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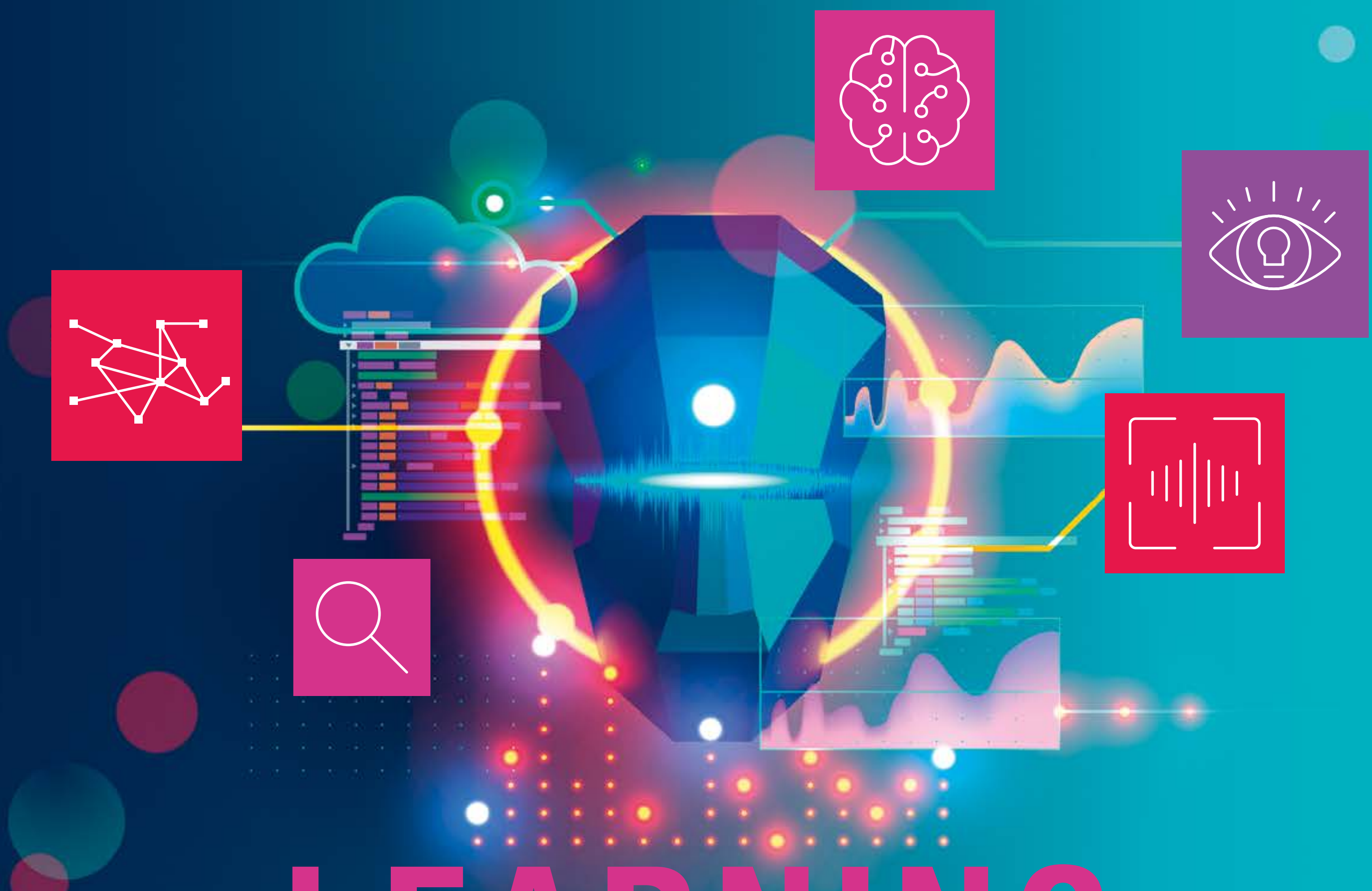
TU Graz research
Research Journal of Graz University of Technology

TU Graz
SCIENCE PASSION TECHNOLOGY



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Fire tests

What are the dangers of burning battery-electric vehicles in Austria's road tunnels? This question was investigated by TU Graz, the University of Leoben, the professional fire brigade association and the consulting firm ILF Consulting Engineers Austria, and supported by ASFINAG and the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology. The results of the investigations are reassuring. The risk potential is not significantly more critical than in the case of fires involving passenger cars with conventional combustion engines. engines.

Lunghammer – TU Graz

Dear colleagues, research partners, and everyone interested in research at TU Graz,

Horst Bischof
Vice Rector for Research
Oliver Wolf

A year ago I wrote in this space "Right now it seems like there's only one issue: COVID-19. No matter where you look, it is the dominant theme." It seems that not much has changed. In mid-November, as these lines were being written, the government announced a new lockdown.

Nevertheless, a lot has happened this year. I had expressed the hope in the 2020 foreword that science would soon provide a highly effective vaccine. And that is exactly what it did. Based on decades of basic research, highly effective vaccines were able to be developed in no time at all. However, they also have to be made use of. Vaccination scepticism (or should I say vaccination ignorance?) in Austria is the only reason why we need this fourth lockdown. That is why I am still making this appeal: **Go and get yourself vaccinated!**

It seems that vaccination scepticism in Austria is based on a general scepticism about science. In a recent Eurobarometer survey, when asked about the importance of young people's engagement with science and research for our prosperity, only 27 per cent of respondents answered "yes". In Portugal, the country with the highest vaccination rate, it was 80 per cent. Similarly disappointing are the answers to the question about whether people want to know more about science and research. Only a disappointing 40 per cent answered this question in the affirmative – 80 per cent in Portugal. But that can't be surprising when even state governors make negative public statements about science. Unfortunately, getting angry and berating people doesn't help. We at TU Graz can only try to do our part to present research in a positive light and thus help to reduce scientific scepticism somewhat. And this is also a challenge to you, dear reader, so please become a **science ambassador**. Take the positive examples of successful research out into the world – you will find some ideas in TU Graz research. And many more will follow.

Portrait

The "Powerhouse" at Campus Inffeldgasse

Lia Gruber

Infrastructure

In the Turbomachinery Laboratory at TU Graz

Regardless of this situation, I wish you and your loved ones a wonderful start to the new year, with time to browse through our research magazine. With this in mind, I hope you enjoy reading this issue of TU Graz research, but above all, stay well!

Horst Bischof

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Learning Machines

Artificial intelligence and machine learning are becoming one of the most important tools of the future. “Machine learning will change our world, just as the internet and computers have done,” says a convinced Robert Legenstein from TU Graz.

Birgit Baustädter

A machine that makes decisions as a matter of course. Which can talk, play and give tuition in a meaningful way. Or: a swarm of heavily armed drones that wants to subjugate humanity. This or something similar is the common image of artificial intelligence. But the reality (still) looks a little different.

“Artificial intelligence has always been understood to mean what was not yet possible by machine at the time,” says TU Graz researcher Robert Legenstein, attempting a definition. “Fifty years ago, that was playing chess, for example. Then it was image and speech recognition. Today, all this can be done by machines.” All of these capabilities are now part of what is known as “weak artificial intelligence”. It is “strong artificial intelligence” that is currently still in the stars – in other words, cognitive systems that have human-like abilities. “Today’s artificial intelligence lacks the ability to generalize. It is perfectly trained for a certain task, but cannot transfer this knowledge to other situations on its own.” For example, a properly trained algorithm can play chess beautifully, or even the more complex game of Go. But even in ludo it wouldn’t stand a chance without prior training.

Robert Legenstein deals with biologically inspired artificial intelligence.
Lunghammer – TU Graz

GRAML – short for Graz Research Center for Machine Learning – is currently being set up at TU Graz. According to its director, Robert Legenstein, it is intended to create a TU Graz-wide network linking researchers who are working on machine learning in different ways. “The initiative comes from institutes in the field of computer science. But we’ve also deliberately brought colleagues from physics and chemistry on board, for example, because we see a lot of potential in these areas.”

SPIKING NEURONS

In his work, Robert Legenstein, from the Institute of Theoretical Computer Science, takes the currently most powerful and yet most energy-efficient computer as his model: the human brain. In a nutshell, he deals with biology-inspired artificial intelligence and builds neural networks – mathematical structures that are similar to the human brain. “The brain is so energy-efficient because only the neurons that are currently needed to pass on >


AndSus –AdobeStock

the information are active. All the others are 'asleep' and don't consume any energy. These are called 'spiking neurons'." Using this way of working, Legenstein and his team build spiking neural networks that can complete complex computational tasks with little energy.

Most recently, as part of an international team, Legenstein developed a robotic arm controlled by a neural network and shaped like an elephant's trunk. "The control problem is very complex because 300 individual motors have to be controlled in coordination with each other to enable smooth movement. This control task can be done by our neural network and is additionally energy-efficient."

UNCERTAIN COMPUTERS

Robert Peharz, from the Institute of Theoretical Computer Science, is also working on foundations of artificial intelligence and machine learning. His main interest lies in probabilistic machine learning, that is, he incorporates probability theory into his algorithms. "Probability theory already covers a fair bit of what artificial intelligence is supposed to do," he explains. "Most importantly, it takes uncertainty into account, represents dependencies in the data, and comes with an integrated reasoning process." In this way, probability theory allows the possibility of learning from data and updating to new situations. "One of my favorite examples is when I ask the question: Can Tim fly? When we assume that Tim is human, then the probability for this event is rather low. However, if I add the information that Tim is a bird, then the probability increases dramatically. But, if I then add that Tim is sick, the probability goes down again. This is an example of non-monotonous reasoning, which is present both in probability and everyday human reasoning."

The most important aspect of machine learning as a tool of the future is its ability to adapt. "Essentially, I can write a meta-program for which I provide the rules of some generic task – for example, 'distinguishing between different things'. This meta-system can then be adapted to more specific tasks – for example, in waste-sorting units or quality control."

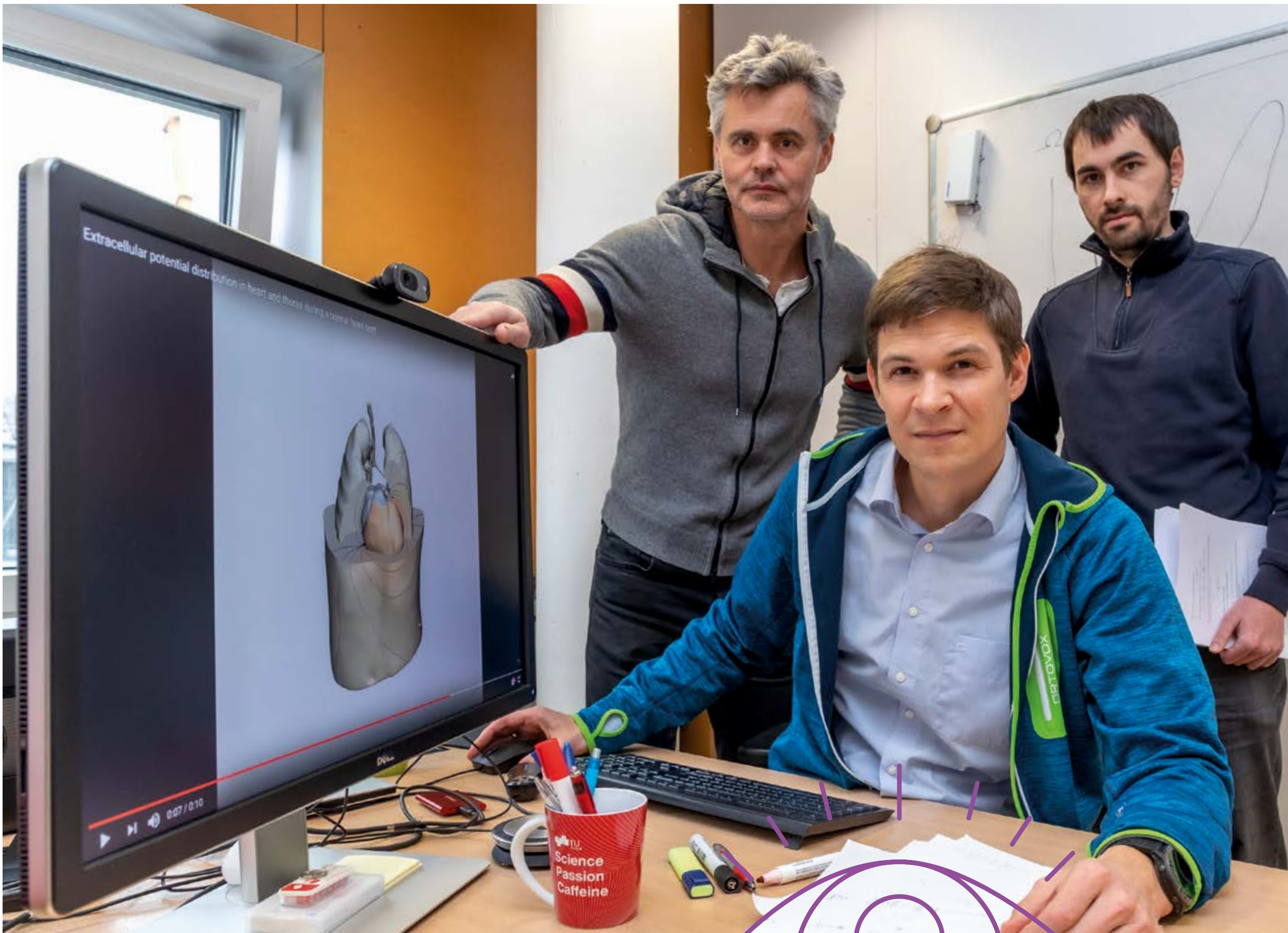
According to Robert Peharz, the future journey of AI is uncertain, as it is a scientific field which is simultaneously inventing and researching itself. "To quote Niels Bohr: Predictions are hard, especially if they are about the future."

Franz Pernkopf.
Lunghammer – TU Graz

A sleep mode for Siri and Alexa.

HEARING MACHINES

For Franz Pernkopf, Institute of Signal Processing and Speech Communication, artificial intelligence and machine learning is one thing above all: a tool. "Especially a tool for lazy people," the researcher laughs. "We are faced with complex problems that can no longer be described using easy mathematical models. That's why we use learning algorithms that look for correlations from large amounts of data that would take me, as a researcher, vast amounts of time." Especially in dynamic situations, artificial intelligence has enormous advantages – for example, when it comes to Pernkopf's field of research: language. Hearing machines have now arrived in all our lives in the form of voice assistance systems. But, proper machine hearing is not trivial, as Pernkopf explains: "Due to different ways of speaking, dialects and, above all, background noises, it is hard to assign a particular word to a single acoustic wave. But I can train an algorithm with a large database." This can be taken so far that individual speakers can be filtered out of, for example, a cocktail party situation.



Thomas Pock improves the vision of machines.
Lunghammer – TU Graz

What is machine learning?

SEEING MACHINES

Thomas Pock, Institute of Computer Graphics and Vision, works in a similar field, but his focus is on a different human sense: vision. Our visual cortex can capture images and recognize objects in a fraction of a second, even if they are barely visible or only fragmentary. Thomas Pock bases his algorithms on the way the visual cortex works in order to automatically optimize images in medical diagnostic procedures, for example. As application-oriented as his research sounds, it is nevertheless very much in the area of basic research. “I am actually a very big advocate of ‘handmade’ mathematical models, but I see that they are far from sufficient to describe reality,” he explains. “So I take algorithms that I have designed by hand and give them some free parameters. Then I get them to learn from existing data and improve the model. If I add more and more parameters, I eventually end up with deep learning – a relatively simple but heavily parameterized model in which we can no longer understand at all how the algorithm comes to its conclusions because we can’t interpret the learned parameters.”

Pock thinks the vision of an actual thinking system is still in the distant future – possibly not even realizable at all. “Artificial intelligence is currently to a large extent pattern recognition, not real intelligence. But it’s a great tool when researchers get stuck at certain points and the algorithm can still pick things out of the data because it’s much faster and of course it doesn’t get tired.” >

Computer Vision: TU Graz Researchers Define New State of the Art.

Olga Saukh.
Lunghammer – TU Graz

MACHINE LEARNING – THE TECHNOLOGY OF THE FUTURE

Machine Learning is a method of Artificial Intelligence and just as old – both had their beginnings in 1956 at the Dartmouth Conference, which dealt with Self-Improvement among other things. A lot has happened since then.

Machine learning emerged as a method from the 2000s onwards. In particular with the boom in deep neural networks, which moved into the centre of scientific interest in 2012 with the paper "ImageNet classification with deep convolutional neural networks" and have since experienced a real boom. I would even go so far as to say that machine learning is the technology that will only allow us in the future to make sense of the huge amounts of data that digitalization is generating.

Horst Bischof
Vice Rector for Research
Oliver Wolf

FLOWING AIR

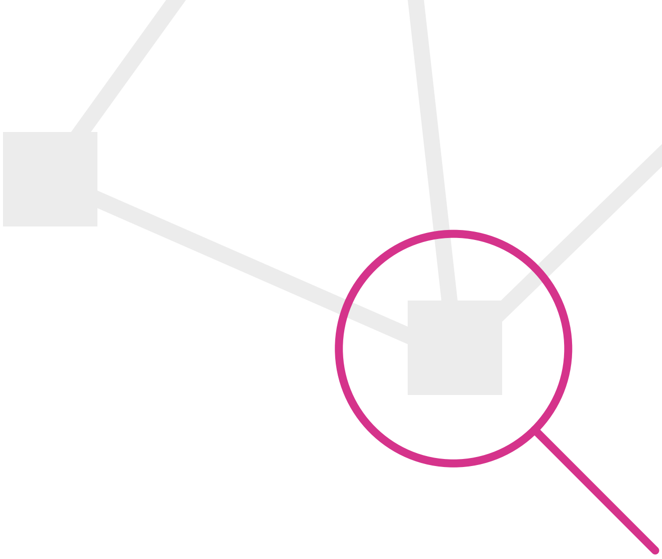
Olga Saukh researches complex systems for both the Institute of Technical Informatics at TU Graz and the Complexity Science Hub Vienna. Opinion formation in societies, for example, is a complex system. But also is, for example, the movement of fine dust particles in the air, which Saukh has been studying for several years. The focus is on air quality forecasts, which should enable legislation to react flexibly to current changes. "We include the air currents that can blow particulate matter from one region to another, for example, and thus cause short-term changes in air quality," says Saukh, explaining her approach. In previous models, these air currents would have had little to no influence. "We use machine learning to improve these short-term predictions. In this area, artificial intelligence is far superior to expert models. But when it comes to long-term predictions, the expert models are still more reliable."

In addition to air pollution, Saukh is also working on the combination of embedded systems and machine learning. "If I want to improve current models, I make them bigger and expand the data sets. Which of course goes hand in hand with higher energy requirements and is not feasible on small systems such as smart watches. So I'm trying to find small, sparse but powerful models and optimize their execution to the underlying hardware capabilities and resource constraints, so that the overall system can operate for months or years on a single pair of batteries. Small is mighty is our motto."

Machine learning is now used in virtually all areas of science and achieves excellent results. The best-known example is probably the Alpha Go algorithm, which was able to defeat the reigning world champion, Lee Sedol, in the complex Japanese game of Go in 2016 thanks to deep reinforcement learning. AlphaFold, a system also developed by DeepMind, can predict protein structures based on the amino acid sequence of the protein and achieved top scores in the Critical Assessment of Techniques for Protein Structure Prediction (CASP) competition in 2018 and 2020. And machine learning algorithms are also driving development in the field of autonomous driving. The reason for the rapid progress is probably also the fact that many systems are open source and can thus be viewed and further developed by anyone.

Despite all its successes, machine learning is still a very young field. Far-reaching developments are still needed in both theory (we often don't understand why an algorithm works) and method (algorithms need too much data and too much energy). But I dare to predict that no data-based science will be able to do without machine learning in the future. Only in this way are we able to make sense of the data and create forecasts. Some researchers even go so far as to say that machine learning will change science itself. Algorithms, they predict, will formulate hypotheses in the future, and we researchers will design experiments to prove causality – something algorithms cannot do at present.

Regardless of which scenario occurs, machine learning will play a central role and is one of the most important technologies of the future. ■



RACING NANOPARTICLES

Solid-state physicist Oliver Hofmann uses a playful approach in his research on machine learning and wants to relieve researchers of tedious routine work. "We want to have learning algorithms search for promising material structures that our team would otherwise have to spend weeks painstakingly digging through," explains Hofmann. But the algorithm does not decide on its own: "We then look at the result and of course recalculate the most attractive structures ourselves. The algorithm can recognize correlations based on previously trained knowledge, but not whether they are also scientifically correct."

Hofmann would then like to have the structures found in this way replicated and tested in an experiment. "But it's also a lengthy job to build that structure and often we as researchers have no idea how to even go about it." Here, too, a trained algorithm should give support and learn to build structures independently. Currently, however, this technology is being explored in an entertaining setting: with a "car race" on a nano scale. In the process, nanoparticles – the cars – have to be steered through a course by means of an electrical impulse under the STM – the scanning tunnelling microscope. "All of this takes place in the quantum realm. That means these processes are not deterministic all the time – even if I set up the same electrical impulse, the particle will not move the same way all the time." The world's best "racers" would currently manage to actually move the particle every second time they tried. "Whether it then also moves in the right direction is another question," smiles Hofmann. His team has now trained an algorithm instead of a human "driver" and has already achieved great results: "A human has to have years of experience in order to move the particle efficiently. Our algorithm only needed a few weeks to manoeuvre through the course at least equally fast. That's a success."

THINKING MACHINES

The possible applications of artificial intelligence and learning algorithms are therefore diverse – especially as a tool in research. And to return to the vision at the beginning – the thinking robots. Robert Legenstein has a clear opinion here: "I think it is possible up to a certain extent. But they will not behave exactly like humans. Humans are social, sentient beings and a robot does not grow up in the same environment and thus does not have the same experiences. But he might well develop certain human-like behaviours in an artificial environment." ■

50 Years of Biomedical Engineering

Biomedical engineering is concerned with research at the interface between medicine and technology. 50 years ago the foundation of a successful research history was laid in Graz – with the introduction of a group of electrical engineering electives called "Wahlfachgruppe IV Elektromedizin".

Birgit Baustädter

The group of electrical engineering electives laid the foundation of the research genre. Only three years after Stefan Schuy, who later became rector of TU Graz, set up the Institute of Electrical Engineering and Biomedical Engineering. The Austrian Society for Biomedical Engineering was established in 1975.

Today the Biomedical Engineering Building located at Stremayrgasse 16 is home to several institutes – when it comes to clustering specialisations at a single site, TU Graz is second to none in Austria.

INSTITUTE OF NEURAL ENGINEERING

Researchers at the Institute of Neural Engineering focus on communication between the human brain and computers. Processing brain signals – as well as measuring them – is one of the institute's core focuses. Its findings have found their way into various technologies, such as thought-controlled robotic arms and neuroprosthetics. Neurofeedback systems, cognitive neuroscience, and neuron modelling and simulation – in particular of astrocytes – are also on the research agenda.

INSTITUTE OF BIOMEDICAL IMAGING

Research at TU Graz's Institute of Biomedical Imaging focuses on in-vivo magnetic resonance tomography (MRT). The institute collaborates with domestic and international partners to devise new strategies for magnetic resonance imaging (MRI) and identification of magnetic resonance biomarkers. "We have pushed back the boundaries of conventional imaging considerably using special multi-channel measuring procedures and improved variational reconstruction techniques," explains former Institute head Rudolf Stollberger.

INSTITUTE OF HEALTH CARE ENGINEERING WITH EUROPEAN TESTING CENTER OF MEDICAL DEVICES

Researchers at the Institute of Health Care Engineering with European Testing Center of Medical Devices are working on the development of new technological approaches for health diagnostics and therapy. The European Testing Center of Medical Devices is an integral part of the institute. The unit performs testing on newly developed products and certifies their compliance with the relevant standards, which in turn ensures that the products meet certain safety and performance levels. "The testing centre is the only university facility of its kind in Europe," says Institute head Christian Baumgartner.

INSTITUTE OF BIOMECHANICS

"We build on approaches and methods from mechanics and biology in order to gain a better understanding of biomedical processes in the human body, and develop new diagnostic and treatment options," says head of Institute Gernot A. Holzapfel, outlining the research strategy at the Institute of Biomechanics. Using devices developed in house, researchers analyse tissue samples using tensile, shear and failure tests, recording the resulting microstructural changes with the help of imaging microscopes. Their aim is to more accurately describe and simulate biomedical processes, such as those that occur in human organs as well as in body proteins, and the progression of diseases that affect them.

INSTITUTE OF BIOMEDICAL INFORMATICS

Laila Taher, head of the Institute of Biomedical Informatics, is making use of machine learning and big data analysis techniques to gain insights into the human genome. "Once human DNA had been sequenced for the first time, everybody thought it would lift the lid on the secrets of humanity," she says. "Of course, that didn't happen. On the contrary, the sequencing process generated huge amounts of data, a blueprint for our bodies, but it only comes to life through interaction with our genes. At the moment, we still don't really understand these processes." ■

BioTechMed-Graz

Three Graz-based universities – TU Graz, the University of Graz and the Medical University of Graz – have joined forces to form BioTechMed-Graz, a collaboration focused on biomedical research.

Lunghammer – TU Graz

Lia Gruber is a PhD student at the Institute for Electricity Economics and Energy Innovation.
Lunghammer – TU Graz

The “Powerhouse” at Campus Inffeldgasse

Lia Gruber started her academic career on stage at a school with a focus on theatre. Then she soon switched from acting to electrical engineering. Today she is working on energy communities at TU Graz.

Birgit Baustädter

Lia Gruber is standing in the foyer of the institute building at Inffeldgasse 18, at the top of the stairs, right in front of the handwritten “Energie” inscription by Nikola Tesla – an honorary doctor of TU Graz. If she were a character in a superhero comic, she would probably have her arms outstretched and an electric charge would glow around her fingertips. Because that’s how the young electrical engineer appears – full of energy. No wonder, since the 26-year-old is also called a “powerhouse” by Institute head, Sonja Wogrin.

All the more fitting, given that Lia Gruber’s work focuses on electricity economics and energy innovation. As part of her master’s thesis at TU Graz, which recently won a best paper award, she conducted research into areas that would be particularly suitable for deep-sea, offshore wind farms. Included are all wind turbines installed on the open sea with a water depth of not less than 60 metres. “Wind turbines in these areas, which are mostly far from the coast, achieve large yields because of the high wind speeds. More wind means larger turbines and a higher energy yield. But they require costly maintenance work as well as large investments in infrastructure. “Floating wind turbines are anchored to the sea bed. In the future they will nevertheless be less cost-intensive and more sustainable then normal offshore wind turbines,” explains the researcher.

In the meantime, Lia Gruber is employed as a doctoral student at the Institute of Electricity Economics and Energy Innovation and is researching energy communities that have recently been legally established. In such a community, several people join forces to jointly generate, store and consume energy. All Austrians can join an energy community, and can also leave it at any time. For example, if a neighbour owns a solar system that generates too much electricity for their own use, they can sell the electricity in the neighbourhood. And if, in turn, another neighbour has a powerful energy storage system, the energy community can store the generated electricity there together. “Such small communities can be very well balanced. But the question now is what happens when a person, and thus their requirements or ‘commodity’, drops out of the system? If a part suddenly goes missing or is added, how does it affect the overall system?”

FROM THE STAGE TO THE ELECTRICITY INDUSTRY

Lia Gruber’s career is not a classic one. Born in southern Styria, she attended a grammar school with a focus on acting. “I soon realized that I love theatre. But more as a hobby. Professionally, I had other things in mind.” For fun and a little interest, she attended a basic lecture on electrical engineering during some taster days. In doing so, Gruber recalled her childhood, when she watched her grandfather, an electrician, repairing refrigerators. After several internships at TU Graz, the Matura (higher education entrance qualification) graduate decided to study electrical engineering at TU Graz. “Those around me were a bit puzzled. Many people asked me whether I would be able to cope with the hard technical studies without a technical college education,” she says today with a twinkle in her eye. The topic of “women in technology”, especially in electrical engineering, is still relevant, as Lia Gruber knows. “I’ve always had female role models – at TU Graz, for example, Annette Mütze impressed me from the very beginning. She heads the Electric Drives and Machines Institute, where I got my first job. She made me feel that I was in the right place right from the start. And today I have another impressive boss in Sonja Wogrin.” ■

In the Turbomachinery Laboratory at TU Graz

1) In the transonic test turbine facility, the inflow conditions in an aircraft engine can be realistically simulated from take-off to landing at around 60° to 80° Celsius. This allows the turbine centre frame to be tested under realistic operating conditions. The turbine centre frame is the transition duct between the high-pressure and low-pressure turbine, which is located downstream of the combustion chamber and is one of the hot gas path components of a turbine.

2) A wind tunnel installed in 2020 is used for preliminary tests on blade cascades. In a turbine, several blades are placed next to each other, which then transport the air. The blade cascade is kept static in the test rig and air flows through it. "We recreate the inflow conditions behind the turbine using specially made metal screens," explains Göttlich. This makes the test rig much less complex to operate and, above all, much safer than other test rigs where moving components are tested. Promising blade geometries are investigated in the wind tunnel, and these are then tested in the transonic test turbine facility.

3) In addition to the transonic test turbine facility and a wind tunnel for blade cascades, the Institute operates a ring grid cascade – a specially designed transonic cascade – which also works with static inflow, but requires the same amount of air and thus the same amount of electricity as the test turbine. With a second test turbine – the subsonic test turbine facility – the stage at the very end of the engine is checked not only for aerodynamics but also for acoustics and blade vibrations. And in the hot-flow test facility, the combustion chamber of the engine is also examined.

4) The results achieved at Graz are implemented in civil aviation. "The turbines that we are investigating are used in the planes that you and I fly in on holiday," explains Göttlich.

How does an aircraft turbine work?

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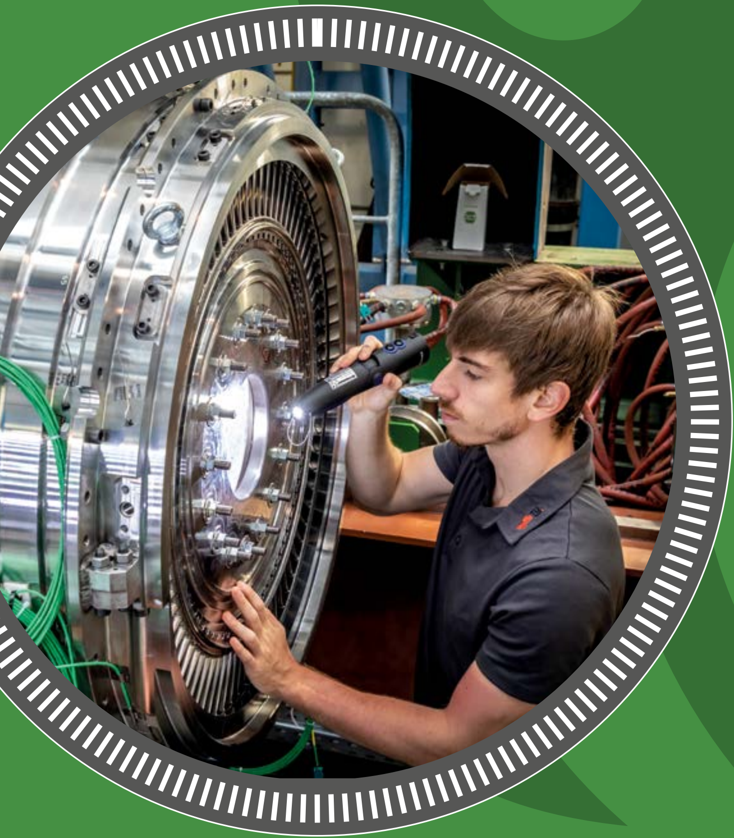

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Bilder: Lunghammer – TU Graz

In the Turbomachinery Laboratory at the Institute of Thermal Turbomachinery and Machine Dynamics at TU Graz, Emil Göttlich, head of the laboratory, and his research team study the aerodynamics of aircraft engines. The focus is on the turbine centre frame – a main component. The goal is aerodynamic and efficient aircraft engines.

A comprehensive insight into the work of the Institute.

The Mobile Robot that Charges the E-Car

Together with the companies ALVERI and ARTI Robots, TU Graz developed a charging robot that can autonomously refuel e-vehicles.

How the robot works.

In the developed prototype a mobile platform that moves autonomously in space and an automated robot arm that guides the charging cable to the car merge into one unit. This is a very complex task for an automated system. In order to orientate itself, the mobile platform permanently scans its surroundings for possible obstacles with laser scanners.

OPTIMIZATION

Before the loading robot is ready for series production, it still needs to be optimized. The robot is still connected to a power cable, but this will be made obsolete in the future by a power supply via ground contacts, which is still under development. The software for controlling the robot, which currently runs separately, will also be integrated. Last but not least, although the robot arm is not yet perfect since there is currently no robot arm explicitly developed for this application, the team resorted to a conventional industrial robot arm for the prototype.

Frankl – TU Graz

Lebensressort – Streibl

Innovative Wood Technology for Roof Conversions

Press release.

Innovative timber construction technology can save valuable building stock in Graz and create additional living space for up to 36,000 people without making use of new ground

Researchers from TU Graz took a close look at 45 historic roof constructions in Graz. “82 per cent of the roof structures examined needed to be repaired in the next five years. It would be desirable to record a complete inventory of all historical roof structures,” emphasizes Gerhard Schickhofer from the Institute of Timber Engineering and Wood Technology at TU Graz.

Especially in urban areas, where the aim is to preserve green and recreational spaces, it is important to use the potential of already built-up areas, for example by adding storeys or converting attics. On the basis of a cadastre of added storeys compiled at TU Graz, the corresponding block structures were examined with regard to their potential for extension. The legal situation was also examined.

The aim of the study was also to investigate specific options for adding storeys using modular timber construction systems and thus offer concrete possibilities for creating new living space. The most suitable of all proved to be the “folded plate” solution, which uses prefabricated wooden elements, in which the original roof shape is retained. This innovative solution allows a support-free and enormously flexible design of the roof space in the form of a two-storey usage option. A pilot project has now been planned to establish the folded plate solution. Interested owners can contact the Institute of Timber Engineering and Wood Technology at TU Graz. Attic conversions for the creation of new living space are also eligible for funding in the framework of renovation subsidies from the State of Styria.

Sabine Biedermann

Graz Universities Honour their Inventors

University research is a driver of innovation. For this reason, the three Graz universities – TU Graz, the University of Graz and the Medical University of Graz – honour their most successful inventors every two years.

At the beginning of November, 239 researchers were duly honoured for their inventiveness over the past two years. The Rectors of the three universities – Harald Kainz (TU Graz), Martin Polaschek (Uni Graz) and Hellmut Samonigg (Med Uni Graz) – released the following statement: "The innovative power of research can be measured by inventions and patents. Through cooperation, it gives local companies a competitive advantage. New applications and technologies continue to drive progress and benefit society in many ways."

In the course of the event, the researcher who had been granted the most patents at TU Graz in the past five years was also lauded: Anton Glieder from the Institute of Molecular Biotechnology. For his services, he received the Nikola Tesla Medal, which is awarded for particularly outstanding and application-oriented research achievements at TU Graz.

All the honoured inventors can be found on the TU Graz website

Mind_the Gap

Graz University of Technology recently again awarded outstanding projects that specifically focus on people. This year's Mind_the Gap prizes were awarded to: Anna Napetschnig for her Master's thesis "Frauen@TUG - DO IT!"; Jasmin Grosinger for her publication "Distinguished Women in Microwaves"; Christoph Leo, Corina Klub and Ernst Tomasch for their publication "Are there any significant differences in terms of age and sex in pedestrian and cyclist accidents? "; Ena Kukuc, Petra Petersson, Anna Sachsenhofer and Budour Khalil for their initiative "Gender Taskforce"; Alexander Kreis, Mario Hirz, Bernhard Walzel and Ute Schäfer for their conference paper "Onsite Medical Implants Creation by Combination of Enhances Design Methods and 3D-Printing".

Hedy Lamarr Prize

Johanna Pirker, Institute of Interactive Systems and Data Science, has won this year's Hedy Lamarr Prize, which is awarded to women shaping the digital world.

Graz Center of Physics

In the architectural competition for the Graz Center of Physics, which is currently being built on the grounds of the University of Graz, the decision was made in favour of the design by the architectural firm fasch&fuchs.architekten. Highlights of the building will be a city terrace and five wood-clad lecture halls. It will cover a total of 50,000 square metres and provide space for up to 1,700 students and 600 employees.

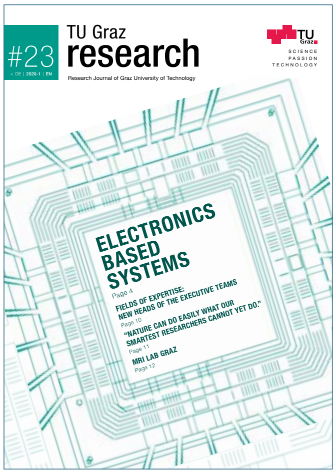
TU Graz research: The variety of research topics at TU Graz

In each new issue, the research magazine TU Graz research focuses on a socially and scientifically relevant topic. The QR code next to the respective issue will take you directly to the e-paper.

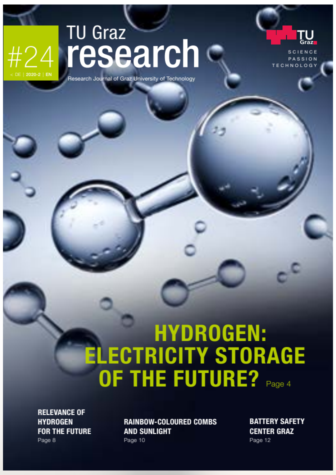
#21: CYBERSECURITY

#22: ADDITIVE MANUFACTURING

#23: ELECTRONICS BASED SYSTEMS



#24: HYDROGEN



#25: BIOTECHNOLOGY

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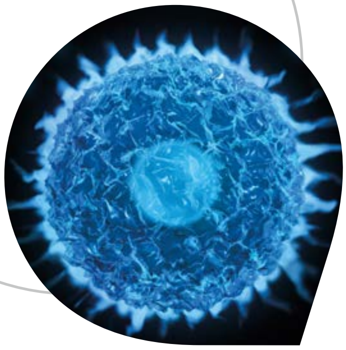
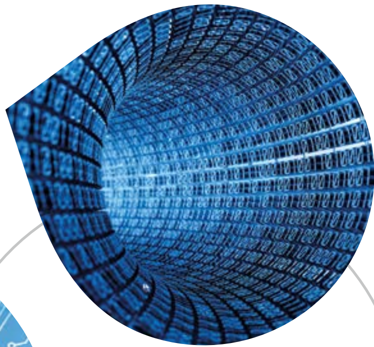
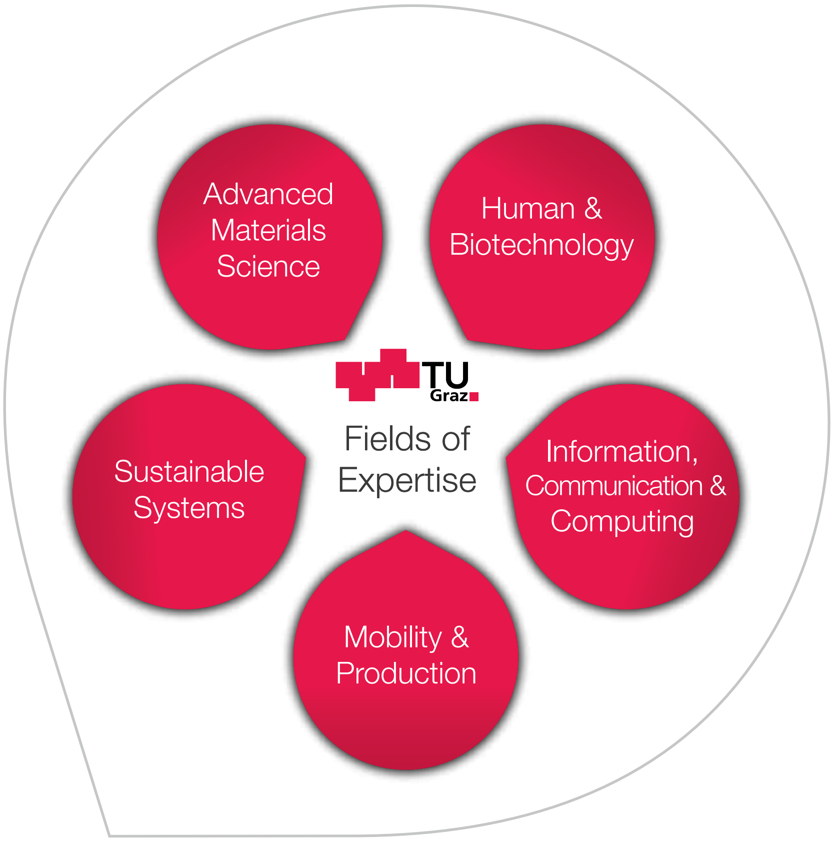




Fields of Expertise

TU Graz's research activities are grouped into five strategic, forward-looking Fields of Expertise. Researchers engage in interdisciplinary cooperation and benefit from different approaches and methods, shared resources and international exchange.



TU Graz has divided its research into five innovative areas: the Fields of Expertise. Researchers in the Fields of Expertise break new ground in basic research. They take part in interdisciplinary cooperation, gain support for outstanding projects and are based in the region as well as part of international networks. They also develop key technologies for industry and commerce, and perform research in the framework of company shareholdings and partnerships.

Source: TU Graz

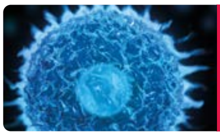
ADVANCED MATERIALS SCIENCE
Researchers aim to understand the smallest components in the structure and function of new materials, and develop and assemble them in special processes.

HUMAN & BIOTECHNOLOGY
Researchers develop devices and methods for medical applications and therapies, and focus on using enzymes and living microorganisms such as bacteria, fungi and yeast in technical applications.

INFORMATION, COMMUNICATION & COMPUTING
Researchers face challenges prompted by the information age, for example data security and efficient use of the ever-increasing volume of data.

MOBILITY & PRODUCTION
Researchers investigate novel vehicle technologies, new drive systems and more economical product manufacturing processes.

SUSTAINABLE SYSTEMS
Scientists focus on the complex challenges presented by a growing population and increasingly scarce natural resources.



ADVANCED MATERIALS SCIENCE

Fields of Expertise TU Graz

Source: istockphoto.com

**Anna Maria Coclite,
Christof Sommitsch,
Gregor Trimmel,
Advanced Materials Science**

Source: Lunghammer – TU Graz

Machine learning and artificial intelligence is also changing research into materials, i.e. by the predictive modelling of structures and materials as well as finding a hidden structure-properties relationship in large sets of experimental data. Already today, researchers in the FoE AMS, among others Oliver Hofmann, are using AI in their research and we are sure that the importance of AI will increase in the future.

AI in Materials Science was already present in quite a few talks at the EUROMAT conference, the most important European congress in Materials Science, which was organized by ASMET and chaired by Christof Sommitsch this year. Scientists of all areas of Materials Research (metals, ceramics and polymers) presented and discussed their latest results. Nowadays, tailored functional and structural materials are developed for specific applications in modern society. Climate change calls for rapid sustainable transformation in energy production, transport and storage, for circular economies as well as for new lightweight and smart materials to mitigate CO_2 emissions. Advanced, tailored and graded materials are developed by efficient processing. Here, additive manufacturing by manifold process variants opens possibilities of lightweight design, complex and hybrid structures, tailored local properties and functional integrations. Artificial approaches combined with deterministic physically based models pave the way to future materials design and process optimization. In the area of biomaterials, the latest results of bioceramics, bioglasses, bioinspired materials, metallic, polymeric and smart biomaterials are shown.

The 14th polymer meeting (PM14) focusing on all aspects of polymer science took place in late summer at TU Graz. Organized by the Institute for Chemistry and Technology of Materials this conference was the first on-site conference for many scientists for almost two years.

In the 15th call of initial seed funding of TU Graz, we are proud to finance eight interesting project ideas in chemistry, physics and mechanical engineering. The awardees are Anne-Marie Kelterer (Institute of Physical and Theoretical Chemistry), Stefan Topolovec (Institute of Materials Physics), Andreas Hauser, Florian Lackner (both Institute of Experimental Physics), Katrin Unger, Oliver Hofmann (both Institute of Solid State Physics), Ricardo Henrique Buzolin (Institute of Materials Science, Joining and Forming), Rupert Kargl (Institute of Chemistry and Technology of Biobased Systems). We wish them good luck for the proposal submission and we look forward to your submissions to the next call.

In the second online edition of the FoE AMS update, we had two very interesting talks given by IMAT's Fulbright visiting professor, Herman F. Nied, (Lehigh University, USA) on both his university and his own research focus, viz. modelling of materials joining, fatigue and fracture mechanics, and by Martin Leitner on fatigue design considering local material properties.

Regarding future activities, please save the date of the Advanced Materials poster day on the 22nd April 2022, where the latest research of the FoE will be presented in a poster and discussion session.

Finally, on the next pages, the newly appointed FoE tenure-track assistant professor for chemical or physical properties of materials, Jurij Koruza, will elucidate his excellent research on functional ceramics and talk about his future plans at the Institute for Chemistry and Technology of Materials.

Jurij Koruza

Linear and 3D Defects in Piezoelectric Materials: Useful Imperfections

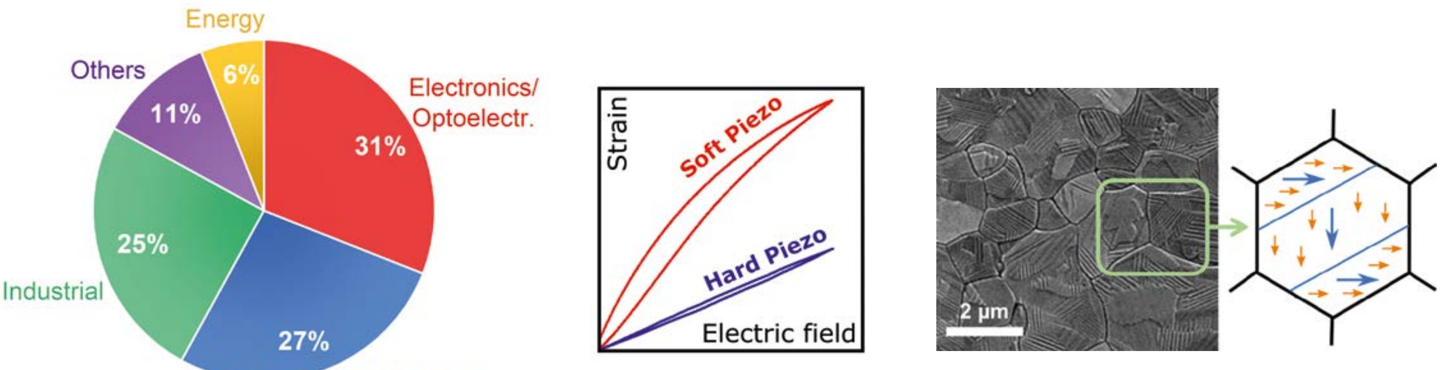
It is our imperfections that make us humans interesting. A similar statement can be made for many electroceramics. While one- and multidimensional defects are conventionally being avoided, we demonstrate that their selective use can lead to a strong enhancement of piezoelectric and dielectric properties. Moreover, their stability can help to extend the operating limits of our electronic devices.

Piezoceramics have the unique ability to convert mechanical signals into electrical ones and vice versa. This property made them indispensable in many everyday devices, such as sensors, actuators, miniature motors, and ultrasonic transducers (Fig. 1a). Moreover, they are becoming increasingly important parts of emerging technologies in consumer electronics, autonomous vehicles, Internet of Things, medical robotics, and in-body sensors. Recently, they were predicted to be the fastest growing segment of the electroceramics market [1], which was accelerated by their increased use during the pandemic (e.g., in ultrasonic welding of face masks).

Since most piezoceramics are also ferroelectric, the dynamics of ferroelectric domains contributes decisively to their macroscopic response. Historically, researchers have strived to prepare these materials in a single-phase form with uniform microstructures. The only appreciated defects were acceptor/donor dopants (0D defects), which allow controlling the movement of domain walls (Figure 1b,c); increasing the movement increases the strain (soft piezoceramics for actuators and sensors), while clamping the domain walls reduces the losses (hard piezoceramics for high-frequency applications, e.g., transducers). On the other hand, one- and multidimensional defects such as dislocations and secondary phases have always been considered as culprits. However, in real piezoceramics, they can hardly be avoided completely. So why not use them to our advantage?

Jurij Koruza
obtained his PhD at Jožef Stefan International Postgraduate School, Slovenia, in 2013 and was a group leader at the Department of Materials Science at the Technical University of Darmstadt, Germany, until 2021. Since September 2021 he has held a tenure-track position at the Institute for Chemistry and Technology of Materials at TU Graz. His research is focused on the development of new electroceramic materials.

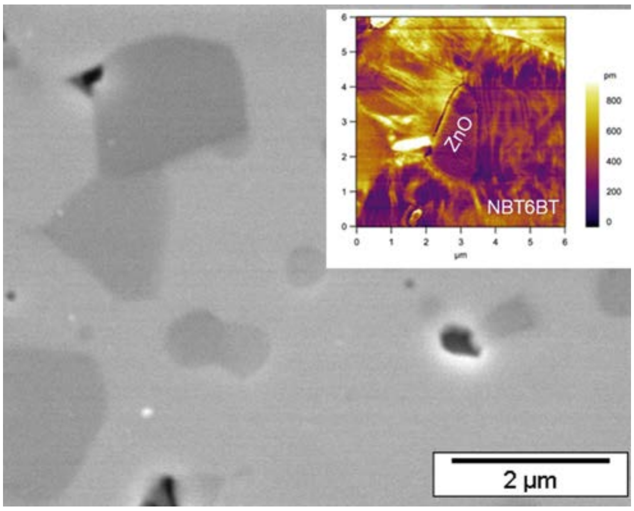
Source: Jurij Koruza

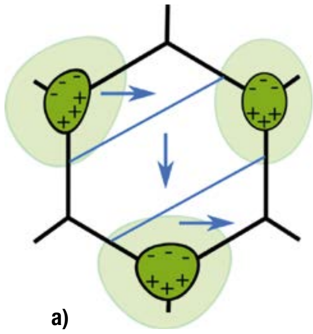


a) b) c)

Figure 1: a) Piezoceramic market by end use [1].
b) Applications require either large strain (soft) or low losses/hysteresis (hard).
c) Piezoceramic microstructure with ferroelectric domains (blue), pinned by point defects (orange).
Source: Jurij Koruza

b)

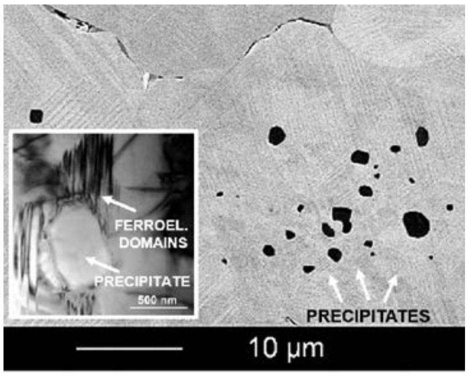




a)

**Figure 2:
Piezoelectric hardening by secondary phases (a). ZnO inclusions in piezoceramic $Na_1/2Bi_{1/2}TiO_3$-$BaTiO_3$ (inset was taken using piezoresponse force microscopy) (b) and $CaTiO_3$ precipitates in piezoceramic $(Ba,Ca)TiO_3$ (c) [2-4]. Scanning and transmission electron microscopy.**
Source: AIP Publishing and Elsevier

c)



The typically-used piezoceramics have a perovskite crystal structure and can thus be described as ferroelectric and ferroelastic. This means that the motion of the domain walls is affected by both electric fields and mechanical stress. However, clamping the domain walls externally using these stimuli is impractical. It would therefore be more efficient if the clamping could originate from the sample´s own microstructure, e.g., from a defect “sitting” in the piezoceramic matrix (Figure. 2a,b). To achieve this, we introduced ZnO inclusions [2], which have previously been shown to increase material´s depolarization temperature [3]. The different thermal expansion of these 3D defects imposed thermal stress on the matrix grains, while their non-ferroelectric behaviour rendered them rigid during electric field application [4]. Moreover, the charge separation in the semiconducting ZnO additionally pinned the domain walls at the semiconductor/piezoceramic boundaries. Both effects resulted in reduced domain wall movement and a twofold reduction in mechanical and piezoelectric losses, which is crucial for high-frequency applications.

Although ZnO inclusions interacted with domain walls, their positioning enabled only domains located near the boundaries to be pinned, while those positions inside the matrix grains remained unaffected. A homogeneous distribution of the secondary phase within the piezoceramic grains would have been much more desired. However, this is not easily achieved with conventional ceramic processing. To solve this problem, we “borrowed” an approach from metallurgy. Precipitation hardening is an established method for increasing the yield strength of metals, whereby precipitates are formed by annealing a supersaturated solid solution. We selected the piezoceramic system $(Ba,Ca)TiO_3$, which exhibits a curved line of solid solubility in its phase diagram. The material was first sintered at high temperature in the single-phase region (high solubility of Ca in $BaTiO_3$) and subsequently quenched to preserve this state. The supersaturated solution was then aged at an intermediate temperature, forming non-ferroelectric $CaTiO_3$-rich precipitates in the piezoceramic $BaTiO_3$-rich matrix (Fig. 2c). The precipitates pinned the domain walls and thus reduced the losses [5].

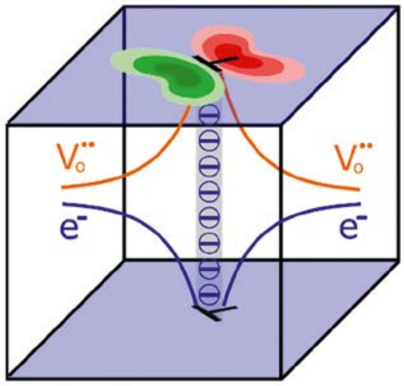
3D defects are not the only microstructural imperfections that can be used to our advantage. An even stronger interaction can be expected when the defect size is reduced below the domain size, i.e. to the range of a few nanometres. Example are 1D linear defects called dislocations. While dislocation movement is one of the fundamental mechanisms in metals, they have not attracted much attention in ceramics. However, dislocations in ionic materials are expected to exhibit

>

not only strain fields but also a charged core and an associated space charge layer (Figure 3). Thus, they offer an easy way to introduce local mechanical and electric fields into the microstructure. The main challenge is to introduce a sufficiently large dislocation density into brittle oxides. We have demonstrated that dislocation networks can be imprinted either by room-temperature plastic deformation (in $KNbO_3$ [6]) or by high-temperature mechanical creep (in $BaTiO_3$ [7]). Interestingly, the dislocations pinned the domain walls and hardened the piezoelectric at low applied electric fields, but got depinned at higher electric fields and caused a mechanical restoring force that returned the domain walls to their original position. This led to a huge increase in the piezoelectric coefficient from 100 pm/V in undeformed samples to 1890 pm/V in samples with dislocation networks [7] (Figure 3c). In addition, the permittivity increased from 170 to 5810.

These examples demonstrate that 1D and 3D defects can be used to tune the functional properties of electroceramics. A major advantage over 0D point defects is their thermal and electric field stability, which allows their use under severe drive conditions. Remaining challenges include simplification of the processing steps, extension to other piezoelectric systems, and detailed investigation of the underlying physical mechanisms.

a)



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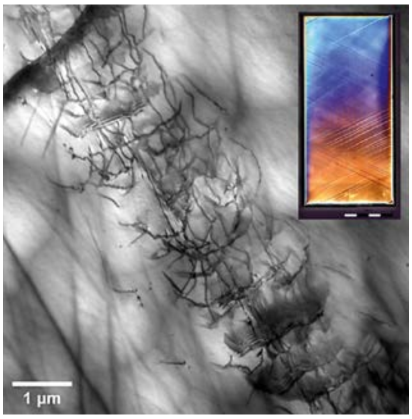

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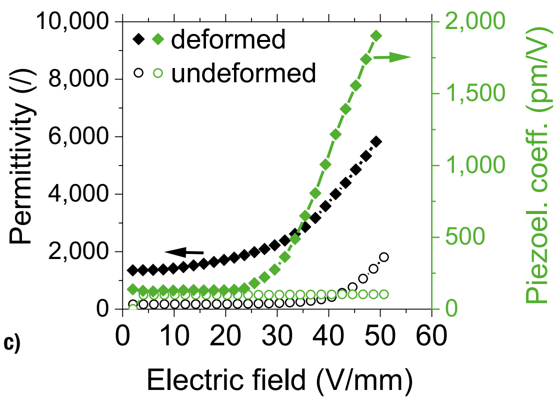

Figure 3: a) Charged dislocation with space charge layer and elastic strain field. b) TEM image of a slip band with edge dislocations in deformed $KNbO_3$. Inset shows the image of the deformed sample. Courtesy M. Trapp and M. Höfling. [6] c) Giant increase of piezoelectric coefficient and permittivity in deformed $BaTiO_3$, after depinning of domain walls at large E-fields [7].

Source: Marion Höfling

ACKNOWLEDGEMENTS

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Source: fotolia.com

HUMAN & BIOTECHNOLOGY

Fields of Expertise TU Graz

Gernot Müller-Putz, Human & Biotechnology

Source: Lunghammer – TU Graz

2021 is an anniversary year for Biomedical Engineering at TU Graz. The subject area is celebrating its 50th anniversary. As an elective subject bundle in the field of electrical engineering, one of the most successful teaching and research areas at TU Graz started in 1970/71 as an elective subject group: Biomedical Engineering. Only three years later, the specialized Institute of Electrical and Biomedical Engineering was founded under Stefan Schuy, later Rector of TU Graz. After a few years of development, the institute housed four departments: Biophysics, Medical Informatics, Medical Electronics and Health Care Engineering and two Ludwig Boltzmann Institutes (Assistive Technology, Medical Informatics and Neuroinformatics) as well as a testing facility for biomedical engineering. In 2001, the biomedical engineering branch of study was established as part of the electrical engineering diploma programme. In 2004, the organization was divided into four independent institutes: Genomics and Bioinformatics, Human-Computer Interfaces, Medical Technology, and Health Care Engineering with a European Test Centre for Medical Devices. Later, the Institute of Genomics and Bioinformatics was dissolved, and in 2007 the Institute of Biomechanics founded. The Bachelor's programme started in 2007, followed immediately by the Master's programme in Biomedical Engineering. Today, the institutes, including the Institute of Biomedical Informatics, are housed in the Biomedical Engineering Building at Stremayrgasse 16, which was renovated a few years ago.

At the Annual Conference of the Austrian Society for Biomedical Engineering, which took place at TU Graz, a festive evening was held to celebrate the anniversary. Rudolf Stollberger announced his retirement and received great applause, and his successor, Martin Uecker, was welcomed as head of the Institute of Biomedical Imaging.

After last year's call for FoE tenure-track positions, we were able to enlist Kerstin Lenk, who is setting up the Computational & Experimental Neuroscience working area at the Institute of Neural Engineering. She writes about her work in this issue of TU Graz research.

Kerstin Lenk

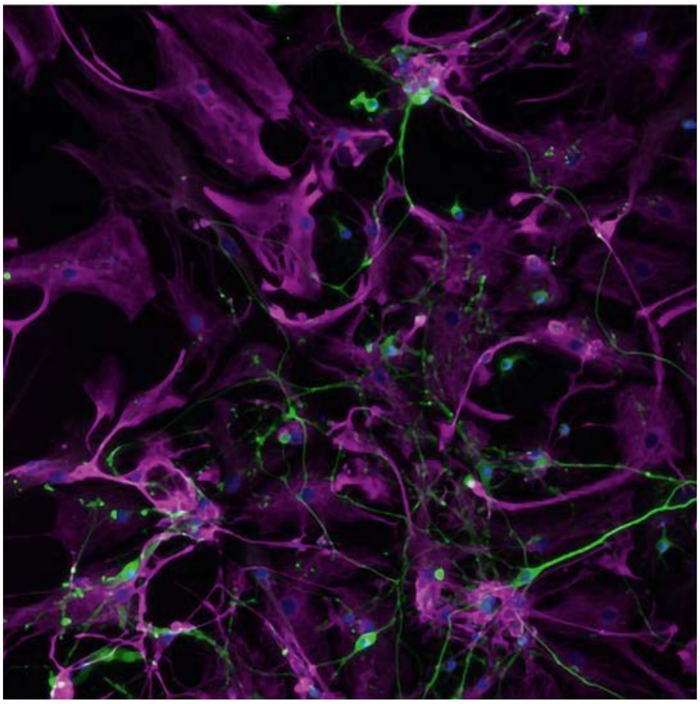
Computational Models of Neurons and Astrocytes in Studying Brain Dynamics in Health and Disease

Kerstin Lenk has been an assistant professor at the Institute of Neural Engineering since April 2021, focusing on computational neuroscience. The goal is to understand how neurons and other brain cells such as astrocytes interact with each other and how this interplay is disturbed in diseases.

Source: Hannah Pulferer

Astrocytes are non-neuronal brain cells that contribute to the exchange of neurotransmitters and ions. They are involved in various cognitive functions like sleep and memory formation. Using computational models, we simulate the interaction between neurons and astrocytes. By perturbing parts of the signaling pathways, we investigate astrocyte behavior in diseases like Alzheimer's, epilepsy, and schizophrenia.

In the past, neurons in the brain were considered the sole contributors to cognitive function. This view has been changing over the last four centuries, and other non-neuronal cells are now being investigated as to whether or how they >



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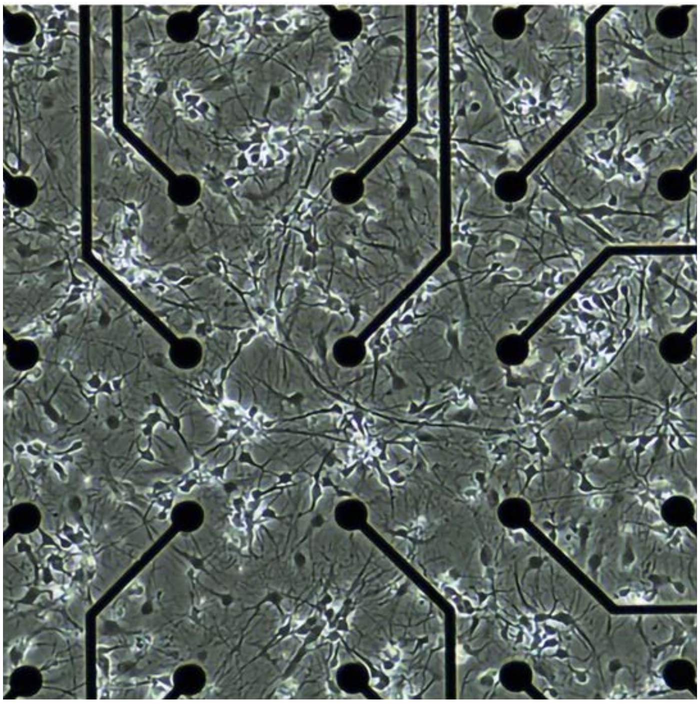


b)

contribute to normal and pathological functions of the brain. One of these so-called glial cells are astrocytes, which even outnumber neurons in the human brain. They were initially described as star-shaped. A few main branches extend from the soma and subdivide in a very fine tree of subbranches. Hence, astrocytes look rather like a sponge. Astrocytes in the human brain are twenty times larger than their counterparts in rodents.

Astrocytes are involved in various homeostatic processes in the brain. They take up and release neurotransmitters and ions. Astrocytes are also connected to blood vessels in the brain and transport nutrients to neurons and other cells. They play a role in the sleep cycle and memory.

At a synapse, electrical and chemical signals can be passed from one neuron to another. An astrocyte can enwrap the synapse, and exchange neurotransmitters, ions, and nutrients with the contacted neurons. In the human brain, one astrocyte can contact up to two million neuronal synapses. Astrocytes also link to other astrocytes by gap junctions and, in this way, form non-overlapping domains. Hence, neurons and astrocytes build tightly interconnected networks (Figure 1a).

Figure 1:
a) Stained neurons in green, astrocytes in magenta, and the cell nuclei in blue.
b) Neurons and astrocytes distributed over the electrode field of a microelectrode array.
Source: Annika Ahtiainen, Tampere University

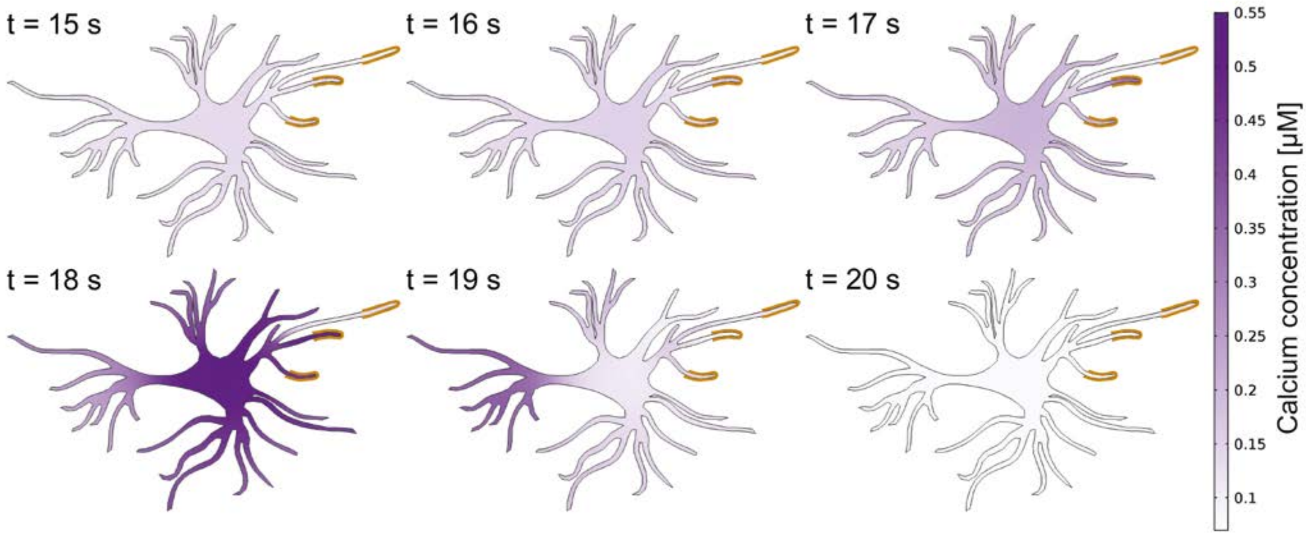


Figure 2: Simulation of the calcium dynamics over time (second 15 to 20) in an astrocyte. The astrocyte was stimulated by glutamate (indicated by the yellow lines at the tips of the astrocyte).
Source: Aapo Tervonen, Tampere University/ Kerstin Lenk

Unlike neurons, astrocytes are considered non-excitable, which means that they do not exhibit action potentials. Their primary signal is calcium and can be captured by means of calcium imaging. In this way, the binding of fluorescent molecules to calcium ions can be measured using microscopes. Astrocytes are involved in almost all brain pathology which influences the morphology and function of those glial cells.

At the Institute of Neural Engineering, one of our research areas is to develop computational models of single astrocytes (Figure 2) and in combination with neurons. As a first step, we analyze experimental data, for example, from calcium imaging and extract features such as the peaks in the signals. Then, we develop mathematical equations that describe underlying biophysical processes inside and outside of a cell. The parameters of the computational model are then adapted so that they resemble the experimental data at hand. One aspect that we investigate using the computational models is how different morphologies influence calcium and other ionic dynamics. Furthermore, we study the neuron and astrocyte interaction in larger networks. So far, we have been interested in specific aspects of the role of astrocytes in Alzheimer's disease, epilepsy, and schizophrenia. Using our computational models, we can study pathways in the astrocytes that are currently not accessible by experimental techniques or where the experiments are too expensive.

I learned about astrocytes during my time at the former Tampere University of Technology, now part of Tampere University, in Finland. There, we started to develop our first computational models of astrocytes. Side-by-side, we were also doing in vitro experiments with calcium imaging and microelectrode arrays (MEAs). Neuronal and astrocytic cells can be cultured on those MEAs (Figure 1b). These chips contain a field of electrodes over which the cells form a network over time (Figure 1b). After roughly a week, the first signal of electrical activity from the neurons can be measured. The networks can then be perturbated with chemicals or electrical stimulation, mimicking specific alterations in a disease. In collaboration with Christian Baumgartner and his PhD student Daniel Ziesel from the Institute of Health Care Engineering, we are currently establishing in vitro experiments with neuron-astrocyte co-cultures to be able to continue that research line.

One crucial part of our work is developing and implementing tools to analyze the experimental data, which we often do in close collaboration with our experimental partners. For example, we have written software to analyze electrical activity of neurons on MEAs and calcium imaging data of neurons and astrocytes. The analyzed results and insights from the in vitro experiments can also be used to build and refine our computational models.

Source: istockphoto.com

INFORMATION, COMMUNICATION & COMPUTING

Fields of Expertise TU Graz

Kay Uwe Römer,
Information, Communication & Computing
Source: Lunghammer – TU Graz

15 years after the Excellence Initiative was introduced in Germany, an Excellence program is now coming to Austria as well, with 36 letters of intent submitted over the summer out of which five will be funded initially. What did Austria learn from Germany? The German program originally foresaw graduate schools (PhD training), Excellence clusters (collaborative research), and future concepts (an Excellence label for universities that managed to win a minimum number of Excellence clusters and graduate schools and proposed a convincing Excellence strategy). Both the graduate schools, (“there are other good funding instruments for PhD training”) and the future concepts (“Excellence should be assessed on past achievements, not on plans”) received substantial criticism, as a result of which the graduate schools were dropped, but the future concepts were continued largely unchanged. Given this assessment, it seems a wise choice that the Austrian version focuses on Excellence clusters initially. Other criticism of the German program included a division of universities into a few “Excellent” winners and many losers, and too much focus on research and too little on education. The total yearly funding of about 500m euros of the whole program is ridiculous compared to Harvard’s annual multi-billion-dollar budget, and a huge waste of resources regarding writing proposal “bibles” of which only a tiny fraction is funded. Despite this, the German program has been successful without doubt in strengthening research and international visibility, especially by forming research teams of critical mass and having universities focus on their strengths. Let’s see how much of this carries over to Austria=Excellent and which new aspects we will experience over the coming decade.

In September Yannic Maus joined the Institute of Software Technology as the FoE ICC tenure-track assistant professor. In this edition of TU Graz research, he introduces himself and his research. Welcome, Yannic!

Yannic Maus

Foundations for Modern Distributed Computing

Many of today’s and tomorrow’s computer systems distribute data to several machines, or the systems are built on top of large-scale networks, such as the internet or sensor networks. Our research builds the theoretical foundations for these settings. We analyse and develop distributed algorithms that are fast and communication efficient.

Yannic Maus
is an assistant professor at
the Institute of Software Technology.

Source: Yannic Maus

Distributed algorithms are becoming increasingly important. Networks and the size of the data are often already too large to be stored, processed or controlled by a single central authority, or are distributed by design.

BENCHMARK PROBLEM GRAPH COLORING

Let us illustrate this with an artificial example. Consider a large network of sensors deployed in the vineyards in the south

Figure 1: Sensor networks are distributed if there is no central base station.
Source: Yannic Maus / Institute of Software Technology

of Styria that measure parameters such as temperature or humidity. Due to the steep nature of the vineyards, obstacles and limited battery capacity, these sensors cannot communicate to a central base station. Instead, they build a multi-hop network and a sensor only communicates with the sensors in its vicinity. Furthermore, their communication is wireless, so two close-by sensors cannot use the same frequency to send their messages, as otherwise interference might occur. Thus, our goal is to assign frequencies such that close-by sensors do not receive the same frequency. This can be modelled as a classic graph coloring problem. The network is abstracted as a graph where each vertex resembles a sensor and each edge between two vertices indicates that the two sensors are so close that they cannot use the same frequency. The objective is to assign a colour (= frequency) to each vertex such that neighbouring vertices receive different colours. To save resources, one desires to use as few colours as possible. Although so simple, graph coloring has played an influential role in computer science, maths and also in distributed computing. Computing an assignment using the minimal number of colours cannot be solved efficiently unless P = NP. In the distributed setting, we use more colours,

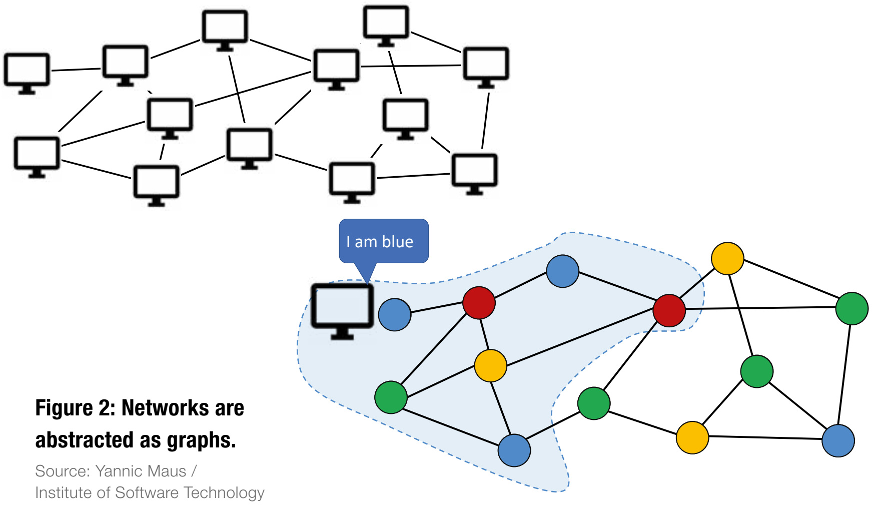


Figure 2: Networks are abstracted as graphs.
Source: Yannic Maus / Institute of Software Technology

but the problem still remains challenging. Recall our example. Each vertex of the graph is its own computer and does not know the network. How should one of these decide to use a specific colour without a central coordinator? Should it go for blue, red or green? It has to coordinate with its neighbours to not pick the same colour, and its neighbours have to coordinate with their neighbours, etc. Where do we begin? By rolling a dice.

THE ROLE OF RANDOMNESS

Let each node simultaneously pick a random candidate colour by rolling a dice. If no neighbour tries the same candidate colour, stick to it, otherwise just roll the dice again. This is a simple and efficient algorithm. Unfortunately, its efficiency relies on having fair dices. Scientists call such algorithms randomized. Interestingly, many problems (not just the graph coloring problem) can be solved efficiently with randomization. Many of these have in common the fact that the correctness of a solution can be verified efficiently, e.g. you can ask your neighbour for its colour to see whether you have the same colour. But what if one wants so-called deterministic algorithms that do not use dices and are not only efficient if the "gods of the dices" are with us? Over the decades, >

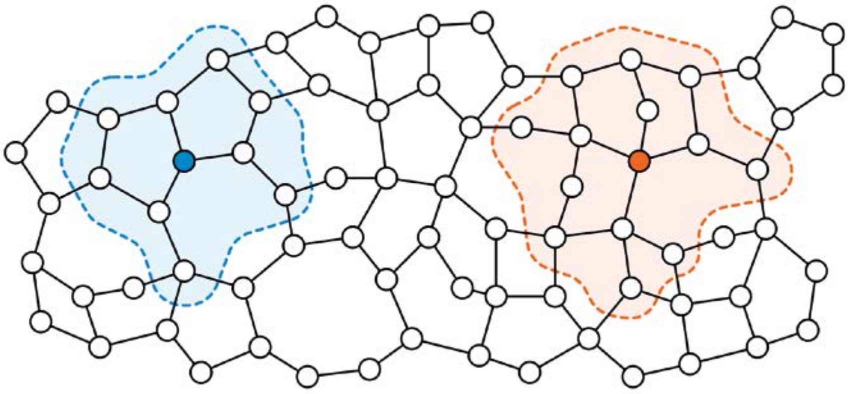


Figure 3: Classic distributed graph algorithms are allowed to use large messages and thus study the distance from which information in a graph has to be gathered to produce an output.

Source: Yannic Maus / Institute of Software Technology

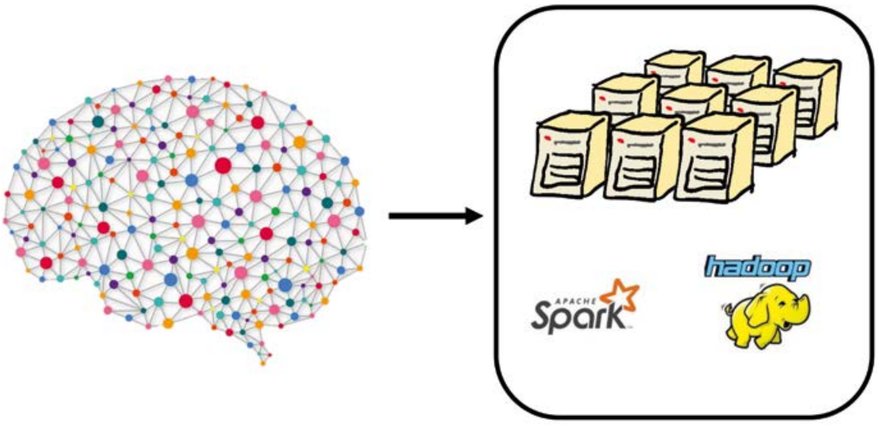


Figure 4: The figure shows the massively parallel computing framework to which network algorithms contribute.

Source: This figure is licensed under CC-BY.

the quest for efficient deterministic distributed algorithms has become the distributed version of the P vs. NP question: Can every problem whose solution can be verified efficiently by a distributed algorithm also be solved efficiently by a distributed algorithm? The classic P vs. NP question asks the same question for non-distributed algorithms. The answer to the distributed question is affirmative if we allow randomization. In order to also answer it for deterministic algorithms, we have built a large theory that relates randomized and deterministic complexities. Then, building on our theory, researchers from ETH Zurich have resolved the distributed P vs. NP question in the affirmative. Alas, these results come with expensive downsides; that is, they rely on a really large communication bandwidth in the network, something which is infeasible in practice.

COMMUNICATION EFFICIENT AND SIMPLE ALGORITHMS

Thus, in recent years we have successfully focused on the design of communication- and bandwidth-efficient algorithms. State-of-the-art algorithms are often very complicated and involved. Thus, besides being communication efficient and fast, one of our objectives is to design simple algorithms. Staying with our graph coloring example, we have shown that small changes to the aforementioned "roll-a-dice" algorithm suffice to make it exponentially faster.

MASSIVELY PARALLEL COMPUTING

In large graph-processing frameworks, such as Google's MapReduce or the open-source version Hadoop, a huge graph is arbitrarily distributed on a cluster of machines that communicate with each other in an all-to-all fashion. So, in contrast to the previous setting, there is no relation between the communication network and the input. Surprisingly, insights from network algorithms are very helpful in these frameworks, e.g. our communication-efficient algorithms are robust and run in such settings.

ALGORITHMIC CHALLENGES IN OUR MODERN WORLD

Our future research will build foundations for the emerging algorithmic challenges in our modern world, e.g. the design of streaming and sublinear algorithms. Most real-world graphs are non-static in nature, e.g. the Facebook graph keeps changing when new users join or leave the network. We aim to design dynamic algorithms that react quickly to changes without recomputing solutions from scratch. The impact of distributed computing in these areas has been growing and new connections are being drawn each day.

MOBILITY & PRODUCTION

Fields of Expertise TU Graz

Source: istockphoto.com/fotolia.com

Viktor Hacker,
Mobility & Production
Source: Lunghammer – TU Graz

The FoE Mobility & Production is more than ever confronted with new technologies for the production, storage and use of green hydrogen. In its recently published *Global Hydrogen Review 2021*, the International Energy Agency (IEA) discusses the role of hydrogen on the path to net zero CO_2 emissions from the global energy sector by 2050. Currently, the consumption of grey fossil hydrogen amounts to almost 90 million tonnes, making it one of the important global sources of CO_2 emissions. The scenario foresees the production of (green) hydrogen increasing to over 500 million tonnes by 2050 (approx. 60 kg hydrogen per capita and year worldwide), with hydrogen and hydrogen-based fuels such as ammonia, methanol and power-to-liquid, being used in production and transport, including shipping and aviation. Hydrogen production is mainly based on electrolysis using wind and solar energy. Biomass and biogas will also contribute to hydrogen production and can be used in combination with carbon capture and storage as negative emission technologies to remove carbon dioxide from the atmosphere. To achieve the competitive cost of green hydrogen of three euros per kilogram of hydrogen, electricity from renewable sources must be available at a price of around 2 cents per kWh. The broad expansion of electricity generation from renewable sources leads directly to the second challenge, the storage of surplus energy in large quantities and the management of seasonal fluctuations of sun and wind. The storage medium green hydrogen can be converted back into electricity with efficient technologies such as the fuel cell or used industrially via sector coupling and will thus make a significant contribution to decarbonisation by 2050.

In May 2021, Merit Bodner was appointed to the tenure-track assistant professorship in the area of Mobility and Production and assigned to the Institute of Chemical Engineering and Environmental Technology. Bodner is continuing her scientific career at TU Graz with a habilitation in the field of hydrogen fuel cells after several years of research work with European fuel-cell developers.

Merit Bodner

Moving towards 80,000 Hours of Fuel Cell Operation and Beyond

Hydrogen and fuel cell technologies as viable and sustainable approaches to a renewable energy supply chain are experiencing unprecedented attention. As the industry is growing, its view is becoming increasingly holistic. Novel and innovative ways of maximising product utilisation and minimising product footprint are crucial in establishing a true alternative to conventional solutions.

Hydrogen-fuelled low temperature polymer electrolyte fuel cells have throughout the years been regarded as a viable and sustainable option in the transition to a green energy supply chain from a technological point of view, yet a lack of pressure in often purely economically driven trade-offs have for a long time hindered a large scale roll-out. As the impact and the accompanying challenges posed by climate change are becoming increasingly pressing and a threat to life as we know it, hydrogen as an energy carrier and fuel cells as a highly efficient converter thereof, are experiencing unprecedented attention.

As a price tag is more and more often put on the emission of pollutants and greenhouse gases, economic viability shifts too. However, this abruptly increased interest in the technology has put an industry, which is in the critical phase of the transition from a small scale and research-driven mind-set to mass manufacturing and the holistic >

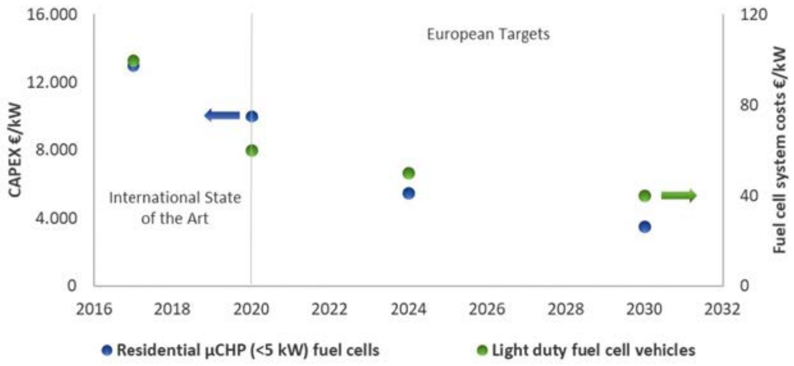


Figure 1: State of the art and targeted costs for fuel cell systems in different applications.
Adapted from: https://www.fch.europa.eu/soa-and-targets.
Source: Merit Bodner

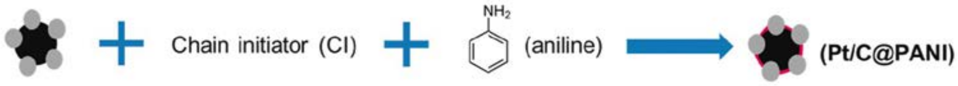


Figure 2: Fuel cell catalyst synthesis.
Source: M. Grandi

Merit Bodner has been working in the field of fuel cell research since 2011, with particular focus on degradation phenomena and lifetime limitations of low-temperature polymer electrolyte fuel cells.

After her graduation, she had leading positions at Danish Power Systems in Denmark and Nedstack Fuel Cell Technology in the Netherlands. Since May 2021, she has held a tenure-track position at Graz University of Technology. Merit Bodner has over 40 scientific publications and presentations and has contributed scientifically as an expert in commissions and in the peer-reviewing process.

Source: Foto Fischer

analysis of processes in the spotlight. Important questions in this transition process largely concern quality assurance, reliability, predictability and extension of the lifetime of fuel cell systems as well as the inclusion of the entire manufacturing and utilisation chain in a circular economy. Economically, fuel cells are as of now still in a disadvantaged position in comparison to more established technologies, such as the internal combustion engine. However, several means to close this gap are in reach.

CONNECTING THE DOTS

Beyond the obvious economy of scale, which is anticipated to come into effect as the industry shifts towards mass manufacturing, improving material utilisation – in particular of the high-cost, mostly platinum-based electrocatalyst – is a key factor in cost reduction. Research includes the development of new catalysts with a higher activity, paired with a lower Pt loading, as well as the stabilisation of catalyst and support.

Another critical electrochemically active component is the polymer electrolyte, which is needed both as the membrane and as a part of the electrodes to provide ionic conductivity. As the membrane separates both reactants, the chemical and physical stability are crucial not only to performance, efficiency and lifetime, but also to safety.

Both polymer electrolyte membrane and catalyst exhibit a large interconnection between their chemical composition, physical properties and their performance and durability. The Institute of Chemical Engineering and Environmental Technologies has a long history in the investigation of degradation mechanisms of fuel cells and their prevention as well as in the development of materials for the use in fuel cells. Through the increasing understanding of degradation mechanisms, their connection to the used materials and their impact on the behaviour of fuel cells, increasingly advanced monitoring techniques emerge, which are crucial to long term reliable fuel cell operation. >

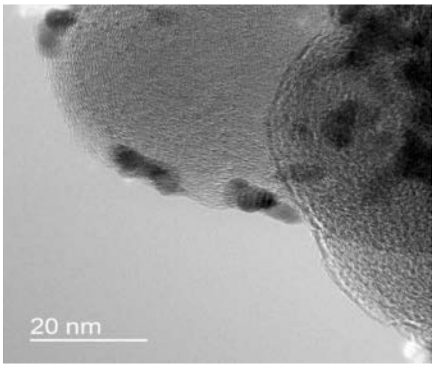


Figure 2b: TEM image of the deposited protective layer on the fuel cell catalyst.
Source: K. Kocher

Figure 3: CEET staff working in the fuel cell laboratory.
Source: E. Kuhnert

Figure 4: Fuel cell short stack.
Source: K. Mayer

REDUCING THE FOOTPRINT OF FUEL CELLS

Every technology possesses an individual footprint, be it based on renewable resources or not. This naturally includes fuel cells and as production is rapidly upscaling, these processes are experiencing increasing attention as well. Research and development is aiming at the implementation of new and resource-efficient manufacturing techniques. Another path towards a smaller footprint, however, is to increase the duration of the fuel cell utilisation. Targets set for fuel cells, such as the one of 80,000 h for stationary applications given by the US Department of Energy [1], are, however, difficult to prove in a reasonable time, as this is equivalent to 10 years of up-time. Relying entirely on use case data would result in unacceptably long development iteration intervals.

It is furthermore worth noting that in these orders of magnitude, the contribution of system components becomes critical as well and the actual duration of the fuel cell may be overshadowed by degradation of other components, further complicating the proof of such lifetime durations. One of the longest running systems reported has exceeded 65,000 h of operation within 12 years [2] and is still counting.

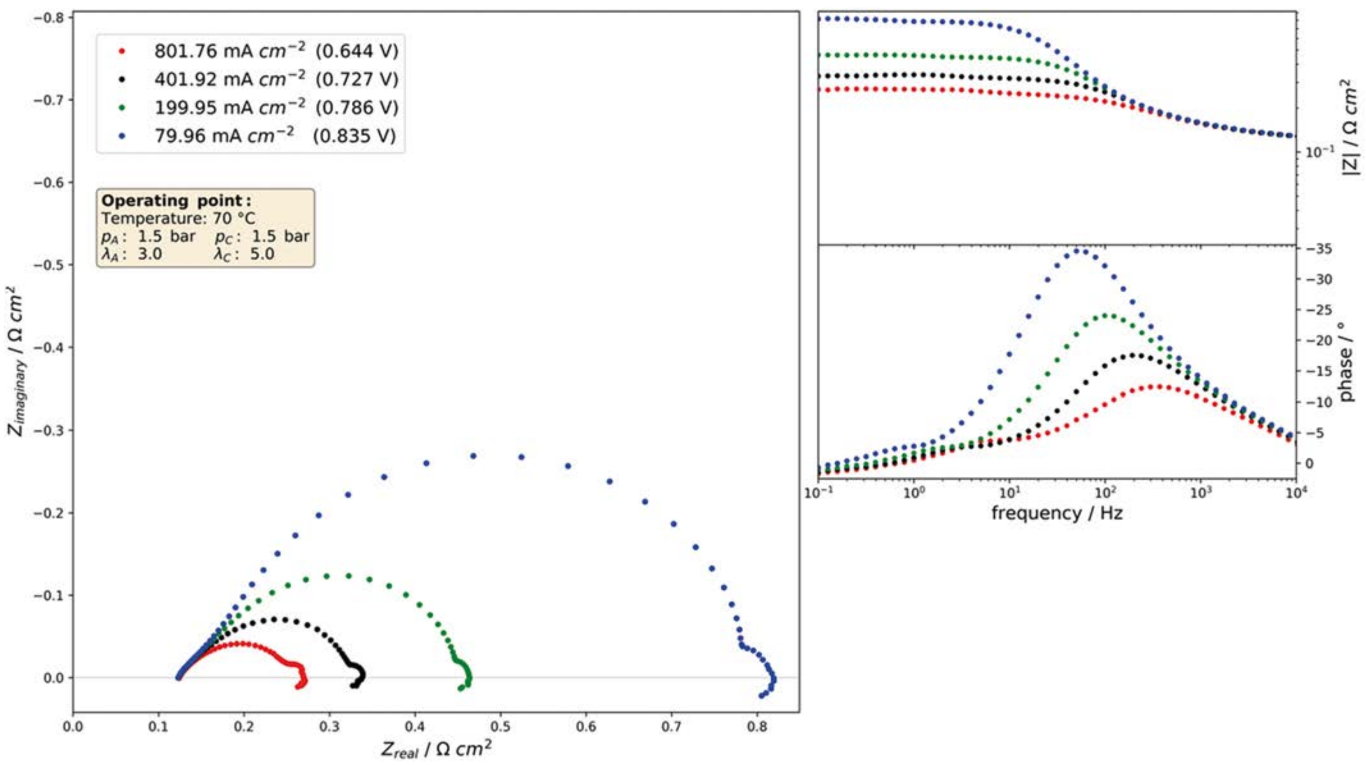
Therefore, in order to accelerate the development process, accelerated stress tests are made use of. Individual stressors are selected based on the respective use case or targeted material and deliberately applied in an operation profile. This allows for a far quicker identification of future lifetime limitations of the fuel cell itself.

With this information, it is possible to give lifetime estimations in a reasonable time. At the same time, triggering specific degradation mechanisms allows us to understand the impact they have on the stability and behaviour of the fuel cell. This behaviour can then – like a fingerprint – be looked for in use case data, giving an early insight into ongoing degradation and allowing fast actions for mitigation.

[1] Durability working group, Hydrogen and Fuel Cell Technologies Office, U.S. Department of Energy; https://www.energy.gov/eere/fuelcells/durability-working-group (accessed 23/08/2021)

[2] Nedstack fuel cell technology: 65.000 running hours and counting; https://nedstack.com/en/news/65000-running-hours-and-counting (accessed 20/08/2021)

Figure 5: Electrochemical impedance spectra at differnt operating points.
Source: K. Mayer



Source: ymgerman – fotolia.com

SUSTAINABLE SYSTEMS

Fields of Expertise TU Graz

Urs Leonhard Hirschberg, Sustainable Systems

Source: Lunghammer – TU Graz

Last summer the FoE Sustainable Systems announced the search for a tenure-track assistant professor for "low carbon building technologies". Previously delayed by the pandemic, the selection process was concluded this spring. The selection committee deemed Marcella Ruschi Mendes Saade the most promising of a diverse and strong field of candidates. A civil engineer specialized in life cycle assessment, she joined the Institute of Structural Design (ITE) at the Faculty of Architecture in May.

Marcella Ruschi Mendes Saade is also the author of one of the successful bids in the 15th round of our field's initial funding program. She is proposing 3DProspect, a prospective study on the environmental feasibility of 3D-printed concrete structures. Additive Manufacturing (AM) methods are gaining importance in construction and are seen as a potentially disruptive technology for the building sector. The 3D printing of concrete is a particularly interesting AM method and ITE researchers have successfully developed applications for this technology that promise to significantly reduce the carbon footprint of concrete structures. Saade's proposed FFG Bridge project promises to put these efforts into a broader context and to provide guidance on how to move towards the integration of AM methods in construction while ensuring that environmental targets are met.

Another successful bid to do with concrete was by Isabel Galan Garcia from the Institute of Applied Geosciences. She has assembled an interdisciplinary consortium of leading scientists from institutions across Europe to study the Durability of Low Carbon Cements. The consortium plans to apply for funding of a EU HORIZON Doctoral Network under the Marie Skłodowska-Curie Actions program. Coordinated by TU Graz, the goal of the proposed network is to train the next generation of young scientists, empowering them with the skills and knowledge necessary to develop by 2050 a carbon-neutral and durable cement for Europe, thereby paving the way to meet the aims of the Paris Agreement.

While looking for new low-carbon construction methods is doubtlessly necessary, achieving carbon neutrality will also require making better use of existing building stock. Under the title Counterintuitive Typologies, Andreas Lechner of the Institute of Building Typologies is proposing to develop novel design strategies that can enhance the attractiveness of urban sprawl areas by re-using rather than destroying derelict buildings in these zones. Along with a consortium of partners from academia and industry, he wants to apply for funding in the FFG's "Stadt der Zukunft" program.

The study of complex subsurface geosystems is gaining importance in the quest for sustainable energy sources. With the project PreGeoSys, Ronny Boch from the Institute of Applied Geosciences proposes a pioneering geochemical approach to study the access to and investigation of established and new geothermal wells and energy-producing facilities in the Styrian Basin (Austria) and Pannonian Basin (Hungary). With partners from Hungary, Boch plans to apply for funding from the Austrian Science foundation FWF.

Normally we only have funding for four projects, but in this round we agreed with Vice Rector Bischof to fund a particularly prominent fifth project. HyCentA-COMET, a proposal for a K1 competence center put forward by Helmut Eichlseder of the Institute of Internal Combustion Engines and Thermodynamics, builds on the vast experience in hydrogen research already present at TU Graz, with over 50 million euros worth of research infrastructure and 160 researchers across multiple institutes working on hydrogen-related topics. A large consortium of partners from academia and industry is joining in the effort to establish a center for the research and development of solutions in all aspects of green and emission-free hydrogen technologies.

We wish all successful applicants the best of luck with their proposals and hope that the resulting projects can one day be presented on these pages, just like the work of Marcella Ruschi Mendes Saade on page 34.

Marcella Ruschi Mendes Saade

Will Emerging Technologies for Building Construction Help Reduce Our Contribution to Climate Change?

An increasing number of proposed novel technologies in construction claim to be low carbon. Proper methods to estimate the emissions arising from these emerging technologies must be implemented to determine their environmental feasibility. A prospective Life Cycle Assessment study of 3D-printed concrete structures is proposed to investigate whether the technology holds the potential to reduce buildings' contribution to climate change.

Figure 1: 3D printed metallic materials, from the FFG project entitled "3D Welding: Additive Fabrication of Structural Steel Elements", which funds the PhD research from Christoph Holzinger.

Source: Christoph Holzinger – ITE, Graz University of Technology

Designers, engineers, policymakers and all the different stakeholders involved in the construction sector face increasing pressure to reduce GHG emissions generated during the life cycle of the built environment. While this pressure is shared by almost all sectors in society today, the building and construction sector plays a significant role in the overall carbon emissions generated by mankind. A relatively recent report published by the International Energy Agency's Global Alliance for Building and Construction showed that almost 40% of CO_2 emissions generated in 2017 came from activities within the building and construction sector. Due to the sector's magnitude and the consequent massive consumption of materials, its potential for lowering the energy need and emissions below business-as-usual-levels is virtually unmatched. This scenario has led to the establishment of various quantifiable targets related to diminishing the greenhouse gas emissions that arise from construction activities. The increasingly stringent targets stimulate researchers into proposing novel technologies related to material composition, material efficiency or construction techniques, promising significant reductions of carbon intensity.

Marcella Ruschi Mendes Saade has worked in the field of Life Cycle Assessment and Sustainable Construction for the past 10 years. Since April 2021 she holds a tenure-track position at the Institute of Structural Design.

Source: Joris Deschamps

ADDITIVE MANUFACTURING AND CONSTRUCTION

An emerging, potentially disruptive, technology that is starting to gain space in the built environment is Additive Manufacturing (AM). Not long ago, discrete initiatives to assess AM's applicability for building large-scale structures started to arise. In fact, one does not need to look far to find successful examples: the Faculties of Architecture and Civil Engineering Sciences at TU Graz have jointly designed a machining robot system for wet and dry machining of large components. The testing facility, built by ABB AG Austria, is operated primarily by the Institute of Structural Design and the Laboratory for Structural Engineering as a grinding and milling robot system. Moreover, during the last few years the robot facility has been used as a large concrete printing unit.

While the exploration of the interface between robotics and design has been mostly focused on technical and economic fea-

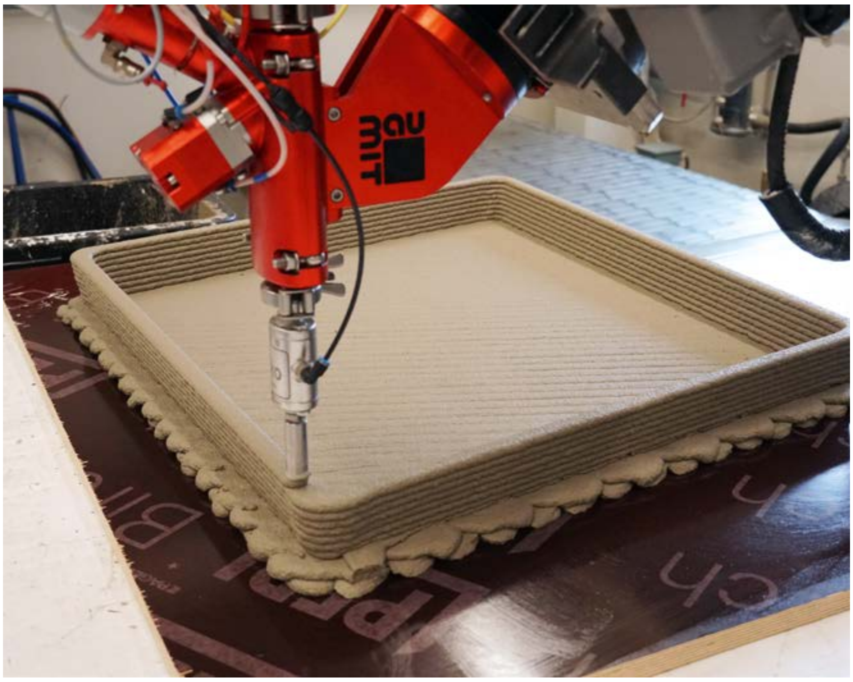


Figure 2: 3D printing of a concrete element, from the project "Stahlbetonleichtbaudecke - Schloss Seehof", which funds the PhD research from Georg Hansemann, in collaboration with the ongoing PhD research from Robert Schmid.
Source: Georg Hansemann – ITE, Graz University of Technology.

sibility, these studies and research initiatives pave the way for the process's consolidation in the construction sector. Although promising from a technological standpoint, the incipiency of AM's environmental impact measurement is quite pronounced. Still, a successful insertion of additive manufacturing technologies within the built environment will depend on its environmental attractiveness. The little evidence that exists points to an impact reduction when assembling highly sophisticated structures, with significant architectural complexity in terms of shape.

EX-ANTE OR PROSPECTIVE LIFE CYCLE ASSESSMENT

Life Cycle Assessments (LCA) have been widely recognized as the most scientifically sound option to quantify the environmental impact of buildings and structures. By tracking material and energy flows throughout the life cycle of a product or system, LCAs can assess the potential environmental impacts associated with different components of the built environment. The challenge in the case of emerging technologies, however, is to properly measure material and energy flows of a technology not yet widely implemented in practice. How does one extrapolate, for instance, how much energy is consumed or how much CO_2 is emitted from a small lab-scale to a real-life construction site, where many other variables come into play?

To overcome this, state-of-the-art research in LCA proposes applying upscaling techniques to define scenarios that predict how the performance of robots and 3D-printing processes will evolve in the decades to come. Learning curves from proxy technologies or from the same type of machinery applied to different sectors support this upscaling process and help determine how e.g. energy and material consumption become more efficient as the technology moves towards an industrial scale.

Apart from determining scenarios for future data gathering, due to the major role played by users, building owners, real estate companies and governments on the demand to implement such technique in a wider scope, reliance on agent-based modelling methods to attempt to predict how these players will respond to the emerging technology is also a proposed added layer to ex-ante LCAs.

PROSPECTIVE STUDY ON THE ENVIRONMENTAL FEASIBILITY OF 3D-PRINTED CONCRETE STRUCTURES

The relevance of the presented subject led to the proposal of a project idea, recently awarded funds from the TU Graz initial funding programme. Spearheaded by a collaboration between the Institute of Structural Design (ITE) and the Sustainable Construction (AGNHB) Working Group, the research project foresees filling the mentioned gaps with a robust ex-ante life cycle assessment applied to 3D-printed concrete large-scale structures. The proposal relies on the hypothesis that (i) 3D-printed concrete structures are an emerging technology that will be increasingly applied in decades to come, displacing traditional construction techniques and (ii) the technology holds the potential to reduce buildings' contribution to climate change due to efficiency in material consumption.

The ultimate goal is to identify the pathways in present and future application of 3D printing on the Austrian building stock that would lead to such reduction, with special focus on conditions that would allow for national decarbonization targets to be met by 2030, 2040 and 2050. The proposed research is expected to generate a reliable outcome on how to move forward and successfully integrate additive fabrication into day-to-day construction practice, assuring environmental targets are met.

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