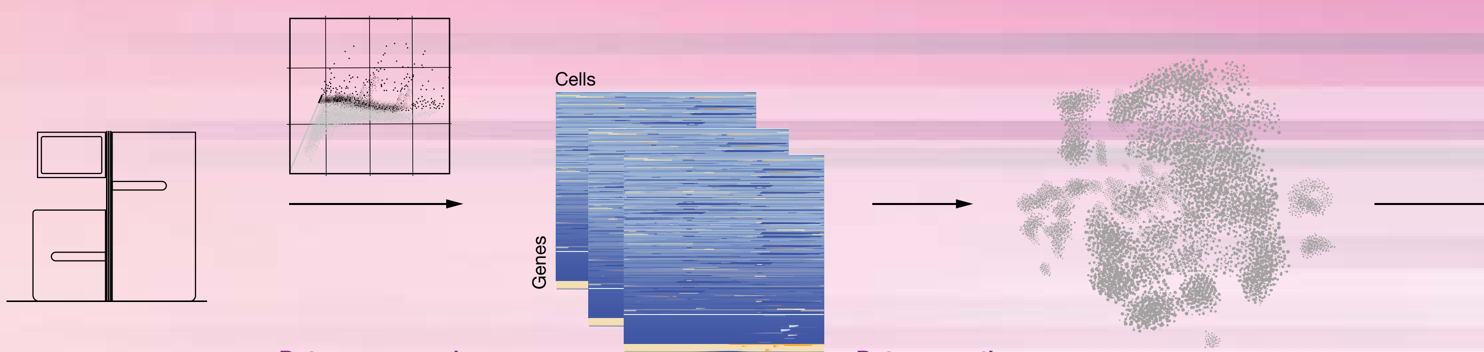
Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Krankheiten besiegen mit Künstlicher Intelligenz

D

In den Biowissenschaften generieren moderne Methoden eine Flut von Daten, die ohne die Hilfe von Computern nicht mehr beherrschbar ist. Der Mathematiker Fabian Theis bewegt sich zwischen den Welten der Bio- und der Computerwissenschaften und nutzt Künstliche Intelligenz (KI) und Maschinelles Lernen, um große Datenmengen für Anwender nutzbar zu machen. Mit seiner Arbeit möchte er vor allem das Verhalten von Zellen verstehen. Dazu nutzt er die Einzelzell-Genomik, mit der er ermitteln kann, welche Gene in einer einzelnen Zelle zu einer bestimmten Zeit aktiv sind. Auf diese Weise lässt sich dann untersuchen, wie sich Zellen unterscheiden, die aus verschiedenen Geweben oder aus Menschen mit unterschiedlichem Lebensstil, aus gesunden oder aus kranken Menschen stammen. Im Rahmen des Humanen Zellatlas, der eine Referenzdatenbank aller menschlichen Zelltypen darstellen soll, hat Theis die Lunge kartiert. Ein weiterer Schwerpunkt seiner Arbeit ist die Diabetesforschung. So entwickelt Theis unter anderem Werkzeuge, um vorhersagen zu können, wie die insulinproduzierenden Zellen der Bauchspeicheldrüse, die bei Diabetes ihre Funktion verlieren, auf verschiedene Medikamente reagieren. □

Link
www.helmholtz-munich.de/en/icb/research-groups/theis-lab



Data preprocessing

Data corrections

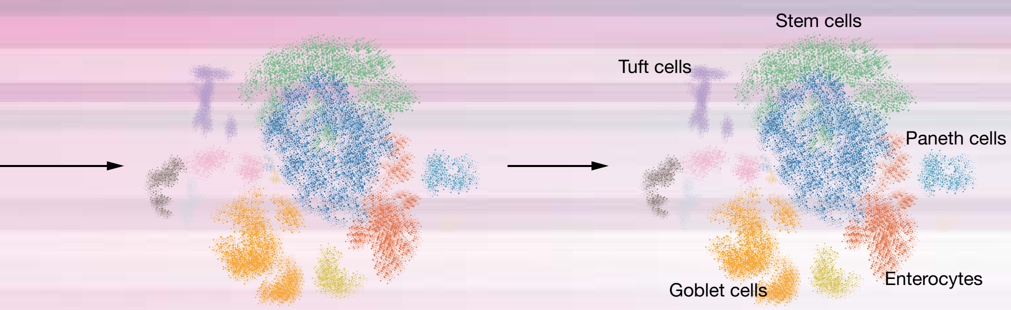
Single-cell analysis data
(Gene sequences of all cells of one or more tissue samples)

For every sample, a matrix is generated describing the gene expression for each cell.

Visualization
of the data

Mathematics has long since found its way into the biosciences. This is primarily due to the immense quantities of data, pithily referred to as big data, that are generated in many research disciplines, and which have become too vast for the human brain to handle. That said, big data is not quite as abstract as it might appear. “In principle,” explains Fabian Theis, “big data is anything that cannot be analyzed in an Excel spreadsheet.” A Professor of Mathematical Modeling of Biological Systems at TUM and Director of the Computational Health Centers at Helmholtz Munich, Theis is an authority in such matters, having specialized in the evaluation of large data volumes. He achieves this by harnessing artificial intelligence (AI). In simple terms, he and his team develop sophisticated software programs that make it possible to search for patterns in data, draw appropriate conclusions, and thereby make research results usable in the first place.

Fabian Theis’ path to the biosciences, however, has been far from direct. It was only after studying mathematics and physics in Regensburg that he began to develop an interest in algorithms – definite instructions that programmers input into computers to enable them to solve specific problems. From that point on, Theis was squarely focused on problem-solving. He saw particular challenges in the biosciences given their links to medically significant issues. “I find it gratifying that, in addition to proposing hypotheses, I can also test them in experiments,” enthuses the mathematician, explaining his love of biomedicine. “In biology, we encounter unbelievably complex systems, such as cells, which we are still unable to describe in clear models. That means mathematicians like me still have a lot of work to do.”



Clustering

Annotation: Each cluster is assigned a certain cell type.

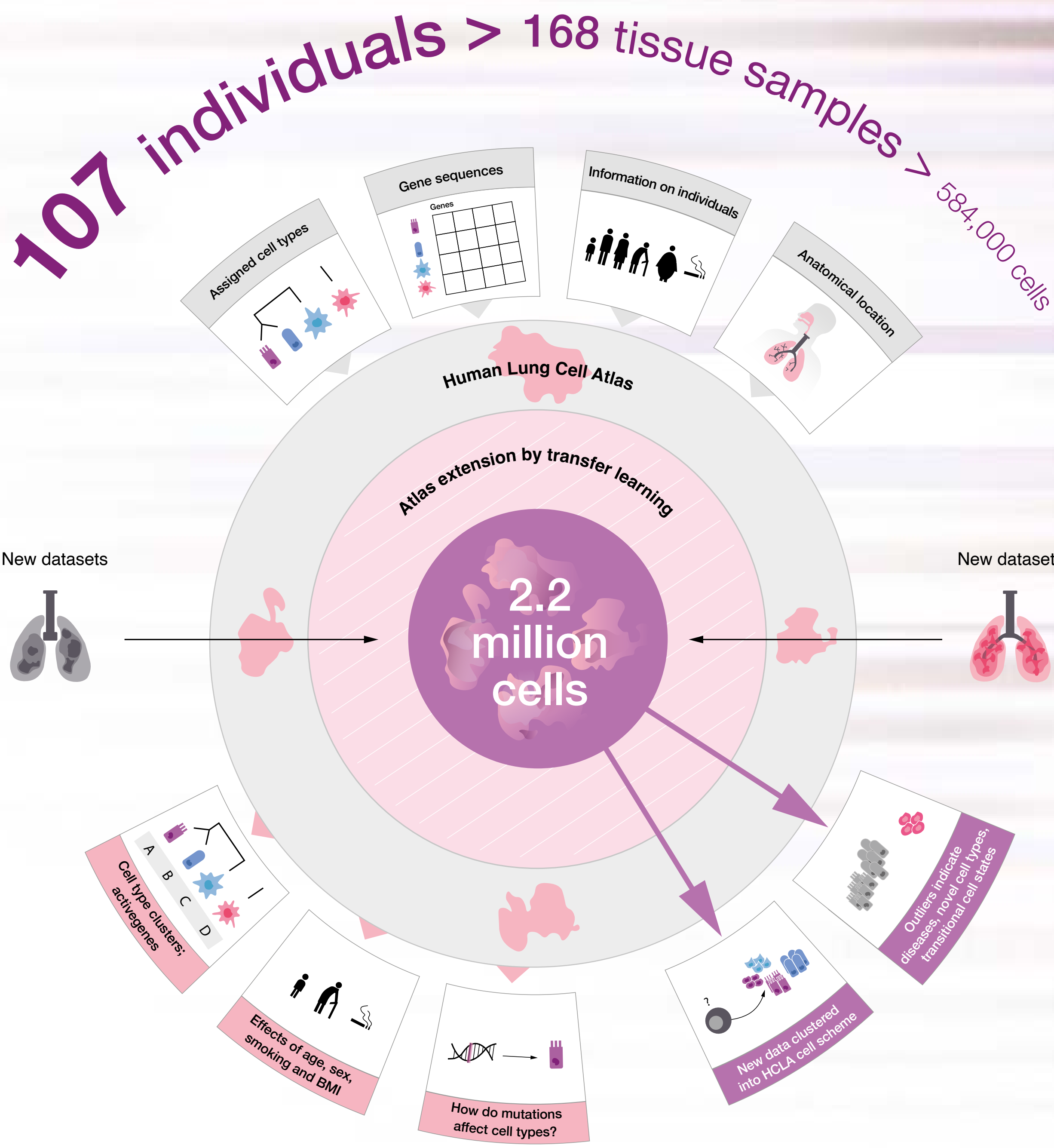
Graphics: ediundsepp/midjourney, ediundsepp (source: Theis/TUM)

A man at home in both worlds

Theis decided to focus on biophysics for his doctoral thesis. A second doctorate followed a year later, this time in computer science from the University of Granada. These studies equipped Theis with the tools required to tackle one of the most complex systems in existence: the living cell, with its thousands of genes, proteins and metabolic pathways. One promising method for understanding cell behavior is single-cell genomics. It can shine a spotlight on various aspects of cells, such as the genome itself or the totality of all genes active at a given moment in time. Theis is particularly interested in the latter aspect, as active genes determine the identity of a cell.

Before delving any deeper, a quick refresher may be helpful. Each human cell contains the same genetic material and yet we have liver, skin and lung cells or also immune cells, for example, all with different characteristics. This is because different genes are active in different cell types – and only these active genes influence a cell's characteristics. Researchers can detect gene activity, which in turn allows them to compare different types of cells. They can also compare young and old cells in a given type of tissue, as well as healthy and diseased cells.

Although these kinds of investigations have been conducted for some time, they usually examine a piece of tissue made up of numerous cells. It is only very recently that highly sensitive methods have made it possible to examine a single, tiny cell. Theis likes to compare the conventional method to a fruit salad, as it always provides an average value across numerous cells – just like the taste experience of eating a fruit salad. "By contrast, we are now able to pick out individual fruits and examine them separately," effuses the researcher. This clearly illustrates the potential of single-cell genomics as a powerful tool for getting to the bottom of how cells function. But surely analyzing a single cell can't produce big data? "On the contrary," says Theis. "Every single cell obviously contains vast numbers of different genes and there are often millions of individual cells to look at. This means we rapidly generate vast amounts of data." ▷



Human cell atlases should capture the diversity of people as thoroughly as possible. Theis' team developed so-called transfer learning in order to integrate additional datasets, especially from sick people, into the Human Lung Cell Atlas (HLCA). They expanded the HLCA from 14 datasets with data from a total of 584,000 cells from 107 people to 44 datasets comprising data from 2.2 million cells from 444 people.

Reference database of all human cell types

This is where **machine learning**[1] comes in. Algorithms are trained with huge sets of known data until they reach a point where what they have learned enables them to interpret new datasets. “If our methods allow us to understand the messages hidden in this data, we can start to ask the right questions,” says a delighted Theis. “Ultimately, we not only want to develop new methods, we also hope to find new applications in biomedical research.” A prime example is the Human Cell Atlas (HCA), a major scientific undertaking involving hundreds of working groups all around the world. The project’s goal is to produce precise maps of every organ in the human body and thereby explain how these organs function and how they differ – in people of different ages and sexes, people with different lifestyles, and with various diseases. Working groups around the world have come together to analyze and catalog millions of cells from different organs and tissues. “We hope that our atlas will give rise to a model of reality,” says Theis, a member of the HCA Organizing Committee, as he outlines the project’s vision. “I find it incredibly exciting because I’ve always wanted to see the big picture.” In light of the project’s complexity, it has been organized into sub-projects, with a separate atlas created for each organ. Theis and a team comprising several working groups focused on the lungs. This saw some groups working with lung tissue in laboratories and generating data for other groups – like the group led by Theis – to process and analyze. The coronavirus pandemic gave the Munich-based researcher the opportunity to test the capabilities of the new database. “I’m always asking myself where I can make a meaningful contribution,” says Theis. “Given that COVID-19 affects the lungs above all, we wanted to use our lung atlas to find out more about the disease.” In fact, Theis’ team were able to identify why elderly people and smokers were particularly susceptible to a COVID-19 infection: their lung cells form more of the receptor that the virus uses to gain access to the cells. Of course, an atlas like this will never be complete, as the research teams are constantly adding new datasets and refining their findings. The main bulk of the work has been done, however, as Theis proudly reports: “Version 1.0 of our lung atlas has now been published.” ▷

1 Machine learning_
is a subset of artificial intelligence involving the use of extensive datasets to train algorithms to detect patterns and correlations in big data.

Integrating countless datasets in the Human Cell Atlas

A mammoth undertaking like the Human Cell Atlas faces very specific challenges. One is the fact that the results that underpin the entire project are being developed and produced at numerous laboratories around the world. Even when the same protocols are followed, experiments to measure gene activity in cells differ ever so slightly across the various locations. This is also reflected in the data. In order to harmonize the numerous datasets despite these minor discrepancies, the researchers once again turn to machine learning – this time using a variant called transfer learning. Software developed by Theis’ team enables the computer to translate what it has learned from one dataset to another dataset with slightly different data. This means that new datasets from other labs can be integrated into the atlas at any time, while other researchers can use the atlas to better understand their own datasets.

Graphics: ediundsepp/midjourney, ediundsepp (source: Theis/TUM)

“I want to learn to speak with cells.”

Fabian Theis

Bringing the best minds to Munich

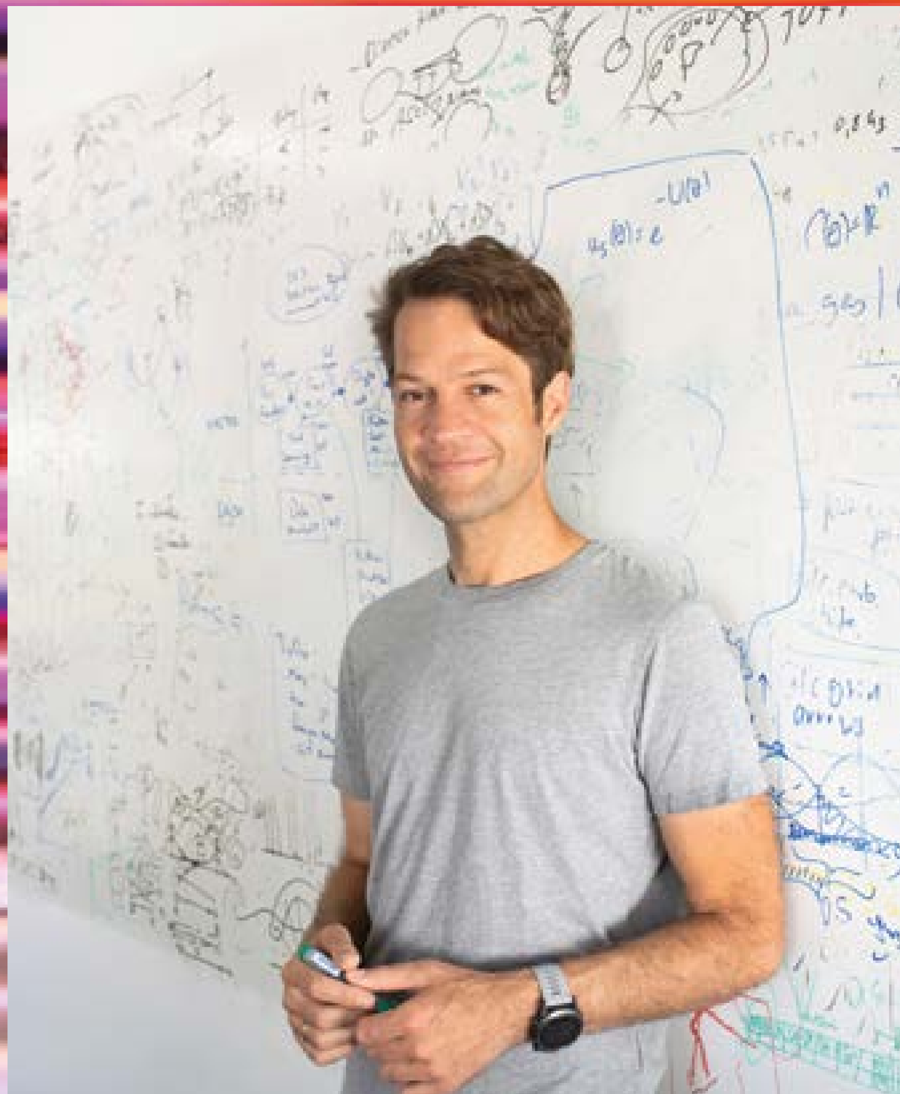
Nowadays, cooperation is the only route to cutting-edge research. With this in mind, Theis collaborates with other working groups who conduct experiments with cell cultures in the wet lab before sending their data to Theis for analyses. The cooperation is so close that doctoral students usually belong to two working groups, which enables them to explore both worlds during their studies – the world of biosciences and the world of computing. “This way, junior researchers learn to speak both languages,” states a confident Theis. In an effort to attract outstanding graduates to Munich for doctoral study, Theis has founded the Munich School of Data Science. It receives around 200 international applications per semester and selects only the best ten. This new institution is supported by Munich’s two public universities, TUM and LMU, as well as Helmholtz Munich and the German Aerospace Center.

Recently, Theis received one of the most prestigious research awards in Germany, the Gottfried Wilhelm Leibniz Prize, from the German Research Foundation. The prize money of €2.5 million has swelled the biomathematician’s coffers and spurred on his research. “I want to learn to speak with cells,” the award winner claims, with complete sincerity. By modeling cells’ responses to external inputs, researchers can simulate how two cells will communicate with each other or how cells will react to a given medication. “How a specific patient’s cells will respond to a given medication,” specifies Theis. You have arrived in the medical world of the future. Welcome! ■ *Larissa Tetsch*

Machine learning in diabetes research

Given that Helmholtz Munich has a specialist research center dedicated to diabetes, it is no surprise that Theis is examining various issues related to the deadly metabolic disorder. “Based on our single-cell genomics approach, we were able to find an explanation for why, in the case of type 2 diabetes – also known as adult-onset diabetes – certain cells in the pancreas lose the ability to respond to blood sugar over time,” explains Theis. He describes how he and his colleague Heiko Lickert, a specialist in pancreatic cells altered by diabetes, are searching for substances to reverse this process. In this context, single-cell genomics can monitor a medication’s success and potentially, at some point, even predict how a cell will respond to a given medication before any experiments are conducted. It represents a major step towards personalized medicine. The prestigious European Research Council certainly agrees, having provided generous financial support for the project.

Working in cooperation with the Department of Ophthalmology at the LMU Klinikum, Theis has also used machine learning to train an algorithm to identify diabetic retinopathy. This secondary disease of type 1 diabetes mellitus is the most common cause of blindness in adults. The training used public datasets comprising images of the fundus of healthy and diseased eyes. Once the training was complete, the computer was also able to identify symptoms of disease on unknown images. “In Munich, the high numbers of specialist doctors means we don’t necessarily need this tool,” qualifies Theis. “But, in rural areas, our algorithm can help family doctors to assess risks and, one day, a doctor in Africa might be able to examine their patient’s eyes with their phone.”



Prof. Fabian Theis

studied mathematics and physics in Regensburg before receiving doctorates in biophysics (Regensburg) and computer science (Granada). Following research stays in Japan, the USA and at the Max Planck Institute for Dynamics and Self-Organization in Göttingen, he completed his post-doctoral lecturing qualification (Habilitation) in Regensburg before accepting a position as Associate Professor at TUM. Theis has held the Chair of Mathematical Modeling at TUM since 2013 and is Director of the Computational Health Center and the Institute of Computational Biology at Helmholtz Munich. He is a member of the Munich Data Science Institute at TUM, a central interface and innovation platform for issues and solutions arising from data sciences, machine learning and artificial intelligence. Additionally, he and two colleagues lead the Munich branch of the European Laboratory for Learning and Intelligent Systems (ELLIS), an international research network with around 30 locations throughout Europe at present. In 2020, he became Co-Chair of the Bavarian state government's AI Council. Theis is also Scientific Director of the Helmholtz Artificial Intelligence Cooperation Unit (Helmholtz AI) and an Associate Faculty Member at the Wellcome Sanger Institute in Hinxton, UK. His scientific achievements have been recognized on multiple occasions, most recently with the ERC Advanced Grant and the German Research Foundation's Leibniz Prize.

Picture credit: Astrid Eckert/TUM; Graphics: ediundsepp/midjourney

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

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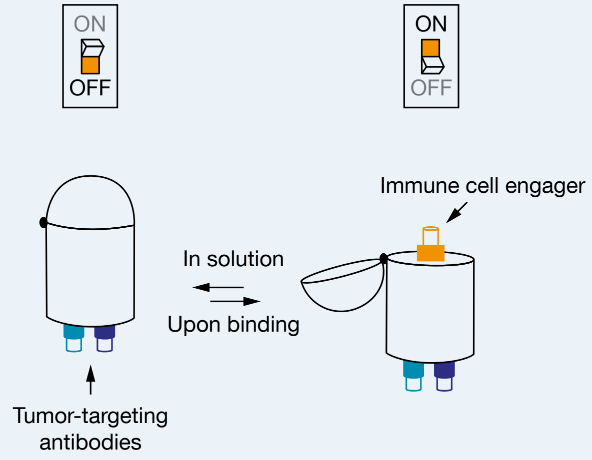
Krebs behandeln ohne Kollateralschaden

Krebszellen gezielt angreifen und gesunde Zellen intakt lassen: Das Start-up-Unternehmen Plectonic hat einen Nanoschalter aus DNA entwickelt, der gezielte Antikörper-Immuntherapien ermöglicht.



Made from DNA, the LOGIBODY nanoswitch will only turn on when an antibody binds to a target cell with two different antigens.

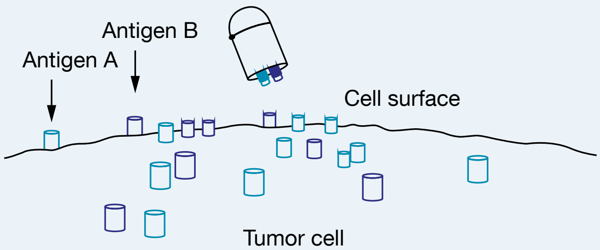
Cancer Treatment **without Collateral Damage**

For many, conventional cancer treatments are lifesaving. But when healthy cells are caught in the crossfire, these same treatments can substantially decrease patients' quality of life. Enter Plectonic, a start-up with a game-changing approach: DNA nanoswitches that enable the body's own immune system to target cancer cells without harming healthy cells.

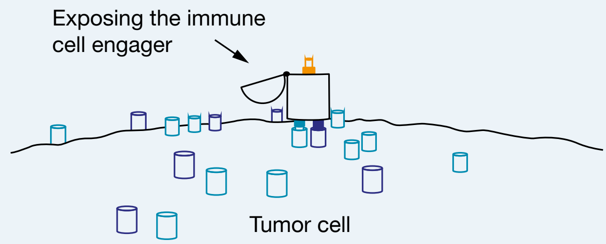
Link
www.plectonic.com

The start-up Plectonic began with a lofty goal – and a long way to go to reach it. "Revolutionizing cancer immunotherapy from a biophysics lab is like starting a Formula 1 team with nothing but a driver's license," says Dr. Klaus Wagenbauer, one of the company's co-founders. He met Dr. Jonas Funke and Dr. Benjamin Kick in Prof. Hendrik Dietz's lab at TUM where each was working on a different PhD project centered around DNA origami. An approach that exploits the ability of DNA to self-assemble, fold, and encode information, DNA origami makes it possible to build ultra-miniature molecular devices that can carry out tasks. As their doctoral work ended, the three searched for a real-world application for DNA origami. "The idea that this technology can be used therapeutically came up very quickly because DNA origami is really made for it. But which type of therapeutic application it is used for is very important. You can employ it as a drug-targeting agent, but utilizing it for targeted cancer immunotherapy, as we're doing, really gives our approach an edge over existing therapies," says Funke.

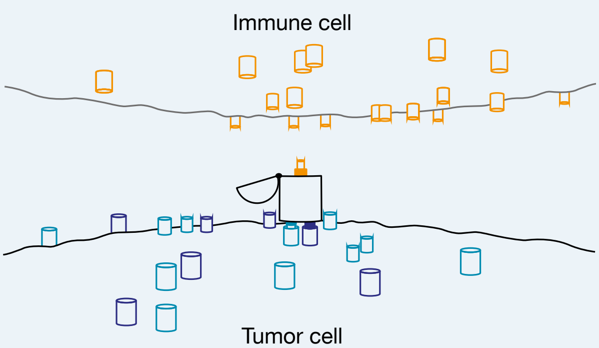
A major problem with some existing immunotherapeutic approaches is that they rely on identifying tumor cells by only one antigen. When healthy cells also have that same antigen, as is often the case, the treatment results in the destruction of both tumor cells and healthy cells. This is



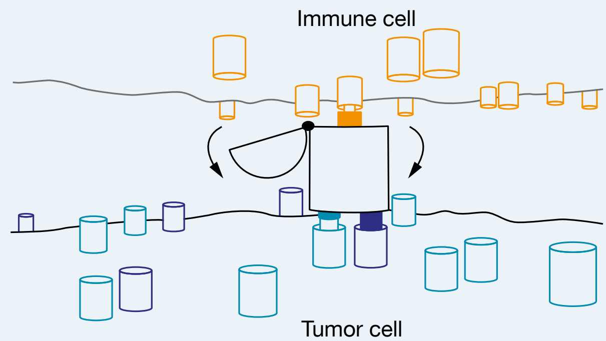
1. Binding to a tumor-specific antigen pattern



2. The switch turns on and changes its shape



3. Immune cell engaging



4. Tumor cell killing

Graphics: ediundsepp (source: TUM)

what is so innovative about the LOGIBODY technology developed by co-founders Wagenbauer, Funke and Kick with support from their mentor and co-founder Dietz. Made from DNA, a LOGIBODY nanoswitch will only turn on when an antibody binds to a target cell with two different antigens. “We call it a switch because like switching on a light, you want to switch on – or activate – a drug at the tumor site,” says Kick.

Making two antigens the target rather than just one makes all the difference – this way, the two antigens serve as a tumor cell’s unique fingerprint. If a tumor-targeting antibody binds to a cell with only one of the two necessary antigens, the switch remains off. If, however, the antibody binds to a cell with both kinds of antigen, the switch turns on and changes its shape. This change exposes the antibody’s immune cell engager, which directs killer T cells – the body’s immune cells – to bind to the cell in question so that they can destroy it. Thanks to a LOGIBODY switch, tumor cells previously flying under the immune system’s radar become detectable so they can be killed, while healthy cells remain out of the crossfire.

Armed with funding from the German Federal Ministry of Education and Research’s (BMBF) GO-Bio initiative, the Else Kröner-Fresenius Foundation, and their winnings from the Bavarian Ministry of Economic Affairs, Regional Development and Energy’s m4 Award, the team has already passed a number of important milestones. They have ensured that their origami structures bind to antibodies on tumor cells and built T cell engagers that recruit T cells to tumor cells, both of which were done in cell culture. They then checked that these successes translate to studies on living mice, and were happy to discover that they do. “We are very grateful to Hendrik Dietz, who, besides being a great co-founder, gave us the opportunity to use his lab. This lab is part of the Munich Institute for Biomedical Engineering (MIBE), one of TUM’s Integrative Research Institutes, so we are also grateful to Bernhard Gleich, the MIBE General Manager, who has been very supportive,” says Funke. Now, the team has big plans for the future of the company, currently fifteen employees strong, which they will carry out thanks to funding from the Federal Agency for Disruptive Innovation SPRIND. The founders have what they call a very promising lead candidate for treating one type of blood cancer, a manufacturing process for their LOGIBODY technology, and intend to submit an Investigational New Drug Application to the United States Food and Drug Administration. From there, they hope to use their technology to treat solid tumors. “Sounds easy!” says Kick, with a smile. ■

Sarah Puschmann

TUM's activities in the **Global South**

Three questions for Prof. Juliane Winkelmann, Senior Vice President for International Alliances & Alumni

Prof. Winkelmann, why does TUM engage in an array of multifaceted partnerships with institutions in the Global South?
As a leading university operating on a global scale, TUM is responsible for promoting and advancing technical progress, knowledge and entrepreneurial skills, not only here in Bavaria, but also together with our partners in the interests of spreading scientific knowledge in other parts of the world. This includes, of course, the Global South, which – depending on how you define it – is home to up to 85% of the world's population. It has become a truism that only through global cooperation will we be able to find solutions to the major challenges of our time. In our efforts to live up to our responsibilities, we want to empower and encourage talented scientific minds to create the technological and economic conditions for shared prosperity in the Global South.

Our magazine reports on research at TUM. However, TUM also participates in education and exchange programs in the Global South. What part does research play in this?
TUM is committed to the Humboldtian ideal of excellent teaching and research – and I would like to emphasize that it is difficult to conceive of excellent teaching without excellent research. In this respect, research is obviously an essential element of our cooperation with the Global South, and this issue presents a wide range of fascinating examples. What is particularly exciting about research collaborations with the Global South is that research often aims to have a direct, tangible impact. It can be very gratifying to see how solution-oriented, practical research can have an immediate impact on the ground. One example is SEED's Living Labs, which are bringing electricity to communities for the first time and studying the impact.

What can TUM researchers learn from conducting research together with colleagues from the Global South?
Research thrives on the inclusion of diverse perspectives and knowledge – and this is the absolute top priority in our cooperation activities with the Global South. In the past, however, the perspectives and knowledge of the Global South have been marginalized in scientific collaborations, and researchers have not always worked together on an equal footing. Today, we have moved on: we understand that we can – and must – learn a great deal from our colleagues and communities in the Global South, from local sociocultural and economic conditions to natural circumstances, the relevance of different issues and what data we should collect, where and how. It is only together that we can explore complex issues, so everyone has a lot to contribute. ■

Picture credit: Astrid Eckert; Graphics: ediundsepp

What exactly is the Global South?

The term Global South is used to describe the situation of countries in our globalized world in the most neutral, non-hierarchical way possible. Countries considered part of the Global South are politically, economically or socially deprived states. By contrast, countries in the Global North are described as having a position of privilege in terms of their prosperity, political freedom and economic development. These terms only correspond to geographical location to a limited extent. For example, Australia and New Zealand and considered part of the Global North, while countries like Afghanistan and Mongolia are assigned to the Global South.

A Parasite with **Side Effects**

Pork tapeworm infection is one of the major causes of epilepsy, which affects around 50 million people worldwide, mostly in the Global South. The condition is curable with the right treatment. Even better, however, is awareness raising and disease prevention as part of the One Health concept.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Ein Parasit mit Nebenwirkungen

D

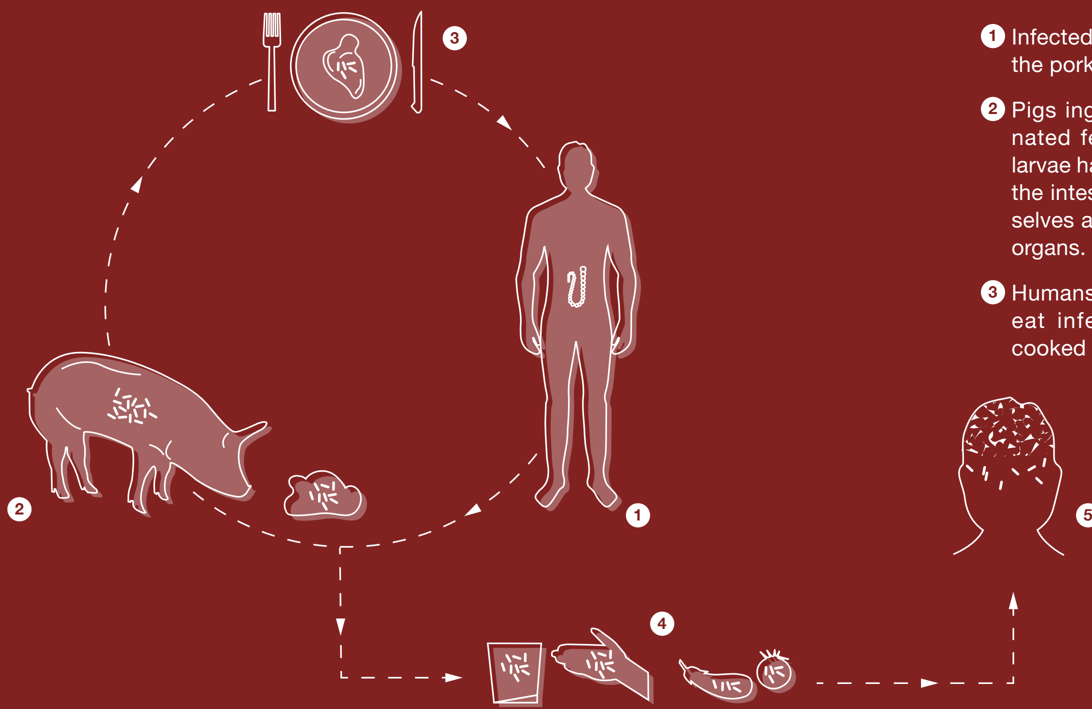
Neurologische Krankheiten haben weltweit die höchste Krankheitslast und die zweithöchste Mortalität. Prof. Andrea Winkler erforscht den Zusammenhang zwischen Epilepsie und Neurozystizerkose – einer Infektion mit Larven des Schweinebandwurms *(Taenia solium)* im Gehirn. Ihr Fokus liegt jedoch nicht nur auf neuen Diagnose- und Therapieoptionen, sondern auch auf verbesserter Prävention im Sinne eines One Health-Ansatzes. □

Link

www.med.tum.de/en/center-global-health-0

www.neurologie.mri.tum.de/de/arbeitsgruppen/globale-neurologie-neuroinfektiologie

Graphics: ediundsepp



1 Infected humans excrete the eggs of the pork tapeworm.

2 Pigs ingest the eggs with contaminated feces. In the pig's intestine, larvae hatch from the eggs, penetrate the intestinal wall and deposit themselves as cysts in muscles and other organs.

3 Humans ingest the cysts when they eat infected raw or insufficiently cooked pork.

4 Humans ingest the eggs accidentally via contaminated water, vegetables or fruits and via their hands.

5 Larvae hatch in the intestine, penetrate the intestinal wall and migrate through blood vessels into the tissue. They settle mainly in the brain and cause neurocysticercosis.

Neurocysticercosis: a major cause of epilepsy. The life cycle of the pork tapeworm *(Taenia solium)* includes humans as main hosts and pigs as intermediary hosts; through lack of hygiene and sanitation humans can become accidental intermediary hosts and develop neurocysticercosis.

In 2002, Andrea Sylvia Winkler traveled to Tanzania. While others went on a photo safari in the savannah, the young doctor wanted to help local people suffering from epilepsy. She soon noticed that very little was known about the condition and its specific local causes. Even today, more than 20 years later, the expert in global neurology at TUM is not letting go of the topic. “A large number of patients have hope of a cure,” explains Winkler. Neurological disorders like epilepsy, stroke and dementia account for the world's largest burden of disease, have the second highest mortality rate, and increasingly affect the Global South. However, especially in low-income countries, these conditions often have different causes, resulting in a need for specific research.

Unlike in Germany, for instance, around one third of all epilepsy cases in Tanzania are caused by an infection with *Taenia solium*, commonly known as pork tapeworm. This parasite lives primarily as a larva in the muscle tissue of pigs and as an adult tapeworm in the intestines of humans. However, people can ingest the eggs of this tapeworm through contaminated water and food, and also through poor hygiene. The eggs hatch into larvae, each about half a centimeter to a centimeter in size, which can penetrate the intestinal wall and migrate to muscles, skin or especially the brain.

The larvae encapsulate themselves and are therefore not recognized by the immune system. Many patients remain asymptomatic for years, and have no idea that they are carrying a ticking time bomb. It is only when a trigger – which remains unknown – causes the immune system to attack the encapsulated larvae that an inflammatory response occurs, which can lead to neurological signs or symptoms including severe headaches, paralysis, a loss of intellectual capacity or even epilepsy. The medical term for this infection is neurocysticercosis (NCC).

A neglected tropical disease

The pork tapeworm does not only occur in Tanzania; other countries in sub-Saharan Africa, Latin America or Southeast Asia are also affected. Nevertheless, **NCC**[1] is one of the neglected tropical diseases. There has been little research in this area so far. Funding? Not a chance. In the beginning, Andrea Winkler has to convince donors that it is worthwhile to invest in research on the prevention and treatment of such poverty-related diseases. Her demand is clear: "We Europeans must take the issue seriously! We have a moral and social obligation to do so and we will see more and more NCC cases also in Europe due to migration. Moreover, research on NCC generates valuable knowledge that can be transferred to other neurological diseases."

Since 2016, there has been genuine, major progress on the issue. Through funding from the German Federal Ministry for Education and Research (BMBF) and the EU, the SOLID and CYSTINET-Africa cooperation projects were launched. Andrea Winkler, who is now a Consultant Neurologist at TUM and Professor of Global One Health at the University of Oslo, is Co-Director of CYSTINET-Africa. Also on board is her colleague Prof. Clarissa Prazeres da Costa from TUM, along with four research institutes and universities from Tanzania, Zambia and Mozambique. Together they want to find out how to better diagnose and treat NCC. At the same time, educational initiatives in local communities serve to raise awareness of the disease. One problem so far has been that NCC can only be diagnosed beyond doubt with neuroimaging such as CT or MRI. But the necessary equipment is expensive and rarely found in Africa. Within the framework of SOLID, an inexpensive and easy-to-use blood test was developed that provides very good indications of whether someone is infected with the pork tapeworm or not. Only those who receive such a positive blood test should subsequently be examined further. The test has already been explored in hospitals and under field conditions. The results have recently been published in *The Lancet Infectious Diseases.* ▷

1 Neurocysticercosis (NCC) is an infection with larvae of the pork tapeworm within the brain, which can cause neurological disorders such as epilepsy.

During her stay in Tanzania, Andrea Winkler examines a child for possible neurological disorders.

Picture credit: private collection; Graphics: ediundsepp (source: TUM)

Interdisciplinary research for better results

The special feature of both projects is their interdisciplinarity. “We don’t just see the problem as strictly medical,” says Andrea Winkler. A medical doctor herself, she knows the boundaries of her field only too well. Would it be possible to offer the millions of people who suffer from NCC adequate treatment with expensive medications and complex surgeries? Unfortunately not. But could new infections be prevented or at least reduced? Now, that’s feasible.

With this in mind, Winkler takes a step back – to a point in time before an individual even requires treatment. That is why veterinarians and social scientists are part of the project team. Working together, these experts discuss where the problems lie and where improvement is needed. Together with political representatives and other decision-makers, they develop policies that are later adopted by local and global decision-making bodies such as the World Health Organization (WHO). “Our focus is not only on treatment but also on prevention, because, although treatment is possible, it is expensive,” explains Winkler.

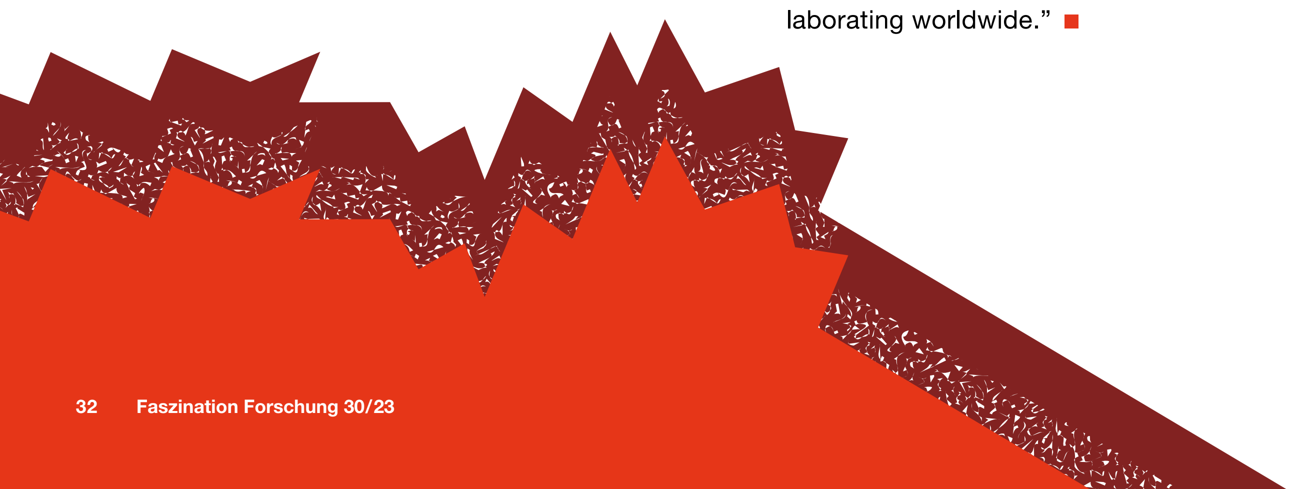
“We Europeans must take poverty-related diseases seriously. We have a moral and social obligation to do so and we will see more and more NCC cases also in Europe due to migration.”

Andrea Sylvia Winkler

Experts travel to the villages and talk to local people about the spread of the parasite and how to contain it. This includes not eating raw pork, treating sick animals with low-cost deworming medication and keeping animals in pens rather than allowing them to roam freely through the villages where they could become infected by ingesting the feces of people carrying the tapeworm. The overarching concept behind these efforts is the Global One Health approach, in which human health is only possible when animals and the environment are also healthy.

To get closer to this goal, Andrea Winkler founded the Center for Global Health at TUM in 2017 together with Clarissa Prazeres da Costa, supported by the Department of Neurology and the Institute of Medical Microbiology, Immunology and Hygiene. The CGH aims to initiate research and teaching projects on the topic of global health, bringing together specialists from various disciplines: “We’re moving beyond the national framework and collaborating worldwide.” ■ *Claudia Doyle*

Picture credit: Stephan Rumpf; Graphics: ediundsepp



Prof. Andrea Sylvia Winkler

studied medicine at LMU Munich, where she also completed a doctorate in neuroscience. She received a second doctorate in clinical neurology from the University of London. She became a Consultant Neurologist at TUM in 2011 and, later, a co-founding Director of the TUM Center for Global Health together with Prof. Prazeres da Costa. Winkler accepted a professorship in Global One Health at the University of Oslo in 2016. In May 2023, she started a visiting professorship at Harvard Medical School. One focus of her work is research into neglected neurological diseases in sub-Saharan Africa together with the One Health concept.

Affordable Electricity for **Remote Rural Communities**

What happens when a village gains access to solar power? Prof. Frank-Martin Belz and his team work in rural regions of developing countries to examine which entrepreneurial activities unfold with the benefit of electricity.

Link
www.ie.mgt.tum.de/en/sustainability www.seed.tum.de

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

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Bezahlbarer Strom für entlegene Dorfgemeinschaften

Prof. Frank-Martin Belz baut in ländlichen Regionen von Entwicklungsländern Reallabore auf und untersucht, welche unternehmerischen Aktivitäten sich entfalten, wenn eine Energieversorgung vorhanden ist. Seine ehemalige Doktorandin Esther Salvi erforscht die Schattenwirtschaft in solchen ländlichen Regionen. Der Sektor wird vom Staat weder reguliert noch besteuert oder beaufsichtigt und ist von mündlichen Absprachen, Traditionen oder Riten geprägt. □

Prof. Frank-Martin Belz

studied business administration at the University of Mannheim, before receiving his doctorate and qualifying as a professor at the University of St. Gallen (Switzerland). He is a Professor of Corporate Sustainability at the TUM School of Management and Director of the TUM SEED (Sustainable Energies, Entrepreneurship and Development) Center, which pursues an international and interdisciplinary approach.

"Around 700 million people around the world have no access of any kind to electricity. The majority live in sub-Saharan Africa – in locations far from national electricity grids. In such cases, mini-grids consisting of photovoltaic systems and batteries can provide a reliable supply of affordable electricity for entire villages," explains Frank-Martin Belz, Professor of Corporate Sustainability at TUM.

Rural communities can use these mini-grids to turn their mills, operate water pumps to irrigate their fields, and thereby advance the local economy. In most cases, these local economies are made up of small, family-run agricultural businesses. However, with a secure electricity supply at their disposal, local people could run an Internet kiosk, a TV bar or a clothing repair service.

In the past, Belz has examined the sustainability activities undertaken by large corporations in industrial nations. He was struck by the lack of willingness to embrace change. Belz, who is a keen triathlete, was determined to make a difference – so he changed himself. He reoriented his research, focusing on entrepreneurs "who pursue social and ecological goals, developing entrepreneurial solutions for sustainability-related problems".

"As I move into the last ten years of my career," the 57-year-old researcher explains, "I am investigating the relationship between sustainable energy systems and entrepreneurship in the Global South. In addition to academic publications, I also want to create living labs by setting up mini-grids in rural areas and giving people access to electricity from renewable sources."

"I want to create living labs by setting up mini-grids in rural areas and giving people access to electricity from renewable sources."

Frank-Martin Belz

One such living lab has been set up in Kyampisi, Uganda, where researchers and project partners established an electricity grid, including storage, powered by 28 solar panels. The TUM research team is now analyzing the economic activities that develop when a local grid provides a secure electricity supply. In the past, papayas and mangoes had been left in the field to rot. Giving farmers access to power empowers them. It gives them the ability to cool and process their fruits. This allows them to grow commercially and increase their quality of life. ▷

Picture credit: Astrid Eckert/TUM; Africa Greentech

From experience gained in a previous mini-grid project in Kenya, the researchers know that local electricity grid operators cannot rely on private customers alone in their efforts to turn a profit. Instead, they also need a certain number of small-scale entrepreneurs to purchase electricity. At present, the project participants are working with micro-businesses in Kyampisi to create a suitable business model capable of driving sustainable development.

A second factor relates to social aspects: once people achieve commercial success, they find themselves with a financial obligation to their extended family. It is therefore important to research the paths that new entrepreneurs forge, how their family situations change and what opportunities are open to women. Another area of research focuses on the informal economy, which Belz and his team has investigated in Mali.

To Belz, the current situation in rural regions of Africa is reminiscent of Germany in the early 1900s, with the establishment of energy supplies laying the foundations for economic success. By 2030, the Konstanz-born researcher aims to implement the infrastructure required to electrify eight villages in various African countries, thereby aiding and supporting the development of around 8,000 people. ■ *Eve Tsakiridou*

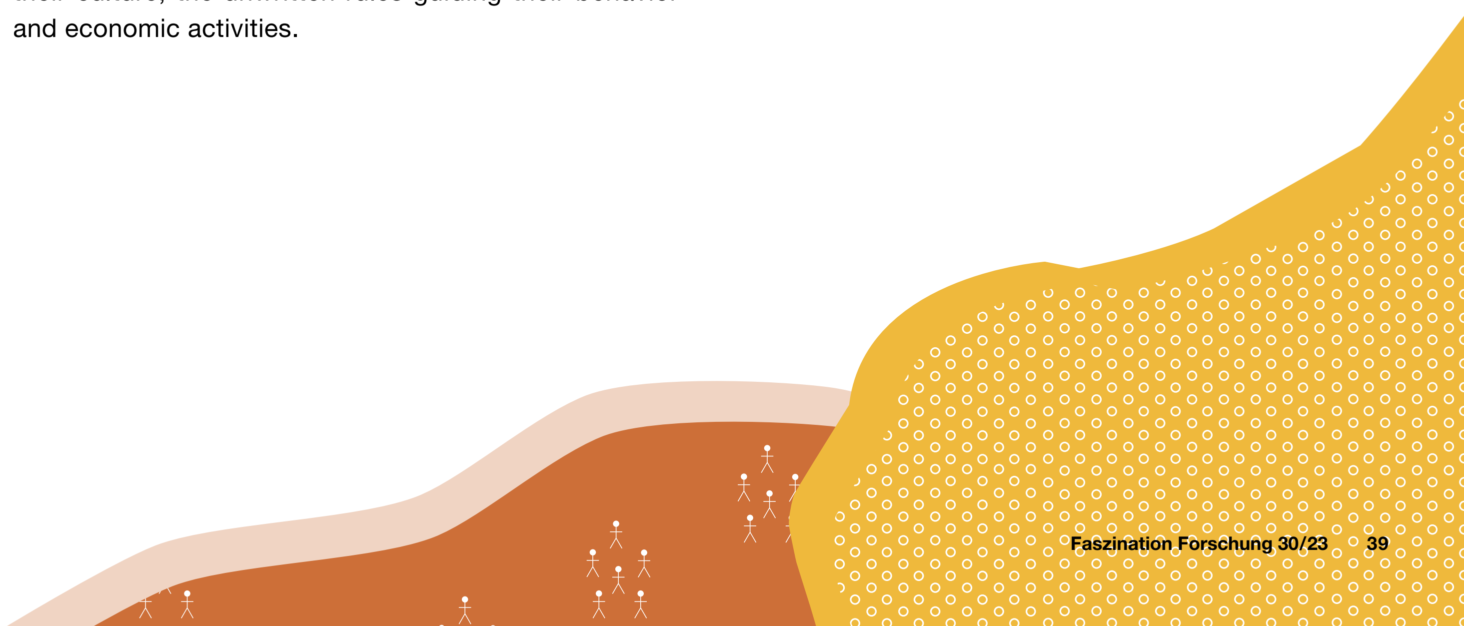
Picture credit: Kats David/Makerere University;
Graphics: ediundsepp

Informal Economies: The West Needs to Abandon its Misconceptions

As a PhD student at the Chair of Corporate Sustainability, Dr. Esther Salvi conducted field studies in rural Mali to find out how informal economies work. The sector follows uncodified rules such as oral agreements, traditions and rites. It is the part of the economy that is neither registered, taxed nor monitored by the state.

Dr. Salvi, how did you arrive at your field of research?
I spent several weeks in five rural villages in Mali, conducting interviews with shop owners, farmers, agriculturists, welders, hairdressers, village chiefs, women leaders and religious leaders. The more I talked to these entrepreneurs, the more I understood the key role they play within their society and for local development. I noticed that they do not fit into any "classical" entrepreneurship box. I realized how important it is to understand their culture, the unwritten rules guiding their behavior and economic activities.

So how is your field of research different from others?
In its interdisciplinarity and the need to abandon our Western misconceptions. To truly understand how rural informal entrepreneurs operate their ventures in some of the most fragile settings in the world – with absent or ineffective state authorities – and how they create value for their society, you also need to take a sociological and anthropological perspective. ▷



What are the most important findings of your project?

Informal entrepreneurs in rural Mali are facing formal fragility due to the lack of effectiveness of the national government, which is too far from the local villages to truly understand their needs, intervene in local dynamics, and provide functioning services and infrastructure. However, the rural villages are characterized by a high level of stability in terms of informal institutions, which guide entrepreneurial activities. These informal institutions differ across villages and are constituted by large family rules, community practices and ethnic traditions.

For example, in agricultural villages you are not allowed to start an enterprise if you do not harvest your family field beforehand, or if you do not provide for the livelihood of your large family, which generally includes a husband and wife, plus the husband's parents, husband's brothers and unmarried sisters, children, husband's grandparents and so on. You also need to make sure that the chief of the village gives you permission to start your business in the village.

What impressed you the most?

I was most impressed by how rich the rural villages are. We usually see them as settings that are "lacking": they lack infrastructure, they lack reliable access to electricity, they lack enforcement of formal rules, etc. However, they are extremely rich in terms of cultural practices, traditions and social values. Rural villagers, including informal entrepreneurs, truly care for each other, understand each other and support each other through reciprocity and solidarity practices. They tend to engage in their daily activities prioritizing collective rather than individual needs. Entrepreneurs in rural Mali thus show us examples of alternative business models beyond the capitalist one.

Besides this, what can we do with the knowledge of informal economies?

Basically, you cannot succeed as an entrepreneur in rural Mali if you do not understand these dynamics, nor can you succeed as an NGO or social enterprise willing to work in this setting if you do not understand the informal rules. ■

Eve Tsakiridou

Picture credit: Patrick Reimers; Astrid Eckert/TUM

Dr. Esther Salvi

obtained her PhD at TUM School of Management, where she graduated with highest distinction in May 2023. In her dissertation she developed a theoretical basis for informal economies. During that time, she served as research assistant at the Chair of Corporate Sustainability at TUM and as research coordinator of the TUM SEED Center. In her Bachelor's degree, Esther Salvi studied food technology (University of Turin) and she holds a Master's degree in Nutritional Sciences (University of Milan). In May 2023, she started a postdoc position at LMU School of Management in Munich.

Resolving Conflicts Between **Artificial Intelligence and Ethics**

While AI harbors tremendous potential for African countries, its use can sometimes present different ethical and social challenges than in more industrial nations. A team at the Institute of Ethics in Artificial Intelligence has co-founded a platform that brings African AI experts together – and promotes ethical, sustainable AI development.

Link
www.gov.sot.tum.de/en/wirtschaftsethik www.ieai.sot.tum.de www.rainafrica.org

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

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Künstliche Intelligenz und Ethik zusammenbringen

Künstliche Intelligenz kann afrikanische Länder entscheidend voranbringen, zum Beispiel in der Landwirtschaft, im Gesundheitswesen oder in der Stadtplanung. Auch die TUM ist über ihr Partnernetzwerk in Afrika an vielen KI-Projekten beteiligt. Dort spielen nachhaltige und ethische Aspekte in der KI-Entwicklung eine viel stärkere Rolle als in Europa oder den USA. Ein Team des TUM Institute of Ethics in Artificial Intelligence (IEAI) hat eine Plattform mitgegründet, die afrikanische KI-Experten vernetzt und eine ethische und nachhaltige KI-Entwicklung fördert. □

Graphics: ediundsepp

When we think about Africa, artificial intelligence is unlikely to be the first thing to spring to mind. And yet, AI is a topic of huge importance on the African continent. One reason is that the technology does not require heavy industrial infrastructure or conventional factories and is not necessarily capital-intensive to develop.

A more important factor, however, is that AI enables African countries to take steps forward in their development that that would otherwise not be possible. Take agriculture, for example – a crucial sector for the continent – where AI can help farmers to optimize fertilization and irrigation processes. In urban development, AI-based Earth observation systems can identify and support the planning for informal settlements (commonly known as slums). And, in the healthcare sector, AI can help to improve the medical situation for rural populations.

Many African researchers and scientists are cooperating with European institutions. TUM is no exception, having established an extensive partner network in Africa and participating in many AI-related and other projects. Through this work, it has become apparent that, in addition to technological issues, aspects surrounding sustainability and ethics have an important role to play in Africa – possibly far more so than in Europe or the USA.

"Responsible AI" is a high priority in African countries, and with good reason. For instance, while facilitating the AI-based monitoring of informal settlements may appear a purely technical problem at first glance, the ethical implications can make the entire project appear dubious. If excavators move in on the basis of such data because the government wants to hide the existence of such settlements from the public, the consequences could be grave. The residents would be evicted and forced to find a new place to live.

Prof. Christoph Lütge can recount a series of stories of similarly problematic ethical consequences of AI development projects. Director of the Institute of Ethics in Artificial Intelligence (IEAI) at TUM and co-founder of the Responsible AI Network in Africa, Lütge is convinced that AI will inherently fail to function without ethical considerations – and that such aspects should be taken into consideration when developing AI applications. "We're frequently confronted with similar ethical problems with AI, all around the world," explains Lütge. "So, it's important we tackle these problems not only by working at the local level but also through networking."

Members of TUM IEAI participate in a conference on "Responsible AI and Ethics – A Panacea to Digital Transformation in Sub-Saharan Africa" at KNUST, Ghana. RAIN-Africa co-hosted this event with the KNUST Responsible AI Lab.

Professor Mrs. Rita Akosua Dickson, Vice-Chancellor, KNUST speaking at the Responsible AI and Ethics Conference in Kumasi, Ghana.

Connecting African AI experts

In recent years, the IEAI has established several networks to promote the discussion of ethical challenges related to AI use and prevent social dislocation. One such network, the Responsible AI Network Africa (RAIN-Africa), focuses specifically on African countries. It was founded in 2020 through a partnership between the IEAI and the Faculty of Electrical and Computer Engineering at the Kwame Nkrumah University of Science and Technology in Ghana (KNUST) in Ghana. In addition to Lütge, the other co-founders of RAIN are his colleague Dr. Caitlin Corrigan, TUM doctoral student Laud Ammah, and Prof. Jerry Kponyo from KNUST.

"In RAIN-Africa, we are bringing African AI experts together," explains Caitlin Corrigan, Executive Director at the IEAI. "The platform enables users to jointly discuss and develop projects related to the ethical and social challenges at the interface of technology and human values – and especially with regard to sustainable development."

Specifically, Corrigan organizes events, online workshops and live conferences on the platform – supported by her colleagues at TUM in Munich and at KNUST in Ghana. "This gives scientists and AI experts a platform for exchanging ideas – about ongoing projects and how they're implementing them. They can also find research partners in their fields of work," says Corrigan. The RAIN-Africa project hopes to stimulate international and interdisciplinary cooperation through a series of virtual and in-person workshops.

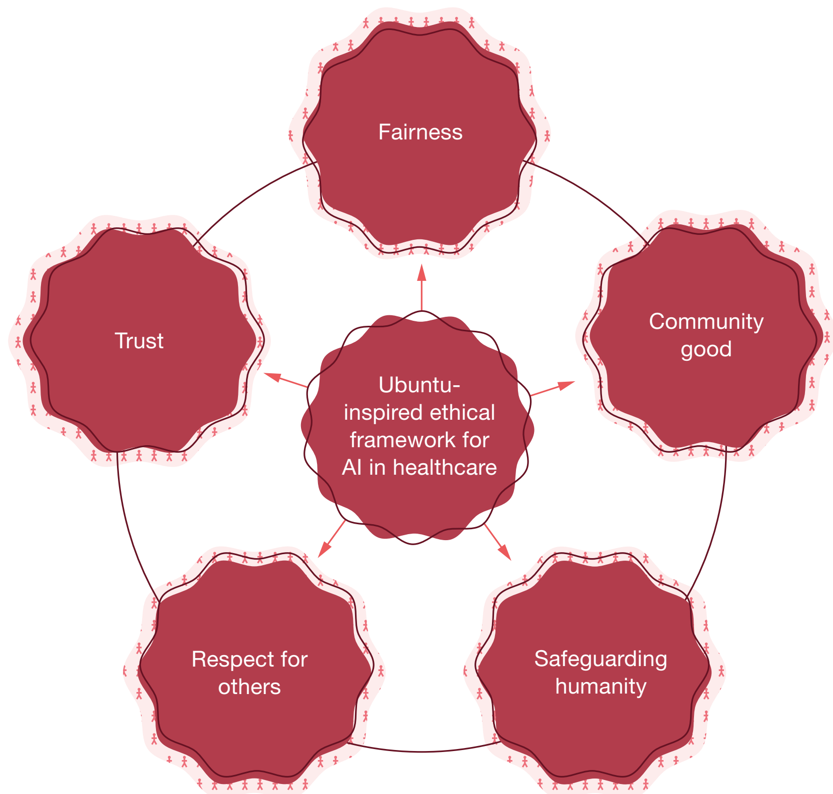
Picture credit: KNUST/TUM

Putting community benefits first

Fairness is a perennial ethical challenge at the conferences and workshops hosted by the RAIN-Africa platform. "For many people, the central question is whether the benefits of this technology are distributed fairly, justly, or whether only a select few stand to profit," explains Corrigan. "This aspect is decidedly crucial in Africa."

People in the south of the continent in particular draw on a special ethical approach: Ubuntu ethics. Unlike Western ethical concepts, which often have an individualistic focus – such as Kantianism, utilitarianism and virtue ethics – Ubuntu ethics considers the individual as inextricably linked with others and prioritizes the community above the individual. Given the inherent links between the well-being of the individual and their society, the rights of the individual are subordinate to the benefits to society.

This ethical concept has very tangible impacts: "If a community can use a healthcare app, the individual should be willing to disclose their data," says Corrigan. "Data protection is sometimes sacrificed in a Covid tracing app, for instance – but, in return, that app can protect the whole community." As Corrigan explains, this issue has been raised time and again at recent RAIN-Africa conferences – though it has also been the subject of considerable discussion in other countries in the context of the Covid-19 pandemic. ▷



Ubuntu ethics, which emphasizes the interconnectedness and interdependence of all people, provides a promising framework for addressing ethical concerns in AI for healthcare. Researchers at the IEAI, along with partners in Namibia, developed the framework above.

In some cases, speed is also given priority over individual data protection – especially in critical situations. “A discussion point at the latest RAIN-Africa conference was about the ‘responsibility’ of launching an AI-enabled app in society as quickly as possible, even if it isn’t perfect,” says Corrigan. Developers from African countries want to help people who might live too far from a hospital or don’t have a doctor nearby. It can therefore be important to deploy such apps as quickly as possible and then iteratively refine them. “Socially beneficial applications like this are often associated with the question of how we define ‘responsible’ and how different ethical concerns could come into conflict. For example, should data processing regulations be given priority over promoting access to healthcare?”

These examples are just a fraction of the entire range of AI-related ethical problems that are discussed in the RAIN-Africa Network with the aim of creating solutions to a variety of challenges related to sustainable development. In all probability, such networks could also yield benefits in other regions, given their potential to bring discussions of AI and ethics together worldwide. ■

Klaus Manhart

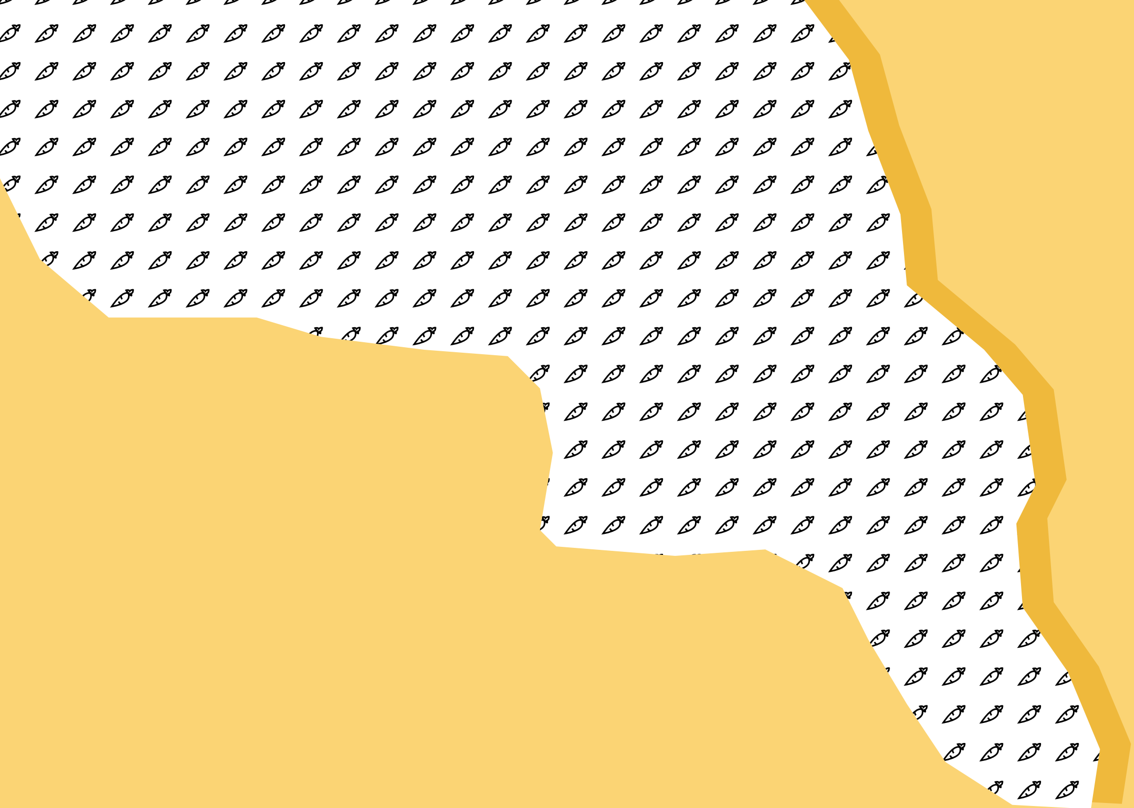
Picture credit: Astrid Eckert/TUM, Graphics: ediundsepp (source: TUM/https://dl.acm.org/doi/10.1145/3593013.3594024)

Prof. Christoph Lütge

has held the Chair of Business Ethics at TUM since 2010 and has been active as Director of the Institute for Ethics in AI (IEAI) since 2019. He studied business informatics and philosophy, completed his doctorate at TU Braunschweig and earned his habilitation at LMU Munich. Lütge was awarded a Heisenberg Fellowship in 2007 and appointed a Distinguished Visiting Professor by the University of Tokyo in 2020 and has been a guest lecturer at Harvard, Pittsburgh, Taipei, Kyoto and Venice. Moreover, he is a member of the Scientific Committee of the European AI ethics initiative AI4People, and of the German government's Ethics Commission on Automated and Connected Driving. Lütge has been actively engaged in projects in Africa for some time. In March 2023, he traveled extensively in sub-Saharan Africa and visited universities associated with RAIN-Africa in South Africa, Namibia, Cape Verde and Senegal.

Dr. Caitlin Corrigan

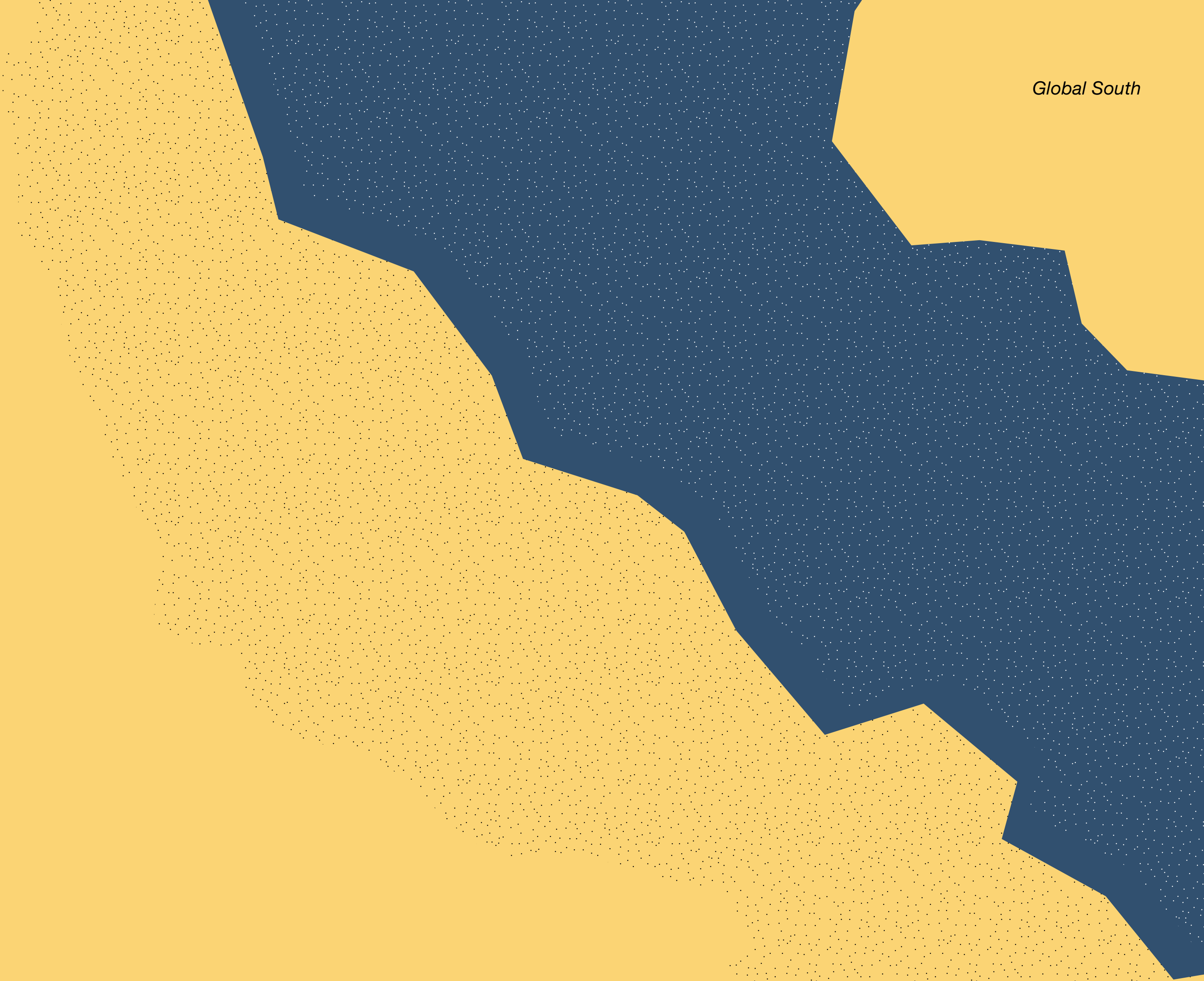
has been engaging with issues surrounding sustainable development in Africa for over ten years. She received her doctorate in Public and International Affairs from the University of Pittsburgh. For her doctoral thesis, she focused on the governance of natural resources, specifically in sub-Saharan Africa, including conducting field research in Botswana and South Africa. She was also the Program Development Manager, developing research projects and grant applications, for the University of Pittsburgh's Africa Studies Program. As Executive Director of the IEAI at TUM, Caitlin Corrigan is responsible for developing and coordinating all its research and administrative activities. She also works closely with the institute's director to shape its agenda.

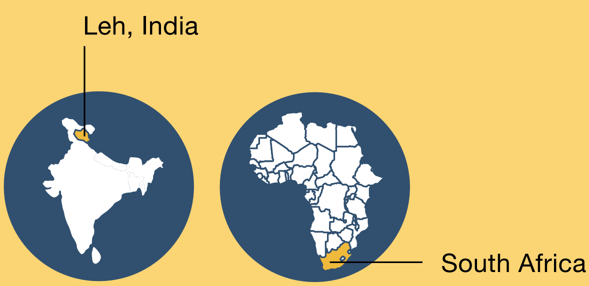


Link
www.cee.ed.tum.de/en/sww/home/ www.nexus.wasser.tum.de

A Long-Term **Ménage à Trois**

Connecting water, energy and food to save the world – that's the mission undertaken by an international research initiative focusing on the Water-Energy-Food (WEF) Nexus. Its researchers are developing alternative solutions to the consumption of natural resources in large and small cities and their surroundings around the world.





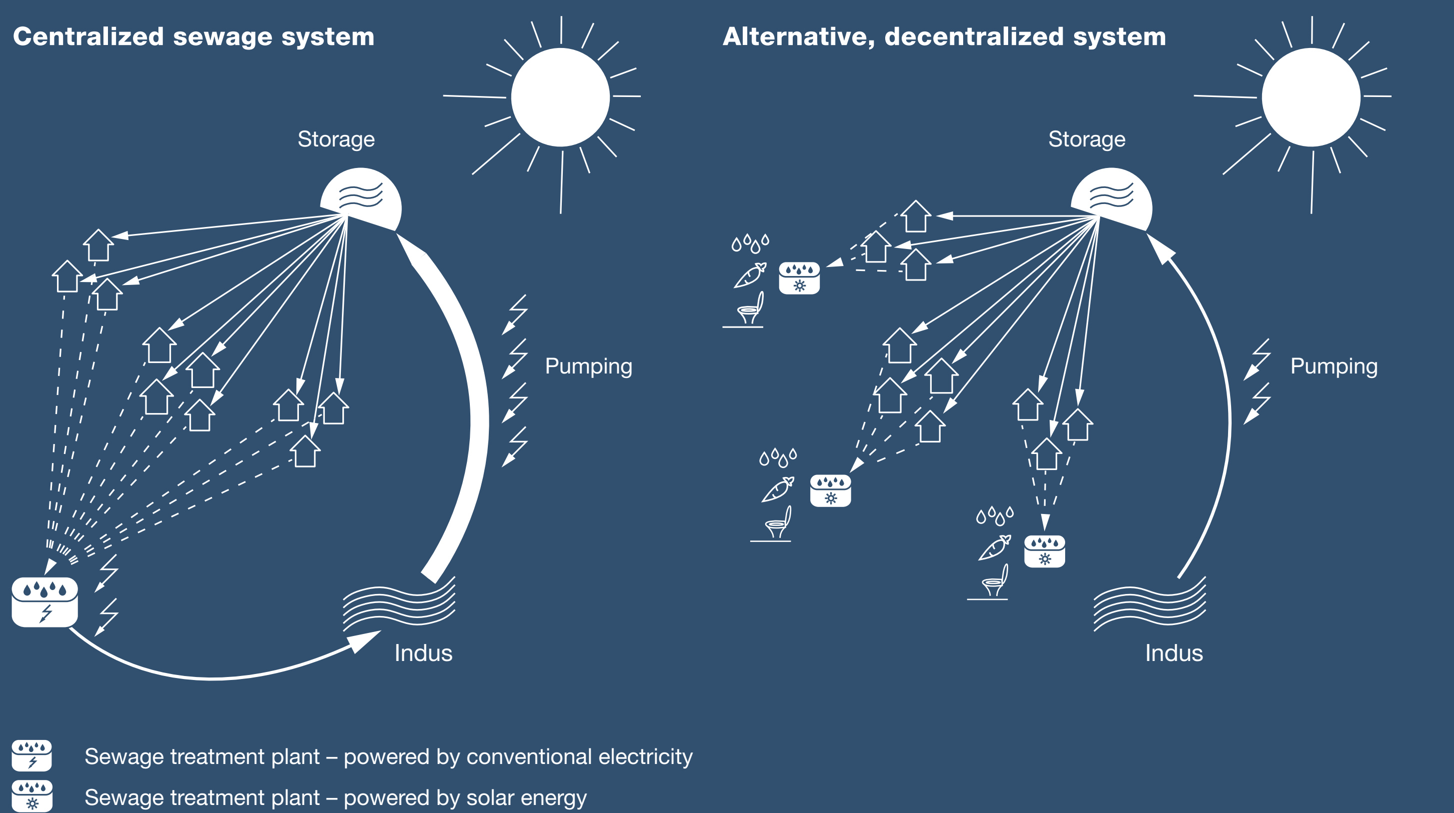
Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Langfristige Ménage-à-trois

D

Wasser, Energie und Nahrung: An alternativen Lösungen für den Verbrauch dieser Ressourcen in großen und kleinen Städten forschen Prof. Jörg Drewes und Dr. Daphne Keilmann-Gondhalekar. Etwa für die kleine Stadt Leh im indischen Himalaya, die an Wassermangel leidet. Hier entwickeln sie ein dezentrales System zur Wasserwiederverwendung, das die Stadt unabhängiger von externen und weit entfernten Wasserquellen machen könnte. □

Graphics: ediundsepp



A concept for a decentralized wastewater system developed with the residents of the city of Leh. The water is reused locally, such as to cultivate vegetables or flush toilets. This type of system would reduce demand for fresh water, cut the waste stream, save energy and help to grow food locally.

A morning shower followed by brushing your teeth, turning on the radio and making a coffee. Sound familiar? This morning routine, which many of us take for granted, is actually a significant organizational effort – especially in major cities. Particular complications include the rising demand for natural resources like water, energy and food, which is caused in part by a further complication: the consequences of climate change. In Los Angeles, for example, high temperatures drive up energy consumption due to increased use of air-conditioning systems in buildings. Glacial melting in the Swiss Alps is reducing water supplies, meaning that water has to be sourced from elsewhere. These are just two of many examples of the impacts of climate change. Against this backdrop, it is essential that we bring our consumption of resources down to a sustainable level.

But how can we achieve this? While this ultimately means consuming less, we can also promote integrated planning of three closely connected sectors: water, energy and food. Agriculture and energy production facilities both require water. Transporting water and food also requires energy. Integrating plans for supplying these resources can generate synergies. Or, to put it differently: if water, energy and food were engaged in a ménage à trois, they would be equal partners who support and rely on each other – and communicate effectively to maintain a functioning and optimal relationship.

However, consideration of the interrelationships between these resources has barely penetrated teaching and research, and practice even less so. “We need a circular perspective rather than a linear one,” underscores Prof. Jörg Drewes, who heads the Chair of Urban Water Systems Engineering at TUM. Since 2017, the Chair has been home to the Urban Water-Energy-Food Nexus research group, led by Dr. Daphne Keilmann-Gondhalekar. Together, they initiated the Nexus@TUM research and teaching agenda in 2021.

> *“We need a circular perspective on water, energy and food rather than a linear one.”*
>
> Jörg E. Drewes

Using a small city in the Himalayas as a model for sustainable resource management

Drewes, Keilmann-Gondhalekar and their team have already completed several pilot projects, including in India and Niger, but also in Bavaria. Their interest is in regions where natural resources are scarce and there is a need for novel solutions usually not yet financed by the public purse. One example is Leh, a city in the Indian Himalayas, surrounded by desert. Over recent decades, the city has experienced exponential growth, driven by tourism, and is now grappling with limited water resources. Drewes, Keilmann-Gondhalekar and their team have been working in the area for over a decade. Conventional concepts developed and financed externally – such as a time-consuming, expensive plan to install a pipeline to pump water to Leh – have not yet yielded the desired results. The Nexus researchers have recorded and measured demand for water and spoken with many local residents. They agree that, rather than transporting water to the city from elsewhere, a better option would be to capture, treat and reuse the wastewater generated in Leh. Every hotel, guesthouse and household could feed their used water into a decentralized system so that it could be used, for example, to irrigate fields and serve as fertilizer. This type of system would reduce demand for fresh water, cut the waste stream, save energy and help to grow food locally. It would also give the city greater independence than having to rely on (and pay for) water to be transported from elsewhere. “This example shows the need for new concepts that are developed, implemented and financed together with local people,” comments Dr. Keilmann-Gondhalekar.

Leh has also afforded Keilmann-Gondhalekar another vital insight: “We need new computational models to calculate potential demand,” she says. “The most affordable solution in the short term is usually not the most affordable in the long term.” For instance, it may cost more to build a decentralized water system than a centralized one. Conventional calculation methods, however, usually fail to take into account the sharply rising value of water. Consequently, the researchers have turned to multi-criteria decision-making analysis. This is a decision-making method that affords equal weight to various criteria that are not easy to compare or quantify. ▷

Graphics: ediundsepp (source: TUM)

> *“The Indian city of Leh is an example showing the need for new concepts that are developed, implemented and financed together with local people.”*
>
> Daphne Keilmann-Gondhalekar

Time to turn words into action

In South Africa, Drewes’ team is currently developing concepts for informal settlements – more commonly known as slums. In these areas, electricity, water and adequate sanitary facilities are all in short supply, with local people unable to establish farming fields and produce food. Streams and rivers are contaminated with waste, which leads to health problems. These problems are linked and can exacerbate each other in a downward spiral.

In this project, like in their other research, the scientists gather information and record demand for water, energy and food, while students write papers on potential solutions – such as using renewable energy sources like wind, solar and biomass, producing biogas from waste, and capturing rainwater. “The latter is something we don’t even do in a modern city like Munich,” says Drewes. “There are plenty of ideas and we already have some solutions but, unfortunately, we aren’t implementing them.” Keilmann-Gondhalekar adds: “We urgently need to act.” This is why Nexus@TUM goes far beyond examining technical aspects. It aims to motivate people, create acceptance, highlight transformation pathways, win the support of various stakeholders (including governments), teach environmental engineers the importance of Nexus approaches – and much more besides. Consequently, Nexus@TUM also relies on input from researchers in the social and political sciences. “Our research is made meaningful by adopting an interdisciplinary approach. Implementation will only succeed if we work together with local people in a long-term, transdisciplinary approach that is built on trust,” says Drewes. ■ *Gitta Rohling*

Get involved!

Nexus@TUM welcomes researchers from all disciplines. For more information, visit: www.nexus.wasser.tum.de

Picture credit: Astrid Eckert/TUM; Graphics: ediundsepp

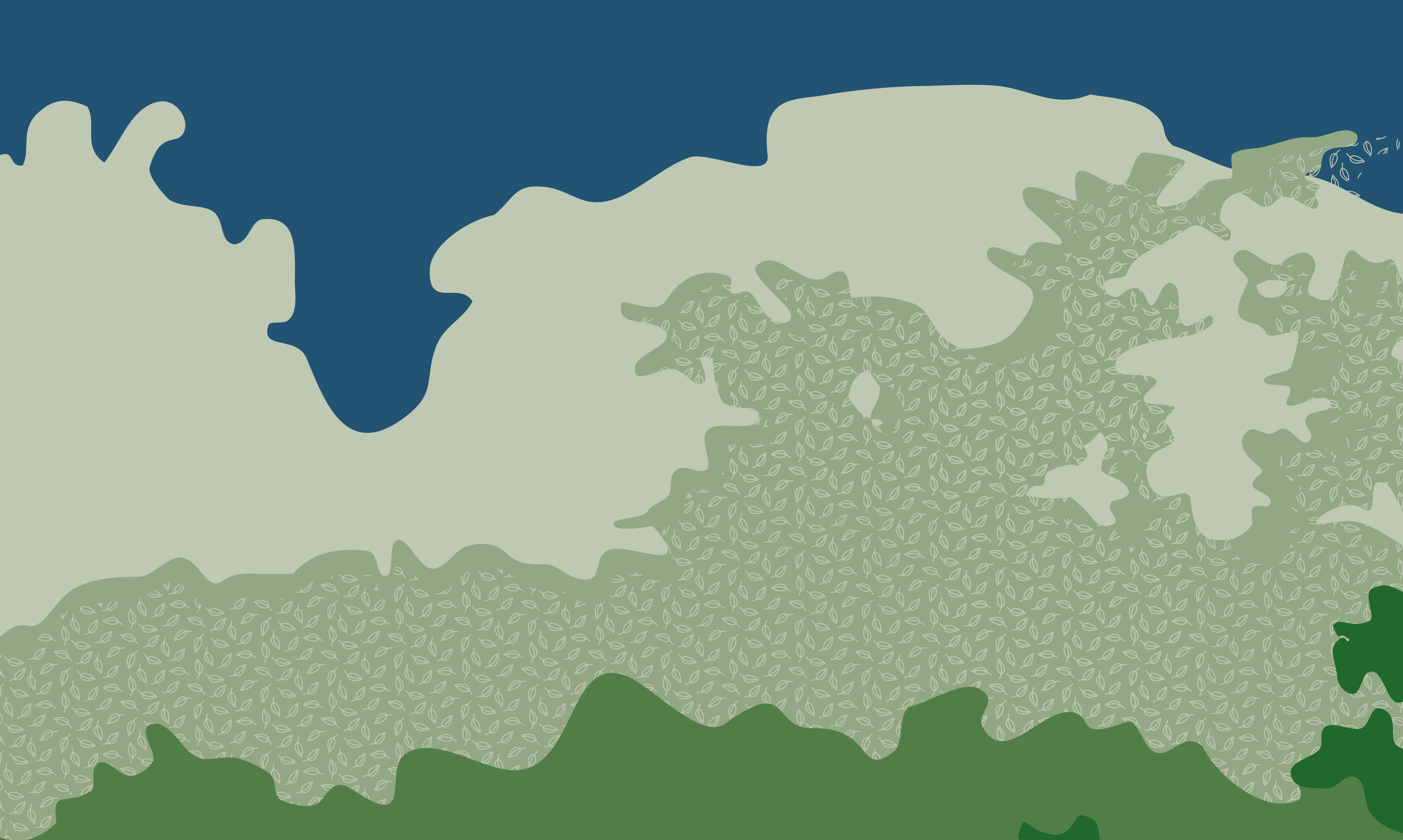
Prof. Jörg E. Drewes

has led the Chair of Urban Water Systems Engineering at TUM, along with the associated research center, since 2013. Before taking up his position at TUM, he was a Full Professor at the Colorado School of Mines, USA and Director of Research at the NSF Engineering Research Center on Reinventing the Nation's Urban Water Infrastructure. He is a member of the German Advisory Council on Global Change (WBGU) and Co-Chair of the Drinking Water Commission at the German Federal Ministry of Health.

Dr. Daphne Keilmann-Gondhalekar

is an urban planner and leader of the Nexus research group at the Chair of Urban Water Systems Engineering at TUM, concentrating on integrated urban planning, the urban Water-Energy-Food Nexus and multi-stakeholder processes. She received her doctorate from the University of Tokyo and was a Postdoctoral Associate at the Massachusetts Institute of Technology (MIT).

How Much CO_2 Can Forests Absorb in the Future?



Tropical rainforests absorb huge amounts of carbon dioxide. But how are increasing levels of this greenhouse gas likely to affect the forests' future growth? A large outdoor experiment in Amazonia aims to cast light on this issue by subjecting sections of the forest to elevated carbon dioxide levels. Ecosystem modeler Prof. Anja Rammig is part of the research effort.

Graphics: ediundsepp

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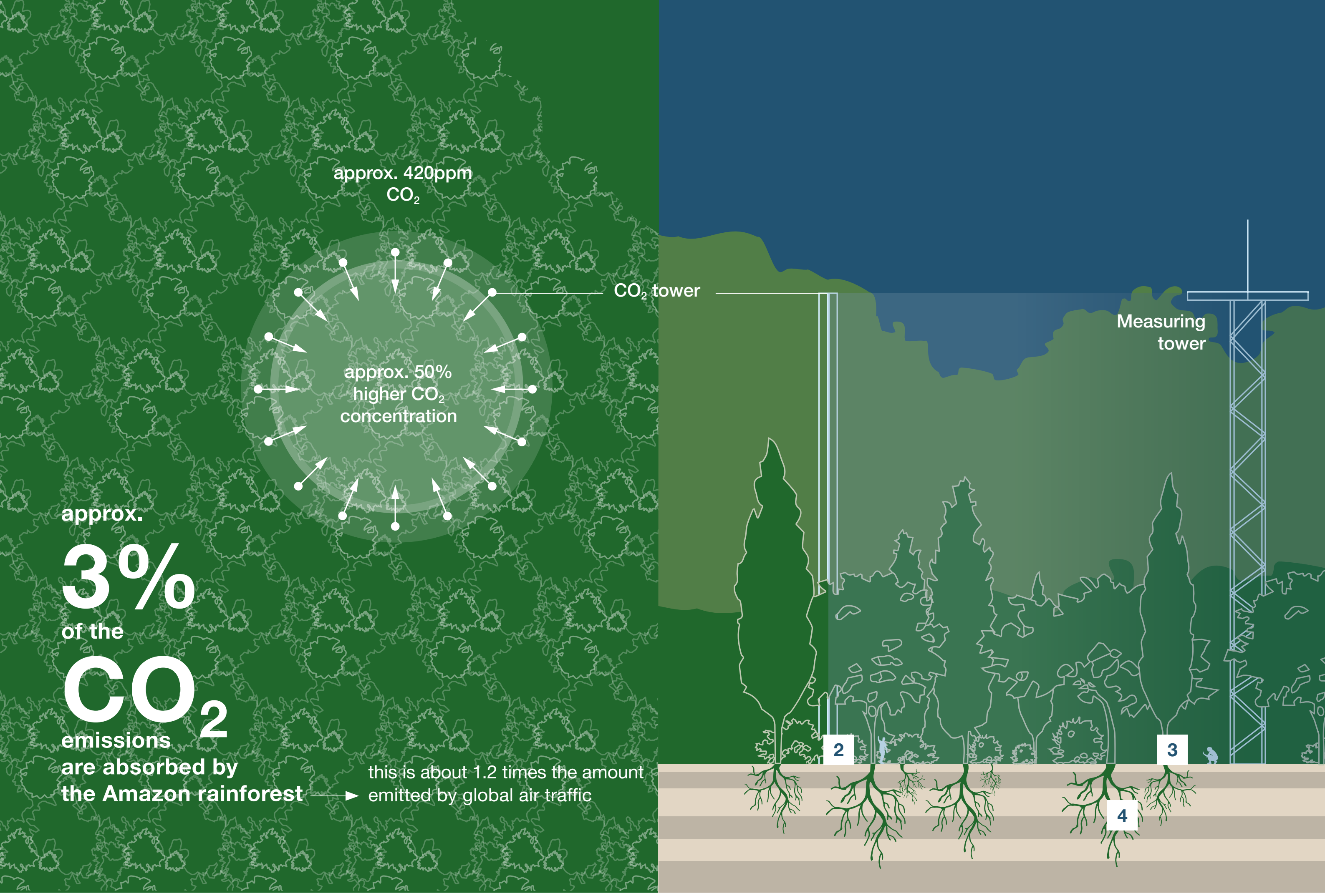
www.lsai.wzw.tum.de/en/home www.amazonface.unicamp.br/en/

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Wieviel CO_2 können Wälder künftig noch aufnehmen?

D

Der Amazonas spielt eine wichtige Rolle im Klimasystem der Erde. Er nimmt einen großen Teil des Klimagases Kohlendioxid (CO_2) auf und bremst so die Erderwärmung. Wieviel CO_2 der Amazonas in Zukunft speichern kann, ist ein wichtiger Parameter für globale Klimamodelle, aber bisher noch weitgehend ungeklärt. Klimamodelle nehmen vereinfachend an, dass der Wald umso stärker wächst, je mehr CO_2 er aufnimmt. Ob das tatsächlich stimmt oder ob beispielsweise die Nährstoffversorgung ab einem bestimmten Punkt das Wachstum hemmt, klärt nun ein internationales Experiment, das ein definiertes Gebiet im Amazonas mit CO_2 begast. Mit dabei ist die Ökosystemmodelliererin Prof. Anja Rammig. □

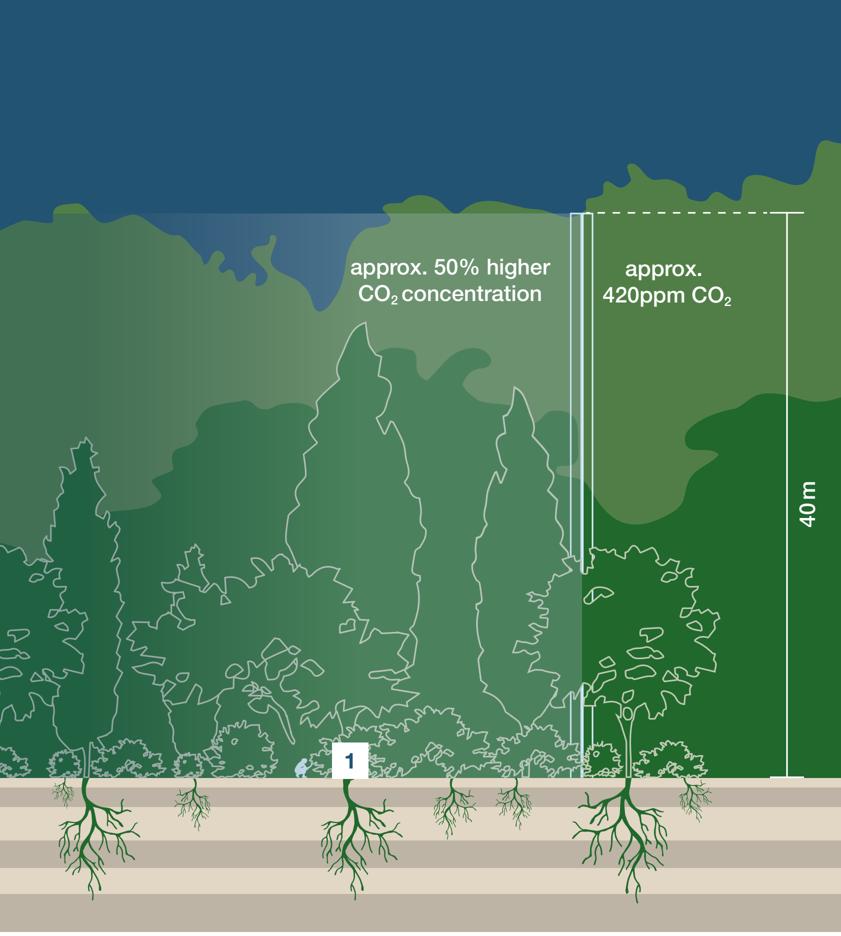


The Amazon rainforest is vast; a seemingly endless green carpet, sprawling over an area around 14 times the size of Germany. In addition to serving as a habitat for plants and animals, the rainforest plays a vital role in regulating the Earth's climate. This involves absorbing a large amount of the carbon dioxide (CO_2) released by humans burning oil, gas and coal. Without the Amazon, climate change would progress even faster. However, exactly how much carbon dioxide the Amazon rainforest will be able to store in the future remains largely unknown because, until now, there has been no field experiment investigating how this huge ecosystem processes the greenhouse gas.

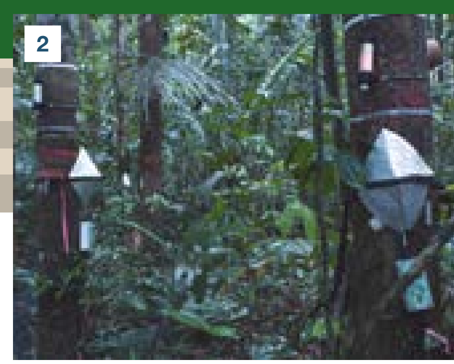
A forest of gas-emitting towers

To date, climate models have relied on the assumption that increasing concentrations of carbon dioxide in the atmosphere would stimulate forest growth. Ultimately, plants absorb the gas from the air and convert it into energy-rich carbon compounds, i.e. sugars, through photosynthesis. They need these compounds to grow their biomass, such as stems and roots. A major international project is now conducting the first detailed examination of whether this assumption – more CO_2 equals more plant growth – actually holds. In the heart of the rainforest, not far from the Brazilian city of Manaus, numerous towers are under construction: 96 towers in total, each almost 40 meters in height. These towers will emit carbon dioxide, spreading it across sections of the forest. This will allow the researchers to simulate the elevated carbon dioxide concentrations expected by the middle of the century. Amazon Free-Air CO_2 Enrichment – AmazonFACE – is an open-air CO_2 fertilization experiment that, after around a decade of planning, has now entered the construction phase. The international team of researchers includes Anja Rammig, an expert in ecosystem modeling at TUM. "We provide the trees with far more CO_2 than usual, which allows us to measure the response of the whole ecosystem," she states. It is far from certain that the trees will actually grow better. As Rammig explains, it is also conceivable that tree growth will be stunted by nutrient deficiencies in the soil – which could occur if the increased growth leads to a reduction in vital phosphorus compounds.

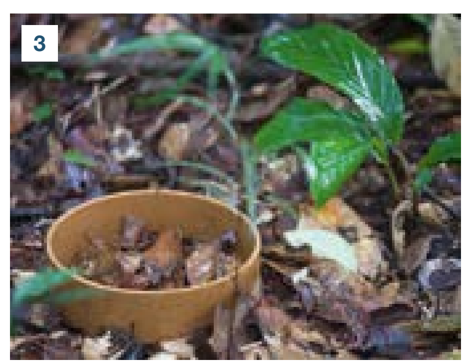
Picture credit: João M. Rosa/AmazonFACE; Graphics: ediundsepp (source: Rammig/TUM)



Measuring photosynthetic activity in leaves



Measuring the circumference and sap flow in the tree trunks



Monitoring soil and root respiration

Analyzing changes in belowground processes, here root samples

A field project, not a lab experiment

Anja Rammig reconstructs the complex processes at work in ecosystems on computers in order to understand them better and make forecasts. This work involves translating natural processes into numbers, such as the quantities of carbon exchanged between the atmosphere, the leaves and roots of a tree, and the soil. These ecosystem models rely on measurement values and figures that depict reality. Until now, such data has been lacking. Researchers have previously conducted laboratory-based experiments, subjecting specific plants to elevated CO_2 concentrations. However, conducting an open-air experiment on an entire section of forest – on the living object, as it were – is another proposition altogether. It is, as Anja Rammig explains, the only way to record natural processes in all their complexity. Not least because elevated CO_2 concentrations can also have other far reaching effects. ▷

Prof. Anja Rammig

studied biology at FAU Erlangen and received her doctorate from ETH Zurich in environmental science in 2005. She then worked as a postdoc at the University of Lund in Sweden. From 2008 to 2015, Rammig conducted research at the Potsdam Institute for Climate Impact Research (PIK). She was appointed to the Professorship for Land Surface-Atmosphere Interactions at the TUM School of Life Sciences in 2015.

Central measurement tower inside the CO_2 rings that are currently being built

Picture credit: Astrid Eckert/TUM; AmazonFACE

More CO_2 – less rain?

Plants absorb CO_2 through stomates, which are tiny openings in their leaves. They also release water vapor through their stomates in a process called transpiration. If the air contains more carbon dioxide, the assumption goes, the plants can open stomates less. This would also reduce transpiration – which could become a problem for the entire Amazon rainforest. In effect, transpiration enables the forest to produce its own rain, as moisture that rises during the day pours down again at night. If transpiration rates from leaves fall, it could have a knock-on effect on the amount of rainfall. The result? A drier ecosystem. It is also these effects that the research team aim to investigate in the rainforest near Manaus.

The first towers have now been erected. Each plot under examination is surrounded by 16 towers. The plan is to examine six plots in total, with construction in two areas completed so far. The CO_2 taps are set to be turned on by the end of the year. The full AmazonFACE experiment is scheduled to run for around ten years, during which the research team will measure a variety of parameters – such as photosynthesis, water fluxes, tree growth, root growth, leaf growth and nutrient levels in the soil. The project is set to produce initial results at the beginning of 2024.

Anja Rammig hopes the project will provide a wealth of new data for her ecosystem models – models whose results are also incorporated into calculations of the Intergovernmental Panel on Climate Change (IPCC). "Our models can only ever be as good as the data we feed into them," she says. "The ideal scenario would be if, in a few years' time, the measurement results from the rainforest could be input directly into our models, enabling us to model processes in real time." This would make it possible to forecast the fate of the Amazon rainforest, and the process of climate change, far more reliably than is currently the case. ■ *Tim Schröder*

What if...?

Urban simulations provide answers to key questions for the future

Saving energy, promoting autonomous driving and improving safety are important goals that many cities share. But how exactly can we achieve them? Geodata-based semantic city models are pointing the way forward. They simulate future scenarios and therefore represent a vital decision-making tool.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Was wäre, wenn ...? Stadtsimulationen beantworten wichtige Zukunftsfragen

D

Energie sparen, autonome Fahrzeuge einsetzen und die Sicherheit erhöhen – das sind wichtige Ziele von Städten. Wie lassen sie sich erreichen? Geodatenbasierte, semantische Stadtmodelle weisen den Weg. Prof. Thomas H. Kolbe und sein Team forschen an solchen 3D-Modellen, in die vielfältige Daten einfließen – etwa zu Verkehr, Infrastruktur, Mobilfunkmasten, Gebäudestruktur und Bauvorhaben. Damit berechneten sie beispielsweise den zukünftigen Energieverbrauch der Wohngebäude in München bis 2035 in zwei Szenarien. □

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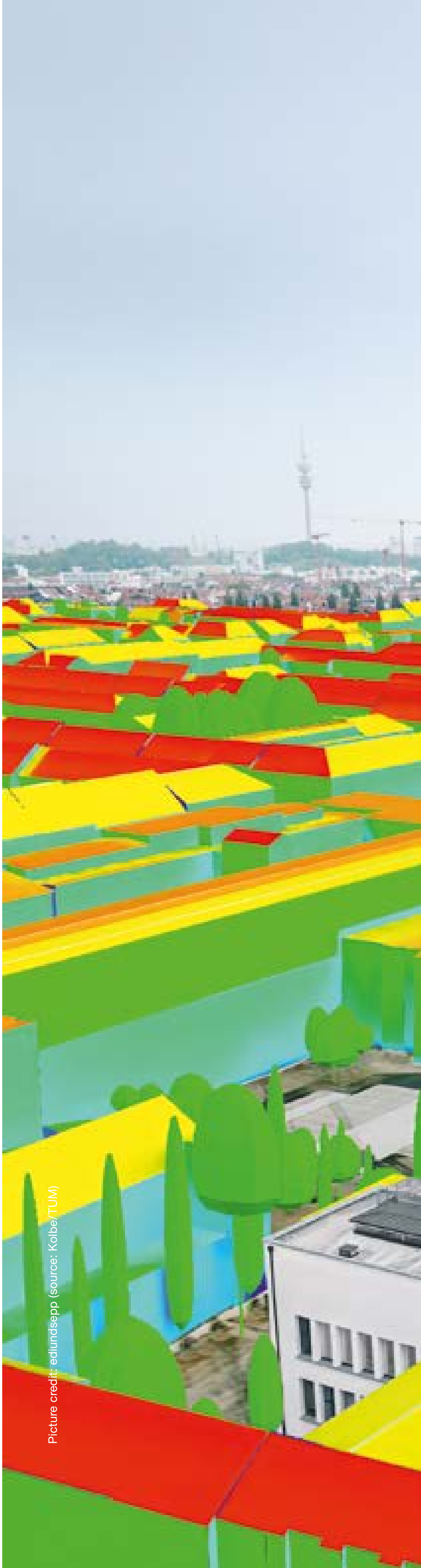
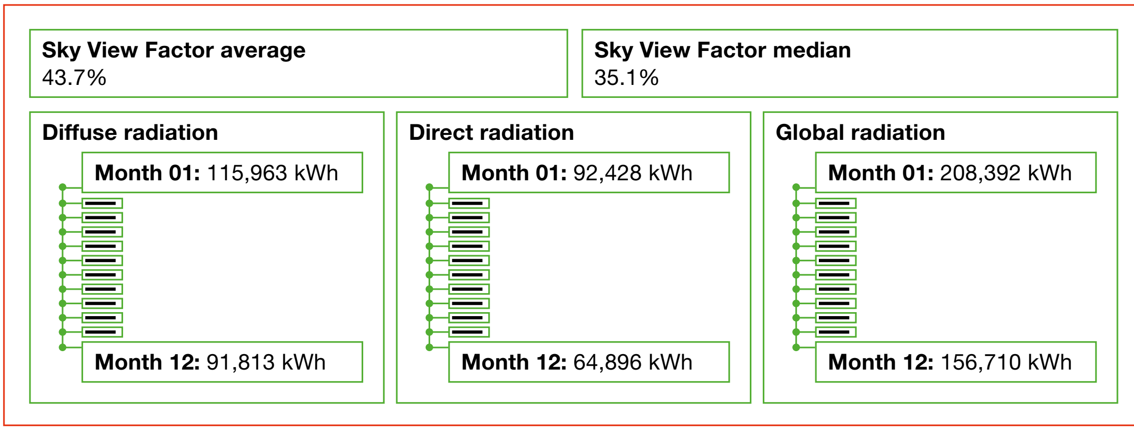


Picture credit: ediundsepp (source: Kolbe/TUM)



Semantic 3D city models can be enriched with any data of interest for the actual use case. This model of Munich features diffuse and direct solar energy on the different surfaces of a building, given in monthly and annual totals. The sky view factor (SVF), which indicates the fraction of the sky that is visible, is also computed for the individual surfaces and aggregated for each building.

What if we retrofitted every residential building in Munich with district heating systems and heat pumps to replace oil and gas fired systems? What if domestic hot water supplies relied primarily on solar thermal energy? And what if underfloor heating was installed to replace most radiators?
Well, what would happen? A geodata-based semantic model of Munich can show us by determining potential energy savings based on detailed building information.

More than a visualization: a semantic 3D model

So, where does the information for the model come from? The geodata is provided by public authorities like state surveyors and land registry offices, with further input from topographical maps, aerial photographs and satellite images. Additionally, sensors provide data on traffic flows, the environment and infrastructure. Companies in the telecommunications, transport and real estate sectors can also contribute data, including on cell phone towers, traffic flows and construction projects.
From Berlin to New York to Tokyo, many cities around the world make use of such 3D models. The best way to explain what these models are is to compare them with other systems. The 3D views in Google Maps, for example, rely on a purely visual model that does not contain any semantic data, which means that it does not supply information about any of the buildings it displays. There's no information about usage types like office or residential buildings, how old they are, how many stories they have, and so on. In contrast, geodata-based semantic models include these types of data. "These models are therefore able to collate information from different areas very effectively and simulate scenarios for different questions," says Prof. Thomas H. Kolbe, holder of the Chair of Geoinformatics at TUM, who researches these models.
These 3D models can be used to forecast energy consumption, as the analysis of residential buildings in Munich shows. However, they can also play a vital role in urban planning, transportation planning, safety management and disaster management. "I'm fascinated by these wide-ranging applications," Kolbe explains. "We develop them together with experts in different disciplines and are constantly integrating more data." ▷

Picture credit: ediundsepp

Applications

ranging from urban planning to disaster management

Urban planning
Example: Which areas are suitable for new residential developments?

Required data (RD) from 3D model: All buildings, incl. 3D geometry, usage type, year of construction and number of stories

Traffic planning
Example: Where would autonomous (self-driving) minibuses provide benefits?

RD: Spatial models of roads with precise lane data, traffic density and demand figures, terrain models and building models

Energy planning
Example: Which energy technologies would function efficiently in different areas?

RD: All buildings, incl. 3D geometry, usage type and year of construction

Property management
Example: What is the market value and insurance value of real estate?

RD: All buildings, incl. 3D geometry, usage type, year of construction and number of stories

Safety and disaster management
Example: Which areas are at risk of flooding, a terror attack or a tsunami?

RD: Terrain models, water bodies, all buildings and transport routes in a potentially at-risk area

"These models are able to collate information from different areas and simulate scenarios for different questions."

Thomas H. Kolbe

Ever-improving forecasts – thanks to data collected and harmonized from different disciplines

A research project undertaken by Kolbe and his team is a prime example of how these models can be applied. It examines the intensity of sunlight on Munich's buildings and how it then heats buildings up. South-facing surfaces heat up more than north-facing surfaces – that much is obvious. Temperatures on roofs rise more than those on façades. Trees and chimneys cast shadows, however, while poor air quality reduces insolation. The geodata used in this project has been provided by the Bavarian State Agency for Survey (LDBV); solar irradiance data was calibrated with information procured from NASA, and details of Munich's tree population were obtained using methods developed by the Leibniz Institute of Ecological Urban and Regional Development in Dresden. Kolbe's team integrated all this information to develop a semantic, three-dimensional model of Munich. The end result was a city model highlighting areas in which photovoltaics and solar thermal installations would be worthwhile.

It is essential for collaboration to produce standardized datasets. This is achieved here by the CityGML standard, the development of which was launched and masterminded by Kolbe. It defines how buildings, roads, bridges and even trees should be described in digital terms. This makes models comparable, which, in turn, also makes them cost-efficient. Numerous countries and cities around the world are now providing their 3D models free of charge as CityGML-compliant open data. This enables the integration of more and more data, which, in turn, results in increasingly detailed simulation results. Some urban authorities have already created digital twins – virtual, real-time representations of their cities. So, what if a city aims to become climate-neutral, car-free or safe from natural disasters? These models point the way. ■

Gitta Rohling

3DCityDB – an open source database for 3D city models and semantic objects

The award-winning 3D City Database is a free geodatabase to store, represent and manage virtual 3D city models. It implements the CityGML standard with semantically rich and multi-scale urban objects facilitating complex analysis tasks, far beyond visualization. 3DCityDB has been in productive and commercial use for more than 14 years in many places around the world as well as in numerous research projects related.

www.3dcitydb.org

Picture credit: ediundsepp

Prof. Thomas H. Kolbe

studied computer science at Dortmund University and earned his doctorate at the University of Vechta and the University of Bonn. He worked as a research assistant, and later a senior research assistant, at the University of Bonn. Kolbe then held the Chair of Methods of Geoinformation Science at TU Berlin. Since 2012, he has been the holder of the Chair of Geoinformatics at TUM. Kolbe researches methods that facilitate the spatial, temporal and semantic analysis, modeling and visualization of cities. He is initiator and co-author of CityGML, the international modeling standard to promote the storage and exchange of semantic 3D city models. In 2021, Kolbe became a core member of the Munich Data Science Institute.

A climate-neutral Munich?

Munich has more than 100,000 residential buildings that require heating, cooling and lighting – three processes that generate greenhouse gas emissions. But that's not all: in addition to this direct energy, there's another type – namely embodied energy. This is the energy consumed in the building's construction and the manufacturing, transport, installation and disposal of all the heating, ventilation, air-conditioning, sanitary, electrical, lighting and security systems and technologies.

Energy consumption analyses often fail to take this embodied energy into account. In 2021, Hannes Harter examined this issue in his dissertation, which he completed in cooperation with Kolbe's Chair. Building on a geodata-based semantic model of a city, he developed a method that integrated both direct and embodied energy into its analyses. This was a genuine first. The model contains information about what systems are currently in place for heating, domestic hot water supply and heat exchange. It allows us to answer a number of questions with meaningful figures: How much would it cost to replace existing systems? How much embodied energy would retrofitting involve? Where would energy consumption levels stand afterwards?

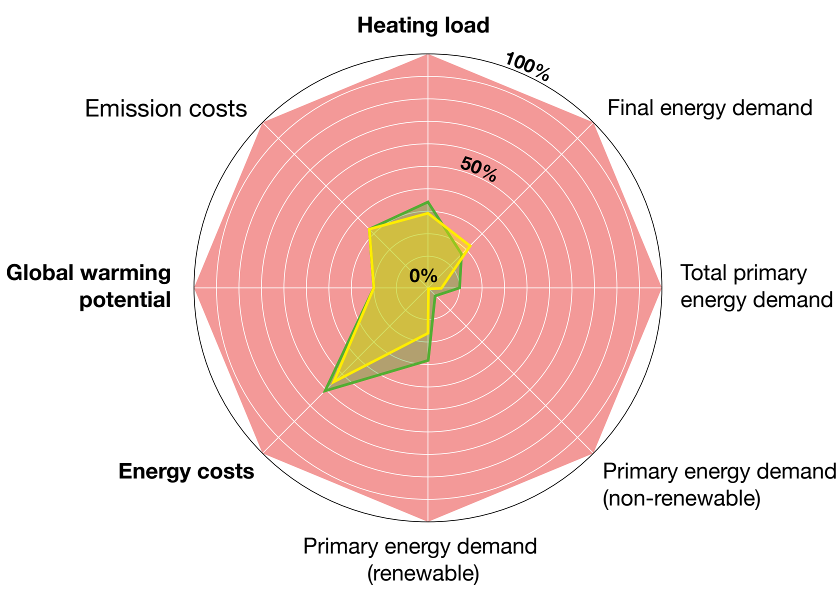
Harter's model estimates the future energy consumption of residential buildings in Munich up to 2035 in two scenarios. Scenario 1 involves using a combination of gas, district heating and heat pumps for domestic heating. In scenario 2, however, gas is removed from the equation entirely. Both scenarios rely exclusively on solar thermal technology for hot water supply, with underfloor heating for heat transfer. The model could also be used to simulate other scenarios.

Now, here's the bad news: when it comes to residential buildings, Munich would not achieve its goal of climate neutrality by 2035. The overhaul required in both scenarios would be so laborious and expensive that it is simply not realistic. And, because buildings require constant repairs and renovation, it is simply not possible for the building sector to become completely climate-neutral. The good news, however, is that retrofitting can save vast amounts of energy. "This shows that we shouldn't stick our heads in the sand – instead, we should use city models to analyze the areas in which retrofitting would be most worthwhile," says Thomas Kolbe.

Picture credit: Juli Eberle; Graphics: ediundsepp, (source: Harter, Willenborg, Lang, Kolbe (2023): Climate-neutral municipal building stock - life cycle assessment of large residential building stocks based on semantic 3D city models, Energy and Buildings, Vol. 292. https://doi.org/10.1016/j.enbuild.2023.113141)

What if...

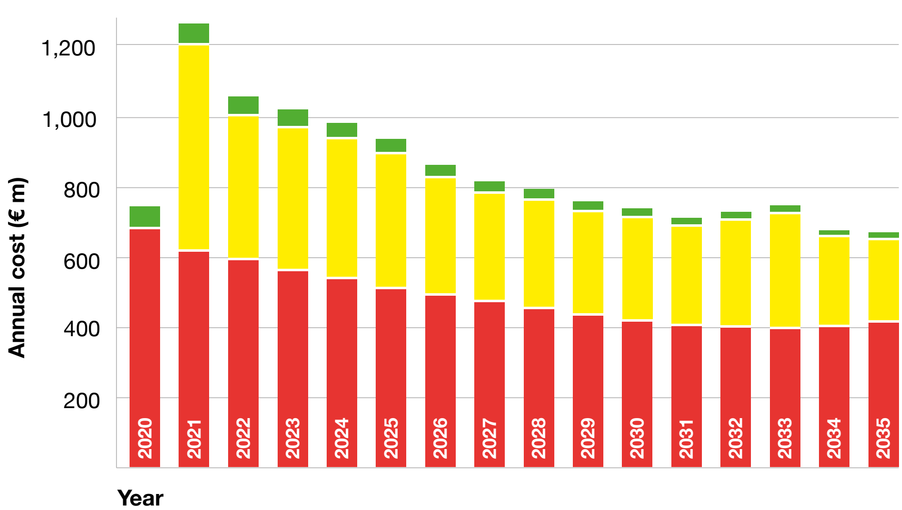
all residential buildings in Munich were given an energy overhaul?



Status quo: Heating energy from gas (70%), oil (20%) and district heating (10%)

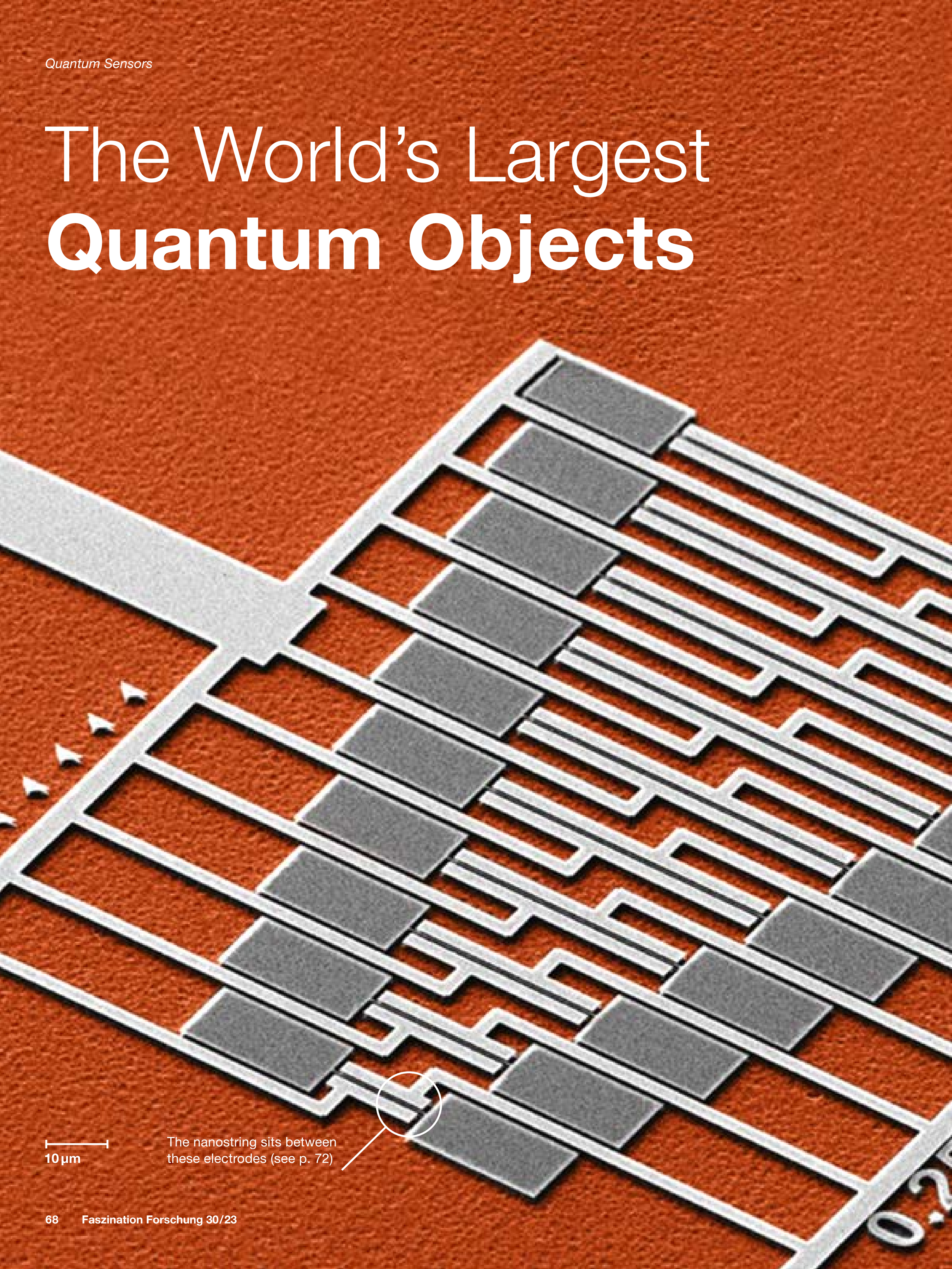
Scenario 1: Heating energy from heat pumps (70%; mainly powered with renewable energy), gas (20%) and district heating (10%); warm water: solar thermal; 100% underfloor heating

Scenario 2: Like scenario 1, but heating based on district heating (80%, of which 90% is provided by renewable sources) and heat pumps (20%)



Energy and emissions costs per year if all residential buildings in Munich are overhauled between 2020 and 2035 to meet scenario 1. Substantial costs remain for direct and embedded energy and for emissions, even after the overhaul is finished. (Initial emissions cost €25/t CO_2e; annual rise in energy and emission costs 5%; annual rise in construction costs 2%).

The World's Largest **Quantum Objects**



The nanostring sits between these electrodes (see p. 72)

Picture credit: Y. Klaß & E. Weig (TUM)

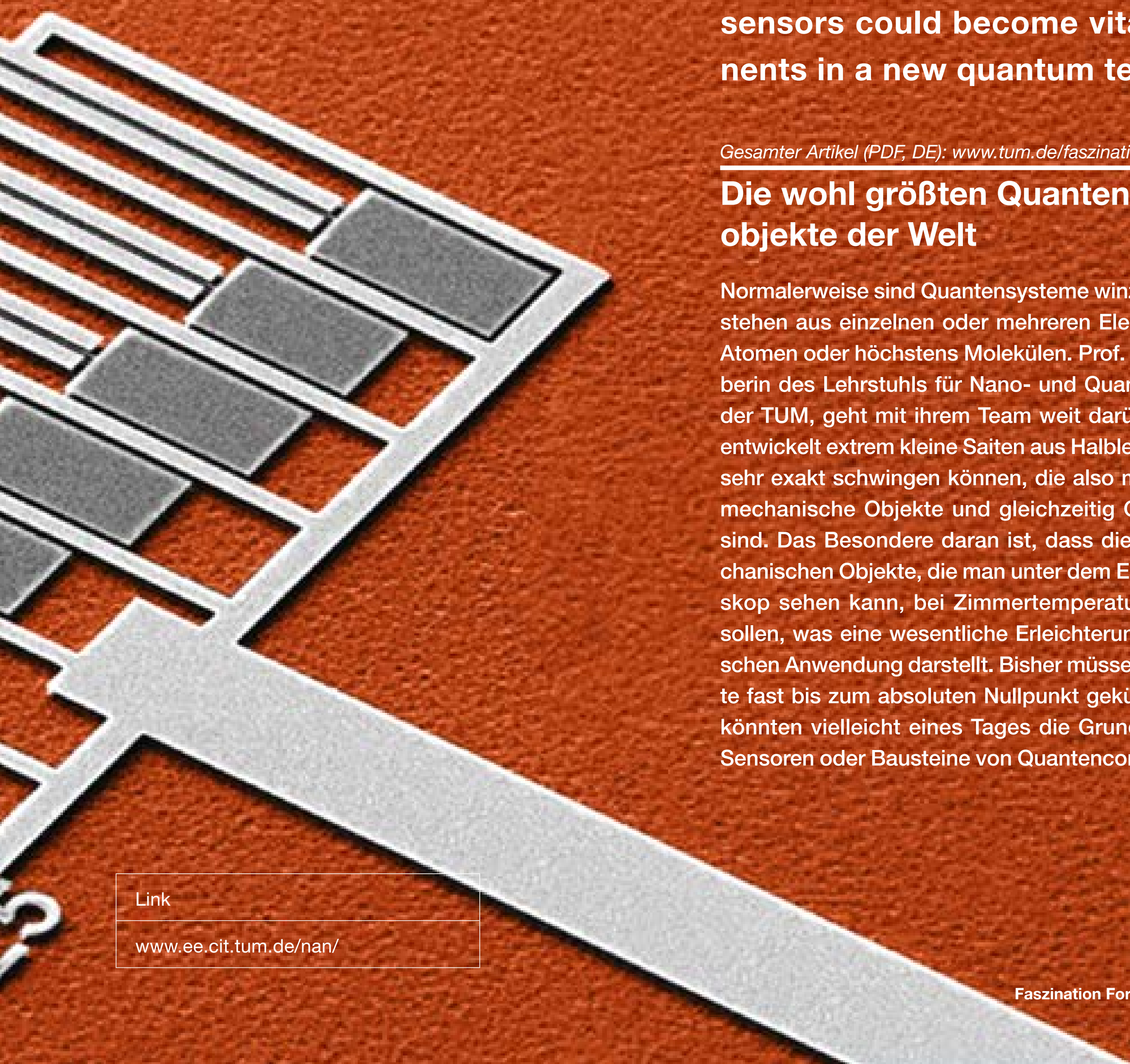
In the quantum world, the very smallest scale of existence, being the largest object should hardly pose a challenge. However, complying with normal laws in this minute world at the same time is virtually impossible. Yet, Prof. Eva Weig and her team of researchers are striving to do exactly that – by creating mechanical quantum sensors large enough to be visible under an electron microscope. One day, these sensors could become vital components in a new quantum technology.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-30

Die wohl größten Quantenobjekte der Welt

D

Normalerweise sind Quantensysteme winzig klein, sie bestehen aus einzelnen oder mehreren Elementarteilchen, Atomen oder höchstens Molekülen. Prof. Eva Weig, Inhaberin des Lehrstuhls für Nano- und Quantensensorik an der TUM, geht mit ihrem Team weit darüber hinaus: Sie entwickelt extrem kleine Saiten aus Halbleitermaterial, die sehr exakt schwingen können, die also makroskopische mechanische Objekte und gleichzeitig Quantenobjekte sind. Das Besondere daran ist, dass diese quantenmechanischen Objekte, die man unter dem Elektronenmikroskop sehen kann, bei Zimmertemperatur funktionieren sollen, was eine wesentliche Erleichterung in der praktischen Anwendung darstellt. Bisher müssen solche Objekte fast bis zum absoluten Nullpunkt gekühlt werden. Sie könnten vielleicht eines Tages die Grundlage wichtiger Sensoren oder Bausteine von Quantencomputern sein. □

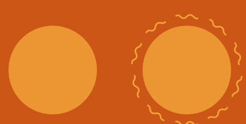


Link
www.ee.cit.tum.de/nan/

When is an object a quantum object?

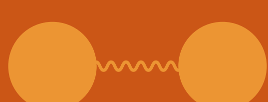
In the quantum world, the world on the smallest scale, there are objects with properties that completely contradict our natural sensibilities and cannot be explained by classical physics:

While we can measure their energy and identify their position, we cannot do both at the same time. This phenomenon is known as Heisenberg's Uncertainty Principle.



They can only take on very specific energy states. There is no continuous transition between these states, only quantum jumps – hence their name, "quantum objects".

They can, however, exist in multiple states at once through a principle called superposition. It is only when we measure their energy that we can attribute a specific state to them. This property is used, for example, in quantum computers.



They can also become entangled with other quantum objects, a phenomenon Einstein described as "spooky action at a distance". If one object changes state, the other objects entangled with it do the same. As a result, quantum objects are also able to teleport.

If an object displays one or more of these properties, it is described as a quantum object.

To ordinary people with a healthy dose of common sense, the processes at work in the quantum world sound more like a fairytale than reality. Particles that change into waves and back again, and even communicate through telepathy; cats that are simultaneously dead and alive, and objects present in two different locations simultaneously. These are not fairytales, though – they are the very foundations of our modern world. Without these astonishing phenomena we would not have computers, lasers or magnetic resonance imaging, not even a common television. So, although the underlying principles might appear inexplicable and mysterious to ordinary people, they have been proven in practice millions of times over.
Their development is progressing at pace: the properties of the quantum world, which still appear so peculiar to us, might soon become the basis of a new quantum technology that we come to take for granted, just as we do electricity and semiconductor technology today. This technology will not only use these phenomena behind the scenes but will instead make conscious, deliberate use of them. However, scientists are only now starting to develop technical components for this new quantum world. They capture atoms and ions in traps, integrate designer atoms into solids, and create ultra-fine electrical junctions in superconductors. Also included are devices that can connect, activate and deactivate these elements.

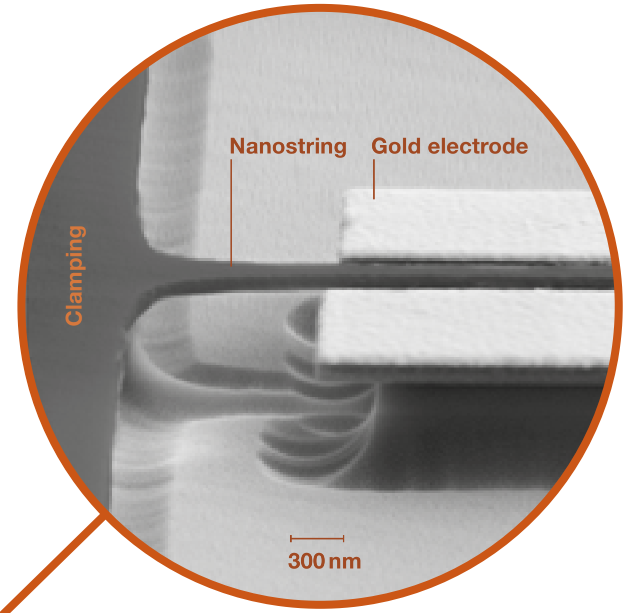
Vibrating nanostrings

Normally, quantum systems comprise one or several elementary particles, atoms or at most molecules. Eva Weig and her team, however, are pursuing a very different path. The researchers at her Chair of Nano and Quantum Sensors are working to create extremely fine strings made from ceramic and semiconductor materials, which are still macroscopic objects, containing around a billion (10^{12}) atoms. But can a system like this serve as a quantum component? It might sound quite outlandish – and, in truth, it is – but this approach offers a series of advantages. "Our objects can be compared with nanoscale guitar strings, which vibrate when plucked," explains Weig. "And, under certain conditions, these objects behave like quantum-mechanical systems. This means they can take on states that can be stored, transferred and even entangled with others. I find that fascinating." Measuring up to 50 micrometers in length, these nanostrings are now among the largest quantum-mechanical systems on the planet. ▷

Picture credit: Magdalena Jooss; Graphics: ediundsepp

Prof. Eva Maria Weig

never lost her love of Munich. Born in the city, she studied physics at LMU, where she received her doctorate in 2004 at the Chair of Solid State Physics. And, although she took up a postdoctoral research position in Santa Barbara in California, she returned to Munich in 2008, working as a Senior Researcher from 2007 to 2012 and a Substitute Professor at her old institute at LMU from 2008 to 2009. As a professor at the University of Konstanz, she headed up the Nanomechanical Systems working group at the Department of Physics. She accepted a professorship and joined TUM on October 1, 2020, where she has held the Chair of Nano and Quantum Sensors ever since. Eva Weig is also director of the TUM Center for QuantumEngineering (ZQE).



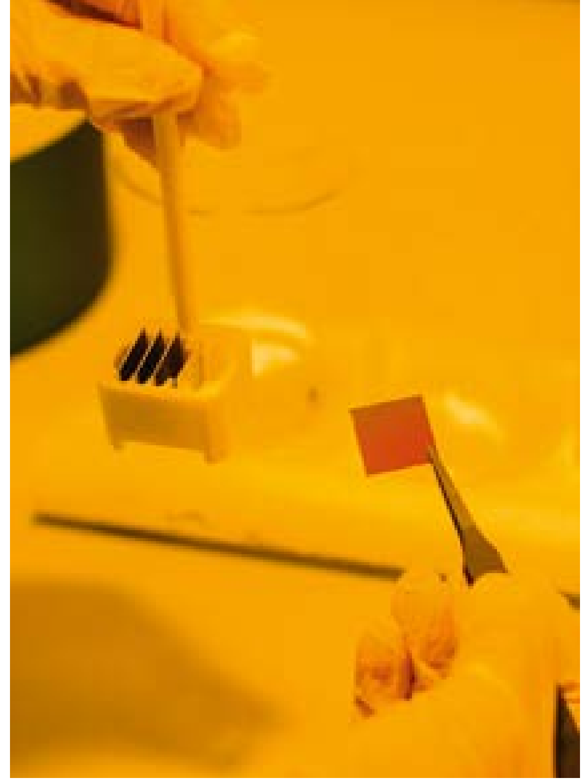
"Producing our prototypes is still highly complex at present."

Eva Weig

Picture credit: Magdalena Jooss

△ **Top: Scanning electron micrograph of a nanostring** between two gold electrodes.

△ **Bottom: In the course of her career as a researcher,** Eva Weig has spent countless days and weeks in the cleanroom. Today, as a professor, she only dons the cleanroom suit on special occasions.



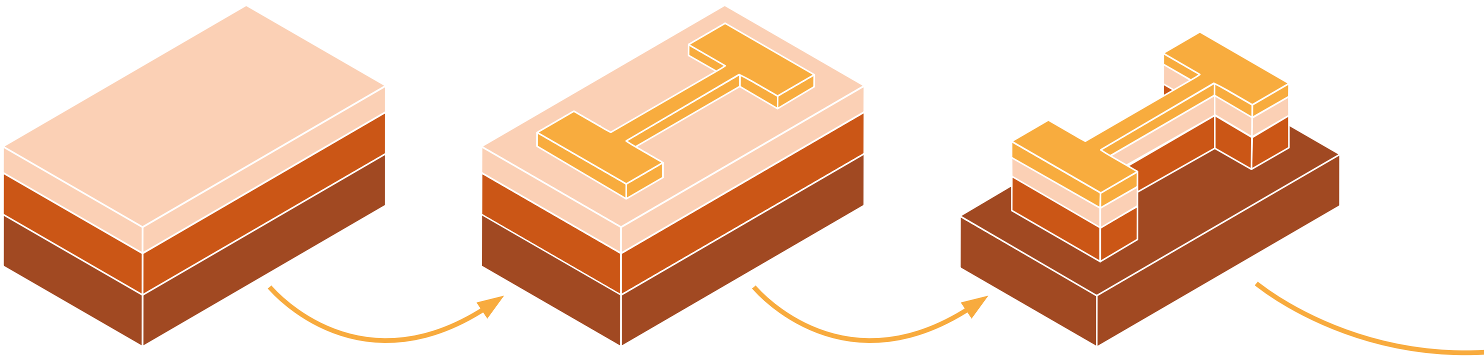
This is still an emerging field: in early 2010, 29-year-old Aaron D. O'Connell made waves around the world with his doctoral dissertation at the University of California, Santa Barbara. Under the tutelage of his supervisor Andrew N. Cleland, O'Connell linked a superconducting quantum bit – a component used in quantum computers – with a vibrating, macroscopic mechanical resonator. He achieved this using a superconducting circuit. The ingenious part was using a resonator made from piezoelectric materials, which deform when subjected to electrical voltage and generate electrical voltage when subjected to mechanical stress. This experiment achieved a world first, namely establishing a connection between the minute quantum world and our "normal" macroworld. The journal *Science* named his accomplishment "Breakthrough of the Year 2010", calling the structure "the first quantum machine".

This breakthrough was only possible because the vibrating object was shielded against all external influences, given that it was supercooled, in darkness and in a vacuum chamber. Several groups around the world have achieved similar successes since O'Connell's initial breakthrough, but only by working at extremely low temperatures.

△ **Chip processing in the cleanroom:** Under the fume hood, resist is coated on the sample to prepare for lithography and developed after exposure.

Making supercooling superfluous

The nanostrings developed by Eva Weig, however, are significantly finer than O'Connell's system. Together with her ten-strong team, Weig is now striving to create a quantum-mechanical system at room temperature. This would open up new uses for such systems and simplify their use in existing applications. The researchers produce their nanostrings in cleanrooms, relying on electron beam lithography for the laborious, painstaking process of applying layer upon layer on a silicon wafer, corroding and burning off sections at specific points. The result is a miniature masterpiece: each string is typically 30 to 50 micrometers in length and less than 100 nanometers wide. "Producing our prototypes is still highly complex at present," says Weig. "Our Master's students spend around half their working hours on that step alone but, with appropriate process controls, we'll be able to produce industrial quantities at some point." The strings are then transferred to a vacuum chamber, where they are precisely measured for the first time. It is vital that the strings do not come into contact with the air because collisions with air molecules would immediately dampen them, just as the wind can disrupt waves of water in the sea. The strings are "plucked" by means of laser light, electrical fields or even acoustic waves. ▷

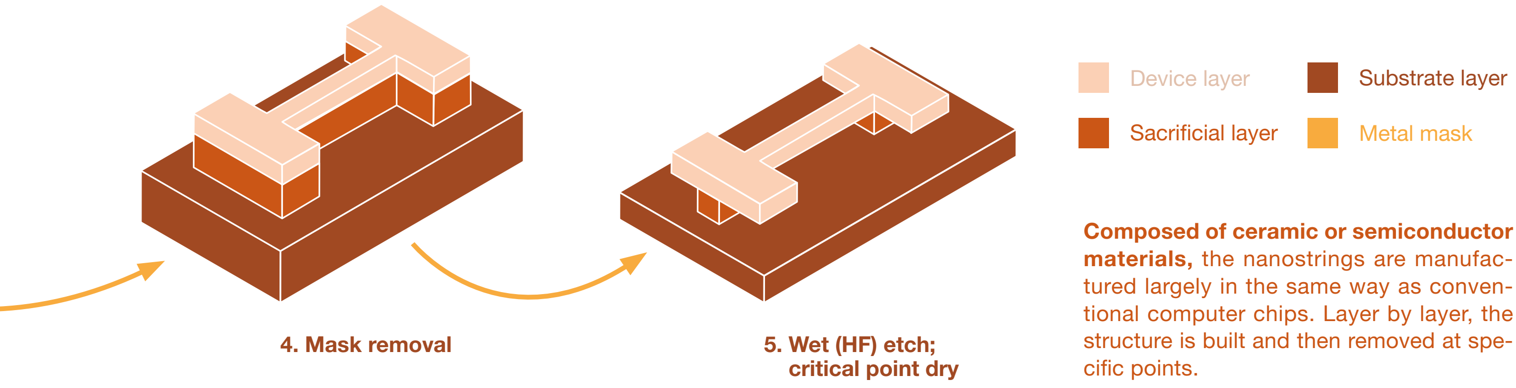


▷ **Left: The nanostrings are measured at room temperature** inside a vaccuum chamber. The lab has various measurement set-ups.

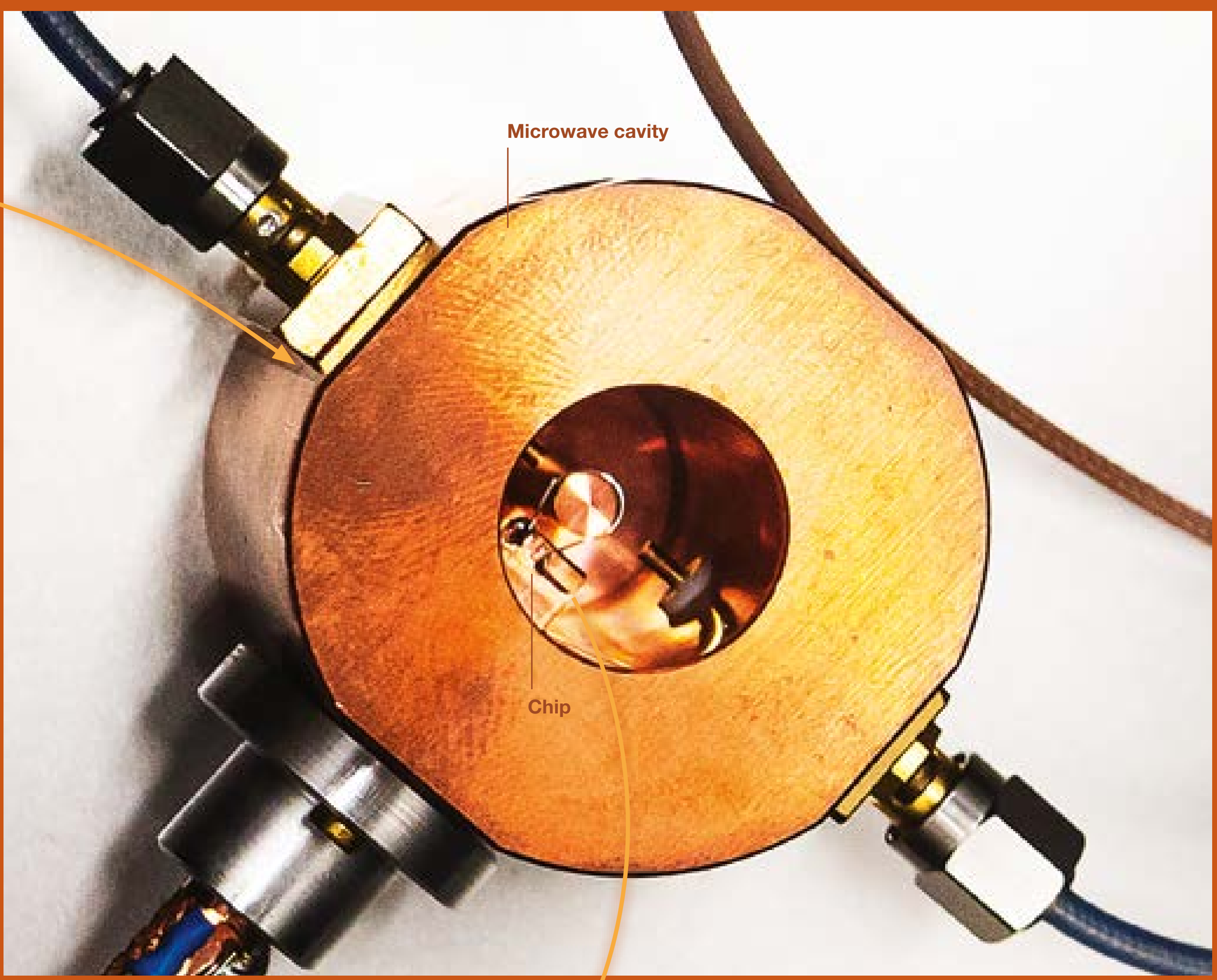
Right: A look from the top into a chamber with a microwave cavity for measuring the string's vibration. The transparent chip contains the nanostring, invisible to the human eye.

These nanostrings have an extraordinary quality factor: Eva Weig and her team have continuously refined them, so much so that some of these strings can be made to vibrate with the same frequency for a few milliseconds. It might not sound like much but, in terms of quantum mechanics, this is a vast period of time. Translating this to the macroworld, it would mean ordinary guitar strings vibrating in the same tone for around an hour. "It's truly spectacular," the physicist explains, "because this ability could enable us to use such systems as a temporary storage of quantum-mechanical information, such as to park qubits in quantum computers." This has not been possible to date. There are various options for transmission, either using a similar approach to O'Connell's experiment or using lasers.

Until now, the vibrating nanostrings were only able to maintain a constant frequency for long periods when cooled to extremely low temperatures. The newly produced prototypes, however, have achieved this at room temperature because the string only emits a tiny quantity of energy to its surroundings. Having said this, the strings are particularly sensitive to any kind of external disruption – though this sensitivity can be leveraged with targeted "disruptions". The strings can therefore be connected



Composed of ceramic or semiconductor materials, the nanostrings are manufactured largely in the same way as conventional computer chips. Layer by layer, the structure is built and then removed at specific points.



Picture credit: Magdalena Jooss; Graphics: ediundsepp (source: TUM)

“It’s still basic research, but initial applications are already emerging.”

Eva Weig

to other systems, either to control the strings or to use them as detectors. “This field fascinates me,” says Eva Weig. “It’s still basic research, but initial applications are already emerging. In ten years’ time, we will certainly be seeing applications.”

The underlying principle of these applications always relies on how the string interacts with what is to be measured. This is supported by a quantum-mechanical property of the string: in addition to its basic state, it can also take on excited energy states. These states are precisely determined by the laws of quantum mechanics. So, by linking it to a measured value, the string can be made to jump back and forth between two states – the very property required for a quantum sensor. Eva Weig’s team has already constructed a series of test platforms for exactly this purpose. “Our aim is effectively to develop a quantum sensor that works at room temperature,” explains Weig. “It would enable us to detect tiny magnetic fields and forces, perhaps even spin effects.”

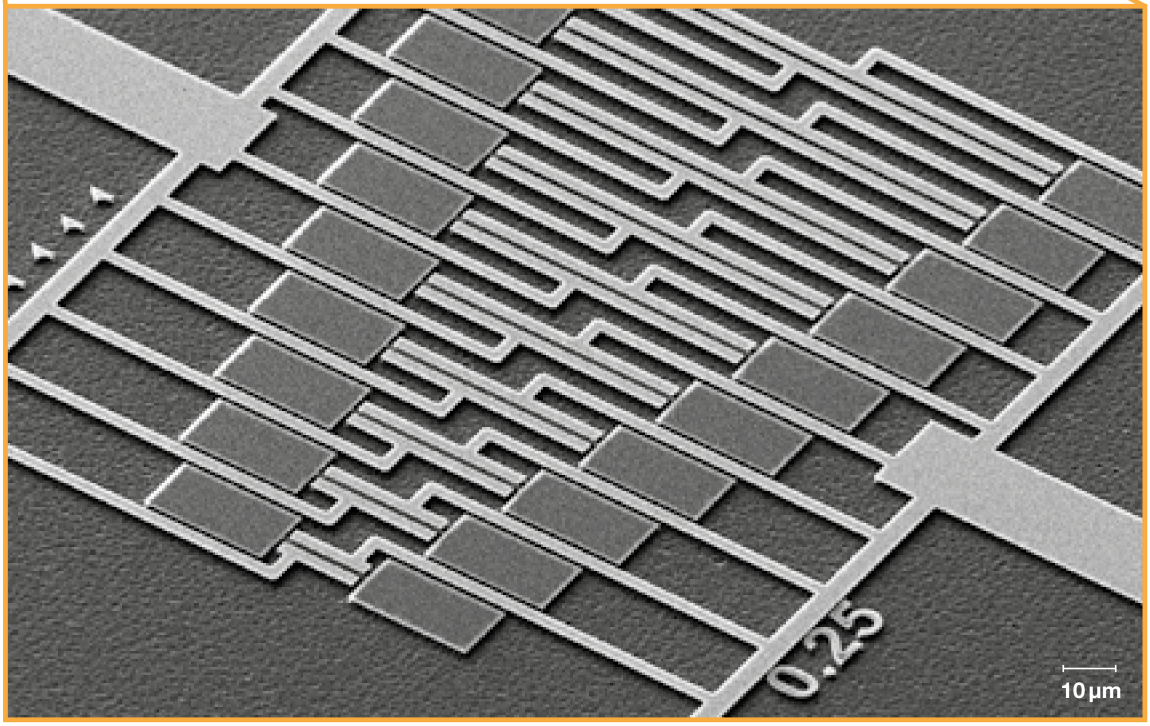
The Chair led by Eva Weig will soon move into new laboratories on the Garching research campus. Its current facilities are not entirely suitable for these experiments, as they cannot be sufficiently shielded against external influences, such as vibrations. The projects then continue in many directions. For instance, the researchers strive to achieve their systems’ basic state. Although they have not managed this to date, it would be of considerable interest for basic research. Another avenue focuses on other forms, because the principle of using mechanical vibrations as a quantum object is not limited to a single string. The Garching-based researchers are also examining carbon nanotubes, which grow like a blade of grass on a substrate, nanomembranes that look like a tiny drumhead, and nano-sized colonnades with tiny heads evenly oscillating back and forth. Further experiments will show which methods ultimately work best in practice. ■

Brigitte Röthlein

Picture credit: Magdalena Jooss, Y. Klaß & E. Weig (TUM)

◁ **Integrated platform to control nanostrings.** The 5 x 5 mm sized chip containing the nanostrings is located in the center. To its left, a microwave cavity connects via bond wire to the gold electrodes, which create an electric field around the nanostring. The circuit board on the right-hand side provides the connection to the measurement system.

▽ **The transparent chip** made of ceramic material contains a set of 12 nanostrings of different lengths, each between two gold electrodes, as shown in this scanning electron micrograph. Each string can be controlled and measured individually.



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TUM Innovation Networks are funded by the German Federal Ministry of Education and Research (BMBF) and the Free State of Bavaria as part of the Excellence Strategy of the federal and state governments.

Masthead

Faszination Forschung
Technical University of Munich's Science Magazine, supported by the Excellence Initiative of the German federal and state governments
Publisher
Prof. Thomas F. Hofmann,
President of the Technical University of Munich
Editors
Dr. Jeanne Rubner (responsible), Dr. Christine Rüth, Tina Heun-Rattei
Photo editor
Andrea Klee
Translation and proofreading
Baker & Company, Munich
Design and layout
ediundsepp Gestaltungsgesellschaft, Munich
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D-80290 Munich
Website
www.tum.de/faszination-forschung
Email
faszination-forschung@zv.tum.de
Printing
Druckerei Joh. Walch GmbH & Co. KG, Augsburg
Circulation
71,500
ISSN: 1865-3022
Publication frequency
Twice a year
Publication date of this issue
September 2023
Cover photo
Stefan Woidig/TUM
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